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# A Thematic and Reference Analysis of Touchless Technologies

Eric R. Curia

**A THEMATIC AND REFERENCE ANALYSIS OF TOUCHLESS TECHNOLOGIES**

THESIS


Eric R. Curia, Captain, USAF



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## Abstract

The purpose of this research is to explore the utility and current state of touchless technologies, which are simply devices that do not require touch to activate. Five categories of touchless technologies are identified as a result of collecting and reviewing literature: facial/biometric recognition, gesture recognition, touchless sensing, personal devices, and voice recognition. While the total number of articles provided informative research on the topic, specific articles were selected for analysis based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard formatting procedures. The 31 PRISMA-compliant documents were then analyzed thematically, evaluating the contents of the articles for advantages and disadvantages, as well as their reference sections for matches and similarities between articles. Thematically, touchless sensing technologies had the greatest advantage to disadvantage ratio, followed by personal devices, voice recognition, facial/biometric recognition, and gesture recognition. For both the direct and indirect reference analyses, the categories were shown to have differences in similarity within their reference sections. The references for gesture recognition technologies shared the most similarities, followed by voice recognition, facial/biometric recognition, personal devices, and touchless sensing. Comparing the results of the two analyses, the conclusion was that newer technologies likely had lower advantage counts due to less known application and higher reference similarities because of the fewer articles written on them. The reverse applies to older technologies, which had higher advantages and greater applicability.

*This thesis is dedicated to my best childhood friend, who sadly passed away during my enrollment at AFIT.*

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Eric Russell Curia

# Table of Contents

Page

**List of Figures**

Page

## List of Tables

Page

## A THEMATIC AND REFERENCE ANALYSIS OF TOUCHLESS TECHNOLOGIES

### I. Introduction

Touchless technologies are devices that can be operated without having to utilize physical touch, and in recent years, they have been increasing in application, development, functionality, and implementation (Cronin & Doherty, 2019). Initially, the main purposes of implementing touchless technologies have been towards energy efficiency, slowing the spread of contagious diseases, and general convenience (Taylor, 2020). For example, several public spaces around the United States, to include offices and airports, have long ago implemented hand-waving sensors in restrooms for these reasons (Taylor, 2020). These types of sensors have also been integrated with facility lighting systems, where the simple entering of a room would activate the lights without having to flip a switch (Nicol, 2020). With that said, the constantly evolving technology sector has dramatically raised the potential for applying touchless technologies in different ways. For example, simple touchless technologies that trigger binary operations (i.e., on or off) by tripping a sensor have evolved into devices that require high-quality cameras to interpret movement and produce complex outputs (Liu et al., 2020). To further push the boundaries of touchless technologies, there are examples of devices that do not even require human interaction. For instance, smart sensors integrated in facilities can measure a facility's life-cycle health automatically (Landgrebe, 2011). On that note, fixtures within medical areas can emit powerful rays of light that disinfect pathogens

automatically as well (Landgrebe, 2011). Even though the availability and functionality of touchless technologies continue to grow, many people still do not view them as mandatory for facilities. However, this perception towards touchless technologies is beginning to change. The background section will further discuss this shift in mindset.

**Background**

As of July 2021, the Centers for Disease Control and Prevention (2021) discovered that fomite transmission (i.e., the touching of surfaces) was not a primary method in which COVID-19 spreads. In the past, many touchless technologies were simply viewed as "nice to have" infrastructure and equipment, but the dramatic effects of the pandemic made people reconsider their necessity (Iqbal, 2020). Organizations across the world have experienced a significant decrease in productivity due to the pandemic, and the primary reason is the reduction of working together in person to prevent further spreading of the virus (Grover and Sabherwal, 2020). The reason that human interaction has been minimized is because the virus often remains dormant within a host, showing little to no symptoms, which makes the ability to track its spread challenging (Na et al., 2020). Not only is the virus problematic to contain, but its side effects can be deadly; models signal that an infected individual can die from the virus up to 42 days after exposure (Na et al., 2020). Because of this, the logical and conservative protocol for organizations to implement touchless technologies is for their employees to reduce contact with each other (Na et al., 2020).

While the most generally understood method of transmission is through direct contact with infected individuals, diseases of many kinds can also be contracted

indirectly through the touching of common surface objects (Kurgat et al., 2019). Within offices for example, common surfaces that contain highly concentrated bacteria and/or viruses include the following: door handles, door push bars, drinking fountains, restroom soap dispensers, restroom sinks, kitchen faucets, file cabinets, copiers, microwave ovens, candy jars, refrigerators, coffee pots, drawer handles, and communal keyboards (Kurgat et al., 2019). Additionally, surfaces that are considered for individual use, such as personal desks, keyboards, mouses, and chairs, can also contain large concentrations of similar bacteria and/or viruses (Kurgat et al., 2019). Figure 1 shows the transmission susceptibility of various surfaces in a typical office setting.

On one hand, it is important to understand that implementing proper hygiene can effectively fight these diseases; when these surfaces are disinfected regularly, 85.4% of the germs on those surfaces are immediately killed, thereby reducing the probability of infection (Kurgat et al., 2019). On the other hand, the touching of these common surfaces is still inevitable, and although active cleaning is highly effective, any amount of surface contact still exposes users to the risk of infection. Because of this, methods need to be explored to further reduce fomite transmission, which is the scientific term for the spread of disease through touching infected surfaces.

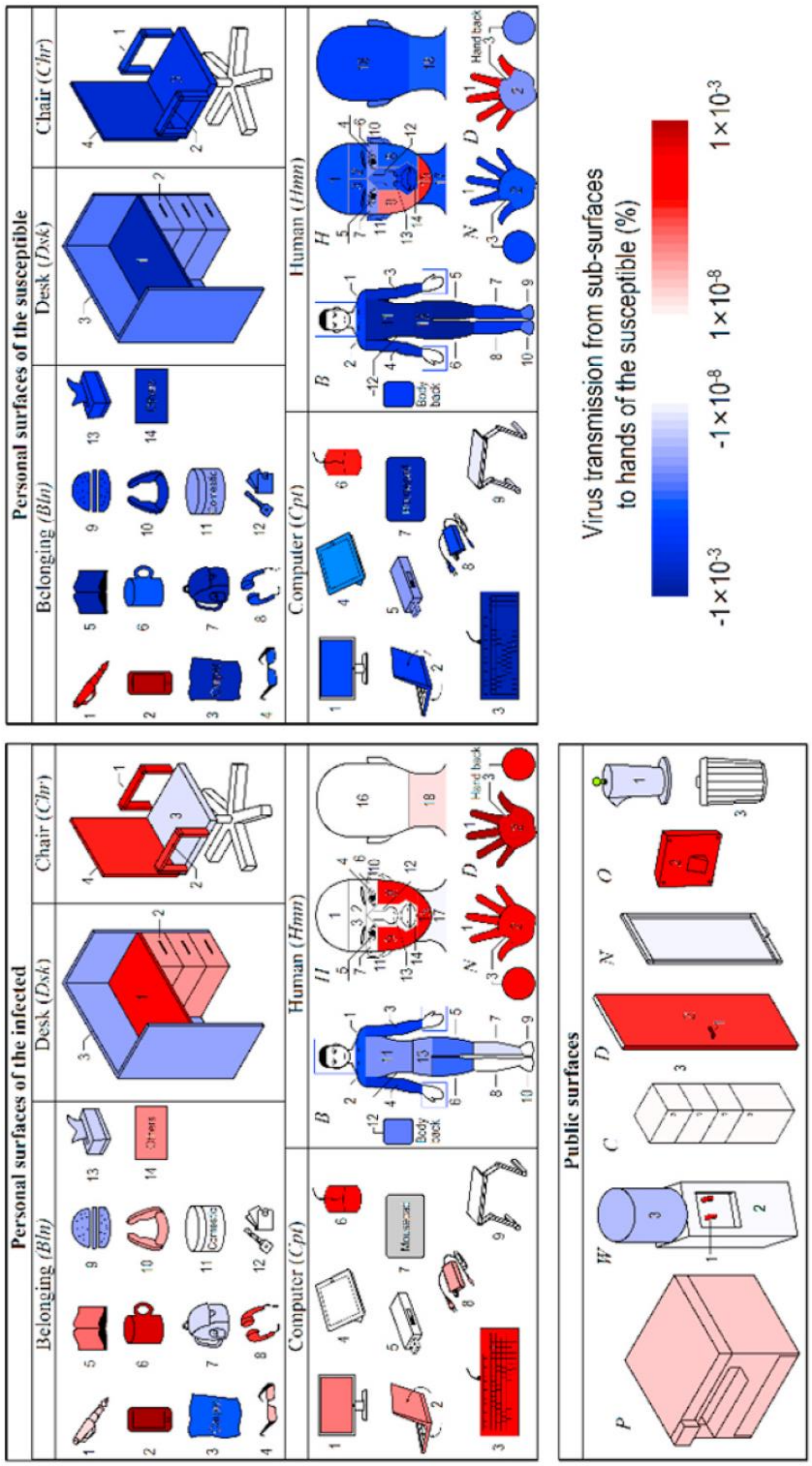



Figure 1. Virus Transmission to Hands of the Susceptible (Kurgat et al., 2019)

While “easier to implement” mitigation efforts, such as lockdowns, have helped minimize the spread of COVID-19, they have also resulted in a severe economic downturn (Coccia, 2021). Lockdowns have produced adverse effects on several nations' economies, where global productivity declined between 13% and 21% during just the second quarter of 2020 (Coccia, 2021). Similarly, there are organizations turning to telework in efforts to adapt, but recreating work environments solely around telework has also been shown to have negative effects, specifically regarding the mental health of employees (Bufquin et al., 2021). The lack of opportunities for employees to interact, collaborate, and create friendships during the pandemic has likely caused the spike in reported psychological distress and substance abuse during 2020 (Bufquin et al., 2021). In efforts to find a smarter solution that addresses safety, economic productivity, and mental health concerns, it may be worth pursuing touchless technologies. Stein (2020) identified five categories of commonly used touchless technology: facial/biometric recognition technologies, gesture recognition technologies, touchless sensing technologies, personal devices, and voice recognition technologies. These categories, which served as a framework for the research, will be further explained in the literature review chapter.

**Problem Statement**

The purpose of this research is to explore touchless technologies by collecting literature on or related to the topic, thoroughly reviewing the literature for background information, and conducting both a thematic and reference analysis on that literature. The findings from meeting these objectives will be used to draw conclusions and answer

the investigative questions. The purpose of the investigative questions is to address the overarching problem, which is understanding the capabilities, conveniences, and drawbacks associated with touchless technologies.

To search the literature, the resources found on the AFIT online library, primarily Science Direct Open Access Journals, will be utilized. An additional resource that will also be used for both finding and citing literature will be Google Scholar. From there, these resources will help build the framework of background/related information in the introduction, and it will later be used for the literature review process.

To conduct the literature review effectively, it will need to be collected in an organized and efficient manner. After finding general background information, it will be important to structure the categories of touchless technologies in a manner that would make sense for eventual analysis. This coordination of searching for literature is used to prevent searches that may go off on an irrelevant tangent; every found article will be used to gain an understanding of a specified category of touchless technology.

After collecting the literature, performing both thematic and reference analyses needs to be done. The generalized idea/theory behind the thematic and reference analyses will be further explained in the methodology section of this chapter. To briefly discuss the approach of the thematic analysis, the total collection of literature will be filtered down to a smaller group. This reduced sample of articles will be structured in a manner that meets Preferred Reporting Items for Systematic reviews and Meta-Analyses, or PRISMA, standards. The purpose for eliminating articles that do not meet the preferred format is so that this process can be more easily repeatable for future researchers. From there, the articles will be thoroughly read to identify clear and obvious

themes. The themes would need to communicate the pros and cons of touchless technologies, so the themes that will be extracted will be each category's advantages and disadvantages. When all of the themes are collected, an advantage to disadvantage ratio of each category will be calculated. Along with that, the advantage to disadvantage ratio for touchless technologies, as a whole, will also be assessed. The thematic analysis process will be further explained in the methodology chapter. The thematic analysis results will be further explained and shown in the results chapter.

After conducting the thematic analysis, the reference analysis for the collection of PRISMA literature will be done. To summarize the process, the reference analysis compares the articles' reference sections for similarities. This will be accomplished using two different methods: direct and indirect. The direct reference analysis compares the articles for exact matches within their reference sections. This process will be conducted through Microsoft Excel, where the program will compare references of each article as separate data points. In contrast, the indirect reference analysis compares any two articles by reading their reference sections and correlating them by word similarity. The recognized word similarities will compare the article's contributing authors, titles, and journal issues. This process, being executed in the program NVivo, will be conducted for each of the five categories and for touchless technologies as a whole, where Pearson correlation ($R^2$) values for each category will be obtained. This will then be exported into the program JMP, where the correlation data will undergo statistical tests to analyze their differences in mean correlation and variance. The reference analysis process will be further explained in the methodology chapter. The reference analysis results will be further explained and shown in the results chapter.

Once results are obtained from the thematic and reference analyses, the two completed data sets will be compared.  The two results will be plotted on a singular graph, where each point on the graph will represent the five touchless technology categories and touchless technologies as a whole.  The combined plot will be further explained and shown in the results chapter.

All of the efforts put into this thesis will be used to create observations, draw conclusions, and answer the investigative questions.  These findings will be further explained in the conclusions chapter.  These investigative questions will be stated in the upcoming section.

## Research/Investigative Questions

The overarching umbrella research question, which is not addressed or answered directly, is instead addressed by answering a series of investigative questions, which help "paint the picture" that focuses on tackling the issues stated in the background section. Simply put, the point of this research is to discuss touchless technologies as an industrial advancement of tools in the modern workplace.  Therefore, the investigative questions are the reasons that people would be interested in learning about the topic.  To support the overarching research question, which is to gain a full understanding of the capabilities, conveniences, and drawbacks of touchless technologies, the following investigative questions were addressed.

1) What is the current state of touchless technologies?
2) How are the results of the thematic and reference analyses related?  What can be concluded from evaluating the results of the two analyses together?

By answering these questions, this research will explain the current state of touchless technologies, how the scientific community views them, the discoveries made comparing the literature's themes and references, and the feasibility of applying the topic to real-world scenarios.

**Methodology**

The purpose of this section is to provide a high-level summary of the methodology chapter. This section will briefly explain the process used for this research, to include the broader theory of both analyses, literature collection, clustering, correlation, and statistical processes. This section helps ensure that the reader understands the legitimacy and utility of using both analyses within the overall methodology.

The umbrella term which incorporates both thematic and reference analysis, bibliometric analysis, is the process in which statistical and mathematical methods are used to analyze scientific literature (Diodato, 1994). In this overarching process, scientific books, journals, and articles are collected, and information within the literature is used as data (Diodato, 1994). It is commonly used in the scientific community to investigate the composition of a particular topic with existing literature, and this field of study is frequently implemented in both subjective evaluations (i.e., thematic analysis) and objective evaluations (i.e., reference analysis) (Donthu et al., 2021).

Data, being literature articles, were collected based on using common terms and phrases (i.e., touchless technologies, benefits, costs, fomite transmission, biometric recognition, gesture recognition, touchless sensing, personal devices, voice recognition,

etc.) and without the intention of reaching a conclusion artificially. All of the articles that were collected were numbered and saved within a folder, which served as the database for the research. This strategy proved to be effective because regardless of the iterations taken, it was easy to identify iterations to the database by simply creating folders within folders. Additionally, the number assigned to a journal article remained consistent throughout the research process, which made the data easily recognizable when adapting to different platforms. The first iteration of the database was the screening of literature based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-compliant standards. This essentially filtered out articles from the total literature collection process that would not be used in the thematic and reference analyses. Once the list of PRISMA articles was finalized, there were multiple computer programs that were utilized.

CiteSpace was utilized to provide cluster-based illustrations of all the PRISMA articles based on similarity. NVivo was used for both the thematic and reference analyses, where the program scanned for thematic codes for advantages and disadvantages and the reference sections of the articles to determine Pearson correlation coefficients based on likeness. Similarly, Microsoft Excel was used to scan the reference sections of the PRISMA articles to find reference matches between them. The Pearson correlation data was transferred to JMP, which used statistical tests to identify descriptive and inferential statistics for each of the categories. Once the thematic and reference analyses were completed, the two results were compared by plotting the results on the same graph, identifying possible trends, and creating observations for each of the touchless technology categories.

**Assumptions & Limitations**

Since the topic of touchless technologies is relatively new, there were several assumptions made and limitations found when conducting the research. Regardless of the category of touchless technology, each article was collected independently from one another, and all of the thematic and reference data within the sample were assumed to demonstrate independence. While this assumption applies throughout the research, it played a significant role during the statistical testing phase of the reference analysis, where the assumption of independence is required. It was also assumed that the collected literature is an accurate representation of how the scientific community at large views touchless technologies. This assumption ensures that the sample of data reflects the population of data on the topic, so the results will serve as accurate models. The last primary assumption, which will be further elaborated on in the methodology chapter, is that the filtered and selected articles used for analysis were indeed PRISMA-compliant. The PRISMA certification process is an extremely articulate and time-consuming task. To compile a sample of articles that officially "checks all of the boxes" is extremely difficult, so rather than going through each individual item, articles were filtered out if they were clear and obvious in not following the desired format. Therefore, it is assumed that the remaining articles did meet compliance because they met the requirements from a simple surface-level perspective.

There were also several limitations that impacted the research. For one, there is not a lot of literature available on touchless technologies, meaning that the literature review's ability to provide multiple sources for a singular subject matter is lower than desired. Additionally, touchless technologies are constantly changing, meaning that

introducing future literature may impact the outcomes of this study if the research is repeated. Perhaps the biggest limitation lies within the methodology of collecting themes for the thematic analysis. Simply put, inserting text from the articles into a software can check for word similarity, but it will not read and interpret what is actually being communicated. Where the reference analysis can be completed through a program, the thematic analysis requires the researcher to read and interpret the papers. This introduces an element of user error and bias into the results of the study, which could potentially impact the replicability of results if repeated by another researcher.

**Significance of Study**

As previously mentioned, the negative effects of the COVID-19 pandemic were felt by organizations across the globe, which provided further evidence that organizations must consider adapting their work environments to be safer to maintain their economic productivity. This is where touchless technologies could come into play; it could be an effective way to reduce the spread of germs while allowing employees to come to work and be productive. With that said, it would be financially irresponsible for organizations to completely shift their business models around touchless technologies since a fully adapted workplace may not be practical. There may be types of touchless technologies that are worth considering, and there may be others that are not. This all depends on the advantages and disadvantages of touchless technologies themselves and the subjective needs of the organization. By understanding the different uses of touchless technologies and evaluating their advantages and disadvantages, organizations can responsibly make calculated decisions on implementing them around their business models.

## Remaining Chapters

Chapter II is the literature review for this research. It includes the information that is relevant to thoroughly describing the different touchless technology types and their capabilities. Chapter III describes the methodology used during this research. It elaborates in greater detail on the executive-level style summary discussed in the methodology section of this chapter. Chapter IV presents the results of this research. It follows a similar pattern to that of the methodology chapter, displaying each of the results found from following the methodology. Chapter V provides the conclusions reached during this research. It addresses the investigative questions, applications to the United States Air Force, and future research needed to continue the goal of exploring the capabilities, conveniences, and drawbacks of touchless technologies.

# II. Literature Review

The purpose of this chapter is to provide the reader the foundational knowledge required to understand the topic at large. This chapter will begin with an introduction to touchless technologies in general. This topic will allow the reader to understand what they are and the reasoning behind why organizations are considering them more heavily. The chapter will then introduce each of the five categories of touchless technologies, where each type will be broken down into more detail. Following the breakdown of each category, the key themes identified across the contributing literature will be discussed. The chapter will then conclude by summarizing the importance of touchless technologies and by transitioning towards the upcoming methodology chapter.

## Introduction to Touchless Technology

Simply put, touchless technologies are devices that do not require the physical touch of the operator to achieve its function (Stein, 2020). They do not have to look similar in size, shape, or even perform the same tasks; the aspect that connects touchless technologies to each other is the elimination of physical contact from the user to the device (Vinson, 2020).

Touchless technologies in general were created for many different applications. Some were made to reduce the amount of energy and resources being used within facilities; examples of this include automatic faucets that conserve water (Lozier, 2016). Some have been created to increase the level of safety in terms of public health; for instance, there are light fixtures which emit different frequencies of light that are

activated periodically within hospitals to sterilize rooms from transmissible disease (Landgrebe, 2011). Some have been designed to reinforce levels of security within infrastructure; this includes biometric scanning for entering both physical spaces and cyberspace (Ramanthan, 2021; Lin et al., 2018). Some have been made to proactively monitor the health of infrastructure systems and automatically report data to engineers and facility managers, thereby informing them on the current state of the building (Meyer et al., 2014). No matter which application though, these technologies share the trait of not requiring physical touch to control.

## Functional Categories

To understand touchless technologies in greater detail, a more in-depth breakdown of their different categories needs to be discussed. All of the touchless technology literature can be organized into five groups based on their general functionality: (1) facial/biometric recognition technologies, (2) gesture recognition technologies, (3) touchless sensing technologies, (4) personal devices which prevent public touch, and (5) voice recognition technologies (Stein, 2020). This remainder of this section will further explain each category of touchless technology.

### Facial/Biometric Recognition

The first category that will be discussed are technologies that are designed to identify and track the biometrics of the user. The crucial element that separates this type of technology from the rest is the role of the user (Ratha & Govindaraju, 2007). Unlike the other categories, biometric analysis distinguishes users from non-users, thus allowing

only specific people to utilize the device (Ratha and Govindaraju, 2007). Biorecognition technologies are used to compare data collected from a particular individual to a database; this is done to identify positive or negative matches between the user and the system (Ratha and Govindaraju, 2007). The most common uses of this category are for security purposes, and the means by which these technologies collect biometric data include contactless fingerprinting, facial recognition, and eye/iris recognition (Ratha and Govindaraju, 2007). For all the means by which these technologies gather data, it is important that the equipment is as accurate as possible so that security breaches are avoided. A visual explaining facial/biometric recognition's capabilities can be found in Figure 2.

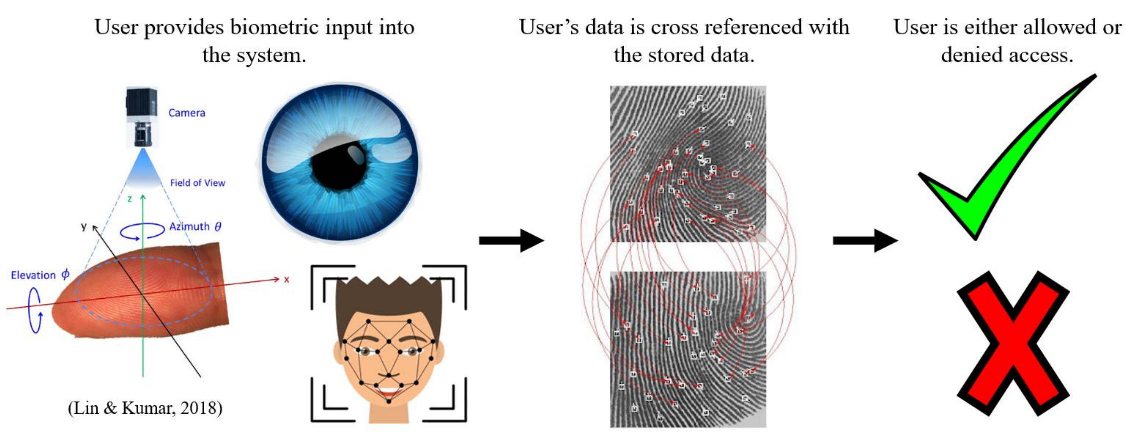



Figure 2. Visual of Facial/Biometric Recognition

Fingerprinting technologies are considered to be the most common of all biometric technologies, as each appendage's unique ridge pattern can serve as a key for the user in question (Parziale, 2008). Traditionally, fingerprints were captured within

two-dimensional space through the scanning of the print on a transparent surface, but there have been issues with this method. The biggest issue is the potential distortion of the print when "smushed" onto the flat surface. An analogy that captures this problem is like the stretching of continents on maps compared to the globe of the earth; the naturally convex surfaces of the fingertip are distorted when placed onto a pad, thus causing the data to be a less accurate representation of the user (Parziale, 2008). The issue that arises is that the areas of stretching are always inconsistent. Because each fingerprinting action warps the skin in a different way, there is a variance of results between the user's immediate fingerprint and the saved data on file (Parziale, 2008). The most recent advancement to correct this distortion problem is through touchless scanners that capture three-dimensional information (Parziale, 2008). This type of fingerprint scans the finger using lasers, and the finger does not come in contact with a traditional transparent pad (Parziale, 2008). By keeping the biometric data in the form of a round fingertip rather than a stretched two-dimensional image, the user's immediate scan would in theory better match the data that is associated with the account (Parziale, 2008). However, this is so far only theoretical. The reality is that accuracy of the lasers and the consistency of the environment (contrast, lighting, different finger positions, and illumination) have yet to provide consistent results (Parziale, 2008). Higher consistency and accuracy will likely improve as the capability continues to advance.

Facial recognition technology uses similar scanning capabilities to that of the three-dimensional fingerprint, but it aims to recognize the user's face (Sinha, 2019). Because it is possible for the angle of the user's face to vary during scanning, only taking one sample of data would not be sufficient (Sinha, 2019). This also holds true if the face

is displaying different expressions; different emotions will provide different data for the system. Because of this, multiple images need to be taken instantaneously for the purpose of maximizing the possibility of outcomes (Sinha, 2019). The different angles and lighting settings of all the separate pieces of data can combine to create and archive an "eigenface," which often consists of up to 150 eigen images (Sinha, 2019). It is crucial for the eigenmatrix of facial recognition data to be extremely diverse to improve its ability to recognize the user's face and thus reduce the threat of security breaches (Sinha, 2019). This method of cross validating the eigenmatrix's data with the current user is extremely effective at allowing access for the correct people and yields extremely high success rates (Sinha, 2019). Similar to the fingerprint, the ability to render three-dimensional images provides more data for the system, which makes the security protocol more accurate and harder to obtain false positives. With that said, the complexity of the system continues to experience similar errors with respect to camera and sensing (Sinha, 2019). These inaccuracies will likely improve as the technology continues to evolve.

Following a similar trend of the previous examples, another form of biorecognition is through iris scanning. The iris, which is the portion of the human eye that distinguishes eye color, is unique to the human body and hardly changes as one ages, which makes it completely distinguishable from other people (Latman & Herb, 2013). The iris can be individually identified on a person whether or not the user is a contact/glasses wearer, blind, and/or if they experienced eye surgeries (Latman & Herb, 2013). To begin, the system first collects the user's data by scanning the iris using both visible and infrared light waves (Latman & Herb, 2013). For the technology to be able to

scan the iris properly, the user needs to be staring directly into the camera lens at a short to medium distance away (Latman & Herb, 2013). Both of these images combined associate a biometric identity to the user, which gives them a unique “key” consisting of distinct characteristics of their iris (Latman & Herb, 2013). By archiving this image, technologies will be able to compare immediate scans with their archives to either allow or deny the person access. Although the cameras used for iris scanning are considered to be more expensive than the cameras for fingerprints and faces, the technology itself yields more reliable results compared to the other two methods (Sinha, 2019). It is regarded to be the most unforgeable biometric data due to the simplistic camera setup and the truly unique and unchangeable characteristics of the human iris (Latman & Herb, 2013).

<u>Gesture Recognition</u>

The second category consists of technologies that are designed to execute commands based on the motions of the user. The overall concept of these technologies is to read the user’s movements using cameras and sensors, interpret the movement, and perform the necessary actions based on what the user is requesting (Vuletic et al., 2019). This is similar to how a keyboard and mouse operates; if the user is telling the computer to go to the next page of a document, they send the command by scrolling down on their mouse, and the computer interprets that message by shifting the document down on the screen (Vuletic et al., 2019). However, since these are touchable buttons, the interpretation of that request is relatively simple compared to gesture recognition. For these technologies, the system must have accurate cameras and sensors to properly

decipher the commands using their software (Vuletic et al., 2019). A visual explaining gesture recognition's capabilities can be found in Figure 3.

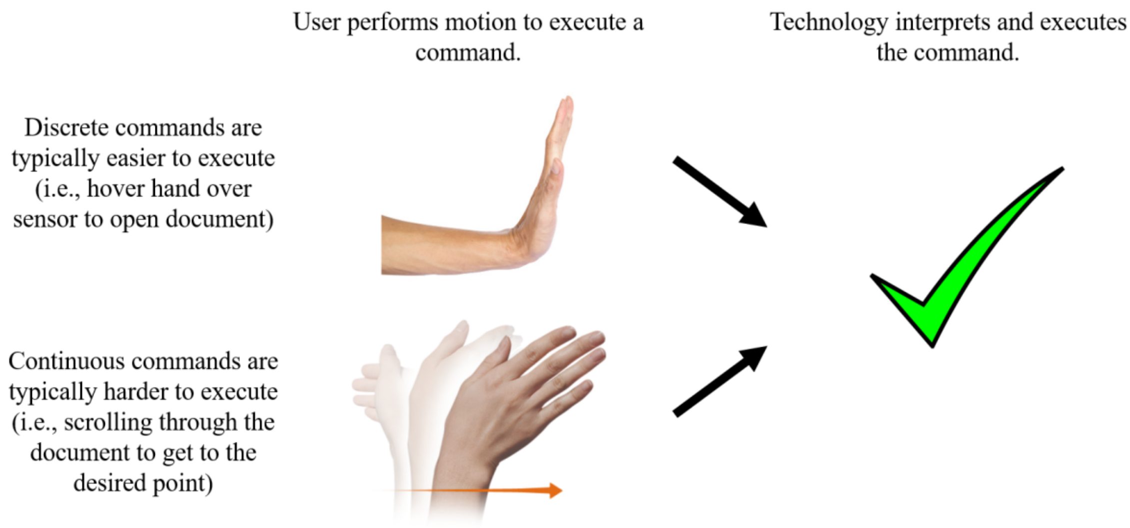



Figure 3. Visual of Gesture Recognition

For the gesture-based command sequence to work, the designers of the system must first understand how humans physically communicate with one another. Throughout human history, people have often used hand gestures to communicate their ideas and feelings (Vuletic et al., 2019). The art of communicating with one's gestures is such a strong method of communication that it is able to overcome language barriers, thereby helping individuals of different nationalities and cultures understand what one is expressing (Vuletic et al., 2019). These commonly understood messages when interpreting gestures can help the programmers/designers create the recognition language for the system (Vuletic et al., 2019). For instance, the act of executing a scrolling command can be done by making an upward swiping motion with your hand. This

upward swipe would then be interpreted by the cameras to execute the command of scrolling (Vuletic et al., 2019). It has been confirmed by studies that this type of communication is quick for a programmer to implement; this is due to the designer's plan to create commands based on instinctual motions that people use every day to communicate messages (Vuletic et al., 2019).

The two main categories of gesture commands are either discrete or continuous commands, and each of these are associated with a wide array of different communicative gestures (Liu et al., 2020; Vuletic et al., 2019). The discrete command, which includes motions such as hovering one's hand in a specific location, is primarily used for computing actions that are definite in nature (Vuletic et al., 2019). For example, hovering over a specific location would indicate that the user wants to select that item; this would be equivalent to clicking on a document in a computer setting (Vuletic et al., 2019). Interpreting static gestures as discrete commands has been relatively successful compared to continuous commands. As the advancement of gesture-based touchless technology has increased, more advanced camera and sensing equipment has been able to interpret discrete commands at higher and higher success rates (Vuletic et al., 2019). Continuous commands, however, fail to meet the same high success rates primarily due to the complexity that is associated with dynamic motion (Vuletic et al., 2019). Since a continuous command is sequential rather than instantaneous, each continuous command goes through five phases which blend with one another: (1) the user prepares to execute the motion, (2) the user begins to place their hand or body in the location where they want to begin the command, (3) the user executes the command at the location where they placed their hand or body, (4) the user begins to retract their hand or body from the

area in which they are executing their command, and (5) the user fully retracts themselves to end the command sequence (Vuletic et al., 2019). Using the scrolling example from earlier, the user must hover their hand over where they want to scroll, continue scrolling with their hand until they want to stop, and then move their hand out of the camera's scope to officially stop the command. This complex sequence of events, and the range of complexities and possibilities within each of these steps, are naturally more difficult for cameras to track and for programs to interpret (Vuletic et al., 2019). With that said, as gesture recognition technology improves with time, continuous commands have been receiving higher success rates (Vuletic et al., 2019).

The capability of gesture recognition technologies has been advancing, but the premise is still considered to be used in only niche areas (Liu et al., 2020). For instance, gesture-based technologies are extremely useful in locations where the traditional keyboard and mouse cannot be used, such as underground mining locations due to active mines not having standard office equipment (Liu et al., 2020). In addition, the technology is typically being developed for recreational use as opposed to operational. An example of this is Microsoft's Kinect One, where the cameras on the device are accurate enough to play games but not precise enough to execute accurate commands for work settings (Liu et al., 2020). Furthermore, gesture recognition technology's easy-to-learn functionality is offset by the fatigue that is created as a result of use. While gesture recognition technology's capabilities are evident, the greatest issue in this category is properly applying utility within the operational environment (Liu et al., 2020).

Touchless Sensing

The third category consists of touchless technologies that are also designed to execute commands based on motion. However, these technologies are more simplistic than gesture recognition; they are either activated or deactivated by tripping a sensor or utilizing a sense of time through an internal clock and schedule (Das et al., 2021; McMullen, 2020). Both methods of sensing do not require physical touch for its operation. A visual explaining touchless sensing's capabilities can be found in Figure 4.

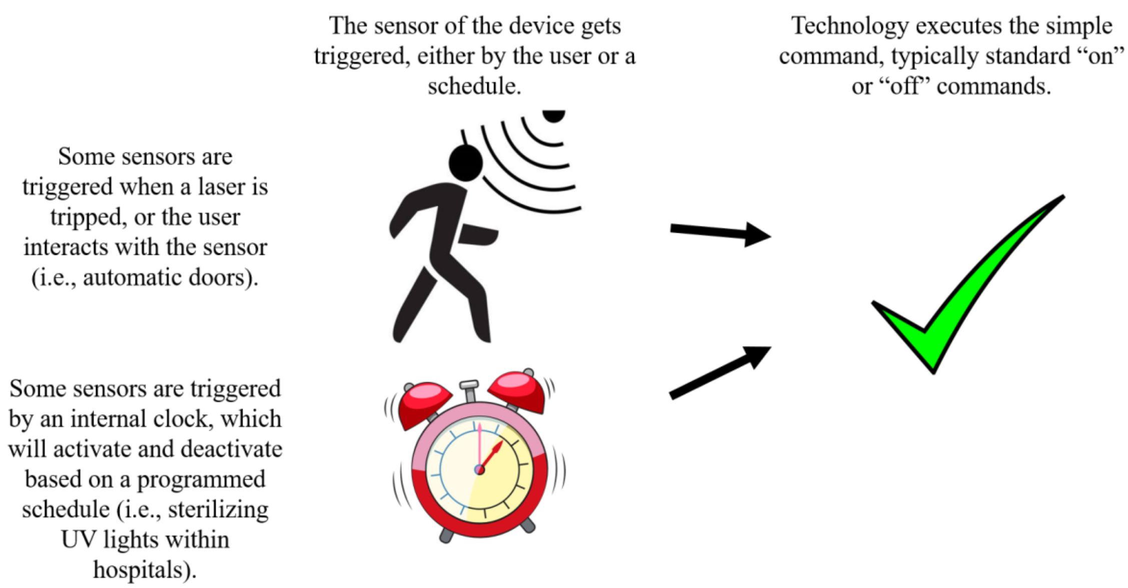



Figure 4. Visual of Touchless Sensing

The most basic form of touchless sensing technologies is where the user interacts with a projected beam of infrared light and/or ultrasonic sensors (Lozier, 2016; Das et al., 2021). As opposed to gesture recognition, the commands that are associated with touchless sensing are much simpler by nature and only require the "tripping" of a sensor

to activate (Lozier, 2016). For a device that uses lasers and sensors, it is initially static when the infrared light and/or ultrasonic sensors are unaffected (Lozier, 2016). The system will continue to remain inactive until the user interferes with the static infrared light and/or ultrasonic sensor of the system (Lozier, 2016). By "getting in the way" of the sensor or infrared beam of light, the action activates the device (Lozier, 2016). A perfect example which illustrates this sequence of events is through touchless sensing faucets; the faucet begins by not running water, and it will continue to not run water until the ultrasonic sensor underneath the nozzle receives interference from the user (Lozier, 2016). Once interfered, the faucet will activate and provide water out of the nozzle (Lozier, 2016). For these types of touchless sensing technologies, the system remains active until the sensor is no longer being interfered with. In other words, once the user is no longer affecting the sensor, the device will return back to its static state (Lozier, 2016). However, some technologies are designed to be inactivated by an automatic timer rather than a second interference event; a common purpose for this is energy conservation (Lozier, 2016). This is so that the device does not have to remain in its active state and waste resources if it is not being properly used (Lozier, 2016). Regardless of how these types of technologies deactivate (re-tripping or timer), the activation of these technologies is executed through the interference of its sensor (Lozier, 2016).

Another common form of touchless sensing is using schedules to activate and deactivate the system. For these types of devices, a sensor or infrared beam is not necessarily required because the system is not reliant on the presence of the user to be activated (Casini et al., 2019). Instead, the system is scheduled to activate and deactivate using a programmed amount of time, meaning that touch is not required for activation

and deactivation (Casini et al., 2019). An example of this type of touchless sensing technology is through ultraviolet light emitting devices; for example, it is imperative that critical rooms, such as operating rooms in hospitals, are disinfected on a consistent basis (McMullen, 2020). An effective method for hospitals to sterilize rooms quickly is to emit specific wavelengths of ultraviolet light throughout the room (McMullen, 2020). Because this light is extremely effective at killing microorganisms, this device cannot be used with people present because its rays can harm humans (McMullen, 2020). Therefore, the devices are activated and deactivated based on a timer, particularly during hours that humans are not inhabiting the critical rooms, thus showing that their functionality does not require the physical touch of the user (McMullen, 2020).

Another useful subcategory of timer-based sensing consists of smart-infrastructure systems that automatically track and report data through a system of links and nodes (Morimoto, 2010). These touchless sensors are becoming more prevalent in modern infrastructure planning due to their utility (Morimoto, 2010). The fundamental purpose of this type of sensors is to provide real-time data about the health and operations of a group of facilities (Morimoto, 2010). The type of information that is collected by these technologies includes (but is not limited to) electricity and water usage, room temperatures, and the structural health of a facility (Morimoto, 2010). This type of technology is utilized to track and report facility data for the purpose of gaining an understanding of the building's health. This way, the users who are collecting data can evaluate a situation accurately, make decisions based on the reported data, and execute projects to optimize their infrastructure's utility (Morimoto, 2013).

Personal Devices

The fourth category consists of touchless technologies that are personalized devices that limit the amount of physical interaction with public surfaces and technologies (Kamble et al., 2021). Regarding personal devices, it is possible for the technologies themselves to utilize a sense of touch, particularly in cases where the user is interacting with their own device (Kamble et al., 2021). With that said, the reason this is still considered a touchless technology is because a personal device acts as a buffer to minimize the effects of fomite transmission (Kamble et al., 2021). In other words, someone touching their own device limits interaction with other public devices and spaces. A visual explaining personal devices' capabilities can be found in Figure 5.

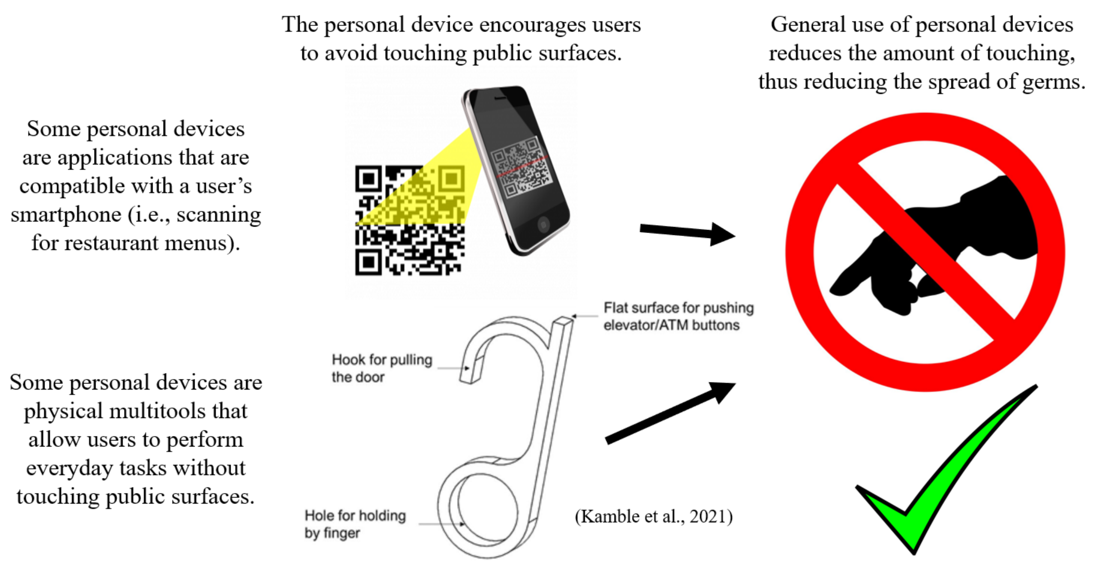



Figure 5. Visual of Personal Devices

An example of a personal device, which illustrates how simple yet effective they can be, is the COVID key; this key is a multifunctional physical tool that can be used to minimize contact from public surfaces (Kamble et al., 2021). Some of the tasks that this device can accomplish include turning doorknobs, pushing/pulling door handles, pushing elevator buttons, gripping rails, grabbing thin surfaces such as dollar bills and credit cards, opening bottles, etc. (Kamble et al., 2021). As many surfaces and objects have been touched by multiple people over an extended period of time, being able to perform these functions through a personal device allows one to avoid touching surfaces (Kamble et al., 2021). Devices such as the COVID key are portable and compact, which encourages users to be equipped with them at all times; however, the key is unable to achieve all necessary goals when it comes to minimizing the spread of germs (Kamble et al., 2021). Where many of the common applications could be accomplished with the key, there will simply be certain functions that a personal device is not built to perform (Kamble et al., 2021).

Where the COVID key serves as a personal device for physical tasks, an individual's smartphone can also be used as a touchless technology (Wanga et al., 2020). Through the use of downloadable applications, people are able to accomplish a wide array of tasks, and this includes both professional and personal/recreational tasks (Wanga et al., 2020). Professionally, during the COVID-19 pandemic, many tasks such as scheduling and conducting meetings, transferring documents, and notifying others of important information, were easily conducted through cyberspace, which allows economic productivity to survive during the shutting down of offices (Wanga et al., 2020). Personally, people were able to discuss medical issues with their doctors,

purchase groceries, order meals for their families, wirelessly book travel information, and complete other errands without having to touch the public domain and thus ensuring safety from infectious germs (Wanga et al., 2020). Recreationally, people were able to stream their favorite content without having to go to public theatres, video chat with their friends and family, and take care of their health by attending exercise classes all without the risk of infecting others (Wanga et al., 2020). For many aspects of everyday life, the COVID-19 pandemic did not stop people from being able to conduct their daily routines while remaining safe due to personal devices.

However, in instances where social interaction is inevitable, people adapted their personal devices to facilitate these interactions (Wanga et al., 2020). The development of applications allowed even the most trivial person-to-person interactions to be minimized, which in turn minimized the spread of fomite-transmitting diseases (Wanga et al., 2020). An example of this application of touchless technology exists in the restaurant business. Normally, the restaurant would distribute their menus to their customers to inform them of what they are serving, but the threat of spreading COVID-19 through the passing and exchanging of menus caused restaurants to adapt (Wanga et al., 2020). Rather than exposing their customers to danger, restaurants created downloadable menus for customers to scan and view through their smartphones (Wanga et al., 2020). Since the users are touching their own devices, they are minimizing the spreading of disease because it is only their personal device they are touching (Wanga et al., 2020).

Not only were smartphone apps helpful in conducting personal business during the pandemic, but personal devices also helped fight the spread of COVID-19 more directly (Utz et al., 2021). Smart phone application developers utilized this philosophy to

achieve the following objectives. It collected COVID-19 infection history from a network of users. Once the data was safely secured, it tracked those users' locations so that other people could identify how and where the disease was spreading (Utz et al., 2021). It also automatically sent the data to research institutions for the purpose of studying the patterns of the disease (Utz et al., 2021). For the purposes of protecting others from potential infection, citizens have generally accepted apps such as these as long as their privacy is protected (Utz et al., 2021). This category of personal devices clearly has a wide application of uses to not only encourage users to limit the touching of public surfaces, but it also helps fight the spread of fomite diseases (Utz et al., 2021).

Voice Recognition

The last of the five categories consists of touchless technologies in which the user's voice gives the device commands to execute. Touchless, hands-free technologies have allowed users to multitask; however, in examples like gesture recognition, the user may be in the middle of a task and cannot make a gesture, meaning they would be unable to multitask (Prathima & Shimi, 2017). Voice recognition technology allows users to be completely engaged in their activities while also giving commands orally, thus serving as a technology with lots of potential (Prathima & Shimi, 2017; Cronin & Doherty, 2019). A visual explaining voice recognition's capabilities can be found in Figure 6.

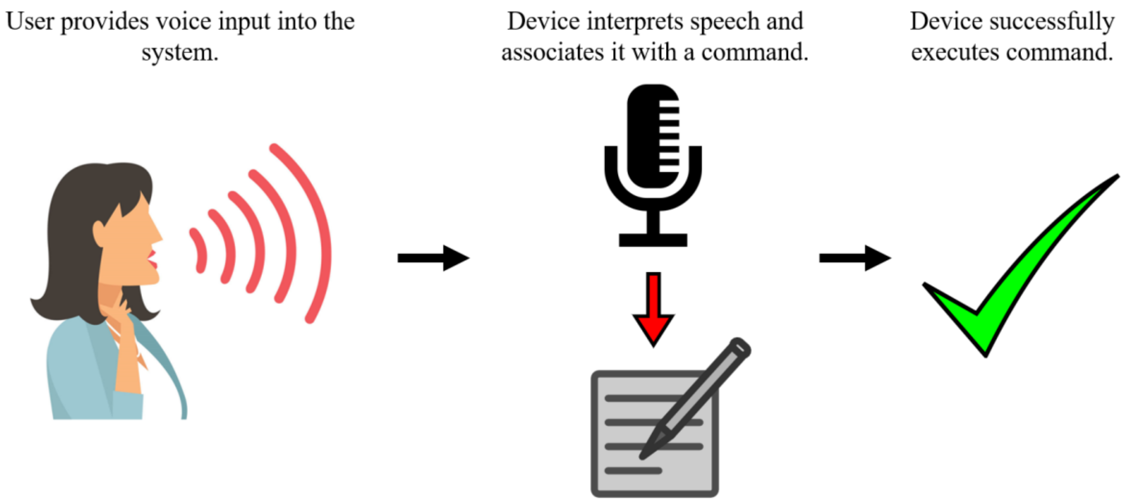



Figure 6. Visual of Voice Recognition

The overall operation of voice recognition technology consists of the user providing a command though the device's microphone, the computer within the device recognizing the speech and interpreting its meaning, and the controller of the device executing the command (Prathima & Shimi, 2017). The key step of this process, which is the interpretation of speech, is conducted through an Arduino platform/microcontroller (Prathima & Shimi, 2017). This piece of technology consists of both the physical hardware and integrated software responsible for dissecting the user's speech through the use of coding languages that transfer human speech to executable code (Prathima & Shimi, 2017). For the voice recognition module to become effective at translating speech, the system needs to be trained in both understanding the user's voice and executing commands (Prathima & Shimi, 2017). Some of the simple household commands that can be executed through this technology include, but are not limited to, switching on and off lights, controlling the television by speaking into a remote, and text-

to-speech capability that will read and send text messages through audio (Prathima & Shimi, 2017).

As previously mentioned, voice recognition technologies allow users to easily multitask, thereby letting them execute commands while simultaneously focusing on their objective at hand (Simmons et al., 2017). An example that demonstrates this is operating an automobile's console and dashboard controls (Simmons et al., 2017). Distractions while driving, particularly from cell phones and extra features built into the car, have been growing in number and causing car accidents to increase (Simmons et al., 2017). While legislation has played a role in reducing the number of people using their cell phones while driving, the demand for connectivity while on the road still remains high (Simmons et al., 2017). Whether the user desires to send a text message, enter a location to navigate to, or update their music selection, the temptation for the driver to operate their phone while driving remains extremely high (Simmons et al., 2017). While hands-free devices, such as buttons on the steering wheel, have allowed users to perform tasks such as switching songs, the growing complexity of what a personal device can accomplish requires more hands-free operability for drivers (Simmons et al., 2017). Many of those tasks can be completed now using voice recognition technology that is built into the automobile; this allows users to completely focus on their driving (Simmons et al., 2017).

This hands-free multitasking approach is not only used with cell phones, but it has been used in professional settings as well (Cronin & Doherty, 2019). In hospitals, surgeons require both of their hands and full attention to perform their work; this is where voice recognition capabilities can aid those doctors (Cronin & Doherty, 2019). It is

crucial for a doctor to remain sterile before and during the entire life of the operation, so in order to execute different commands, they cannot compromise themselves to potential germs (Cronin & Doherty, 2019). Voice-activated commands during surgery not only allows surgeons to fully focus on their tasks, but they keep surgeons from being compromised by surrounding germs (Cronin & Doherty, 2019). In hospital settings, voice recognition technologies are used to achieve multiple types of tasks (Cronin & Doherty, 2019). For example, commands for the purpose of inputting text allow a doctor to simultaneously write a report of the surgery while performing it; this is extremely beneficial because surgeons can record their experiences while the events are fresh in their mind (Cronin & Doherty, 2019). Discrete commands, such as activating lights and machinery, also allow a doctor to utilize technologies to aid them during surgery (Cronin & Doherty, 2019). While vocal fatigue is a possible outcome when constantly speaking to these technologies, utilizing vocal commands proved to be less taxing than using keyboards because the doctor did not have to spend time typing after an exhausting surgery (Cronin & Doherty, 2019).

There have been efforts to integrate facilities with voice recognition technologies in efforts to create touchless facilities (Alexakis et al., 2019). Some smart facilities contain the hardware to execute vocal commands and the proper internet connections to interpret the speech of the user (Alexakis et al., 2019). Infrastructure and built-in appliances that are connected to the internet utilize natural language processing, which is a type of artificial intelligence used to interpret speech (Alexakis et al., 2019). With this capability, users are able to identify and control aspects of the facility such as the temperature, humidity, and which lights are activated throughout the facility (Alexakis et

al., 2019). As appliances' abilities to connect to the internet continues to skyrocket, additional capabilities can be added to a smart building's overall functionality (Alexakis et al., 2019). However, this connectivity has its drawbacks. As this kind of smart facility requires an internet connection, cybersecurity threats remain a concern since the facility could be hacked by outside users (Alexakis et al., 2019). Nevertheless, voice recognition can serve to transform a facility into one that is integrated with touchless technologies, thereby providing convenience to the user (Alexakis et al., 2019).

**Key Themes from Review**

The entire literature review, which covered content in each of the five categories, shared common themes with one another in terms of the overarching thematic and reference analyses. Regardless of the current states of each of the touchless technology categories, a major commonality that they all share is the growing need for these technologies to improve. Vinson (2020) explains the necessity for touchless technologies: "According to market reports, the demand for touchless technology is growing at the rate of 17.4% and will reach $15.3 billion in 2025 from $6.8 billion in 2020. This growth is certainly a reflection of how touchless technology is considered an asset in our collective efforts to mitigate the COVID-19 outbreak." A thorough review of the collected literature confirms that while touchless technologies are evolving, their potential advantages and disadvantages are being evaluated by organizations worldwide to determine if their utility would improve their operations (Vinson, 2020).

Not only is there an evident demand present, but the desire for further exploration and study was present for each of the five categories as well. There is clearly an interest

within the scientific community to further investigate the potential that touchless technologies has to offer.  Both the high demand and growing need for research illustrated the following concepts on the topic.  As the push towards touchless technologies is still relatively new, progress and development of the different categories differs greatly from one another.  The high variability of themes demonstrates that there is little to no universal objectivity of a technology's worth, as the analysis in the literature shows high degrees of subjectivity.  Through examples of case study analyses, in-depth literature reviews, and other types of academic works, the literature identified the subjectivity in utility that touchless technologies can provide.

**Conclusions from Review**

The literature shows that touchless technologies serve the purpose of satisfying a specific objective, while also completing the desired goal of eliminating or minimizing touch.  Determining the worth of these technologies is a difficult task because (1) each technology is different from one another and (2) each resulting outcome that can be accomplished by using them is valued subjectively amongst various organizations.  Nevertheless, the information found in the literature review helps inform the research being addressed.  This chapter also helps provide necessary context to the reader regarding touchless technologies.

# III. Methodology

The objective of this chapter is to describe the methodology that was used to address the overarching goal of the research. The topics that will be covered in this chapter are the selection and observation of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)-compliant literature, the thematic analysis, the multiple components comprising the reference analysis, and the comparison between the two analyses. Figure 7 describes a macro level approach to the entire methodology of the research.

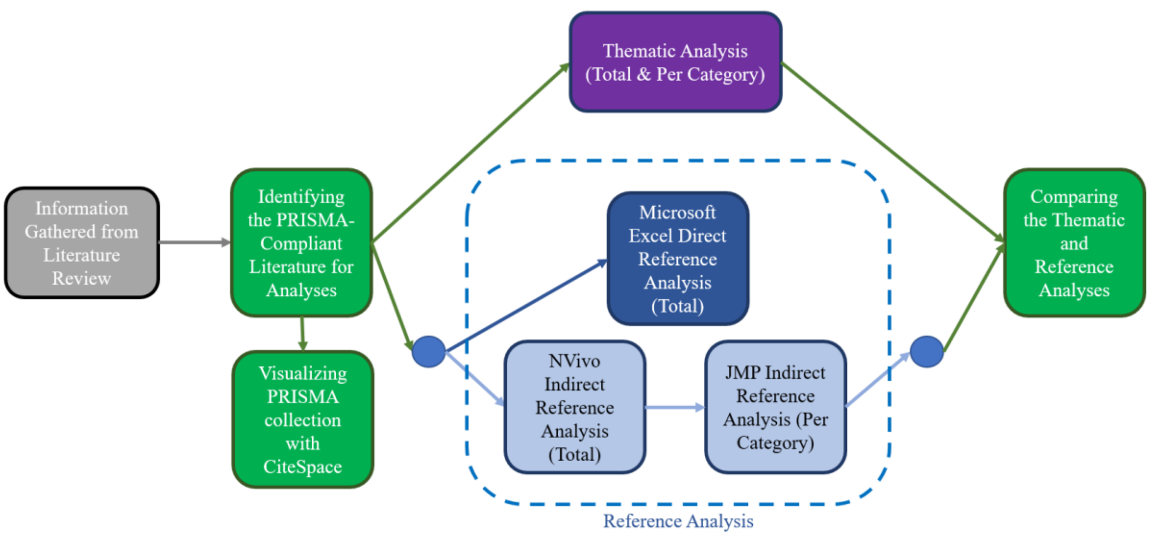



Figure 7. Methodology Flowchart

**Collecting PRISMA Literature**

This section will include the methodologies for identifying PRISMA literature and modeling PRISMA literature. The purpose of identifying PRISMA literature is to establish a list of collected articles that will be used to continue the research. The purpose of modeling PRISMA literature is to gain a better understanding of the selected literature before analyses begin.

Identifying PRISMA Literature

During the literature collection process, it is possible for diverse types of literature to be collected. With that said, accumulating the literature serves to be one of the biggest potential problems to preserve the replicability of the entire methodology. For a process to be repeatable, the method in which those papers are obtained needs to be systematic. If the researcher does not follow a disciplined set of procedures, and instead simply searches for literature freely, there are multiple problems that could arise. For one, the researcher may not be searching for literature in the most unbiased method possible; freely searching for articles may unintentionally insert bias and reader subjectivity into the search engine. Additionally, it is possible for the search engine itself to contain some sort of bias while searching based on the user's keywords. This variability in how a researcher can obtain literature could lead to varied thematic results because of the user's bias and/or the search engine(s)'s bias. A visual representation of identifying PRISMA literature is shown in Figure 8.

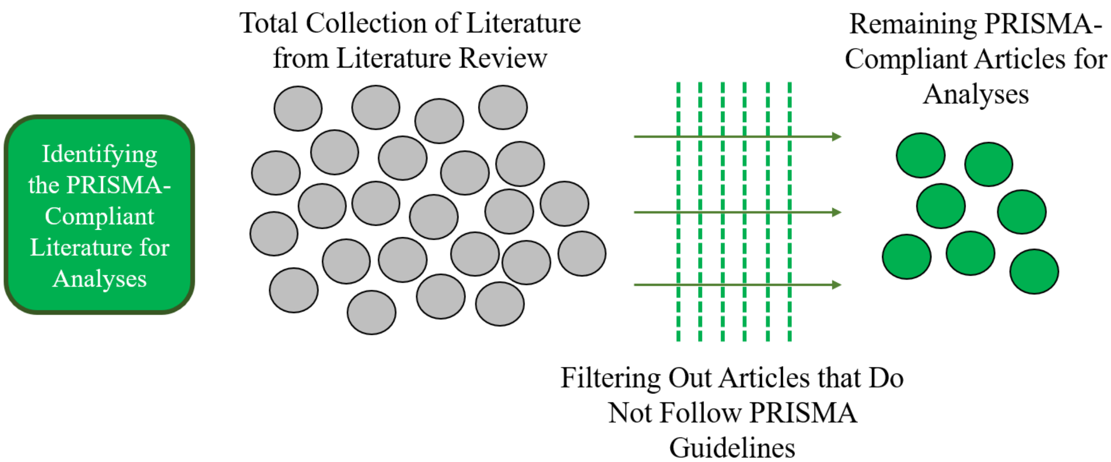



Figure 8. Visual of Identifying PRISMA Literature

An effective method of finding standardized literature is through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Rethlefsen et al., 2021). Essentially, PRISMA stipulates that articles contain the following: a clear title, abstract section, introduction, methods, results, and discussion. The titles of each of these sections may not match exactly, but the article is accepted if the format is still relatively clear. Therefore, to keep the process as repeatable as possible for future iterations, articles that did not follow this standardized structure (i.e., were not PRISMA-compliant) were removed from further analysis. However, the total collection initially provided utility because it was used to help inform the research in the literature review chapter.

In total, 76 articles were collected as a result of conducting the literature review. To determine which of these articles were considered PRISMA-compliant, each article was opened side-by-side with the PRISMA 2020 Item Checklist found from Page (2021). The process consisted of following this checklist and verifying whether or not the 76

articles contained these attributes. An article that was considered PRISMA-compliant contained elements of this checklist. If an article was missing elements of this standardization, it was removed from the collection that would be used to conduct the analyses. The reduction in overall data introduced a potential constraint in that it would be possible that not enough data could be used for analysis. It is imperative that a large enough sample size be collected to account for the potential shrinking of useable data.

The selected articles were classified as either a systematic review of a touchless technology category or a case study that provided key information on a specific touchless technology category. The following observations were made with the articles that were considered to be PRISMA-compliant.

- Each of the abstract sections covered a touchless technology category for the reader to easily identify.
- Each of the introductions provided an articulate rationale and listed their objectives to foreshadow their methodologies and results.
- Each of the methods sections contained eligible criteria regarding the quality of their information sources, data and data collection processes, effective measures regarding analysis outcomes, synthesis methods, and the assessments of those results.
- Each of the results sections contained proper diagrams and/or approaches to presenting their findings, the referenced studies were properly cited, and the results of the syntheses were effectively captured.

- Each of the discussion sections interpreted the analyses effectively, the limitations of the evidence and/or review processes were thoroughly explained, and the future implications of the results were discussed in great detail.

Each PRISMA-compliant article was found using the academic search engine Science Direct Open Access Journals found on the Air Force Institute of Technology (AFIT) online library. Articles and literature that were not found through the AFIT online library were found using Google Scholar. With the PRISMA-compliant articles selected, the methodology section could continue with both the thematic and reference analyses.

Modeling PRISMA Literature

To gain a greater understanding of the articles selected, the articles themselves were visualized according to their contents. In bibliometric analysis, a common practice of identifying the similarity of articles is the use of knowledge mapping (Zuo et al., 2021). The program CiteSpace can compare a collection of literature by identifying the mutual relationships found within patterns in the article (Zuo et al., 2021). Essentially, the higher the similarity, the closer that CiteSpace will plot the articles together (Zuo et al., 2021). Before conducting the specific thematic and reference analyses, the benefit of visualizing the PRISMA articles together is to gain a broader understanding of the collection of articles in general.

By converting the PRISMA iteration of the database into research information systems documents (RISD), they can be plugged into CiteSpace, which would produce a result relatively automatically. Two images will be visualized and examined, one being the authors and one being the contents of the articles. Conducting both will help initially

"tell the story" of the PRISMA articles before the thematic and reference analyses. To create the visualization for authors, the box for "author" was checked prior to running the program. To create the visualization for content, the box for "key words" was checked prior to running the program.

Guo et al. (2021) perfectly describes the utility of using CiteSpace as a tool for painting broader pictures: "CiteSpace usually works as an effective tool for researchers to extract network relations, research emphases, as well as research trends." Since the focus of this methodology is not through the use of bibliometric software, CiteSpace serves as an excellent tool for "scratching the surface." There are more advanced bibliometric programs that "present detailed information on the literature," but since the detailed portion of this analysis would be covered within the thematic and reference analyses, CiteSpace would serve to be a more appropriate application of bibliometric modeling software (Guo et al., 2021).

**Thematic Analysis**

The purpose of this section of the chapter is to explain the methodology used to conduct the thematic analysis. Quoting Zhou (2022): "Thematic analysis is defined as a method to identify, analyze, and discover the patterns of themes for a set of documents. After selecting the data relevant to the objective of the project, it requires encoding the data to uncover the meaningful themes and concepts of one area." Essentially, the overall objective of the thematic analysis portion was to understand the current state of touchless technologies by counting the number of advantages and disadvantages attributed to each technology within the articles. To answer the research questions, qualitative thematic

data needed to be collected for each of the five categories. The results of that data can help illustrate the overall advantages and disadvantages for each of the categories and for touchless technology as a whole. This process consisted of several steps that, when chronologically applied, helped identify the current state of touchless technologies. A visual representation of the thematic analysis is shown in Figure 9.

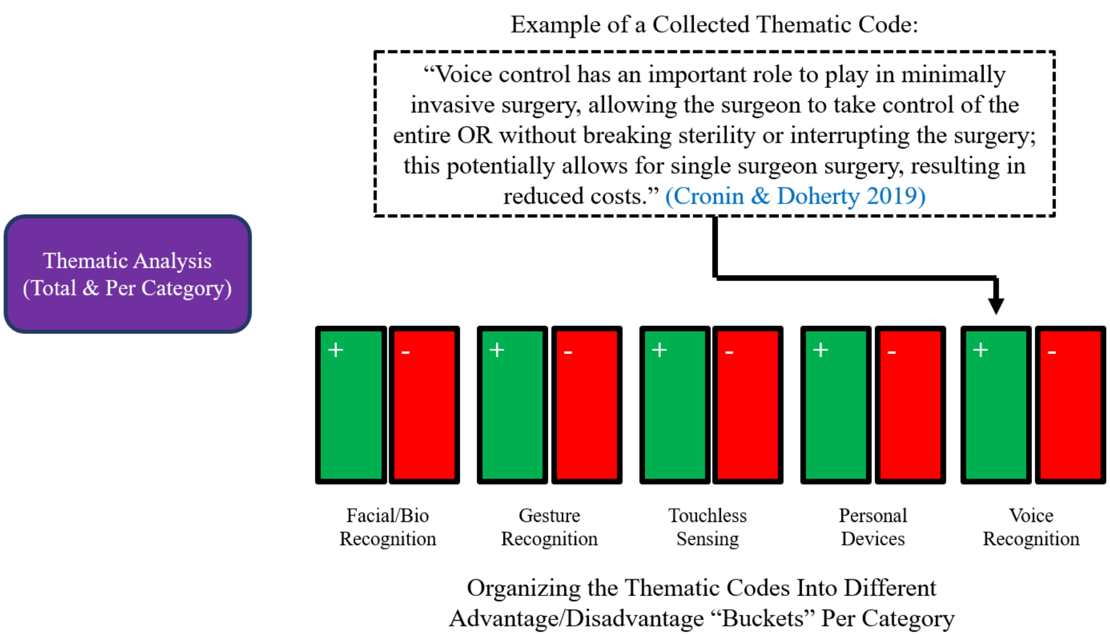



Figure 9. Visual of Thematic Analysis

The first step was gathering the PRISMA-compliant literature that elaborated on the themes of the touchless technology categories through case studies and independent literature reviews. The second step was to categorize the data collected from the literature. Since the overall objective of the thematic analysis is to weigh the advantages and disadvantages for each of the categories, there were multiple types of codes, or excerpts from the literature, that were extracted. For each of the categories, there was a

code "bucket" that collected themes expressing advantages and there was a "bucket" that collected themes talking about disadvantages. With that said, the following list includes each of the code categories: advantages for facial/biometric recognition technologies, disadvantages for facial/biometric recognition, advantages for gesture recognition technologies, disadvantages for gesture recognition technologies, advantages for touchless sensing technologies, disadvantages for touchless sensing technologies, advantages for personal devices, disadvantages for personal devices, advantages for voice recognition technologies, and disadvantages for voice recognition technologies. These code categories served as the foundation for the thematic analysis.

The third step was to read and interpret the collected data for the purposes of loading information within each of the ten code "buckets." This process consisted of identifying when the author was expressing an advantage or disadvantage within a category. An example of this type of thought process can be found in Cronin and Doherty (2019). The following excerpt clearly expresses an advantage of voice recognition technologies within the medical field: "Voice control has an important role to play in minimally invasive surgery, allowing the surgeon to take control of the entire OR without breaking sterility or interrupting the surgery; this potentially allows for single surgeon surgery, resulting in reduced costs" (Cronin & Doherty, 2019). The authors are communicating the convenience of voice recognition technologies during surgery. Because of this, this excerpt was saved as a code, and that code was then placed into the advantages of voice recognition technologies "bucket."

To complete the thematic analysis, it was important to quantify the qualitative information in the most objective and fair manner possible. In other words, it was not the

objective to interpret the collected codes and apply weighted values to them, for that would introduce a new level of bias into the methodology. Therefore, each of the thematic codes in a touchless technology category were weighted equally. To determine the number of advantages and disadvantages a category contained, the number of collected codes for each category's respective "bucket" were simply counted. On top of that, all of the five categories were also combined together, where all of the data that made up those five categories was used to create a composite ratio of advantages to disadvantages for touchless technologies as a whole.

The primary concern with this approach is the potential for bias and human error. Traditional keyword analysis software finds similarities within the text by matching characters and words based on word similarity. The primary problem with this traditional approach is that keywords and character/word recognition do not properly interpret the themes that are being discussed within the literature. To demonstrate an example of this limitation, Cronin and Doherty (2019) will again be referenced: "Voice control has an important role to play in minimally invasive surgery, allowing the surgeon to take control of the entire OR without breaking sterility or interrupting the surgery; this potentially allows for single surgeon surgery, resulting in reduced costs." Within this segment, the traditional keywords expressing an advantage such as "benefit," "value," or "asset" are not found, which means that an automatic keyword detector would not consider this an advantage for voice recognition technologies. In fact, the word "cost" is found within the excerpt, so even though the segment is discussing an advantage within the technology type, a traditional keyword analysis software would mark this segment as a disadvantage due to the word "cost" appearing. When conducting a thematic analysis, it is important

for the researcher to properly interpret the literature because the technology is simply incapable of doing so.  Unfortunately, this leads to the reality that researchers may inject their own biases and make mistakes.  Nevertheless, for a truly qualitative data analysis, it is imperative for the researcher to be diligent and impartial when deciphering both the advantages and disadvantages for any given topic.

### Reference Analysis

The purpose of this section is to explain the methodology used to conduct the overall reference analysis.  Bornmann and Marx (2013) discuss cited reference analysis by elaborating their take on a traditional analysis: "In contrast, we change the perspective and start by selecting all papers dealing with a specific research topic or field… Then we extract all cited references from this field-specific publication set and analyze which papers, scientists, and journals have been cited most often."  Rather than using a traditional citation analysis, which counts the individual citations within the article, the goal behind this reference analysis is to validate the results of the thematic analysis by demonstrating that the contents of the PRISMA-compliant literature are correlated with one another via their reference sections.  Two different approaches were used for the reference analyses.  The first approach consisted of direct reference analysis using Microsoft Excel, and the second approach consisted of indirect reference analysis using both NVivo and JMP software.

Direct Reference Analysis

Direct reference analysis treats every reference as a specific data point, and those specific data points are then cross-referenced across all the literature to find matches. As such, all of the PRISMA-compliant literature was reviewed to identify all exact matches found within their reference sections. However, the main problem that occurred when combing through the reference sections was that not all of the articles used the same bibliometric style. Two other issues that were found were that (1) not all of the references across all the articles were cited correctly and (2) not every saved PDF contained “copy-able and paste-able” reference data. It was clear that the data needed to be standardized, organized properly, and saved into a “copy-able and paste-able” format. A visual representation of direct reference analysis is shown in Figure 10.

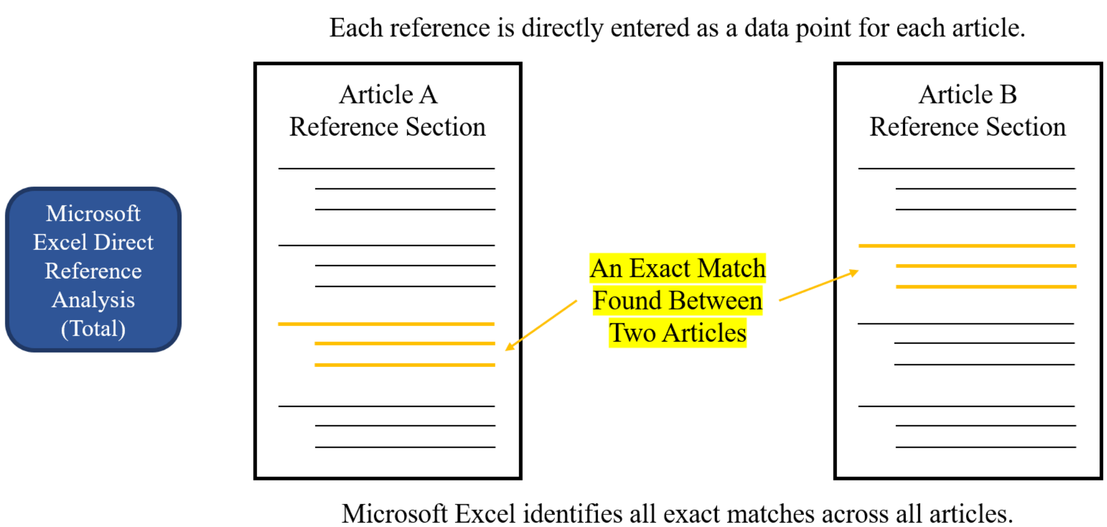



Figure 10. Visual of Direct Reference Analysis

Therefore, a Microsoft Word document was created that corresponds with every respective PRISMA-compliant article used during the analysis, sharing the same numeric label system.  The numbers in the documents' titles also corresponded with each article's abbreviated author and year.  For example, the Word document for the article named "COVID Key: A Multifunctional Device to Avoid Touch" by Kamble, Pushkar, Mittal, Hodgir, and Karunakaran was named "(Kamble et al., 2021)".  Both the article and the Word document shared the number title "64:" within their titles for easy identification.  Next, each article was opened alongside a tab of Google Scholar.  To ensure that each of the article's references were standardized and precise, each reference was copied and pasted from the article directly into the Google Scholar search bar.  From there, the reference was standardized by Google Scholar and available in three different formats: MLA, APA, and Chicago.  The Chicago format was chosen because it uses full names rather than abbreviations.  It was inferred that this format would provide more accurate data for the indirect reference analysis to be conducted next.  The standardized Chicago format for each reference was then copied and pasted into each of the article's associated Word documents.  These references would be considered data points for a data set, where the data set represents the collection of PRISMA-compliant articles.

From there, a Microsoft Excel data table was developed with the columns corresponding with the articles and the rows for each column corresponding to the references in each article.  To transfer the contents from each Microsoft Word document into the Excel data sheet, each reference was copied and pasted into each respective cell of the data sheet.  This process fully populated the data sheet with every reference of every article.  On a separate worksheet, a matrix was created, where the dimensions of

each side of the matrix equaled the number of articles used for analysis. The idea was that each combination of row and column on the matrix would provide the reader a number of exact matches between the two article's references. To accomplish this, a series of commands were utilized on the previous data sheet. These series of commands not only identified whether or not there were exact matches between two specified columns, but it also counted how many exact matches existed between those two columns. These commands applied for every combination of articles, and whenever a successful cross-reference was found between two articles, that cell was highlighted to make it easier for the researcher.

Indirect Reference Analysis (Total)

To contrast the direct reference analysis, the indirect reference analysis finds similarities using a different method. Rather than finding exact matches across distinct data points, the NVivo software reads all the data as one generalized data set for each of the PRISMA-compliant articles. The software is able to find similarities between different article's relationships based on word patterns. These similarities are measured through Pearson correlation coefficients, which track the similarity that is found between different combinations of articles. A visual representation of indirect reference analysis is shown in Figure 11.

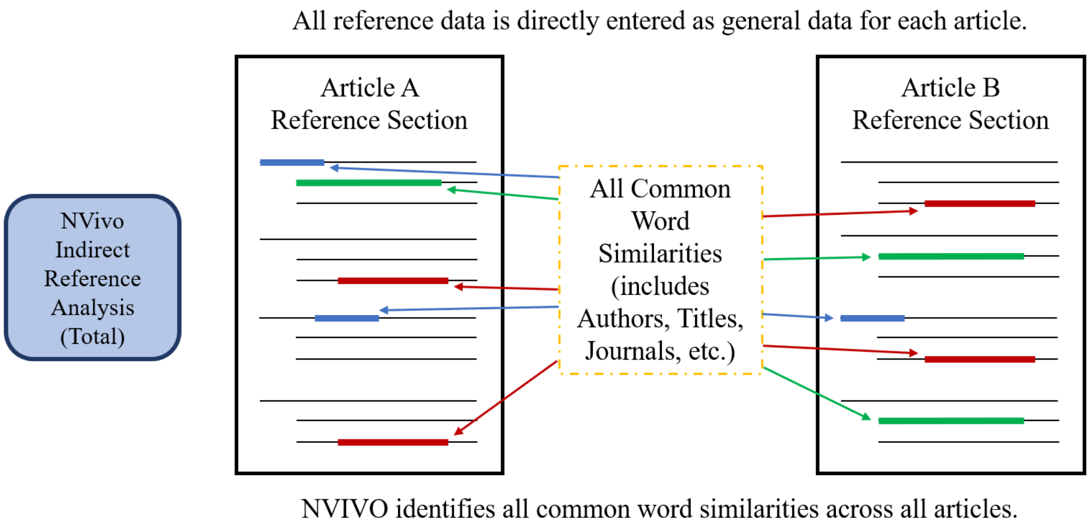



Figure 11. Visual of Indirect Reference Analysis (Total)

Referring to the previous section, all of the Chicago-style references for the PRISMA-compliant articles were saved in separate Microsoft Word documents. Using the already compiled documents, each of them were transferred into the NVivo software, where each article's reference data was a file containing all of the references for that article. To run a correlation analysis for each of the files, each of the article's reference data needed to be entered into the system. This was accomplished by highlighting each of the references and saving them as data within each file. Once that was completed, the correlating process within the software could begin. Similar to that of the direct reference analysis, the NVivo software also evaluates two PRISMA-compliant articles at a time, where the measured correlation between the two selected articles was identified through word similarity. This showed that selecting the Chicago reference was indeed advantageous. The fact that this reference style compared full names and titles, rather than abbreviated ones, meant that a more accurate correlation between two article's

reference sections could be found. From there, the NVivo software produced a data set of Pearson correlation values between different combinations of articles. It also produced a visual representation of the strongest relationships of articles based on Pearson correlation.

When all of the Pearson correlation data was obtained for each of the article relationships, the data was exported to Microsoft Excel, where a histogram was built. The bin sizes were selected to be small enough to show detail, but large enough to be easy for the researcher to interpret. Along with the histogram, descriptive statistics were also calculated and recorded. These descriptive statistics were the mean, median, standard deviation, skewness, and kurtosis of all the Pearson correlation data.

### Indirect Reference Analysis (Per Category)

The purpose of this subsection is to take all of the Pearson correlation values of the article's relationships, sort those relationships into the five touchless technology categories, and run a one-way analysis of variance (ANOVA) statistical test on them. Along with the one-way ANOVA, the three basic assumptions of independently collected samples, equal variance, and normality need to be examined for the purpose of validating the results of the one-way ANOVA. All of the data was obtained from NVivo, transferred into JMP, and then analyzed. A visual representation of indirect reference analysis for each category is shown in Figure 12.

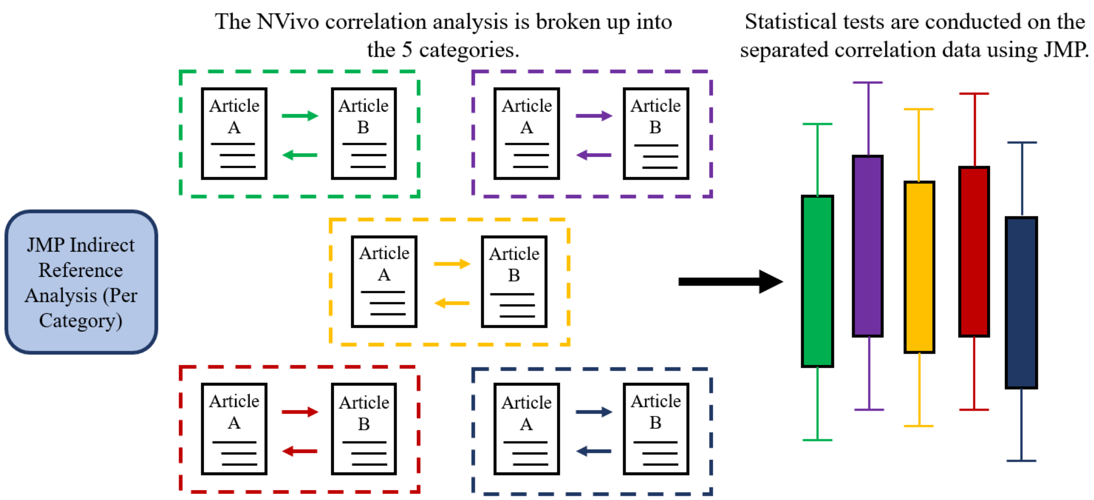



Figure 12. Visual of Indirect Reference Analysis (Per Category)

The initial step in conducting this transition from NVivo to JMP was to first separate the total reference data into the five touchless technology categories. This was accomplished by keeping track of which articles contained thematic data within each of the five touchless technology categories. Within NVivo, five new and separate projects were created, where each of the uploaded Microsoft Word files were re-uploaded into each of those five projects. If there was an article that contained thematic data for multiple touchless technology categories, then that same Word document would be uploaded to each of the projects separately. Similar to the total indirect reference analysis, after the reference data was entered for each of the five categories, five separate data sets were then created. Each of these data sets contained Pearson correlation data for the article relationships only within that touchless technology category. The five separate data sets were exported into the same Microsoft Excel spreadsheet, the data was then "cleaned up" and organized to be all in one data set, and then that data was transferred

over to JMP, where the statistical testing could take place.  The statistical tests included the main ANOVA test and the additional O'Brien, Brown-Forsythe, Levene, Bartlett, Shapiro-Wilk, and Kruskal-Wallis tests.  To conduct each of the necessary statistical tests, the commands were simply searched within JMP's interface and then performed.

## Comparing Analyses

The purpose of this section is to compare the results from the thematic analysis and the reference analysis.  Both analyses produced valuable results for each of the five categories, as well as touchless technologies as a whole.  It is important to take the time to conglomerate all of the collected results into one figure for the purpose of creating observations from the overall results.  A visual representation of comparing analysis is shown in Figure 13.

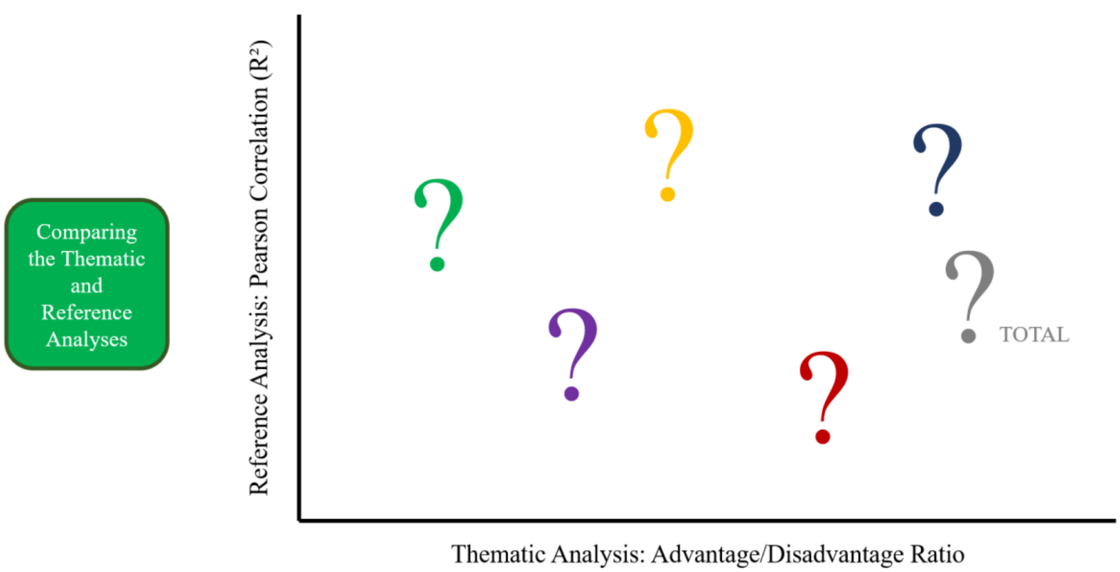



Figure 13.  Visual of Comparing Analyses

The metric that was used to record the thematic analysis data was the advantage to disadvantage ratio, so this metric's data was listed for each of the categories on a column of a Microsoft Excel spreadsheet. The metric that was used to record the reference analysis data was the Pearson correlation coefficient, so this metrics data was also listed for each category on an adjacent column of the spreadsheet. The compared metrics were applied to produce a single scatter plot, where each of the categories would be represented by a separate point on the plot. A regression line was then added to provide some context on the relationship that was occurring between the results of the two analyses. Finally, when interpreting the graph, conceptual clusters were illustrated, which signals to the reader the potential relationship that technology categories within the clusters share.

# IV. Results

The purpose of this chapter is to display and explain the results that were produced from the methodology outlined in the previous chapter. Both the thematic analysis and the reference analysis generated valuable results. Throughout the entire analysis process, multiple sets of results were generated, which will be illustrated in the same format as they were explained in the methodology section. Brief interpretations of the results will also be included for the benefit of the reader.

## Collecting PRISMA Literature

This section will include results both for identifying PRISMA literature and modeling PRISMA literature. The results of identifying PRISMA literature establishes a list of collected articles that were used to continue the research. The results of modeling PRISMA literature helped to gain a better understanding of the selected literature.

### Identifying PRISMA Literature

Of the 76 articles that were used to gain high-level knowledge regarding touchless technologies, 31 were used for the overall bibliometric (both thematic and reference) analyses, as shown in Table 1. These 31 articles followed basic PRISMA standards by containing a proper title, abstract, introduction, methods, results, and discussion. The table also indicates whether the specific article contained thematic data from each of the five touchless technology categories. If the article contained thematic data from a category, the cell is shaded green. If not, the cell is shaded in red.

| | Does the Piece of Literature Contain Themes in this Category? (GREEN = YES) (RED = NO) | | | | |
|---|---|---|---|---|---|
| | Facial/Bio Recognition | Gesture Recognition | Personal Devices | Touchless Sensing | Voice Recognition |
| Alexakis et al., 2019 | YES | NO | NO | NO | YES |
| Casini, 2019 | NO | NO | NO | YES | NO |
| Chenhao & Kimar, 2018 | YES | NO | NO | NO | NO |
| Cronin & Doherty, 2019 | NO | YES | NO | NO | YES |
| Das, 2021 | NO | NO | NO | YES | NO |
| Doll and Bearman, 2018 | NO | NO | NO | YES | NO |
| Gerba, 2015 | NO | NO | NO | YES | NO |
| Grover & Sabherwal, 2020 | NO | NO | YES | YES | NO |
| Habibi & Chattopadhyay, 2021 | NO | YES | YES | NO | NO |
| Iqbal & Campbell, 2020 | YES | YES | NO | YES | NO |
| Kamble et al., 2021 | NO | NO | YES | NO | NO |
| Kumar and Shimi, 2015 | NO | NO | NO | NO | YES |
| Landgrebe, 2011 | NO | NO | NO | YES | NO |
| Latman and Herb, 2013 | YES | NO | NO | NO | NO |
| Li et al., 2021 | NO | NO | NO | YES | NO |
| Liu et al., 2020 | NO | YES | NO | NO | NO |
| Lozier, 2016 | NO | NO | NO | YES | NO |
| Mata and Milner, 2021 | NO | NO | NO | YES | NO |
| McMullen et al., 2021 | NO | NO | NO | YES | NO |
| Meyer et al., 2014 | NO | YES | NO | NO | NO |
| Minagawa et al., 2014 | NO | YES | NO | NO | NO |
| Morimoto, 2010 | NO | NO | NO | YES | NO |
| Morimoto, 2013 | NO | NO | NO | YES | NO |
| Nicol, 2020 | NO | NO | NO | YES | NO |
| Pei-Lee et al., 2015 | NO | YES | NO | NO | NO |
| Ramanthan et al., 2021 | YES | NO | NO | NO | NO |
| Simmons et al., 2017 | NO | NO | NO | NO | YES |
| Tokazhanov et al., 2021 | NO | NO | NO | YES | NO |
| Utz et al., 2021 | NO | NO | YES | NO | NO |
| Vuletic et al., 2019 | NO | YES | NO | NO | NO |
| Wanga et al., 2021 | NO | NO | YES | NO | NO |

Table 1. Table of PRISMA-Compliant Literature

In Table 1, there are multiple occurrences of an article containing multiple themes. For example, the article labeled "Iqbal & Campbell, 2020" contains thematic advantages and/or disadvantages for the facial/bio recognition, gesture recognition, and touchless sensing categories. Elaborating further on this example, it is possible for an article to contain one or more of these themes per category. Therefore, when counting the number of papers that support each functional category, the total number of green cells per column (35) does not add up to the 31 articles used for the overall bibliometric analysis. To be expected, there are more green cells than articles. Rather than using the word "article," the terminology for these green cells will be called "files" for the thematic analysis, which will be further explained and shown in the following section.

Modeling PRISMA Literature

Figures 14 and 15 illustrate the relationship between PRISMA articles through clustering. Figure 14 examines the contributing authors of the PRISMA collection, and Figure 15 examines the contents discussed within the articles. Visualizing the relationships between the different articles helps the researcher gain an understanding of the categories' potential similarities before the official thematic and reference analyses are presented. Note that for both Figures 14 and 15, the rainbow color pattern of each cluster represents the strength of similarity within each cluster (i.e., red represents the most similarity, yellow represents medium similarity, purple represents the least similarity). The lines themselves indicate that a connection exists between authors/content, showing how multiple lines webbed together creates a cluster of information.

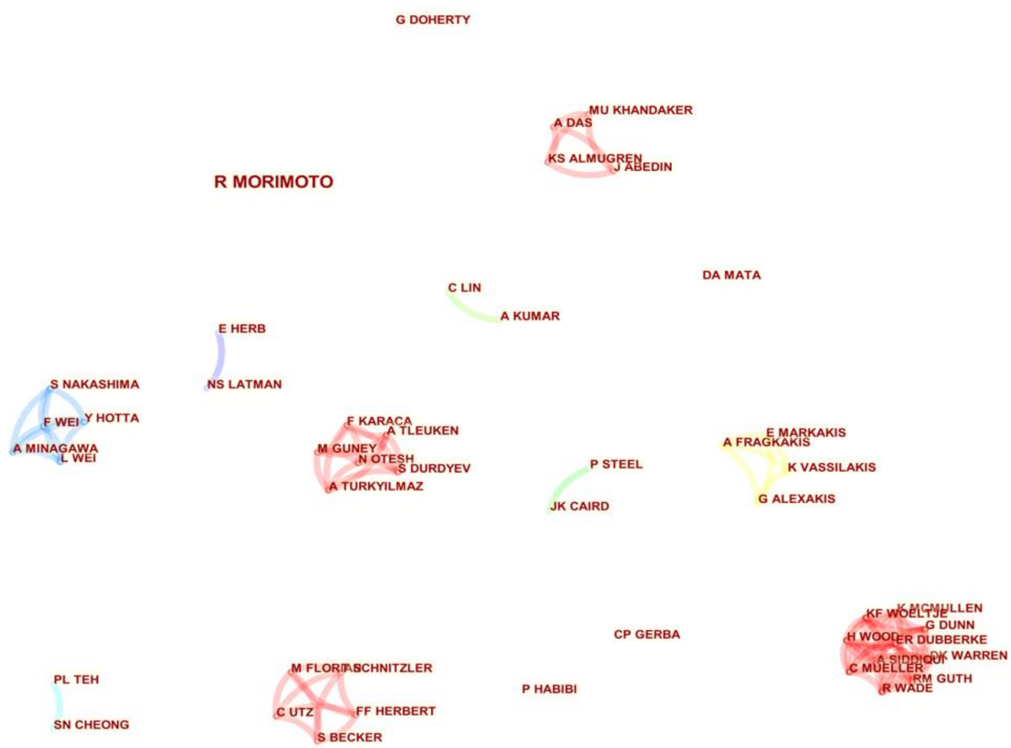



Figure 14. Model of PRISMA Literature (Authors)

Figure 14 communicates several key points. The clusters of authors indicate that certain authors contribute literature within their respective fields. Naturally there are certain fields of expertise that contain more authors, and these are mainly for topics that have a longer history and more literature available. Despite the separation of clusters, the clusters seem relatively equidistant to each other. Although cited authors remain consistent within their areas of expertise, the homogenous distancing of the clusters indicates that authors are cited relatively evenly throughout the collection of literature. When examining the contributing authors across the entire PRISMA collection, it is important that the collection of authors utilizes subject matter experts within their field while also properly diversifying sources. It is clear that Figure 14 supports this concept.

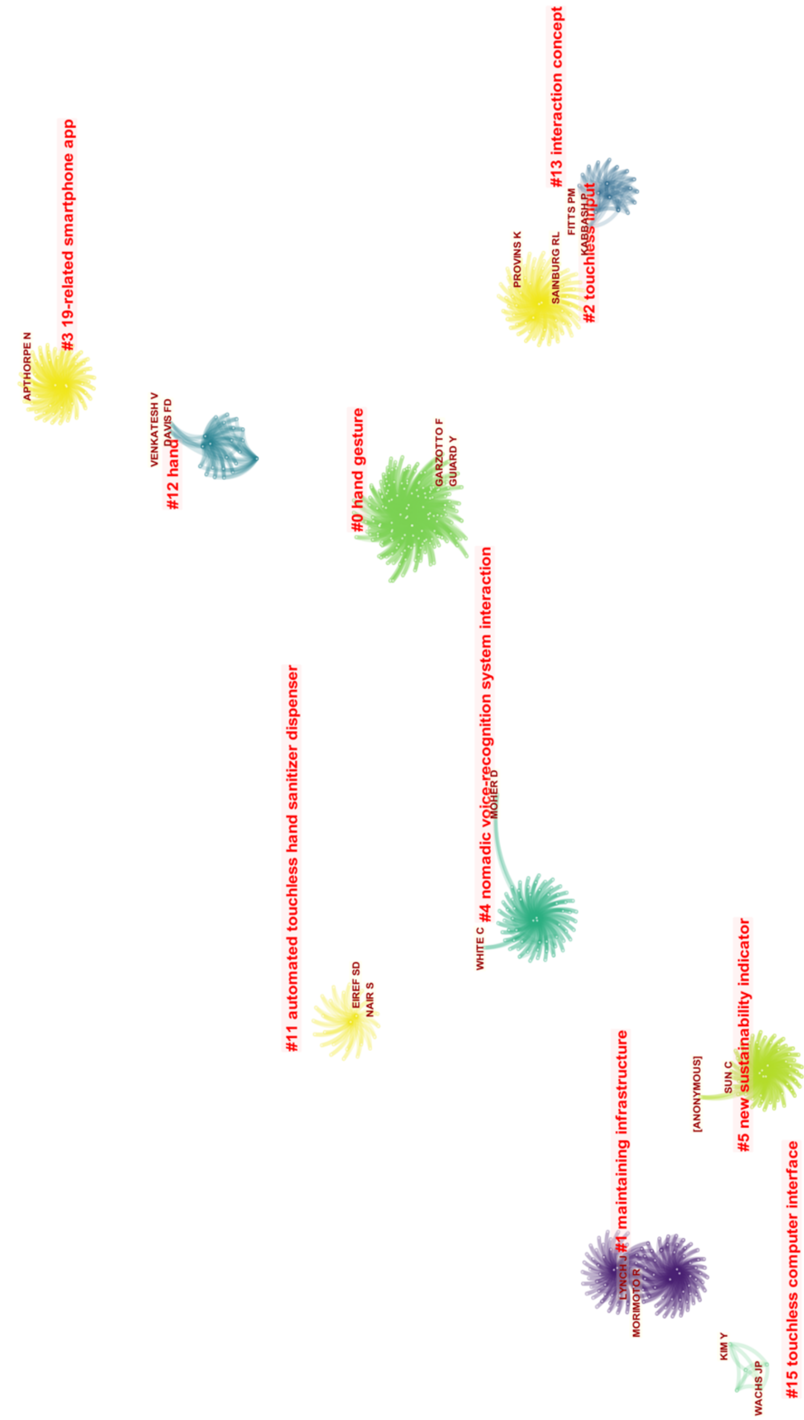



Figure 15. Model of PRISMA Literature (Content)

As expected, based on the shapes of the clusters and the locations of the nodes, the contents within the articles shown in Figure 15 are not equal. There are articles that contain more similarities with one another, and as expected, the similarities correlate with the information presented in Table 1. It is evident that articles that discuss similar touchless technology categories will be closer together and clustered in groups. One of the reasons that five separate and neat clusters based on category do not appear is because there are several articles that discuss more than one topic, thus complicating the visualization. There are also certain subtopics that appear relatively close to one another, such as “new sustainability indicator,” “maintaining infrastructure,” and “touchless computer interface” in the bottom left corner of Figure 15 (i.e., for touchless sensing). These nearby clusters are discussing similar topics within the category, but not necessarily talking about the same technologies, thereby resulting in separate yet nearby clusters. The contents within the articles are not clearly assigned a specific topic, yet they discuss relatively similar subject matter based on the general type of touchless technology. It is clear that Figure 15 supports this concept.

**Thematic Analysis**

The purpose of this section is to display the results of the thematic analysis. As discussed in the methodology section, the purpose of this was to discover the current state of touchless technologies by counting the number of advantages and disadvantages and calculating ratios. Figure 16 represents the overall diagram showing the results of the thematic analysis.

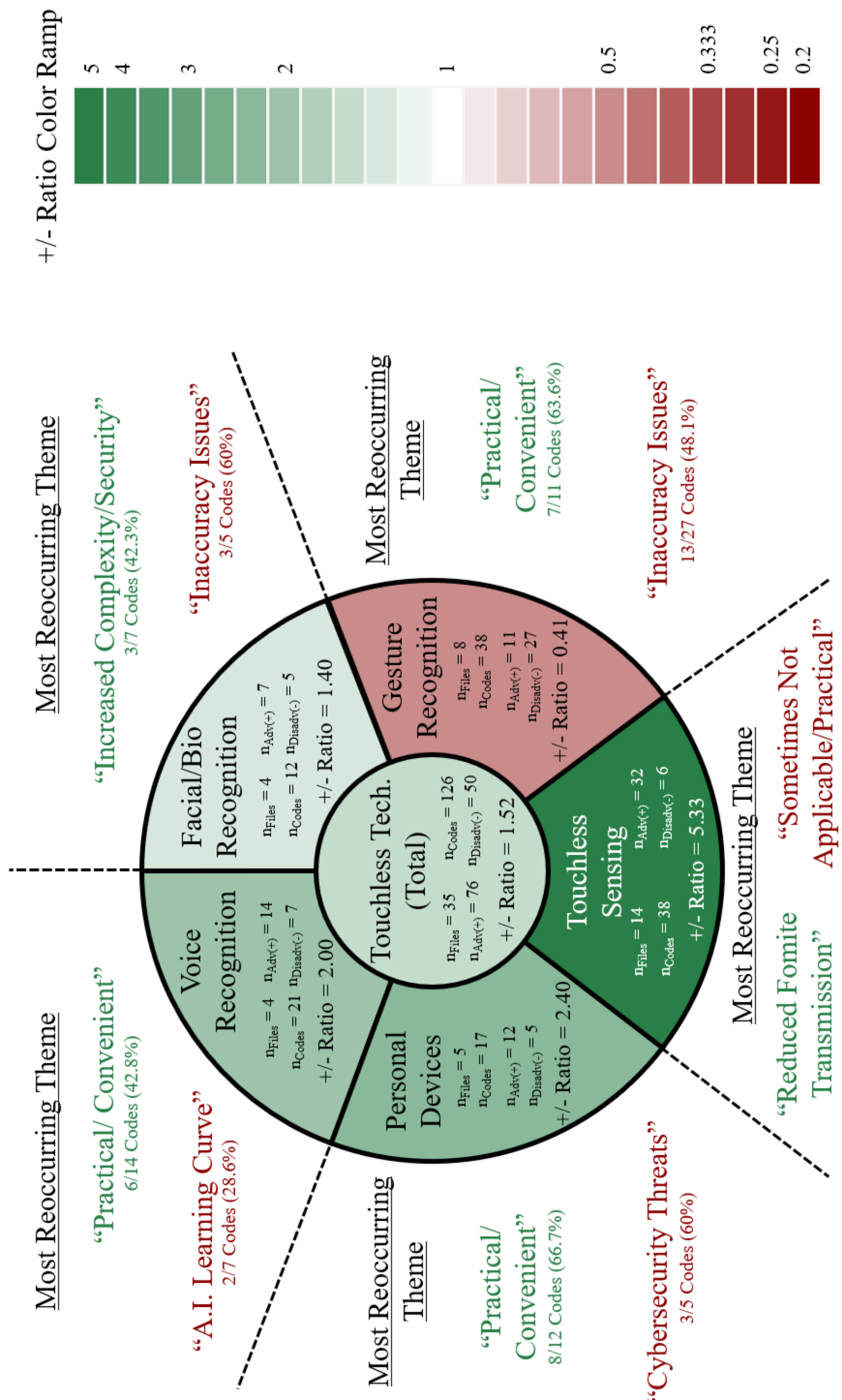



Figure 16. Results of Thematic Analysis

In Figure 16, six cells (the five categories plus touchless technologies as a whole) are displayed to illustrate the results of the analysis. To properly illustrate the results of the thematic analysis, a commonly recognized color ramp is utilized to communicate each category's advantage to disadvantage ratio. The color ramp initially spans from darker greens (high ratios) to lighter greens (lower ratios, but still a ratio above 1). These colors indicate that within the section, there were more advantages that were counted compared to disadvantages. From there, the color ramp turns white, which indicates that a category's number of advantages and disadvantages is the same, which results in a ratio equal to 1. The color ramp then turns into lighter reds (higher ratios that are below a ratio of 1) and darker reds (low ratios), which signals that the results of the analysis contained more counted disadvantages than advantages. The benefit to using the color pattern of dark greens –> light greens –> white –> light reds –> dark reds is that these colors are a universally accepted method of communicating whether something is net positive or negative and by how much.

Not only does the color provide valuable information, but the calculated advantage to disadvantage ratio, the number of files, and the number of collected codes are also available for each category to provide more data on the subject. Because the data here are the collected thematic codes, the figure also provides the most prevalent advantages and disadvantages theme found for each category. The most common themes are also color coded to express whether they are illustrating an advantage or disadvantage; a quantifiable percentage of how prevalent this theme was across all of the codes for that category is also included. Observing all of the aspects of the figure

provides an accurate snapshot of the current state of touchless technologies from the viewpoint of the thematic analysis.

The results of the thematic analysis showed that the different types of touchless technologies are currently experiencing a variety of advantages and disadvantages. More information regarding each thematic code and its categorization as either an advantage or disadvantage can be found in Appendix A. When looking at the facial/biometric recognition category in Figure 16, there were 7 counted advantages and 5 counted disadvantages, which means that the advantage to disadvantage ratio for the category is 1.40. The number of files that were used for the analysis was 4, and the number of codes within the articles for this category was 20. The color of the section in the diagram is a light green color, signaling that its advantage to disadvantage ratio contains a slightly higher count of advantages compared to disadvantages. The most reoccurring theme found for advantages discussed the increased amount of security due to the complexity and non-replicability of biorecognition, and this theme occurred in 42.3% of the category's positive codes. Contrasting this point, the most reoccurring theme for facial/bio recognition's disadvantages, which occurred in 60% of the collected negative codes, was the inaccuracy issues regarding identifying the user.

Moving on to the gesture recognition category, 11 counted advantages and 27 counted disadvantages were found within the articles, leading to an advantage to disadvantage ratio of 0.41. The number of files that were used for this section's analysis was 8, while the number of codes for this category was 38. The color of the section in the diagram displays a medium to medium-dark red color, signaling that its advantage to disadvantage ratio contains a heavier concentration of disadvantages compared to

advantages.  The most common theme found for advantages elaborated on how basic gestures are such a natural way that humans already communicate, meaning that it is relatively practical and convenient for users to communicate through gestures.  This positive theme occurred in 63.6% of the category's advantage codes.  The most common theme found for disadvantages was how there are currently inaccuracy issues with the technology, which means that commands are not properly registered within the technology type.  This theme made up 48.1% of the technology type's disadvantage codes.

The touchless sensing category had the greatest advantage to disadvantage ratio of all the touchless technology categories.  There were 32 counted advantages and 6 counted disadvantages found within its articles, resulting in an advantage to disadvantage ratio of 5.33.  Fourteen files were used for this section's analysis, where 38 codes were found across the section's literature.  Unlike the two previous categories, the color shown for touchless sensing is dark green, indicating that there is a substantially higher number of counted advantages compared to disadvantages.  The highest reoccurring theme found for advantages explained how this type of technology was highly effective in mitigating the effects of fomite transmission.  This theme was found in 71.9% of the category's advantage codes.  The most common theme found for disadvantages was that there were instances where installing this type of touchless technology may not have been the most practical.  This theme appeared in 50% of the technology type's disadvantage codes.

Similar to the positive results for the touchless sensing category but to a lesser degree, the personal devices category had 12 counted advantages and 5 counted disadvantages, resulting in an advantage to disadvantage ratio of 2.40.  To complete this

portion of the analysis, 5 files were utilized, and 17 codes were found within its articles to complete the analysis. The color found in this section within the diagram displayed a medium shade of green, indicating that the number of advantages was not as high as the touchless sensing category, but high enough compared to its disadvantages to give it a solid green color. The most common theme found for personal devices was how practical and convenient users felt this type of technology was, and this theme was found in 66.7% of the advantage codes. The biggest theme against personal devices discussed how integrating personal technology increases the level of cybersecurity risks, and 60% of codes expressed this idea.

Voice recognition technologies followed a similar trend to that of personal devices, where 14 advantages were counted and 7 disadvantages were counted, leading to an advantage to disadvantage ratio of 2.00. This type of touchless technology's analysis was based on 7 files, where the number of codes found within its literature was 21. The color closely followed that of the previously discussed category of a medium green, being that the advantages moderately outweighed the disadvantages. The most reoccurring theme of this portion of the analysis, which was similar to that of the personal devices category, was on the convenience of voice commands and the practicality of simply giving a command orally. This theme was found in 42.8% of the advantage codes. The biggest thematic flaw of voice recognition technologies, which occurred in 28.6% of negative codes, was how the artificial intelligence within the technology takes time to learn the user's voice and understand commands, thus leading to inaccuracies in the beginning.

Combining the advantage and disadvantage counts across all five categories, the current state of touchless technologies can be analyzed to provide a broad snapshot. In total, 84 advantages were counted and 50 disadvantages were counted, thus leading to a total advantage to disadvantage ratio of 1.68. The total number of files for the overarching thematic analysis was 35 (i.e., the total number of green cells from Table 1), and the total number of codes was 134. The color that was shown as a result of combining the count data was a lighter green, which means that there was a slightly higher number of advantages across the board compared to the disadvantages. Thematically, the most common themes were not collected at this level because of the differences in the five major touchless technology types. It would not serve the analysis to find commonalities in themes when the technologies themselves are extremely uncommon/unrelated to each other.

**Reference Analysis**

The purpose of this portion of the chapter is to display the results of the reference analysis. As discussed in the methodology section, the purpose for conducting the reference analysis was to validate the results of the thematic analysis by demonstrating that the respective references used within the 31 articles were correlated with one another. To reiterate from the methodology chapter, this subsection contains the results of two different analyses: the direct reference analysis using Microsoft Excel and the indirect reference analysis using NVivo and JMP (Bornmann & Marx, 2013).

Direct Reference Analysis

Figure 17 compares the number of shared references between any 2 of the 31 PRISMA articles.  Both the vertical and horizontal axes contain the same list of the 31 articles in alphabetical order.  To identify the number of exact matches that two articles share, the researcher would have to find the cell that corresponds to the papers in the vertical and horizontal axes.  For convenience, any positive match between two article's references is shown by highlighting the cell in yellow.  Within the yellow cell, the number of exact matches in their respective reference section is shown.

Across all 465 combinations of different articles, there were 11 instances where two papers shared at least one reference (i.e., the count of yellow boxes above or below the black line).  This means that approximately 2.37% of the cells were yellow, indicating at least one reference match.  Across the entire sample of 1,112 references, there were 29 references that were shared (i.e., the number total within the yellow boxes).  This means that approximately 2.61% of all references are shared between two or more articles.  In total, 29 matches were found across the 11 yellow boxes, leading to the average number of shared references per relationship to be about 2.63.  Of the 11 yellow boxes, 8 of them only share one reference and 3 of them contained multiple shared references.  The yellow boxes with multiple shared references were 2, 3, and 16, respectively.

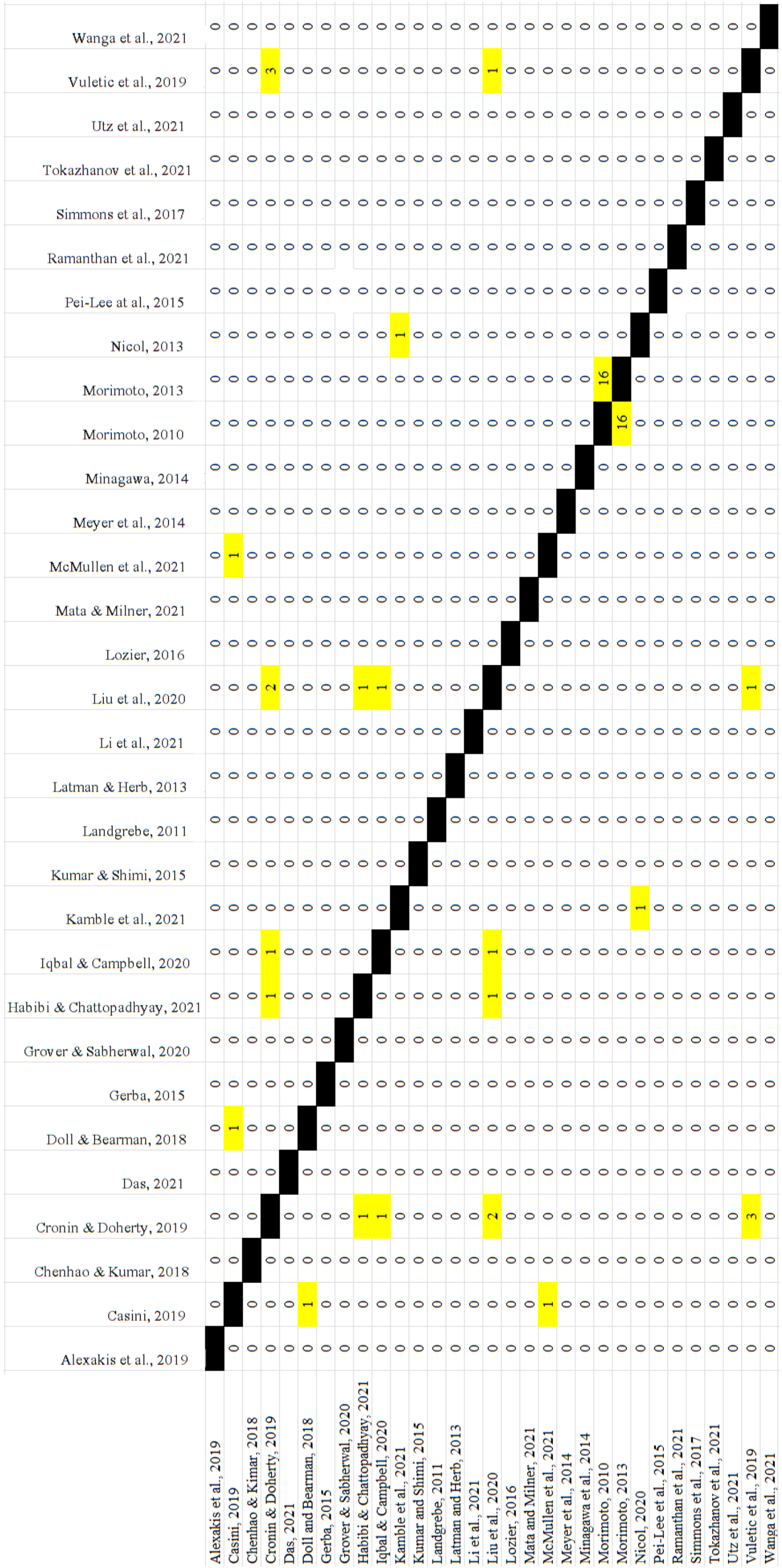



Figure 17. Results of Direct Reference Analysis

It is reasonably inferred that the explanation for 16 shared references between two papers is that the papers were written by the same author(s). In this instance, both articles were written by one sole author (Risako Morimoto), which means that the methods to locate and obtain references were probably similar for both papers. By simply looking at the titles of the two articles, "Estimating the benefits of effectively and proactively maintaining infrastructure with the innovative Smart Infrastructure sensor system" and "A socio-economic analysis of Smart Infrastructure sensor technology," it is likely that they discuss the same type of topic and are built with the same type of contributing information. By removing this outlier, 13 of the 1,096 references were shared across 29 articles, which leads to a percentage of about 1.19% shared references.

As a whole, an observation of the direct reference analysis is that it appears to have a trustworthy degree of validity. On one hand, it would likely be unhelpful if none of the articles had any matches within their reference sections. Since an article's references represent the source of their contributing information, it would be reasonable to conclude that no shared references means that the information is completely disconnected. This could potentially be a problem because information that has zero overlap in sources could result in a disjointed thematic analysis. On the other hand, it would also likely be unfavorable if the articles shared too many matches within their references. Too many matches would symbolize that the collected sample is not diverse enough and likely gathered from the same places, which means that the information and themes extracted from these papers would not be reliable either. Incorporating these two ideas to the collected sample, the fact that 2.61% of the references are shared likely illustrates that there is an ideal balance between referential reinforcement and broadening.

In general, it is reasonable to assume that more matches would be found in a sample if touchless technology research groups existed. The status quo of touchless technologies seems to be that they are only investigated when necessary or needed. In other words, the application drives researching touchless technologies. Theoretically, if touchless technologies drove the research for investigating applications, it is possible to identify more pairings in this type of direct reference analysis. The effort for specifically addressing a technology type could imply that more technology-centric literature would be cited, meaning more references could be shared. While this concept does not apply to this research, investigating this theory as touchless technologies evolve would be interesting and deserves to be mentioned.

Indirect Reference Analysis (Total)

Figure 18 compares the indirect similarities of references across the 31 PRISMA-compliant articles. In summary, each of the references within each article was identified as a collection of data, where they contained a list of attributes including the contributing authors, title, journal issue, and date. The NVivo software reads this information to find similarities based on word patterns. These similarities between articles are measured by utilizing Pearson correlation coefficients.

NVivo calculated Pearson correlation values for every relationship of two articles' similarities of references to include authors, dates of publication, titles of works, and publication data. Figure 18 and Table 2 show a visual and tabular depiction of the results. Note that only the top 25 Pearson correlation values are shown in Table 2; the complete list of Pearson correlations can be found in Appendix B. The purpose of

showing both versions of the results is to illustrate the journal article combinations with the strongest correlated relationships.

In total, there were 465 combinations of papers identified for NVivo's indirect reference analysis.  The measurement metric that was used to track the correlation between two pieces of literature was the Pearson coefficient value.  For easier readability, the results for the visual representation were organized into four different line thicknesses as shown in Figure 18.  In summary, there were 2 article pairings that had a Pearson correlation between 1.0 and 0.7, 7 article pairings that contained a Pearson correlation between 0.7 and 0.5, 63 article pairings that contained a Pearson correlation between 0.5 and 0.3, and 393 article pairings that contained a Pearson correlation between 0.3 and 0. The heavy concentration of Pearson correlations between 0.3 and 0 is demonstrated better in Figure 18.

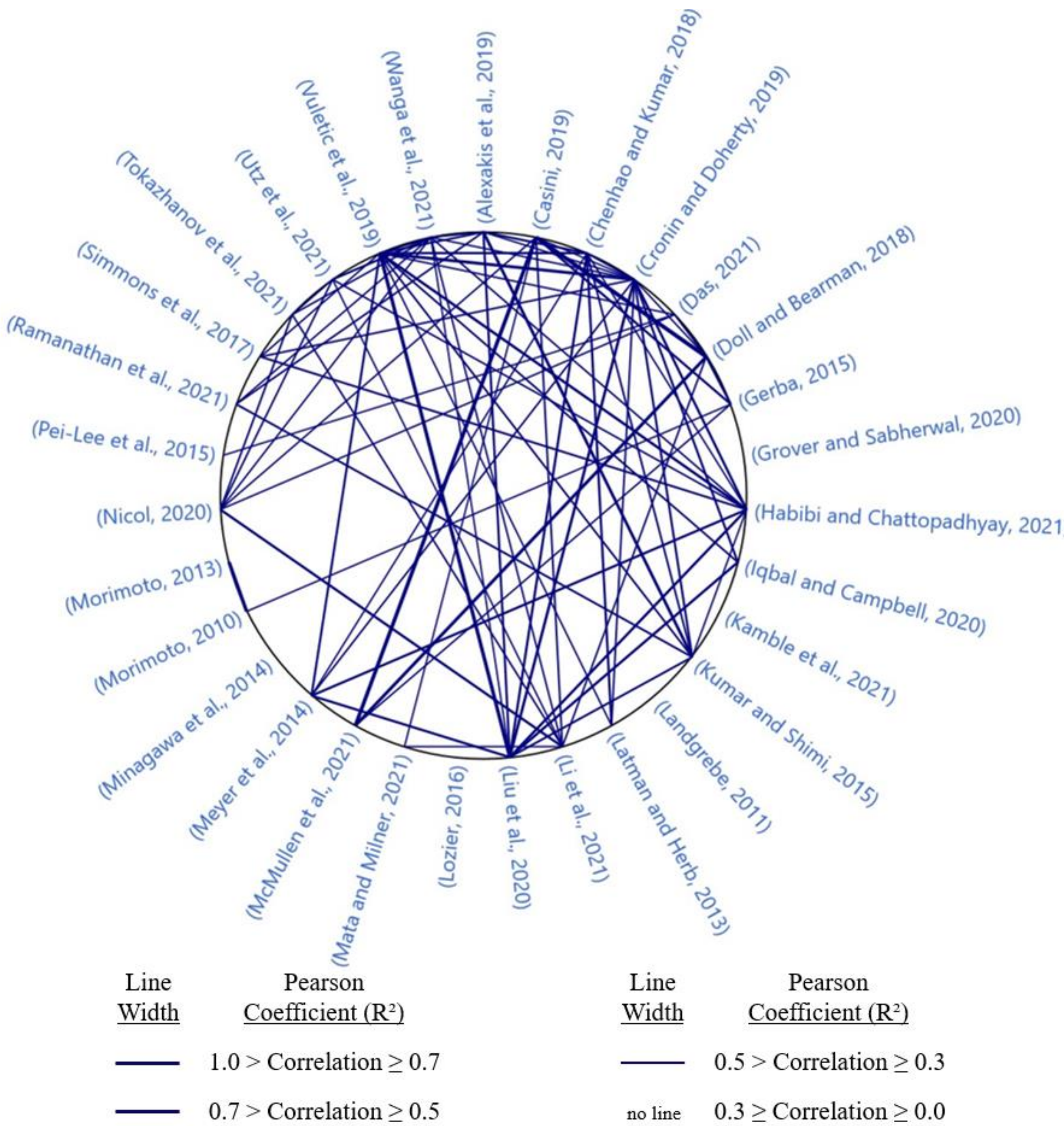



Figure 18. Model of Indirect Reference Analysis (Total)

| Items Clustered By Word Similarity - Correlation Table (Top 25 Listed) | | | |
|---|---|---|---|
| Rank | Literature File #1 | Literature File #2 | Pearson correlation coefficient ($R^2$) |
| 1 | Doll and Bearman, 2018 | Casini, 2019 | 0.759098 |
| 2 | McMullen et al., 2021 | Casini, 2019 | 0.710524 |
| 3 | Vuletic et al., 2019 | Liu et al., 2020 | 0.669154 |
| 4 | Morimoto, 2013 | Morimoto, 2010 | 0.669087 |
| 5 | McMullen et al., 2021 | Doll and Bearman, 2018 | 0.59741 |
| 6 | Vuletic et al., 2019 | Cronin and Doherty, 2019 | 0.573518 |
| 7 | Kumar and Shimi, 2015 | Alexakis et al., 2019 | 0.551421 |
| 8 | Liu et al., 2020 | Cronin and Doherty, 2019 | 0.520423 |
| 9 | Vuletic et al., 2019 | Habibi and Chattopadhyay, 2021 | 0.509417 |
| 10 | Liu et al., 2020 | Habibi and Chattopadhyay, 2021 | 0.498219 |
| 11 | Liu et al., 2020 | Iqbal and Campbell, 2020 | 0.484127 |
| 12 | Nicol, 2020 | Li et al., 2021 | 0.473147 |
| 13 | Habibi and Chattopadhyay, 2021 | Cronin and Doherty, 2019 | 0.468543 |
| 14 | Meyer et al., 2014 | Habibi and Chattopadhyay, 2021 | 0.458949 |
| 15 | Liu et al., 2020 | Chenhao and Kumar, 2018 | 0.454986 |
| 16 | Meyer et al., 2014 | Liu et al., 2020 | 0.453413 |
| 17 | Gerba, 2015 | Doll and Bearman, 2018 | 0.44571 |
| 18 | Vuletic et al., 2019 | Chenhao and Kumar, 2018 | 0.444826 |
| 19 | Gerba, 2015 | Casini, 2019 | 0.444738 |
| 20 | Latman and Herb, 2013 | Chenhao and Kumar, 2018 | 0.433807 |
| 21 | Chenhao and Kumar, 2018 | Alexakis et al., 2019 | 0.43004 |
| 22 | Iqbal and Campbell, 2020 | Cronin and Doherty, 2019 | 0.42612 |
| 23 | Vuletic et al., 2019 | Meyer et al., 2014 | 0.423779 |
| 24 | Liu et al., 2020 | Alexakis et al., 2019 | 0.420611 |
| 25 | Wanga et al., 2021 | Utz et al., 2021 | 0.420417 |

Table 2. Table of Indirect Reference Analysis (Total)

Figure 19 visually shows all 465 article combinations by comparing the Pearson correlation values with the frequency of how often those values occurred. When analyzing the histogram, the descriptive statistics help numerically illustrate the results of the correlations. The mean of the histogram is 0.19 and the median is 0.18; because the histogram's mean and median values are not equal, the histogram's distribution does not take on a Gaussian shape, meaning that the distribution is not symmetrical. The shape and direction of the histogram's non-symmetry can also be identified through the skewness value of 1.16, which signifies that the distribution is right leaning and that the concentration of outliers exist within the right tail of the histogram. The concentration of

correlation data around the mean correspond to the standard deviation of 0.12 and the kurtosis of 2.44. The relatively high standard deviation indicates that the data is more spread out around the mean rather than concentrated centrally, and the relatively low kurtosis value implies that there are more data points located within the tails of the distribution compared to a standard Gaussian distribution.

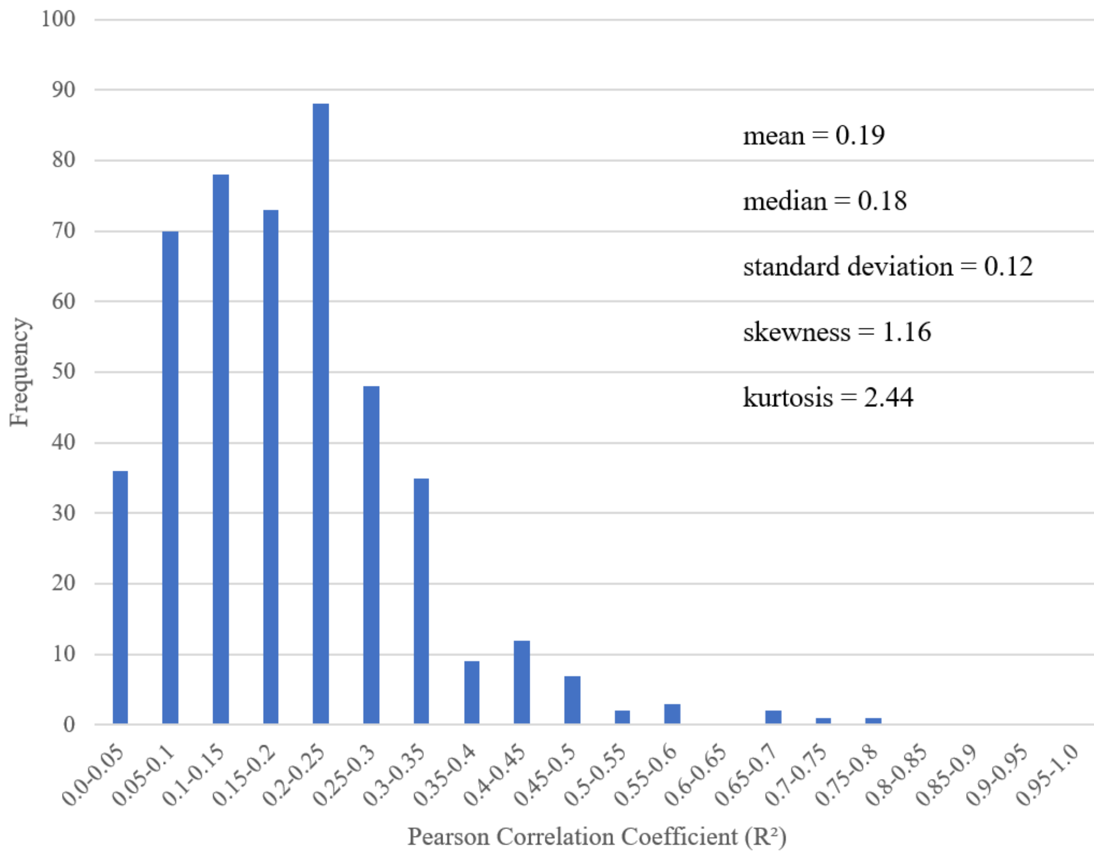



Figure 19. Histogram of Pearson Correlations

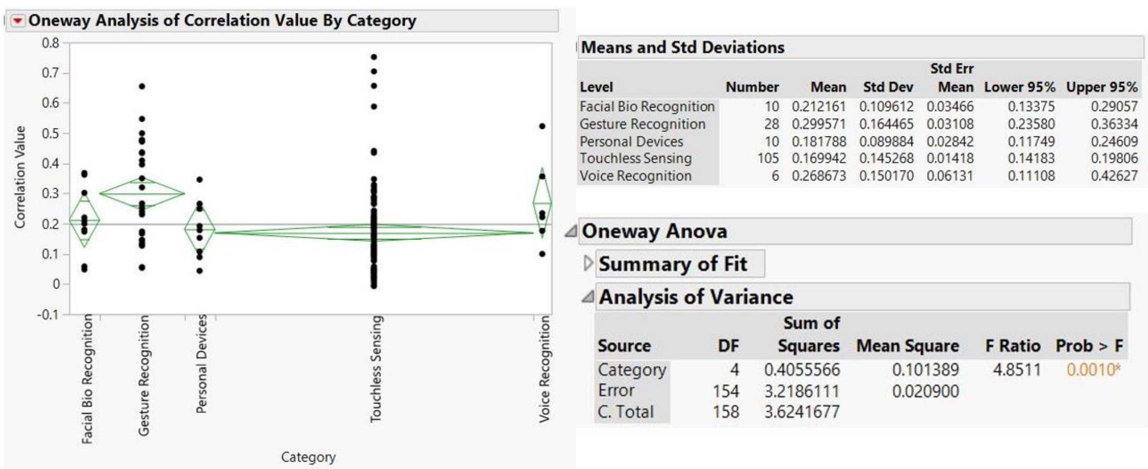
The results of the indirect reference analysis reflect the results of the direct reference analysis, demonstrating validity in both processes. In the direct reference analysis, the vast majority of article pairings did not share a common reference (i.e., the majority of the cells in the matrix were white in color, not yellow). Additionally, there were a few select pairings that contained more than one direct relationship, thus skewing the overall percentage of shared references. These results mirror that of the indirect reference analysis, where the majority of pairings had a Pearson correlation between 0.3 and 0. The few pairings which had the largest Pearson correlations skewed the overall results of the indirect analysis, causing Figure 19 to have a right tailed distribution. The results of both analyses convey the same message. While there are articles that contain similarities with one another, the majority of articles refer to many different articles. This helps reinforce the validity stated in the results of the direct reference analysis, where there is an ideal balance between referential reinforcement and broadening.

## Indirect Reference Analysis (Per Category)

To reiterate, the purpose of this portion of the indirect reference analysis was to take all of the Pearson correlation values of the articles' relationships, isolate those relationships into the five touchless technology categories, and run a one-way analysis of variance (ANOVA) statistical test on the five categories to determine whether the five mean Pearson correlation values were statistically equivalent. Along with the one-way ANOVA, the three basic assumptions of independently collected samples, equal variance, and normality need to be examined for the purpose of validating the results of the one-

way ANOVA.  All of the data was obtained from NVivo, transferred into the program JMP, and analyzed from there.

The first of these statistical tests was the one-way ANOVA, for which the results can be found in Figure 20.  The null hypothesis of the test was that the mean Pearson correlation of each touchless technology category is the same.  The alternative hypothesis was that the five categories do not share the same mean Pearson correlation values.  A probability (α) value of 0.05 was assigned to conduct the analysis.




**Means and Std Deviations**

| Level | Number | Mean | Std Dev | Std Err Mean | Lower 95% | Upper 95% |
|---|---|---|---|---|---|---|
| Facial Bio Recognition | 10 | 0.212161 | 0.109612 | 0.03466 | 0.13375 | 0.29057 |
| Gesture Recognition | 28 | 0.299571 | 0.164465 | 0.03108 | 0.23580 | 0.36334 |
| Personal Devices | 10 | 0.181788 | 0.089884 | 0.02842 | 0.11749 | 0.24609 |
| Touchless Sensing | 105 | 0.169942 | 0.145268 | 0.01418 | 0.14183 | 0.19806 |
| Voice Recognition | 6 | 0.268673 | 0.150170 | 0.06131 | 0.11108 | 0.42627 |

**Analysis of Variance**

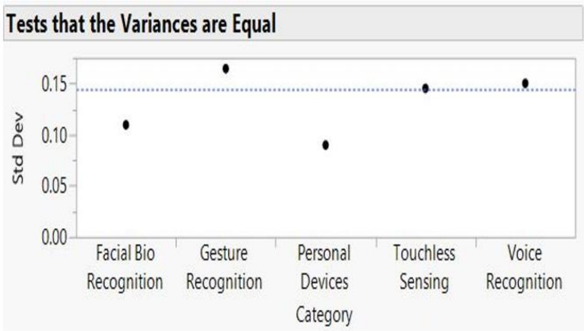
| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Category | 4 | 0.4055566 | 0.101389 | 4.8511 | 0.0010* |
| Error | 154 | 3.2186111 | 0.020900 | | |
| C. Total | 158 | 3.6241677 | | | |

Figure 20.  Results of One-Way ANOVA

The results of the one-way ANOVA test was that the probability value was 0.001, which is less than the assigned probability of 0.05, meaning that the null hypothesis was rejected, and the alternate hypothesis was accepted.  From a statistical viewpoint, the five touchless technology categories did not share the same mean Pearson correlation values for their article's relationships.  The facial/bio recognition category's articles had a mean Pearson correlation of 0.21, the gesture recognition category's articles had a mean

Pearson correlation of 0.30, the personal device category's articles had a mean Pearson correlation of 0.18, the touchless sensing category's articles had a mean Pearson correlation of 0.17, and the voice recognition category's articles had a mean Pearson correlation of 0.27.

To validate the results of the one-way ANOVA, the three assumptions and their respective statistical tests needed to be conducted. The first assumption is that the articles were collected independently. As explained in the methodology section, the approach taken to collect the academic literature demonstrated independence; therefore, the first assumption is met. The second assumption is that the variance of each of the five categories' correlation data are equal. The four statistical tests that were conducted to satisfy this assumption were the O'Brien, Brown-Forsythe, Levene, and Bartlett tests, all of which measure the variance of the Pearson correlation data in different ways. Again, a probability ($\alpha$) value of 0.05 was assigned to conduct the analyses. The null hypothesis was that the variances of each category were equal, and the alternative hypothesis was that they were not equal. The results of those four tests are found in Figure 21. All four of the tests provided probability values that were greater than the assigned test probability of 0.05 (O'Brien -> 0.78, Brown-Forsythe -> 0.20, Levene -> 0.13, Bartlett -> 0.29). For these tests, there was not enough evidence to reject the null hypothesis; therefore, the null hypothesis was accepted, and the Pearson correlation's variance was considered equal across the five categories. The results of the four equivalent variance statistical tests further validate the results of the one-way ANOVA.




| Level | Count | Std Dev | MeanAbsDif to Mean | MeanAbsDif to Median |
|---|---|---|---|---|
| Facial Bio Recognition | 10 | 0.1096122 | 0.0807841 | 0.0801583 |
| Gesture Recognition | 28 | 0.1644650 | 0.1436220 | 0.1412823 |
| Personal Devices | 10 | 0.0898842 | 0.0672982 | 0.0672982 |
| Touchless Sensing | 105 | 0.1452681 | 0.1058456 | 0.1042798 |
| Voice Recognition | 6 | 0.1501704 | 0.1140043 | 0.1026807 |

| Test | F Ratio | DFNum | DFDen | Prob > F |
|---|---|---|---|---|
| O'Brien[.5] | 0.4427 | 4 | 154 | 0.7776 |
| Brown-Forsythe | 1.5060 | 4 | 154 | 0.2031 |
| Levene | 1.8132 | 4 | 154 | 0.1290 |
| Bartlett | 1.2492 | 4 | . | 0.2876 |

Figure 21. Results of ANOVA Equal Variance

The third assumption required to validate the results of the one-way ANOVA is that each of the five categories' correlation residuals were distributed normally. The initial statistical test that was conducted was the Shapiro-Wilk test, which measures the residuals of the data set. The null hypothesis was that the residuals across all of the Pearson correlation data would be normal, where the alternative hypothesis was that those residuals were not normal. The results of the initial test are shown in Figure 22. As shown in Figure 22, the Shapiro-Wilk test failed, meaning that an alternative test must be conducted to validate the ANOVA results.

**Goodness-of-Fit Test**

Shapiro-Wilk W Test

| W | Prob<W |
|---|---|
| 0.906832 | <.0001* |

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

**Wilcoxon / Kruskal-Wallis Tests (Rank Sums)**

| Level | Count | Score Sum | Expected Score | Score Mean | (Mean-Mean0)/Std0 |
|---|---|---|---|---|---|
| Facial Bio Recognition | 10 | 922.000 | 800.000 | 92.200 | 0.862 |
| Gesture Recognition | 28 | 3049.00 | 2240.00 | 108.893 | 3.656 |
| Personal Devices | 10 | 806.000 | 800.000 | 80.600 | 0.039 |
| Touchless Sensing | 105 | 7309.00 | 8400.00 | 69.610 | -3.966 |
| Voice Recognition | 6 | 634.000 | 480.000 | 105.667 | 1.387 |

**1-way Test, ChiSquare Approximation**

| ChiSquare | DF | Prob>ChiSq |
|---|---|---|
| 18.9410 | 4 | 0.0008* |

Figure 22. Results of ANOVA Normal Residuals

Therefore, another statistical test can be performed in the case of non-parametric situations (i.e., non-normal distributions). The results of the Kruskal-Wallis test (which can also be found in Figure 22) can help validate the one-way ANOVA in these unique cases. For this test, the null hypothesis would indicate that the mean Pearson correlation values for the five categories are equal, and the alternative hypothesis would suggest that the mean Pearson correlation values are not the same across the five categories. The probability of the Kruskal-Wallis test was 0.0008, which was lower than the assigned probability ($\alpha$) value of 0.05. This means Pearson correlation values across the five categories are not the same, which agrees with the results of the Shapiro-Wilk test. Therefore, although the third assumption of normality does not apply, the alternative Kruskal-Wallis test for these special circumstances validates the one-way ANOVA results.

The results of the indirect reference analysis per category reflect the initial CiteSpace visualization of data for contents. The cluster diagram vividly showed that the contents of each article differ from one another, where certain clusters form based on similarities that were likely touchless technology categories. The results of the indirect reference analysis reach the same conclusion, showing that the reference sections per category are not equivalent in Pearson correlation value. Both of these results suggest that each of the touchless technology categories differ from one another. This could be explained by the different applications in technologies and how those variations lead to either a broader or more diverse array of research papers on the topic. This idea is further explained in the following section as well as in the conclusion.

**Comparing Analyses**

The purpose of this subsection is to compare the results from the thematic analysis and the reference analysis. The mean Pearson correlation coefficients found from the JMP analysis were graphed with the results from the thematic analysis, where each of the five categories, and touchless technologies as a whole, were plotted as singular data points. Included with the categorical plot points is a trend line showing the relationship between the two analyses, as shown in Figure 23.

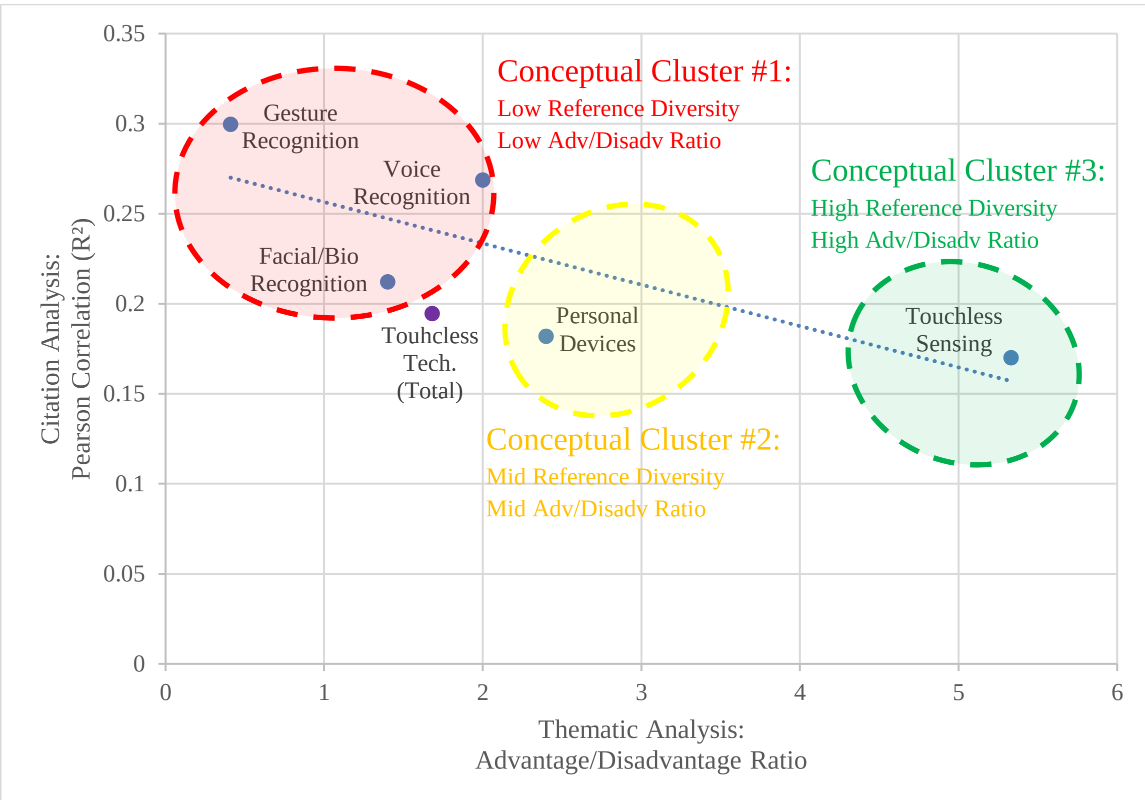



Figure 23. Results of Comparing Analyses

At first glance, it seems as if the results of the thematic analysis and the reference analysis share an inverse relationship; in other words, the category's referential relationship in terms of word similarity appears to increase as the category's advantage to disadvantage ratio decreases.  Due to the fact that these two analyses were radically different from one another, and because each analysis was qualitative and quantitative in nature, respectively, it would not be scientifically feasible or realistically possible to use a trend line like this to predict things such as future touchless technology categories that may appear.  With that said, the results from this plot provide a lot of valuable insight, which will be discussed in the conclusions chapter.

# V. Conclusion

The objective of this chapter is to use the content of the previous chapters to answer the investigative questions posed in the first chapter. The investigative questions were answered as a result of completing the methodology and analyzing the results of the research. The two questions are listed below along with the answers. This chapter also includes a discussion of applications to the U.S. Air Force and recommendations for future research.

## Answers to Investigative Questions

This section addresses the two investigative questions. The first investigative question was, "What is the current state of touchless technologies?" The second investigative question was, "How are the results of the thematic and reference analyses related? What can be concluded from evaluating the results of the two analyses together?" The answers to these questions serve as the foundation for exploring the capabilities, conveniences, and drawbacks of touchless technologies.

### Answer to Investigative Question 1

From examining all of the information presented in this research, it is clear that touchless technologies are incredibly diverse, contain advantages in many different ways, and are constantly growing in both demand and attention. It is impossible to assign an exact value to a technology's worth because of the subjective nature that each technology offers to different users. With that said, from a broad viewpoint, the growing capabilities

and investment towards touchless technologies show that they are indeed being subjectively valued by many people. Whether the attention given to touchless technologies was for convenience or necessity, they have certainly offered organizations methods to achieve desired tasks without physical touch.

It is evident through the information presented in the literature review and the results of this research that certain types of touchless technologies provide more benefit and experience fewer problems than other types. Whether the reasoning behind these realities is the difficulty of the task at hand, complexity of the technology, and/or the technology's track record of improving with each iteration, it is clear that not all categories are created equal. All things considered, this does not mean that certain technologies are considered good, average, or bad. Certain groups of people may find more value in investing in simpler, more convenient technologies that have high reliability. For others, their goals may require specific technologies that have the ability to produce higher benefits than other commonly found devices. This is all up to the user, both in the way they decide to maximize the use of touchless technologies and how they decide to invest in them moving forward.

<u>Answer to Investigative Question 2</u>

In general, the relationship between each category's thematic and reference data deals with the possible utility of each category. Categories that are more limited and specific in utility produce more correlated references. These categories also record fewer overall advantages because the amount of broad applicability is low. In contrast, categories that are broader and diverse in utility produce less correlated references.

These categories also contain a larger number of overall advantages because of the high broad applicability being able to produce many different benefits.

Gesture recognition, facial/bio recognition, and voice recognition technologies have all been included in one conceptual cluster. Each of these three categories appear to have strong Pearson correlation values with one another while having a relatively lower advantage to disadvantage ratio. In terms of evaluating the references for each of these categories' articles, the strong Pearson correlations would suggest that there were many similarities in authors, article titles, and journal editions. A reasonable explanation for these similarities is that the relative recency of these new types of technologies means that the number of authors is probably condensed to a smaller, reoccurring few names. Similarly, the applications for these types of technologies are likely to be very few as well, leading to the assumption that the case studies used in the articles were probably similar. When applying this type of thinking to form a conclusion about the similar ratios, the variability of applications for these types of technologies is limited to a small number of specific uses. This, along with the relative recency of these types of technologies, may indicate that there are simply not enough identified advantages for these types of technologies yet. This conceptual cluster signifies that the amount of diversity with these types of technologies is small, leading to stronger connections in references. This also leads to the smaller number of advantages compared to the inevitable disadvantages that will occur.

Personal devices have been included in another conceptual cluster which has a relatively average Pearson correlation coefficient among its articles, and it also has a relatively average advantage to disadvantage ratio compared to the other categories.

Similar to the previous cluster's analysis, this conceptual cluster appears to have more diversity within its utility. In terms of its references, the wider practicality of personal devices means that a broader array of case study topics can be found, which would lead to a greater number of article titles and journal issues. The authors of these different applications would be more diverse as well, leading to the lower Pearson correlation values compared to the previous cluster. When applying the larger amount of possible utility to the cluster's advantage to disadvantage ratio, the wider number of uses serve to provide a greater number of advantages for this category. The more functionality within this cluster has the potential for more advantages compared to the inevitable disadvantage any piece of technology would have.

The final conceptual cluster includes the touchless sensing category. In general, applying the idea of diversification for each of the three conceptual clusters serves to fit the touchless sensing technology category correctly. Touchless sensing technologies have historically been in use the longest out of all of the categories, meaning that the number of applications and uses exceeds the other categories. This leads to a greater number of contributing authors who could produce literature, a higher number of case studies pertaining to the category, and a larger number of journal issues on the topic, which would cause the mean Pearson correlation value to be relatively lower than the other categories. The larger sample size in terms of technological utility means that the number of advantages compared to its disadvantages exceeds that of any other category. It is reasonable to conclude that this conceptual cluster's broad diversity has led to it containing the greatest advantage to disadvantage ratios and the least correlated reference sections amongst its literature.

The primary conclusion to draw is that technologies that have been able to perform a wide array of tasks have been able to produce lots of benefit for users. While there are clearly advantages for the niche categories, their widespread applicability has not matched that of the more general categories of touchless technologies. In time, as more uses are found for these technologies, they will all have greater ratios and less connections reference-wise. This is inevitable in a continuously evolving technological world.

**Application to U.S. Air Force**

As stated previously, every organization values each piece of technology in a unique manner, and this reality is no different for the U.S. Air Force. It would be impractical for the Air Force to apply touchless technologies universally across all installations and units because not every unit values them in the same way. To contrast that point, it would also be irresponsible to allow every unit commander to customize their own facilities with touchless technologies without sufficient justification. There needs to be a balance achieved between standardization of technologies and interpreting their necessity.

It can be said that some of the touchless technology categories, particularly ones that are simple and diverse in utility, are already found on Air Force installations. Many facilities on Air Force bases take advantage of touchless sensing technology due to the wide array of uses it can offer. Many entrances across the Air Force are automatic, many faucets within restrooms already contain sensors, and many conference rooms contain motion-activated lighting to conserve energy. It is apparent that the Air Force in general

values simplicity, reliability, and conserving resources, so the application of touchless sensing technology remains prevalent within Air Force infrastructure.

On the other hand, certain technology categories are not found to the degree of touchless sensing because of the potential risks they pose. For example, the Air Force greatly values cybersecurity; however, current voice recognition technologies and personal devices contain risks that could expose the Air Force network to potential hacking. Where there are advantages to implementing this technology, the Air Force's subjective stance on protecting their cyberspace shows why they have not integrated these categories within their infrastructure. The Air Force also values being as monetarily efficient as possible, aiming to make responsible decisions with taxpayer dollars while fulfilling its mission needs. Where simple touchless sensing technologies are generally cost effective, there are more complex technologies of each category that are more expensive in comparison. Until the Air Force sees a way in which these high costs are worth the investment, it will continue to execute its missions without these more expensive technologies.

With a constantly advancing technological world, it is likely that touchless technologies will become cheaper to install in the future. On top of that, the initial problems of inaccuracy, cybersecurity threats, and lack of applicability will likely be addressed, thus making them greater potential investments. It will be the Air Force's responsibility to constantly reevaluate their position on touchless technologies. Through the Air Force's subjective lens, where today it may not be advantageous to integrate many different touchless technologies, that conclusion may change in the future.

Through the context of the results, the recommendation of this research is for leadership to identify the needs they have and to explore touchless technologies that address those needs. This does not necessarily mean, however, that the results of this research apply objectively to all situations because value is subjective. For example, it would be irresponsible to recommend "use touchless sensing technologies because they have the most advantages according to this study." Instead, a more appropriate recommendation for Air Force leaders is to be more aware that certain technologies that have evolved to produce more advantages are more likely to contain the solution to a problem. However, this reality does not make a technology type inherently better because the problem that leadership aims to solve can vary depending on the situation. Where it is imperative that the Air Force equips itself with the most effective technology possible to conduct its warfighting capabilities, it is up to decision-makers to determine if the problem they have can be addressed, and if so, which technological solution effectively addresses that problem.

**Future Research**

Iterations of this methodology, as well as different approaches altogether, need to continue in order to track the changing number of advantages and disadvantages within touchless technologies. As more technology develops, more case studies and meta-analysis literature will be available that could then be examined for their themes. Additionally, having multiple researchers conduct this methodology in the future would be beneficial because each researcher contains their own natural biases. Although the thematic and reference analyses will likely change due to the development and

improvement of these technologies, finding similar results across multiple researchers would further validate the effectiveness of the study, saying that the researcher's bias is less of a problem than originally anticipated.

In the future, it is likely that quantifiable cost-benefit analysis data would be available for each of the five categories. When there is enough of this data to conduct an official cost-benefit analysis, this should be pursued by future researchers. However, this does not mean that this methodology should be replaced. Although obtaining quantifiable cost-benefit data would illustrate the state of each category, the reality is that the value for many of these technologies are still subjective in nature. In the future, this methodology can be modified to include objective cost-benefit data, but it should not remove its ability to measure and quantify subjective themes.

# Appendices

## Appendix A.  Thematic Data

| Category | Adv./Disadv. | Article | Thematic Code | Most Reoccuring Theme? (referencing Figure 16) |
|---|---|---|---|---|
| Facial/Bio Recognition | Advantage | Chenhao & Kumar, 2018 | Contactless 3D fingerprint identification has gained significant attentions in recent years as it can offer more hygienic, accurate and ubiquitous personal identification. | X |
| Facial/Bio Recognition | Advantage | Iqbal & Campbell, 2020 | The rapid adoption of biometric systems as official identification to monitor workplace attendance, to control the security of digital devices, and now in the use of ATM machines has created a need for touchless fingerprint detection systems in these areas. | X |
| Facial/Bio Recognition | Advantage | Latman & Herb, 2013 | In this study, the system successfully enrolled all subjects on the first attempt. All 277 subjects were successfully verified and identified on the first day of enrollment. None of the current or prior eye conditions prevented enrollment, verification, or identification. All 35 subjects with alcohol-induced nystagmus were successfully verified and identified. There were no false verifications or false identifications. Two conditions were identified that potentially could circumvent the use of iris recognitions systems in general. | |
| Facial/Bio Recognition | Advantage | Latman & Herb, 2013 | The Mobile-Eyes™ iris recognition system exhibited accurate and reliable enrollment, verification, and identification applications in this study. It may have special applications in subjects with nystagmus. | |
| Facial/Bio Recognition | Advantage | Latman & Herb, 2013 | The lack of basic failures is especially significant given the highly diverse sample demographics, number of attempts and iris comparisons, and varying test conditions. This high success rate is consistent with an International Biometric Group (IBG) study [30] of the Eye Controls SafeMatch™ implementation of the "Eye Controls VectorMatch" algorithms. | |
| Facial/Bio Recognition | Advantage | Latman & Herb, 2013 | In conclusion, this study found the Mobile-Eyes™ iris recognition system to be accurate and reliable under expected indoor applications of enrollment, identity verification, and identification. | X |
| Facial/Bio Recognition | Advantage | Ramanthan et al., 2021 | This technology can be realized real time with low cost and versatile in many aspects. | |
| Facial/Bio Recognition | Disadvantage | Chenhao & Kumar, 2018 | Despite such advantages, contactless 3D imaging often results in partial 3D fingerprints as it requires relatively higher cooperation from users during the contactless 3D imaging. Such contactless 3D fingerprint images significantly degrade matching accuracy due to partial 3D fingerprint imaging. | X |

| | | | | |
|---|---|---|---|---|
| Facial/Bio Recognition | Disadvantage | Chenhao & Kumar, 2018 | Contactless partial 3D fingerprint identification is a more challenging problem due to its high degree of freedom during contactless 3D fingerprint acquisition and is also addressed by using proposed model. | X |
| Facial/Bio Recognition | Disadvantage | Latman & Herb, 2013 | One of the weaknesses of most of the previously published evaluations of accuracy of iris biometric instruments has been a deficiency or complete lack of significant demographic information. | X |
| Facial/Bio Recognition | Disadvantage | Latman & Herb, 2013 | However, a potential problemwith this is the observation that the color of irises is not a constant over time. For example, about 10 to 20% of children between birth and 6 years of age experience a change in iris color. In addition, Bito et al. found that about 10 to 15% of "white subjects" exhibit a change in iris color throughout adolescence and adulthood. The study by Carino et al. indicated that 10 to 20% of adults exhibit a change in eye-color. | |
| Facial/Bio Recognition | Disadvantage | Ramanthan et al., 2021 | The major challenge faced by the team is maintaining the privacy when the scalability and the data density increase. | |
| Gesture Recognition | Advantage | Cronin & Doherty, 2019 | Overcoming hardware restrictions has been a major theme, but in recent research, technical difficulties have receded. | |
| Gesture Recognition | Advantage | Cronin & Doherty, 2019 | Modern technology can contribute to patient care by allowing healthcare staff rich and immediate access to patient information and imaging. | X |
| Gesture Recognition | Advantage | Cronin & Doherty, 2019 | Rosa and Elizondo state that with a little training of the user, use of their gesture interface is easier and faster than changing sterile gloves or having an assistant outside the sterile environment. | X |
| Gesture Recognition | Advantage | Habibi & Chattopadhyay, 2021 | Both types of touchless inputs produced significantly less degradation between hands than the mouse or stylus. | |
| Gesture Recognition | Advantage | Habibi & Chattopadhyay, 2021 | Touchless inputs are location-independent and require neither a hard flat surface, such as a desk, nor awkward equipment. People can move freely with a head-mounted display (HMD) or interact with a very large display from a distance. | X |
| Gesture Recognition | Advantage | Habibi & Chattopadhyay, 2021 | The last decade has seen an exponential growth of touchless technologies, and consequently, interaction techniques. The use of touchless input is only expected to soar with the maturation of virtual reality (VR) and augmented reality (AR) technologies. | |

| | | | | |
|---|---|---|---|---|
| Gesture Recognition | Advantage | Vuletic et al., 2019 | Depth cameras and accelerometers were the most frequently used technologies. However, sensors and cameras are gaining popularity as they provide the ability to implement interfaces requiring no physical contact with the user, which are more intuitive and less invasive. If accuracy and reliability were improved, these could become the primary technology for gesture interfaces in the future. | X |
| Gesture Recognition | Advantage | Liu et al., 2020 | Compared with conventional methods with markers, range-camera-based systems are easier and simpler to use, and a lot cheaper with lower precision. | X |
| Gesture Recognition | Advantage | Liu et al., 2020 | Kinect One is extensively used in many applications for its longer effective detection range and relatively less noisy depth map. | |
| Gesture Recognition | Advantage | Liu et al., 2020 | In many scenarios, where it may be inconvenient or impossible for the user to touch a screen or keyboard, an RGB-D camera will be a fairly useful and powerful interaction tool. | X |
| Gesture Recognition | Advantage | Iqbal & Campbell, 2020 | Today, the average person can certainly appreciate the need for touchless interaction. | X |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | At a practical level, gesture recognition works best at particular distances. | X |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | However, depth segmentation has required an upper and lower threshold, meaning that to use a system the user cannot be too close or too far away. | X |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | Sufficient operational space is one of the factors affecting user comfort. This relates to the question of fatigue, and the need to avoid intense muscle tension over time. Consideration of static ('the effort required to maintain a posture for a fixed amount of time') and dynamic ('the effort required to move a hand through a trajectory') stress is key in promoting user comfort. | |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | As mentioned in 29 papers, and discussed on a practical level in 20 papers, voice control has been found to be slower but more accurate than gesture control, and both were slower than traditional methods. | X |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | However, it is claimed that much existing work from a medical background lacks consideration of practical elements and implementations, remaining experimental and work originating from a technology background often suffers from oversimplification of medical complexity. | |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | There is also a recognised need to minimise unwanted side effects such as accidental gesture recognition. | X |

| | | | | |
|---|---|---|---|---|
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | Major themes in their analysis echo the conclusions presented in this article regarding recent improvements in the feasibility of touchless control; the need for improved evaluations; the need to improve usability, including issues surrounding accuracy and unintended gestures; and the potential of multimodal interaction to address some of the practical difficulties in making these systems appropriate for deployment. | |
| Gesture Recognition | Disadvantage | Cronin & Doherty, 2019 | It is clear that while progress has been made in the field, the literature does not support any instance of the technology being mature enough to gain widespread acceptance or adoption. | X |
| Gesture Recognition | Disadvantage | Habibi & Chattopadhyay, 2021 | Regardless of the potential, individuals perform poorly with touch-<br>less inputs compared with the mouse, pen, or stylus. | X |
| Gesture Recognition | Disadvantage | Habibi & Chattopadhyay, 2021 | Familiarity or practice alone can not explain these performance differences; studies show that motor learning, induced by distributed practice, does not improve touchless performance to become as good as mouse or touch input. | X |
| Gesture Recognition | Disadvantage | Habibi & Chattopadhyay, 2021 | But in spite of its potential, touchless input is limited by the lack of haptic feedback and gorilla-arm fatigue. | |
| Gesture Recognition | Disadvantage | Pei-Lee et al., 2015 | Currently, only limited guidance is provided for designers and manufacturers in their development of consumer somatosensory | |
| Gesture Recognition | Disadvantage | Pei-Lee et al., 2015 | For individuals with small hand-size, they faced incompatibility to technology (i.e., lack of sensitivity or inability of the technology to read the signal) leads frustration to fatigue. | |
| Gesture Recognition | Disadvantage | Pei-Lee et al., 2015 | When people with small hand-size are unable to access the digital appliance using hand gesture, they can break into frustration and fatigue. | X |
| Gesture Recognition | Disadvantage | Vuletic et al., 2019 | From the review, the community seems disparate with little evidence of building upon prior work and a fundamental framework of gesture-based interaction is not evident. | |
| Gesture Recognition | Disadvantage | Vuletic et al., 2019 | Technologies can roughly be divided into visual based sensors and cameras, and physical wearables. The former are unobtrusive, and provide opportunity for natural movement, while the latter are generally more accurate and easier to set up and track, but can encumber the wearer. | |
| Gesture Recognition | Disadvantage | Liu et al., 2020 | However, as an interaction device, Kinect is not precise enough for accurate control, which prevents it from being popular in many real applications. | X |

| | | | | |
|---|---|---|---|---|
| Gesture Recognition | Disadvantage | Liu et al., 2020 | Occlusion is another common problem. While the user is interacting with the device, it is inevitable that part of the user is occluded, which imposes a significant effect on gesture recognition and an uncomfortable experience for the user. | |
| Gesture Recognition | Disadvantage | Liu et al., 2020 | Unlike traditional interactive devices, which provide accurate enough control over the cursor, current touchless interactive systems can offer only limited interaction actions. | X |
| Gesture Recognition | Disadvantage | Liu et al., 2020 | Meanwhile, most applications are focused on particular scenarios, which make these systems inconvenient for users to customize according their own applications and requirements. In addition, these restrictions may bring difficulty to users with different culture backgrounds while they are learning the designed gestures. | |
| Gesture Recognition | Disadvantage | Liu et al., 2020 | Throughout the development of our system, the challenge of low gesture recognition accuracy caused by the limited precision of human body detection emerged. Current RGB-D cameras can capture joint data in real time with acceptable calculation, but the precision is too low for serious applications, such as vehicle control. | X |
| Gesture Recognition | Disadvantage | Liu et al., 2020 | New approaches based on convolutional neural networks (CNN) and RGB cameras can produce more accurate estimations of human pose, but the time cost is too large for real-time interaction applications. It is necessary to work for further achievement to accelerate the calculation while maintaining a relatively high precision. | |
| Gesture Recognition | Disadvantage | Iqbal & Campbell, 2020 | The gesture-based technologies that have been adopted in research have thus far not been popular outside of research labs. | |
| Gesture Recognition | Disadvantage | Iqbal & Campbell, 2020 | There are several issues in the design, development, and adoption of such technologies that should be addressed in the | |
| Gesture Recognition | Disadvantage | Mingawa et al., 2014 | The present prototype allows intutitve operations in two directions including screen scaling, and determines which of the two types of operations is intended according to the shape of the hand held up. However, an increased number of operation commands may require the user to learn the shapes and may generate misjudgement as well. To ensure that the number of operation commands is easy to use for the user, measures are necessary such as assigning small command sets according to situations of use so as to prevent placing an increased burden on the user. | |

| | | | | |
|---|---|---|---|---|
| Gesture Recognition | Disadvantage | Mingawa et al., 2014 | With hand gesture detection using a camera, the position and state of the hand were generally made changeable so that the user could make motions in the detection area by presenting the image to the user showing whether the hand was in the detection area. However, images from a near-IR camera as in the present study are different from visible images that can be usually obtained, which makes it difficult to associate an image with the real space even if it is presented. | X |
| Gesture Recognition | Disadvantage | Mingawa et al., 2014 | As a result of an experiment, it has been found out that non-detection may occur depending on the distance between the hand and face. In the future, we intend to verify the feasibility of the prototype mentioned above to work on easier-to-use integration and build an integrated interface with less non-detection by improving the accuracy. | X |
| Personal Devices | Advantage | Habibi & Chattopadhyay, 2021 | As virtual reality (VR) and augmented reality (AR) technologies mature and high-resolution, large displays become affordable, the use of touchless input in interaction techniques, whether via a device in midair, like a smartphone, or device-less, is expected to rise. | X |
| Personal Devices | Advantage | Grover & Sabherwal, 2020 | Digitalization can play a role here, by using touchless menus on smartphones, robotbased services, coordinating touches delivery, etc. | X |
| Personal Devices | Advantage | Kamble et al., 2021 | The user satisfaction score is recorded based on six basic metrics, viz. ease of use, size, strength, appearance, material and ease of carrying. A satisfaction score of 85% is reported, with ABS being the preferred material of choice. | X |
| Personal Devices | Advantage | Kamble et al., 2021 | Different case studies highlighting the multifunctionality of the presented design of the COVID key are reflected in this work. The detailed FEA analysis shows that the present COVID key is fit to be used in domestic and workplace settings. The prime application for the given COVID key is in the hospital buildings with a high number of people living or being treated for COVID. All majority actions such as pushing, pulling, pinching, tightening, measuring and holding can be performed satisfactorily with the present COVID key. | X |
| Personal Devices | Advantage | Kamble et al., 2021 | A novel key design that gives good protection against infectious surfaces by enabling a remote touch. | |
| Personal Devices | Advantage | Kamble et al., 2021 | Multifunctionality of the key enables the user to perform various actions and reduces the need to carry multiple tools to perform a wide range of actions. | X |
| Personal Devices | Advantage | Kamble et al., 2021 | The size of the key is compact; hence it can be stored in the pockets, handbags and purse after proper sanitization. | X |

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| Personal Devices | Advantage | Kamble et al., 2021 | The geometry is simplified to make it suitable for 3D printing where the CAD model can be shared with people. It can be printed from the nearby 3D printing facility. It makes the distribution of the key easy and widespread. | X |
| Personal Devices | Advantage | Wanga et al., 2021 | Smartphone installed with relevant app brings people together even when this coronavirus (COVID-19) pandemic forces us apart. | X |
| Personal Devices | Advantage | Utz et al, 2021 | Many "corona apps" require widespread adoption to be effective, which has sparked public debates about the privacy, security, and societal implications of government-backed health applications. | |
| Personal Devices | Advantage | Utz et al, 2021 | In all surveyed countries, aspects regarding pandemic control were among the most frequently mentioned positive aspects of corona apps. Thus, many citizens seem to be generally open to the idea of using mobile apps to help limiting the spread of a virus. | |
| Personal Devices | Advantage | Utz et al, 2021 | Such apps can be further developed to be ready for deployment in potential future pandemics. | |
| Personal Devices | Disadvantage | Kamble et al., 2021 | It could be troublesome to use the key initially due to a lack of experience in using it. Thus, the authors suggest using the key repeatedly to get accustomed to social settings. | |
| Personal Devices | Disadvantage | Kamble et al., 2021 | Key is not suitable for some very specific or extreme applications with size and temperature constraints. However, the design and material can be modified to suit the particular application. | |
| Personal Devices | Disadvantage | Utz et al, 2021 | The use of smartphone applications in the fght against the pandemic has sparked intense public debates about the privacy, security, and societal implications of government-recommended health apps and specifc aspects of their implementations. | X |
| Personal Devices | Disadvantage | Utz et al, 2021 | User acceptance and their willingness to use these apps can thus be critical for the overall success of smartphone apps in the eforts to fght the pandemic. Many of the publicly discussed and criticized aspects are well-known elements in the theory of "privacy as contextual integrity", which acknowledges that factors beyond the technical implementation, like social norms and expectations, infuence perceptions of privacy violations. | X |
| Personal Devices | Disadvantage | Utz et al, 2021 | First, designers and developers of apps that collect sensitive health data should keep in mind the factor levels that positively infuence user acceptance (e. g., avoid technical malfunctions, provide data only to health authorities or research institutions, do not collect data that could be used to uniquely identify the user (US and DE)). | X |

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| Touchless Sensing | Advantage | Grover & Sabherwal, 2020 | In doing so, companies that can identify the customer's post-pandemic value points (e.g., touchless service) and then deliver on them – foster customer surplus. | |
| Touchless Sensing | Advantage | Gerba, 2015 | This study evaluated an ultraviolet (UV) light point-of-dispense water treatment system for control of P aeruginosa.No P aeruginosa was detected in 30 different water dispensers in which the UV light device had been operating for 1-34 months. In comparison, P aeruginosa was found in other taps that did not feature this UV light system. | X |
| Touchless Sensing | Advantage | Landgrebe, 2011 | 405nm light is known to kill some species of bacteria. | X |
| Touchless Sensing | Advantage | Landgrebe, 2011 | The following organisms were killed at greater than 4 logs using 405nm light at 1 hour exposure time; Acinetobacter baumannii, Klebsiella pneumoniae, Staphylococcus aureus, Staphylococcus epidermidis, Escherichia coli, Pseudomonas aeruginosa, Enterococcus faecalis, and Streptococcus pneumoniae. | X |
| Touchless Sensing | Advantage | Landgrebe, 2011 | Our results suggest that a therapeutic window may exist for treatment of some inections in human tissues using 405 nm light. | X |
| Touchless Sensing | Advantage | Lozier, 2016 | Therefore, touchless, sensor-operated faucets can contribute to a higher level of handwashing hygiene. | X |
| Touchless Sensing | Advantage | Lozier, 2016 | The advantages of sensor-operated faucets extend beyond the public restroom to almost any other type of handwashing station, especially in applications requiring the highest levels of cleanliness. | X |
| Touchless Sensing | Advantage | Lozier, 2016 | Sensing technologies based on electronics are most often used for hands-free activation of plumbing fittings such as faucets to improve user accessibility in compliance with the Americans with Disabilities Act (ADA) and improve overall hygiene and restroom cleanliness. | X |
| Touchless Sensing | Advantage | Lozier, 2016 | More water can be saved when sensor faucets automatically switch off as soon as users remove their hands from the wash area, as opposed to metered and manual faucets that can be left running for extended cycles, sometimes even after users leave the restroom. These energy savings over the faucet's lifetime reduce a facility's water and wastewater bills. | |
| Touchless Sensing | Advantage | Lozier, 2016 | Since these faucets are preset to shut off after a certain amount of time, they save a significant amount of water, and accidental flooding can't occur if a user leaves it running. And, because they are hands-free, they help reduce the spread of germs and keep the vanity area clean. | X |

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| Touchless Sensing | Advantage | Doll & Bearman, 2018 | Bypassing the variability in human practices, disinfection devices are now increasingly deployed after manual cleaning to further reduce bioburden in patient rooms. | X |
| Touchless Sensing | Advantage | Doll & Bearman, 2018 | Devices include hydrogen peroxide (HP) or UV-light emitting machines. Manual cleaning remains an important precursor step, as gross organic soil must be removed from surfaces to allow penetration of germicidal vapor/aerosol or radiation. | X |
| Touchless Sensing | Advantage | Doll & Bearman, 2018 | There has been a single large, multi-center, controlled study to assess HAI reduction using a UV device. This study found a significant reduction in HAI acquisition when the UV device was added to quaternary ammonium cleaning. Clostridium difficile acquisitions were not significantly impacted. | X |
| Touchless Sensing | Advantage | Nicol, 2020 | In general, fomite transmission opportunities are fewer when "touch-less" sensor-operated amenities such as sinks, soap and paper towel dispensers are provided. | |
| Touchless Sensing | Advantage | Nicol, 2020 | Touchless or automatic paper towel dispenser, as well as automatic doors or doorless entry ways, are even better choices for reducing contamination during hand drying and to keep hands from re-contamination after washing. | X |
| Touchless Sensing | Advantage | Iqbal & Campbell, 2020 | Replacing this button-based interaction with a gesture or interactive hand controller could handle such cases and move the world forward. | X |
| Touchless Sensing | Advantage | Morimoto, 2010 | A probabilistic cost benefit analysis, which takes into account future uncertainty, is conducted using a Monte Carlo simulation. Our findings suggest that if the Smart Infrastructure sensor system is applied to water pipelines in the British market, there are likely to be significant economic benefits. | |
| Touchless Sensing | Advantage | Morimoto, 2010 | They could be realised by avoiding disruption and damage costs (including water loss) due to water pipe bursts, as well as by reducing annual operating and maintenance costs. The mean cumulative net present value of savings derived from the case scenario for the period through year 2056 was estimated at US$ 23.7 billion. | |
| Touchless Sensing | Advantage | Morimoto, 2010 | The Smart Infrastructure can speed up the process of improving the current sensor system, generating direct economic benefits, such as reduced O&M costs due to its automated system. | |
| Touchless Sensing | Advantage | Morimoto, 2010 | The Smart Infrastructure sensor system constitutes an economically sound investment, partly due to its relatively low development and harmonisation costs. Based on our findings, the application of this system is highly likely to generate significant economic, environmental, and social benefits. | |

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| Touchless Sensing | Advantage | Morimoto, 2013 | The advantages of using these wireless sensors are their reliability, low-cost, low power and fast deployment characteristics. | |
| Touchless Sensing | Advantage | Morimoto, 2013 | However, the benefit of managing both industries simultaneously using the Smart Infrastructure sensor could be significant. Thus, this kind of emerging technology is proved to play a major role in improving and integrating the current infrastructure management practice. Moreover, the findings indicate that the potential socio-economic impacts appear to be realised gradually, therefore early implementation could be recommended. | |
| Touchless Sensing | Advantage | Das, 2021 | This study reveals that the LDR-based automated hand sanitizer dispenser system is a novel concept, and it is cost-effective compared to the conventional ones. The presented device is expected to play a key role in contactless hand disinfection in public places, and reduce the spread of infectious diseases in society. | X |
| Touchless Sensing | Advantage | Casini, 2019 | The implementation of the standard cleaning and disinfection procedure with the integration of the PX-UVC treatment had effective results in both the reduction of hygiene failures and in control environmental contamination by high-concern microorganisms. | X |
| Touchless Sensing | Advantage | Casini, 2019 | Implementation of this "no-touch" technology in various hospitals has documented a sustained reduction in surface microbial contamination, reduced cross contamination, and a reduced spread of multi-drug resistant bacterial infections. | X |
| Touchless Sensing | Advantage | Casini, 2019 | In the last few years, no-touch systems for environmental decontamination are increasingly being considered, such as the UVC no-touch technology that can be done routinely and rapidly in different hospital settings after patient discharge or transfer. | X |
| Touchless Sensing | Advantage | Casini, 2019 | No-touch surface decontamination technologies that use ultraviolet light may be effective in enhancing the results of the effort spent to reduce the microbial burden and potentially achieving lower Healthcare-associated Infections HAIs rates, as aimed for in infection control strategies. | X |
| Touchless Sensing | Advantage | Li et al., 2011 | The results and insights derived from the analysis have important implications on adaptive built environment management to prevent infectious disease outbreaks and respond to the on-going pandemic. | X |

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| Touchless Sensing | Advantage | Li et al., 2011 | Providing information to end-users is critically important for them to change behaviors. Human behavior plays an important role in the transmission of pathogens such as SARSCoV-2. Changing behaviors is critical to preventing transmission. | X |
| Touchless Sensing | Advantage | Li et al., 2011 | The occupants can access the useful information via webpage to plan their visit and staying time in the facilities, and practice appropriate personal hygiene and cleaning practices based on the information. | X |
| Touchless Sensing | Advantage | Tokazhanov et al., 2021 | The use of touchless technology (PVP2) is the most important indicator in the prevention of virus propagation according to all three groups of experts (Acd: 5.66; Ind: 5.86; Med: 7.19). The fact that the Med experts gave this indicator the highest score indicates the crucial role of touchless technologies in preventing the spread of the virus via direct contact with contaminated surfaces. | X |
| Touchless Sensing | Advantage | Tokazhanov et al., 2021 | As agreed upon by all experts, the use of touchless technologies was found to be the most promising way to prevent the spread of viruses, along with the use of temperature is very low, it is important to keep a normal temperature inside. Additionally, heaters that are hot all the time decrease the humidity of the indoor air. | X |
| Touchless Sensing | Disadvantage | McMullen et al., 2021 | Findings from 3 hospitals in our health system demonstrated no significant effect of UVL room disinfection on CDI rates. | |
| Touchless Sensing | Disadvantage | McMullen et al., 2021 | Compliance with utilization of the devices varied across hospitals, but despite high utilization in some settings, CDI rates remained unchanged. | X |
| Touchless Sensing | Disadvantage | Landgrebe, 2011 | There has been no practical application of this method in clinical practice. | X |
| Touchless Sensing | Disadvantage | Doll & Bearman, 2018 | The HP or UV light is toxic to humans. Thus, these devices are used only in empty patient rooms – for example, after a patient discharge. | |
| Touchless Sensing | Disadvantage | Doll & Bearman, 2018 | UV and HP devices are costly, and cost-effectiveness has not been well established. They also require human resources to deploy. | X |
| Touchless Sensing | Disadvantage | Das, 2021 | The key problem of the conventional ultrasonic and infra-red-based dispensers is their malfunctioning due to the interference of sunlight, vehicle sound, etc. when deployed in busy public places. | |
| Voice Recognition | Advantage | Cronin & Doherty, 2019 | [It is believed] that voice control has an important role to play in minimally invasive surgery, allowing the surgeon to take control of the entire OR without breaking sterility or interrupting the surgery; this potentially allows for single surgeon surgery, resulting in reduced costs. | X |

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| Voice Recognition | Advantage | Cronin & Doherty, 2019 | Voice recognition has been described as having accuracy as high as 99 per cent; however, some studies have shown slightly lower accuracy than human transcription. | |
| Voice Recognition | Advantage | Cronin & Doherty, 2019 | Voice control is generally deemed good for discrete commands, though it is not appropriate for continuous parameter adjustment, for which gestures are better suited. | |
| Voice Recognition | Advantage | Cronin & Doherty, 2019 | Use of a voice recognition interface resulted in a significantly higher quality of anaesthesia record as compared to the traditional interface (99% of medications recorded vs 56%), as well as a reduced error rate. | |
| Voice Recognition | Advantage | Cronin & Doherty, 2019 | [They] considered the issue of user fatigue when implementing voice recognition as compared to keyboard input and gathered user feedback regarding both input tools by means of a questionnaire. Their results indicated that users found that voice input caused less fatigue and was easier compared with keyboard operation, despite being inexperienced with voice input. | X |
| Voice Recognition | Advantage | Kumar & Shimi, 2015 | The results show the system can provide great assistant to the physically challenged people without any third person's assistances. | X |
| Voice Recognition | Advantage | Kumar & Shimi, 2015 | Integrating voice recognition technology to home automation systems make the system more user friendly and easy to operate. | X |
| Voice Recognition | Advantage | Simmons et al., 2017 | Driver distration is a growing and pervasive issue that requires mulitple solutions. Voice-recognition (V-R) systems may decrease the visual-manual (V-M) demands of a wide range of in-vehicle system and smartphone interactions. | X |
| Voice Recognition | Advantage | Simmons et al., 2017 | Driving while interacting with a VR system is associated with increases in reaction time and lane positioning, and decreases in detection compared to driving without a system. | |
| Voice Recognition | Advantage | Simmons et al., 2017 | While using a V-R system, reaction time was increased and detection was decreased compared to baseline driving. | |
| Voice Recognition | Advantage | Alexakis et al., 2019 | The microcontroller that is programmed to control the home lights in Figure 3 receives MQTT messages by the IoT Agent to handle their states. It is synchronized with the database the first time it boots and, after that, only uses the received MQTT messages for the whole process. As a result, it is working efficiently and very fast. | |

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| Voice Recognition | Advantage | Alexakis et al., 2020 | Firebase synchronizes with the microcontrollers that relate to the DHT11 sensors every 5 s, which keeps the results up to date. Moreover, the microcontrollers compare the present sensor values with the previous ones, so only updated measurements are sent to the database. As a result, the microcontroller does not overload the whole network with unnecessary traffic. | |
| Voice Recognition | Advantage | Alexakis et al., 2021 | The Internet of Things field undoubtedly offers a revolution in the way we interact with everyday objects and devices, still has a lot to offer, and is changing the way we interact with everyday devices. Even though our implementation is still in its early stages, we strongly believe that it can contribute in this direction and offer even more possibilities. | X |
| Voice Recognition | Advantage | Alexakis et al., 2022 | Furthermore, with the use of natural language as an input method, usability is enhanced. People with visual or moving disabilities, or elderly people who are not so accustomed to technology, can be assisted to make every-day actions more easily with the use of our IoT Agent. Furthermore, natural language can also help people with special needs in the matter of safety. | |
| Voice Recognition | Disadvantage | Cronin & Doherty, 2019 | As mentioned in 29 papers, and discussed on a practical level in 20 papers, voice control has been found to be slower but more accurate than gesture control, and both were slower than traditional methods. | |
| Voice Recognition | Disadvantage | Cronin & Doherty, 2019 | Two major issues for voice control are people's accents and ambient noise, with the noise levels of an OR making voice control extremely | X |
| Voice Recognition | Disadvantage | Kumar & Shimi, 2015 | The voice recognition module needs to be trained first before it can be used to recognize commands. | X |
| Voice Recognition | Disadvantage | Kumar & Shimi, 2015 | The Limitation of the system is the use of the computer which makes system more expensive. | |
| Voice Recognition | Disadvantage | Simmons et al., 2017 | However, the degree that V-R systems integrated into vehicles or available in mobile phone applications affect driver distraction is incompletely understood. | |
| Voice Recognition | Disadvantage | Simmons et al., 2017 | Although V-R systems have some driving perfomrance advantages over V-M systems, they have a distraction cost relative to driving without any system at all. The pattern of results indicates that V-R systems impose moderate distraction costs on driving. | |
| Voice Recognition | Disadvantage | Simmons et al., 2017 | Finally, it is important to note that although the current study demonstrates that voice-recognition systems have a distraction cost, it is unclear whether these translate into increased | |

Appendix B. Reference Correlation Data

| Rank | Literature File #1 | Literature File #2 | Pearson correlation coefficient ($R^2$) |
|---|---|---|---|
| 1 | Doll and Bearman, 2018 | Casini, 2019 | 0.759098 |
| 2 | McMullen et al., 2021 | Casini, 2019 | 0.710524 |
| 3 | Vuletic et al., 2019 | Liu et al., 2020 | 0.669154 |
| 4 | Morimoto, 2013 | Morimoto, 2010 | 0.669087 |
| 5 | McMullen et al., 2021 | Doll and Bearman, 2018 | 0.59741 |
| 6 | Vuletic et al., 2019 | Cronin and Doherty, 2019 | 0.573518 |
| 7 | Kumar and Shimi, 2015 | Alexakis et al., 2019 | 0.551421 |
| 8 | Liu et al., 2020 | Cronin and Doherty, 2019 | 0.520423 |
| 9 | Vuletic et al., 2019 | Habibi and Chattopadhyay, 2021 | 0.509417 |
| 10 | Liu et al., 2020 | Habibi and Chattopadhyay, 2021 | 0.498219 |
| 11 | Liu et al., 2020 | Iqbal and Campbell, 2020 | 0.484127 |
| 12 | Nicol, 2020 | Li et al., 2021 | 0.473147 |
| 13 | Habibi and Chattopadhyay, 2021 | Cronin and Doherty, 2019 | 0.468543 |
| 14 | Meyer et al., 2014 | Habibi and Chattopadhyay, 2021 | 0.458949 |
| 15 | Liu et al., 2020 | Chenhao and Kumar, 2018 | 0.454986 |
| 16 | Meyer et al., 2014 | Liu et al., 2020 | 0.453413 |
| 17 | Gerba, 2015 | Doll and Bearman, 2018 | 0.44571 |
| 18 | Vuletic et al., 2019 | Chenhao and Kumar, 2018 | 0.444826 |
| 19 | Gerba, 2015 | Casini, 2019 | 0.444738 |
| 20 | Latman and Herb, 2013 | Chenhao and Kumar, 2018 | 0.433807 |
| 21 | Chenhao and Kumar, 2018 | Alexakis et al., 2019 | 0.43004 |
| 22 | Iqbal and Campbell, 2020 | Cronin and Doherty, 2019 | 0.42612 |
| 23 | Vuletic et al., 2019 | Meyer et al., 2014 | 0.423779 |
| 24 | Liu et al., 2020 | Alexakis et al., 2019 | 0.420611 |
| 25 | Wanga et al., 2021 | Utz et al., 2021 | 0.420417 |
| 26 | Kumar and Shimi, 2015 | Cronin and Doherty, 2019 | 0.40852 |
| 27 | Liu et al., 2020 | Kumar and Shimi, 2015 | 0.405285 |
| 28 | Simmons et al., 2017 | Habibi and Chattopadhyay, 2021 | 0.400673 |
| 29 | Ramanathan et al., 2021 | Kumar and Shimi, 2015 | 0.391955 |
| 30 | Vuletic et al., 2019 | Alexakis et al., 2019 | 0.382032 |
| 31 | Cronin and Doherty, 2019 | Chenhao and Kumar, 2018 | 0.381335 |
| 32 | Vuletic et al., 2019 | Kumar and Shimi, 2015 | 0.37747 |
| 33 | Kumar and Shimi, 2015 | Chenhao and Kumar, 2018 | 0.372395 |
| 34 | Vuletic et al., 2019 | Iqbal and Campbell, 2020 | 0.369898 |
| 35 | Doll and Bearman, 2018 | Das, 2021 | 0.369413 |
| 36 | Ramanathan et al., 2021 | Alexakis et al., 2019 | 0.363844 |
| 37 | Li et al., 2021 | Casini, 2019 | 0.352288 |
| 38 | Meyer et al., 2014 | Cronin and Doherty, 2019 | 0.349909 |
| 39 | Simmons et al., 2017 | Cronin and Doherty, 2019 | 0.349871 |
| 40 | Tokazhanov et al., 2021 | Nicol, 2020 | 0.349235 |
| 41 | Latman and Herb, 2013 | Cronin and Doherty, 2019 | 0.345922 |

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|---|---|---|---|
| 42 | Utz et al., 2021 | Nicol, 2020 | 0.339511 |
| 43 | Wanga et al., 2021 | Tokazhanov et al., 2021 | 0.338982 |
| 44 | Utz et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.338767 |
| 45 | Tokazhanov et al., 2021 | Li et al., 2021 | 0.337609 |
| 46 | Wanga et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.336176 |
| 47 | Wanga et al., 2021 | Vuletic et al., 2019 | 0.330898 |
| 48 | Li et al., 2021 | Doll and Bearman, 2018 | 0.330285 |
| 49 | Utz et al., 2021 | Tokazhanov et al., 2021 | 0.3285 |
| 50 | Wanga et al., 2021 | Li et al., 2021 | 0.323765 |
| 51 | Wanga et al., 2021 | Nicol, 2020 | 0.322389 |
| 52 | Wanga et al., 2021 | Alexakis et al., 2019 | 0.321604 |
| 53 | Vuletic et al., 2019 | Das, 2021 | 0.318533 |
| 54 | McMullen et al., 2021 | Gerba, 2015 | 0.318045 |
| 55 | Nicol, 2020 | Casini, 2019 | 0.316774 |
| 56 | Mata and Milner, 2021 | Li et al., 2021 | 0.316411 |
| 57 | Wanga et al., 2021 | Cronin and Doherty, 2019 | 0.315184 |
| 58 | Cronin and Doherty, 2019 | Alexakis et al., 2019 | 0.315126 |
| 59 | Wanga et al., 2021 | Ramanathan et al., 2021 | 0.314315 |
| 60 | Vuletic et al., 2019 | Simmons et al., 2017 | 0.313464 |
| 61 | Doll and Bearman, 2018 | Cronin and Doherty, 2019 | 0.312598 |
| 62 | Vuletic et al., 2019 | Latman and Herb, 2013 | 0.311333 |
| 63 | Nicol, 2020 | Das, 2021 | 0.310171 |
| 64 | Habibi and Chattopadhyay, 2021 | Chenhao and Kumar, 2018 | 0.308707 |
| 65 | Meyer et al., 2014 | Chenhao and Kumar, 2018 | 0.308703 |
| 66 | Kumar and Shimi, 2015 | Habibi and Chattopadhyay, 2021 | 0.307113 |
| 67 | Wanga et al., 2021 | Liu et al., 2020 | 0.306419 |
| 68 | Utz et al., 2021 | Li et al., 2021 | 0.304472 |
| 69 | Morimoto, 2010 | Gerba, 2015 | 0.303857 |
| 70 | Mata and Milner, 2021 | Casini, 2019 | 0.302065 |
| 71 | Pei-Lee et al., 2015 | Das, 2021 | 0.301649 |
| 72 | Cronin and Doherty, 2019 | Casini, 2019 | 0.301445 |
| 73 | Ramanathan et al., 2021 | Cronin and Doherty, 2019 | 0.299359 |
| 74 | Ramanathan et al., 2021 | Chenhao and Kumar, 2018 | 0.298454 |
| 75 | Meyer et al., 2014 | Alexakis et al., 2019 | 0.29692 |
| 76 | Mata and Milner, 2021 | Doll and Bearman, 2018 | 0.296409 |
| 77 | Das, 2021 | Cronin and Doherty, 2019 | 0.295084 |
| 78 | Nicol, 2020 | Doll and Bearman, 2018 | 0.294727 |
| 79 | Simmons et al., 2017 | Mata and Milner, 2021 | 0.293092 |
| 80 | Mata and Milner, 2021 | Cronin and Doherty, 2019 | 0.289957 |
| 81 | Wanga et al., 2021 | Kumar and Shimi, 2015 | 0.289937 |
| 82 | Das, 2021 | Casini, 2019 | 0.289373 |
| 83 | Iqbal and Campbell, 2020 | Habibi and Chattopadhyay, 2021 | 0.28928 |
| 84 | Vuletic et al., 2019 | Pei-Lee et al., 2015 | 0.287663 |
| 85 | Latman and Herb, 2013 | Alexakis et al., 2019 | 0.287352 |

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|---|---|---|---|
| 86 | Vuletic et al., 2019 | Ramanathan et al., 2021 | 0.286626 |
| 87 | Simmons et al., 2017 | Morimoto, 2013 | 0.285974 |
| 88 | Morimoto, 2013 | Latman and Herb, 2013 | 0.2854 |
| 89 | Latman and Herb, 2013 | Kumar and Shimi, 2015 | 0.285264 |
| 90 | Utz et al., 2021 | Ramanathan et al., 2021 | 0.285158 |
| 91 | Habibi and Chattopadhyay, 2021 | Alexakis et al., 2019 | 0.284441 |
| 92 | Ramanathan et al., 2021 | Das, 2021 | 0.28174 |
| 93 | Nicol, 2020 | Kamble et al., 2021 | 0.278822 |
| 94 | Simmons et al., 2017 | Meyer et al., 2014 | 0.278308 |
| 95 | Wanga et al., 2021 | Kamble et al., 2021 | 0.276528 |
| 96 | Pei-Lee et al., 2015 | Cronin and Doherty, 2019 | 0.27378 |
| 97 | Kumar and Shimi, 2015 | Das, 2021 | 0.272626 |
| 98 | Simmons et al., 2017 | Li et al., 2021 | 0.270347 |
| 99 | Landgrebe, 2011 | Casini, 2019 | 0.269459 |
| 100 | Wanga et al., 2021 | Chenhao and Kumar, 2018 | 0.266233 |
| 101 | Pei-Lee et al., 2015 | Habibi and Chattopadhyay, 2021 | 0.265249 |
| 102 | Simmons et al., 2017 | Liu et al., 2020 | 0.265204 |
| 103 | Ramanathan et al., 2021 | Li et al., 2021 | 0.26423 |
| 104 | Nicol, 2020 | Mata and Milner, 2021 | 0.263588 |
| 105 | Wanga et al., 2021 | Das, 2021 | 0.262941 |
| 106 | Li et al., 2021 | Das, 2021 | 0.261154 |
| 107 | Latman and Herb, 2013 | Habibi and Chattopadhyay, 2021 | 0.261055 |
| 108 | Morimoto, 2013 | Kumar and Shimi, 2015 | 0.260749 |
| 109 | Morimoto, 2010 | Latman and Herb, 2013 | 0.260622 |
| 110 | Liu et al., 2020 | Latman and Herb, 2013 | 0.260589 |
| 111 | Iqbal and Campbell, 2020 | Alexakis et al., 2019 | 0.259104 |
| 112 | Ramanathan et al., 2021 | Latman and Herb, 2013 | 0.256912 |
| 113 | Utz et al., 2021 | Cronin and Doherty, 2019 | 0.256674 |
| 114 | Ramanathan et al., 2021 | Liu et al., 2020 | 0.255818 |
| 115 | Morimoto, 2013 | Cronin and Doherty, 2019 | 0.255752 |
| 116 | Simmons et al., 2017 | Latman and Herb, 2013 | 0.255049 |
| 117 | Gerba, 2015 | Cronin and Doherty, 2019 | 0.254895 |
| 118 | Morimoto, 2013 | Alexakis et al., 2019 | 0.254593 |
| 119 | Wanga et al., 2021 | Simmons et al., 2017 | 0.252936 |
| 120 | Utz et al., 2021 | Simmons et al., 2017 | 0.251823 |
| 121 | Meyer et al., 2014 | Iqbal and Campbell, 2020 | 0.249642 |
| 122 | Simmons et al., 2017 | Kumar and Shimi, 2015 | 0.249528 |
| 123 | Iqbal and Campbell, 2020 | Chenhao and Kumar, 2018 | 0.248459 |
| 124 | Pei-Lee et al., 2015 | Morimoto, 2013 | 0.248237 |
| 125 | Meyer et al., 2014 | Kumar and Shimi, 2015 | 0.248108 |
| 126 | Morimoto, 2013 | Habibi and Chattopadhyay, 2021 | 0.247265 |
| 127 | Utz et al., 2021 | Liu et al., 2020 | 0.245909 |
| 128 | Simmons et al., 2017 | Ramanathan et al., 2021 | 0.245891 |
| 129 | Simmons et al., 2017 | Casini, 2019 | 0.244651 |

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| 130 | Landgrebe, 2011 | Doll and Bearman, 2018 | 0.244076 |
| 131 | Wanga et al., 2021 | Mata and Milner, 2021 | 0.243297 |
| 132 | Li et al., 2021 | Cronin and Doherty, 2019 | 0.243288 |
| 133 | Utz et al., 2021 | Meyer et al., 2014 | 0.242277 |
| 134 | Nicol, 2020 | McMullen et al., 2021 | 0.242242 |
| 135 | Utz et al., 2021 | Das, 2021 | 0.242065 |
| 136 | Ramanathan et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.241688 |
| 137 | Wanga et al., 2021 | Pei-Lee et al., 2015 | 0.241674 |
| 138 | Tokazhanov et al., 2021 | Morimoto, 2010 | 0.241441 |
| 139 | Ramanathan et al., 2021 | Morimoto, 2013 | 0.241377 |
| 140 | Vuletic et al., 2019 | Utz et al., 2021 | 0.240693 |
| 141 | Gerba, 2015 | Das, 2021 | 0.240159 |
| 142 | Habibi and Chattopadhyay, 2021 | Casini, 2019 | 0.240009 |
| 143 | Morimoto, 2010 | Cronin and Doherty, 2019 | 0.239984 |
| 144 | McMullen et al., 2021 | Li et al., 2021 | 0.239474 |
| 145 | Pei-Lee et al., 2015 | Doll and Bearman, 2018 | 0.238359 |
| 146 | Habibi and Chattopadhyay, 2021 | Doll and Bearman, 2018 | 0.237641 |
| 147 | Li et al., 2021 | Kamble et al., 2021 | 0.236599 |
| 148 | Pei-Lee et al., 2015 | Li et al., 2021 | 0.236036 |
| 149 | Pei-Lee et al., 2015 | Morimoto, 2010 | 0.235139 |
| 150 | Wanga et al., 2021 | Casini, 2019 | 0.235094 |
| 151 | Simmons et al., 2017 | Pei-Lee et al., 2015 | 0.234582 |
| 152 | Li et al., 2021 | Gerba, 2015 | 0.234444 |
| 153 | Morimoto, 2010 | Habibi and Chattopadhyay, 2021 | 0.233541 |
| 154 | McMullen et al., 2021 | Mata and Milner, 2021 | 0.232266 |
| 155 | Vuletic et al., 2019 | Morimoto, 2013 | 0.231701 |
| 156 | Li et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.231566 |
| 157 | Wanga et al., 2021 | Morimoto, 2013 | 0.231245 |
| 158 | Mata and Milner, 2021 | Habibi and Chattopadhyay, 2021 | 0.231001 |
| 159 | Simmons et al., 2017 | Morimoto, 2010 | 0.230323 |
| 160 | Tokazhanov et al., 2021 | Kamble et al., 2021 | 0.230127 |
| 161 | Simmons et al., 2017 | Doll and Bearman, 2018 | 0.229708 |
| 162 | Utz et al., 2021 | Kamble et al., 2021 | 0.229208 |
| 163 | Morimoto, 2010 | Li et al., 2021 | 0.228815 |
| 164 | Morimoto, 2010 | Mata and Milner, 2021 | 0.227628 |
| 165 | Kumar and Shimi, 2015 | Iqbal and Campbell, 2020 | 0.225519 |
| 166 | Utz et al., 2021 | Alexakis et al., 2019 | 0.22539 |
| 167 | McMullen et al., 2021 | Landgrebe, 2011 | 0.224986 |
| 168 | McMullen et al., 2021 | Das, 2021 | 0.224402 |
| 169 | Kumar and Shimi, 2015 | Casini, 2019 | 0.223653 |
| 170 | Wanga et al., 2021 | Meyer et al., 2014 | 0.223125 |
| 171 | Mata and Milner, 2021 | Gerba, 2015 | 0.221405 |
| 172 | Nicol, 2020 | Cronin and Doherty, 2019 | 0.221389 |
| 173 | Mata and Milner, 2021 | Latman and Herb, 2013 | 0.221246 |

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| 174 | Morimoto, 2010 | Casini, 2019 | 0.220896 |
| 175 | Pei-Lee et al., 2015 | Casini, 2019 | 0.220785 |
| 176 | Latman and Herb, 2013 | Casini, 2019 | 0.219972 |
| 177 | Morimoto, 2013 | Mata and Milner, 2021 | 0.219729 |
| 178 | Wanga et al., 2021 | Grover and Sabherwal, 2020 | 0.219652 |
| 179 | Meyer et al., 2014 | Latman and Herb, 2013 | 0.218711 |
| 180 | Habibi and Chattopadhyay, 2021 | Das, 2021 | 0.218623 |
| 181 | Morimoto, 2013 | Gerba, 2015 | 0.218547 |
| 182 | Tokazhanov et al., 2021 | Morimoto, 2013 | 0.218044 |
| 183 | Morimoto, 2013 | Meyer et al., 2014 | 0.217958 |
| 184 | Morimoto, 2013 | Li et al., 2021 | 0.215121 |
| 185 | Utz et al., 2021 | Pei-Lee et al., 2015 | 0.214821 |
| 186 | Wanga et al., 2021 | Latman and Herb, 2013 | 0.214747 |
| 187 | Das, 2021 | Alexakis et al., 2019 | 0.214018 |
| 188 | Morimoto, 2013 | Chenhao and Kumar, 2018 | 0.213869 |
| 189 | Utz et al., 2021 | Morimoto, 2013 | 0.213655 |
| 190 | Morimoto, 2013 | Liu et al., 2020 | 0.213012 |
| 191 | Pei-Lee et al., 2015 | Mata and Milner, 2021 | 0.212454 |
| 192 | Utz et al., 2021 | Mata and Milner, 2021 | 0.211968 |
| 193 | Ramanathan et al., 2021 | Pei-Lee et al., 2015 | 0.209931 |
| 194 | Liu et al., 2020 | Das, 2021 | 0.208766 |
| 195 | Simmons et al., 2017 | Chenhao and Kumar, 2018 | 0.208713 |
| 196 | Wanga et al., 2021 | Morimoto, 2010 | 0.208081 |
| 197 | Li et al., 2021 | Latman and Herb, 2013 | 0.207175 |
| 198 | McMullen et al., 2021 | Cronin and Doherty, 2019 | 0.206158 |
| 199 | Utz et al., 2021 | Latman and Herb, 2013 | 0.205484 |
| 200 | Utz et al., 2021 | Grover and Sabherwal, 2020 | 0.204278 |
| 201 | Tokazhanov et al., 2021 | Das, 2021 | 0.204217 |
| 202 | Nicol, 2020 | Habibi and Chattopadhyay, 2021 | 0.202921 |
| 203 | Tokazhanov et al., 2021 | Ramanathan et al., 2021 | 0.202607 |
| 204 | Landgrebe, 2011 | Gerba, 2015 | 0.202061 |
| 205 | Ramanathan et al., 2021 | Mata and Milner, 2021 | 0.201698 |
| 206 | Simmons et al., 2017 | Das, 2021 | 0.20141 |
| 207 | Tokazhanov et al., 2021 | Grover and Sabherwal, 2020 | 0.200422 |
| 208 | Wanga et al., 2021 | Doll and Bearman, 2018 | 0.200152 |
| 209 | Utz et al., 2021 | Kumar and Shimi, 2015 | 0.198981 |
| 210 | Simmons et al., 2017 | Alexakis et al., 2019 | 0.19848 |
| 211 | Ramanathan et al., 2021 | Nicol, 2020 | 0.198299 |
| 212 | Pei-Lee et al., 2015 | Nicol, 2020 | 0.197825 |
| 213 | Kumar and Shimi, 2015 | Doll and Bearman, 2018 | 0.196709 |
| 214 | Pei-Lee et al., 2015 | Kamble et al., 2021 | 0.196709 |
| 215 | Mata and Milner, 2021 | Kamble et al., 2021 | 0.195637 |
| 216 | Mata and Milner, 2021 | Das, 2021 | 0.19265 |
| 217 | Morimoto, 2013 | Casini, 2019 | 0.192328 |

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| 218 | Pei-Lee et al., 2015 | Latman and Herb, 2013 | 0.191789 |
| 219 | Nicol, 2020 | Grover and Sabherwal, 2020 | 0.191303 |
| 220 | Minagawa et al., 2014 | Cronin and Doherty, 2019 | 0.191106 |
| 221 | Latman and Herb, 2013 | Doll and Bearman, 2018 | 0.189796 |
| 222 | Ramanathan et al., 2021 | Casini, 2019 | 0.189666 |
| 223 | Wanga et al., 2021 | Iqbal and Campbell, 2020 | 0.18956 |
| 224 | Vuletic et al., 2019 | Li et al., 2021 | 0.18925 |
| 225 | Ramanathan et al., 2021 | Kamble et al., 2021 | 0.188536 |
| 226 | Li et al., 2021 | Kumar and Shimi, 2015 | 0.188274 |
| 227 | Morimoto, 2013 | Das, 2021 | 0.188148 |
| 228 | Pei-Lee et al., 2015 | Kumar and Shimi, 2015 | 0.188139 |
| 229 | Utz et al., 2021 | Chenhao and Kumar, 2018 | 0.186772 |
| 230 | Kamble et al., 2021 | Das, 2021 | 0.185883 |
| 231 | Vuletic et al., 2019 | Minagawa et al., 2014 | 0.185274 |
| 232 | Nicol, 2020 | Morimoto, 2010 | 0.184623 |
| 233 | Morimoto, 2010 | Doll and Bearman, 2018 | 0.184517 |
| 234 | Vuletic et al., 2019 | Morimoto, 2010 | 0.183568 |
| 235 | Vuletic et al., 2019 | Doll and Bearman, 2018 | 0.183447 |
| 236 | Wanga et al., 2021 | Gerba, 2015 | 0.180752 |
| 237 | Morimoto, 2013 | Doll and Bearman, 2018 | 0.179145 |
| 238 | Morimoto, 2010 | Kumar and Shimi, 2015 | 0.178755 |
| 239 | Ramanathan et al., 2021 | Meyer et al., 2014 | 0.178678 |
| 240 | Tokazhanov et al., 2021 | Mata and Milner, 2021 | 0.178677 |
| 241 | Pei-Lee et al., 2015 | Gerba, 2015 | 0.176882 |
| 242 | Nicol, 2020 | Gerba, 2015 | 0.176035 |
| 243 | Tokazhanov et al., 2021 | Casini, 2019 | 0.175688 |
| 244 | Utz et al., 2021 | Morimoto, 2010 | 0.174982 |
| 245 | Tokazhanov et al., 2021 | Cronin and Doherty, 2019 | 0.174419 |
| 246 | Simmons et al., 2017 | McMullen et al., 2021 | 0.174085 |
| 247 | Pei-Lee et al., 2015 | Liu et al., 2020 | 0.173333 |
| 248 | Vuletic et al., 2019 | Kamble et al., 2021 | 0.173088 |
| 249 | Kamble et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.172402 |
| 250 | McMullen et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.171557 |
| 251 | Nicol, 2020 | Latman and Herb, 2013 | 0.167393 |
| 252 | Ramanathan et al., 2021 | Morimoto, 2010 | 0.166767 |
| 253 | Vuletic et al., 2019 | Mata and Milner, 2021 | 0.166733 |
| 254 | Latman and Herb, 2013 | Das, 2021 | 0.166615 |
| 255 | Kumar and Shimi, 2015 | Gerba, 2015 | 0.16599 |
| 256 | Kamble et al., 2021 | Cronin and Doherty, 2019 | 0.165241 |
| 257 | Vuletic et al., 2019 | Nicol, 2020 | 0.164182 |
| 258 | Morimoto, 2010 | Meyer et al., 2014 | 0.163824 |
| 259 | Habibi and Chattopadhyay, 2021 | Gerba, 2015 | 0.16287 |
| 260 | Utz et al., 2021 | Casini, 2019 | 0.162406 |
| 261 | Vuletic et al., 2019 | Casini, 2019 | 0.161541 |

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| 262 | Minagawa et al., 2014 | Liu et al., 2020 | 0.161085 |
| 263 | Tokazhanov et al., 2021 | Habibi and Chattopadhyay, 2021 | 0.161026 |
| 264 | Simmons et al., 2017 | Nicol, 2020 | 0.160814 |
| 265 | Ramanathan et al., 2021 | Doll and Bearman, 2018 | 0.160805 |
| 266 | Utz et al., 2021 | Doll and Bearman, 2018 | 0.160643 |
| 267 | Pei-Lee et al., 2015 | Meyer et al., 2014 | 0.158025 |
| 268 | Simmons et al., 2017 | Gerba, 2015 | 0.157589 |
| 269 | Wanga et al., 2021 | McMullen et al., 2021 | 0.155588 |
| 270 | Simmons et al., 2017 | Kamble et al., 2021 | 0.154328 |
| 271 | Utz et al., 2021 | Iqbal and Campbell, 2020 | 0.154219 |
| 272 | McMullen et al., 2021 | Latman and Herb, 2013 | 0.154 |
| 273 | Tokazhanov et al., 2021 | Simmons et al., 2017 | 0.153861 |
| 274 | Morimoto, 2010 | Liu et al., 2020 | 0.153318 |
| 275 | Das, 2021 | Chenhao and Kumar, 2018 | 0.153185 |
| 276 | Morimoto, 2010 | Das, 2021 | 0.152574 |
| 277 | Kamble et al., 2021 | Casini, 2019 | 0.152518 |
| 278 | Iqbal and Campbell, 2020 | Das, 2021 | 0.152252 |
| 279 | Minagawa et al., 2014 | Habibi and Chattopadhyay, 2021 | 0.15164 |
| 280 | Landgrebe, 2011 | Cronin and Doherty, 2019 | 0.151499 |
| 281 | Simmons et al., 2017 | Iqbal and Campbell, 2020 | 0.150423 |
| 282 | Vuletic et al., 2019 | Tokazhanov et al., 2021 | 0.149535 |
| 283 | Utz et al., 2021 | McMullen et al., 2021 | 0.1495 |
| 284 | Tokazhanov et al., 2021 | Latman and Herb, 2013 | 0.149069 |
| 285 | Mata and Milner, 2021 | Kumar and Shimi, 2015 | 0.148805 |
| 286 | Morimoto, 2013 | Kamble et al., 2021 | 0.147993 |
| 287 | Pei-Lee et al., 2015 | McMullen et al., 2021 | 0.147569 |
| 288 | Ramanathan et al., 2021 | McMullen et al., 2021 | 0.147005 |
| 289 | Meyer et al., 2014 | Das, 2021 | 0.146315 |
| 290 | Tokazhanov et al., 2021 | Doll and Bearman, 2018 | 0.145994 |
| 291 | Pei-Lee et al., 2015 | Minagawa et al., 2014 | 0.145882 |
| 292 | Liu et al., 2020 | Li et al., 2021 | 0.145769 |
| 293 | Minagawa et al., 2014 | Meyer et al., 2014 | 0.14561 |
| 294 | Kamble et al., 2021 | Doll and Bearman, 2018 | 0.144779 |
| 295 | Morimoto, 2010 | Alexakis et al., 2019 | 0.144192 |
| 296 | Nicol, 2020 | Morimoto, 2013 | 0.142649 |
| 297 | Casini, 2019 | Alexakis et al., 2019 | 0.142355 |
| 298 | Landgrebe, 2011 | Kumar and Shimi, 2015 | 0.142007 |
| 299 | Latman and Herb, 2013 | Gerba, 2015 | 0.141081 |
| 300 | Meyer et al., 2014 | Li et al., 2021 | 0.141015 |
| 301 | Tokazhanov et al., 2021 | Pei-Lee et al., 2015 | 0.140841 |
| 302 | Ramanathan et al., 2021 | Gerba, 2015 | 0.139036 |
| 303 | McMullen et al., 2021 | Kumar and Shimi, 2015 | 0.138975 |
| 304 | Morimoto, 2010 | Chenhao and Kumar, 2018 | 0.138957 |
| 305 | Li et al., 2021 | Grover and Sabherwal, 2020 | 0.138901 |

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| 306 | Kamble et al., 2021 | Grover and Sabherwal, 2020 | 0.135277 |
| 307 | Morimoto, 2010 | Lozier, 2016 | 0.133973 |
| 308 | Morimoto, 2010 | McMullen et al., 2021 | 0.133303 |
| 309 | Tokazhanov et al., 2021 | Kumar and Shimi, 2015 | 0.132721 |
| 310 | Ramanathan et al., 2021 | Grover and Sabherwal, 2020 | 0.132716 |
| 311 | Kamble et al., 2021 | Chenhao and Kumar, 2018 | 0.132206 |
| 312 | Kamble et al., 2021 | Alexakis et al., 2019 | 0.130927 |
| 313 | Pei-Lee et al., 2015 | Landgrebe, 2011 | 0.130341 |
| 314 | Liu et al., 2020 | Kamble et al., 2021 | 0.129877 |
| 315 | Ramanathan et al., 2021 | Iqbal and Campbell, 2020 | 0.129637 |
| 316 | Morimoto, 2013 | Lozier, 2016 | 0.129451 |
| 317 | Latman and Herb, 2013 | Iqbal and Campbell, 2020 | 0.128815 |
| 318 | Mata and Milner, 2021 | Liu et al., 2020 | 0.126577 |
| 319 | Simmons et al., 2017 | Minagawa et al., 2014 | 0.125372 |
| 320 | Tokazhanov et al., 2021 | Liu et al., 2020 | 0.125298 |
| 321 | Tokazhanov et al., 2021 | Alexakis et al., 2019 | 0.125199 |
| 322 | Nicol, 2020 | Kumar and Shimi, 2015 | 0.124843 |
| 323 | Tokazhanov et al., 2021 | McMullen et al., 2021 | 0.124099 |
| 324 | Meyer et al., 2014 | Mata and Milner, 2021 | 0.122573 |
| 325 | Kumar and Shimi, 2015 | Kamble et al., 2021 | 0.121615 |
| 326 | Morimoto, 2013 | Iqbal and Campbell, 2020 | 0.120361 |
| 327 | Doll and Bearman, 2018 | Alexakis et al., 2019 | 0.120337 |
| 328 | Tokazhanov et al., 2021 | Gerba, 2015 | 0.119625 |
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| 330 | Morimoto, 2013 | McMullen et al., 2021 | 0.118268 |
| 331 | Kamble et al., 2021 | Gerba, 2015 | 0.117849 |
| 332 | Liu et al., 2020 | Doll and Bearman, 2018 | 0.117447 |
| 333 | Mata and Milner, 2021 | Chenhao and Kumar, 2018 | 0.116773 |
| 334 | Nicol, 2020 | Liu et al., 2020 | 0.116656 |
| 335 | Nicol, 2020 | Minagawa et al., 2014 | 0.115876 |
| 336 | Pei-Lee et al., 2015 | Alexakis et al., 2019 | 0.115002 |
| 337 | Li et al., 2021 | Alexakis et al., 2019 | 0.114559 |
| 338 | Landgrebe, 2011 | Habibi and Chattopadhyay, 2021 | 0.114174 |
| 339 | Liu et al., 2020 | Casini, 2019 | 0.113594 |
| 340 | Li et al., 2021 | Chenhao and Kumar, 2018 | 0.113389 |
| 341 | Morimoto, 2010 | Kamble et al., 2021 | 0.113346 |
| 342 | Meyer et al., 2014 | Doll and Bearman, 2018 | 0.112568 |
| 343 | Latman and Herb, 2013 | Kamble et al., 2021 | 0.112299 |
| 344 | Utz et al., 2021 | Gerba, 2015 | 0.111734 |
| 345 | Lozier, 2016 | Das, 2021 | 0.110209 |
| 346 | Meyer et al., 2014 | Kamble et al., 2021 | 0.108174 |
| 347 | Meyer et al., 2014 | Casini, 2019 | 0.108117 |
| 348 | Pei-Lee et al., 2015 | Chenhao and Kumar, 2018 | 0.107378 |
| 349 | Minagawa et al., 2014 | Casini, 2019 | 0.107351 |

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| 350 | Vuletic et al., 2019 | Gerba, 2015 | 0.106413 |
| 351 | Minagawa et al., 2014 | Doll and Bearman, 2018 | 0.106258 |
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| 353 | Grover and Sabherwal, 2020 | Das, 2021 | 0.105704 |
| 354 | McMullen et al., 2021 | Alexakis et al., 2019 | 0.104999 |
| 355 | Vuletic et al., 2019 | McMullen et al., 2021 | 0.103997 |
| 356 | Tokazhanov et al., 2021 | Iqbal and Campbell, 2020 | 0.10178 |
| 357 | Vuletic et al., 2019 | Landgrebe, 2011 | 0.10166 |
| 358 | Mata and Milner, 2021 | Alexakis et al., 2019 | 0.100966 |
| 359 | Nicol, 2020 | Landgrebe, 2011 | 0.100217 |
| 360 | Grover and Sabherwal, 2020 | Alexakis et al., 2019 | 0.099696 |
| 361 | Tokazhanov et al., 2021 | Chenhao and Kumar, 2018 | 0.099121 |
| 362 | Minagawa et al., 2014 | Li et al., 2021 | 0.098483 |
| 363 | Tokazhanov et al., 2021 | Meyer et al., 2014 | 0.096386 |
| 364 | Landgrebe, 2011 | Das, 2021 | 0.095805 |
| 365 | Wanga et al., 2021 | Minagawa et al., 2014 | 0.094401 |
| 366 | Minagawa et al., 2014 | Mata and Milner, 2021 | 0.094329 |
| 367 | Lozier, 2016 | Gerba, 2015 | 0.092858 |
| 368 | Wanga et al., 2021 | Landgrebe, 2011 | 0.092815 |
| 369 | Chenhao and Kumar, 2018 | Casini, 2019 | 0.091173 |
| 370 | Mata and Milner, 2021 | Landgrebe, 2011 | 0.087892 |
| 371 | Meyer et al., 2014 | Gerba, 2015 | 0.087106 |
| 372 | Doll and Bearman, 2018 | Chenhao and Kumar, 2018 | 0.086605 |
| 373 | Lozier, 2016 | Doll and Bearman, 2018 | 0.086127 |
| 374 | Pei-Lee et al., 2015 | Grover and Sabherwal, 2020 | 0.085929 |
| 375 | Li et al., 2021 | Landgrebe, 2011 | 0.085395 |
| 376 | Kumar and Shimi, 2015 | Grover and Sabherwal, 2020 | 0.085277 |
| 377 | Ramanathan et al., 2021 | Landgrebe, 2011 | 0.084278 |
| 378 | Morimoto, 2010 | Minagawa et al., 2014 | 0.08339 |
| 379 | Pei-Lee et al., 2015 | Iqbal and Campbell, 2020 | 0.077867 |
| 380 | Nicol, 2020 | Iqbal and Campbell, 2020 | 0.077786 |
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| 384 | Minagawa et al., 2014 | Latman and Herb, 2013 | 0.077049 |
| 385 | Minagawa et al., 2014 | Landgrebe, 2011 | 0.076664 |
| 386 | Nicol, 2020 | Meyer et al., 2014 | 0.076326 |
| 387 | Nicol, 2020 | Chenhao and Kumar, 2018 | 0.076259 |
| 388 | Latman and Herb, 2013 | Landgrebe, 2011 | 0.076257 |
| 389 | Lozier, 2016 | Liu et al., 2020 | 0.075629 |
| 390 | Morimoto, 2013 | Minagawa et al., 2014 | 0.074676 |
| 391 | Liu et al., 2020 | Landgrebe, 2011 | 0.073697 |
| 392 | Ramanathan et al., 2021 | Minagawa et al., 2014 | 0.072878 |
| 393 | Simmons et al., 2017 | Landgrebe, 2011 | 0.072655 |

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| 394 | Landgrebe, 2011 | Kamble et al., 2021 | 0.072348 |
| 395 | Li et al., 2021 | Iqbal and Campbell, 2020 | 0.071001 |
| 396 | Landgrebe, 2011 | Alexakis et al., 2019 | 0.070854 |
| 397 | Minagawa et al., 2014 | Kumar and Shimi, 2015 | 0.069814 |
| 398 | Minagawa et al., 2014 | Alexakis et al., 2019 | 0.069394 |
| 399 | Minagawa et al., 2014 | Iqbal and Campbell, 2020 | 0.068262 |
| 400 | Grover and Sabherwal, 2020 | Cronin and Doherty, 2019 | 0.068 |
| 401 | Utz et al., 2021 | Minagawa et al., 2014 | 0.066477 |
| 402 | Simmons et al., 2017 | Lozier, 2016 | 0.066415 |
| 403 | Meyer et al., 2014 | Grover and Sabherwal, 2020 | 0.065901 |
| 404 | Morimoto, 2013 | Grover and Sabherwal, 2020 | 0.065583 |
| 405 | Morimoto, 2013 | Landgrebe, 2011 | 0.065497 |
| 406 | McMullen et al., 2021 | Chenhao and Kumar, 2018 | 0.065488 |
| 407 | Minagawa et al., 2014 | Kamble et al., 2021 | 0.064631 |
| 408 | Morimoto, 2010 | Iqbal and Campbell, 2020 | 0.062802 |
| 409 | Minagawa et al., 2014 | McMullen et al., 2021 | 0.062662 |
| 410 | Utz et al., 2021 | Lozier, 2016 | 0.062561 |
| 411 | Kamble et al., 2021 | Iqbal and Campbell, 2020 | 0.062372 |
| 412 | Iqbal and Campbell, 2020 | Casini, 2019 | 0.061325 |
| 413 | Morimoto, 2010 | Grover and Sabherwal, 2020 | 0.061177 |
| 414 | Iqbal and Campbell, 2020 | Doll and Bearman, 2018 | 0.061052 |
| 415 | Gerba, 2015 | Alexakis et al., 2019 | 0.060101 |
| 416 | Lozier, 2016 | Casini, 2019 | 0.059182 |
| 417 | Morimoto, 2010 | Landgrebe, 2011 | 0.058694 |
| 418 | Liu et al., 2020 | Grover and Sabherwal, 2020 | 0.057643 |
| 419 | Nicol, 2020 | Alexakis et al., 2019 | 0.05659 |
| 420 | Tokazhanov et al., 2021 | Landgrebe, 2011 | 0.055864 |
| 421 | Gerba, 2015 | Chenhao and Kumar, 2018 | 0.055843 |
| 422 | Vuletic et al., 2019 | Grover and Sabherwal, 2020 | 0.055549 |
| 423 | Mata and Milner, 2021 | Grover and Sabherwal, 2020 | 0.055152 |
| 424 | Minagawa et al., 2014 | Chenhao and Kumar, 2018 | 0.05495 |
| 425 | Wanga et al., 2021 | Lozier, 2016 | 0.054762 |
| 426 | Lozier, 2016 | Cronin and Doherty, 2019 | 0.054439 |
| 427 | Lozier, 2016 | Li et al., 2021 | 0.0538 |
| 428 | Lozier, 2016 | Iqbal and Campbell, 2020 | 0.052097 |
| 429 | Vuletic et al., 2019 | Lozier, 2016 | 0.050218 |
| 430 | Meyer et al., 2014 | Landgrebe, 2011 | 0.049999 |
| 431 | Utz et al., 2021 | Landgrebe, 2011 | 0.049678 |
| 432 | Minagawa et al., 2014 | Gerba, 2015 | 0.048779 |
| 433 | Minagawa et al., 2014 | Das, 2021 | 0.04853 |
| 434 | Lozier, 2016 | Alexakis et al., 2019 | 0.048321 |
| 435 | Tokazhanov et al., 2021 | Minagawa et al., 2014 | 0.04811 |
| 436 | Ramanathan et al., 2021 | Lozier, 2016 | 0.047717 |
| 437 | Lozier, 2016 | Latman and Herb, 2013 | 0.047657 |

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| 438 | Grover and Sabherwal, 2020 | Casini, 2019 | 0.045062 |
| 439 | Nicol, 2020 | Lozier, 2016 | 0.044942 |
| 440 | Landgrebe, 2011 | Chenhao and Kumar, 2018 | 0.044938 |
| 441 | McMullen et al., 2021 | Liu et al., 2020 | 0.044422 |
| 442 | Mata and Milner, 2021 | Lozier, 2016 | 0.043887 |
| 443 | Lozier, 2016 | Chenhao and Kumar, 2018 | 0.042195 |
| 444 | McMullen et al., 2021 | Lozier, 2016 | 0.040662 |
| 445 | Iqbal and Campbell, 2020 | Grover and Sabherwal, 2020 | 0.039912 |
| 446 | Pei-Lee et al., 2015 | Lozier, 2016 | 0.037913 |
| 447 | Lozier, 2016 | Habibi and Chattopadhyay, 2021 | 0.036642 |
| 448 | Grover and Sabherwal, 2020 | Doll and Bearman, 2018 | 0.036216 |
| 449 | McMullen et al., 2021 | Grover and Sabherwal, 2020 | 0.035204 |
| 450 | Simmons et al., 2017 | Grover and Sabherwal, 2020 | 0.034938 |
| 451 | Tokazhanov et al., 2021 | Lozier, 2016 | 0.032672 |
| 452 | Grover and Sabherwal, 2020 | Gerba, 2015 | 0.029528 |
| 453 | McMullen et al., 2021 | Iqbal and Campbell, 2020 | 0.027674 |
| 454 | Grover and Sabherwal, 2020 | Chenhao and Kumar, 2018 | 0.027393 |
| 455 | Minagawa et al., 2014 | Lozier, 2016 | 0.025545 |
| 456 | Landgrebe, 2011 | Grover and Sabherwal, 2020 | 0.02278 |
| 457 | Latman and Herb, 2013 | Grover and Sabherwal, 2020 | 0.020909 |
| 458 | Landgrebe, 2011 | Iqbal and Campbell, 2020 | 0.020899 |
| 459 | Meyer et al., 2014 | Lozier, 2016 | 0.019784 |
| 460 | Iqbal and Campbell, 2020 | Gerba, 2015 | 0.017904 |
| 461 | Lozier, 2016 | Kumar and Shimi, 2015 | 0.011922 |
| 462 | Minagawa et al., 2014 | Grover and Sabherwal, 2020 | 0.008088 |
| 463 | Lozier, 2016 | Kamble et al., 2021 | -0.000755 |
| 464 | Lozier, 2016 | Landgrebe, 2011 | -0.002081 |
| 465 | Lozier, 2016 | Grover and Sabherwal, 2020 | -0.003219 |

# Appendix C. Clip Art Sources

| Figure | Image Description | URL |
|---|---|---|
| Figure 3 | Magnifying Glass | https://www.pngkit.com/bigpic/u2q8r5q8e6i1u2u2/ |
| Figure 4 | Green Light Bulb | https://th.bing.com/th/id/R.fa95cc682d3b2452cb2125c8f040c489?rik=L%2bFPXEUGTQYqqA&riu=http%3a%2f%2fclipart-library.com%2fnewhp%2f14-149350_energy-conservation-efficient-energy-use-solar-energy-efficient.png&ehk=sKRs1yPNPTdHNKdp9G%2b9rMpCQTSEZAWEf5VmD%2bY9nFM%3d&risl=&pid=ImgRaw&r=0 |
| Figure 4 | Face Scan | https://us.123rf.com/450wm/allismagic/allismagic1702/allismagic170200052/72208489-biometrical-identification-facial-recognition-system-concept-asian-man-vector-illustration.jpg?ver=6 |
| Figure 4 | Fingerprint Match | https://2.bp.blogspot.com/_PvIZNwS6Y1o/SbWQNsVAB1I/AAAAAAAAAwI/wnfIwjHoMU0/s400/MinutiaeMatching.jpg |
| Figure 4 | Iris | https://media.istockphoto.com/vectors/human-eye-iris-isolated-on-white-background-vector-id487674227?k=6&m=487674227&s=612x612&w=0&h=Q5RySsUz578QYiqt7hSs8egYtzAQ-h_Ilw5o6phafps= |
| Figure 5 | Static Hand | https://media.istockphoto.com/photos/man-making-stop-gesture-with-hand-isolated-on-white-background-with-picture-id855670474?k=6&m=855670474&s=170667a&w=0&h=jqyWNktt5lYdnpxSEiwsQWlSH-i_ZdlO991t2OaqDCs= |
| Figure 5 | Swiping Hand | https://th.bing.com/th/id/R.92174562360f15c4671a46003a724ff6?rik=33xtoowAAy4epg&riu=http%3a%2f%2fwww.codeproject.com%2fKB%2ftablets%2f636490%2fswiperight.png&ehk=6lDYmGfszRJES6Abs8cq1YX0ZV6065HdS54pKVt%2fd2k%3d&risl=&pid=ImgRaw&r=0&sres=1&sresct=1 |
| Figure 6 | Alarm Clock | https://www.jing.fm/clipimg/full/0-6438_alarm-clock-clipart-png.png |
| Figure 6 | Person Tripping Sensor | https://media.istockphoto.com/vectors/walking-man-symbol-with-motion-sensor-waves-signal-vector-id867747020?k=6&m=867747020&s=612x612&w=0&h=18p2CvoRI23GwWb6XT-WA8FlcbEF6mBOdwf3wHRMeRo= |
| Figure 7 | "Do Not Touch" Sign | https://www.gjplastics.co.uk/wp-content/uploads/2020/02/Do-Not-Touch-Web-File-scaled.jpg |
| Figure 7 | Phone Scanning QR Code | https://thumb.xfactorapp.com/tt/360/247/0/100/v3/uploads/_xfactor/cms/56cdc3795d4b84cf5e8b46f3/56cdc3781a354_Coffee.png |
| Figure 8 | Emitting Voice | https://clipground.com/images/voice-clip-art-10.jpg |
| Figure 8 | Gray Syntax Image | https://www.clker.com/cliparts/2/0/4/4/11949945421472684305edit.svg.med.png |
| Figure 8 | Microphone | https://th.bing.com/th/id/R.24b3e4c251638a3ad80c218e93756278?rik=0l1V8KZb2kVwtQ&riu=http%3a%2f%2fimages.clipartpanda.com%2fmicrophone-icon-vector-microfono_microphone_icon-1969px.png&ehk=fRrxPuDIUSP%2bMwHy5BQDJeWydB0DSFcMbmOQfdklGV8%3d&risl=&pid=ImgRaw&r=0 |
| Multiple Figures | Green Checkmark | https://th.bing.com/th/id/R.52cd1cce5f846879185802cd1fb08f2e?rik=KwkOfHT2DC5n7w&riu=http%3a%2f%2fwww.downloadclipart.net%2flarge%2f44012-small-green-check-mark-clipart.png&ehk=VTW%2bQBZ%2fYp%2f4EmCo0xxuAUOv4GE%2f%2f4ILEMcTeLVmyMo%3d&risl=&pid=ImgRaw&r=0 |

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**14. ABSTRACT**

The purpose of this research is to explore the utility and current state of touchless technologies. Five categories of technologies are identified as a result of collecting and reviewing literature: facial/biometric recognition, gesture recognition, touchless sensing, personal devices, and voice recognition. A thematic analysis was conducted to evaluate the advantages and disadvantages of the five categories. A reference analysis was also conducted to determine the similarities between articles in each category. Touchless sensing showed to have the most advantages and least similar references. Gesture recognition was the opposite. Comparing analyses shows more reliable technology types are more beneficial and diverse.

**15. SUBJECT TERMS**

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