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Challenges using modeling and simulation in architecture development

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Abstract

A discrete event simulation was developed combining the Optical Tracking Network (TeleTrak) and Satellite Position Attained by RF-Keyed Tracking (SPARK) system into one system to track, image, and identify space objects as they pass through the space fence to increase space situational awareness for the United States Air Force. The objectives for this study are threefold: model a "to-be" architecture for a combined TeleTrak and SPARK system to develop system requirements, determine if an optimal position for the telescope exists to return to while waiting for the next collect, and demonstrate knowledge and understanding of DOE and simulation principles and techniques. The paper explores the uses and pitfalls of modeling and simulation with this case study. While a working model remained elusive, several important observations emerged. Six recommendations are given to help others become more successful in a modeling and simulation environment along with ideas to pursue in additional research.

Keywords: modeling; simulation; architecture development

1. Introduction

This paper analyzes the design of experiments (DOE) and discrete event simulation for the Air Force Institute Technology (AFIT) combined Optical Tracking Network (TeleTrak) and Satellite Position Attained by RF-Keyed Tracking (SPARK) system. The objectives for this study are: (1) model a "to-be" architecture for a combined TeleTrak and SPARK system to develop system requirements, (2) determine if an optimal position for the telescope exists to return to while waiting for the next collect, and (3)

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demonstrate knowledge and understanding of DOE and simulation principles and techniques.

The AFIT's TeleTrak goal is to use commercial telescopes to determine orbit estimation and collect object images of low earth orbit (LEO) space objects. If research demonstrates high reliability and usability while providing lower cost, the TeleTrak system could be used to support the space surveillance network in detecting, tracking, identifying and cataloging all manmade objects orbiting the Earth. Currently, the system uses two ten-inch and one sixteen-inch Ritchey-Chretien telescopes geographically separated from each other coupled with MATLAB® software to track and image an observed LEO space object[1]. Meanwhile, the AFIT's SPARK system goal is to use commercially available antennas to collect the signal from the Air Force Space Surveillance System (AFSSS) as a space object crosses the space fence in order to determine orbit estimation and tracking information[2]. The two systems are currently only loosely tied together with analysis being done on the TeleTrak system to enhance image clarity and tracking reliability, and on the SPARK system to develop orbit propagation solution for tracking.

The "to-be" architecture scenario is where the systems working jointly and autonomously together track, image, and determine the orbit for the space object. The scenario begins with a space object crossing the space fence which the SPARK system picks up. Determination is made on the object if it matches an already defined orbit for a satellite orbiting the Earth described in orbital elements by a NORAD two line element (TLE) set. If so then a determination is made if it is a planned collection object or an object of opportunity. If object is not matched then it is classified as unidentified and tracked with a higher priority; the TeleTrak team would take steps to resolve unidentified objects in post-processing of data. Based on the determinations an object's priority and number of telescopes required for tracking are assigned according to table 1.

Table 1: Space Object Priority and Telescopes Required when Tracking

	Priority	Number of Telescopes for Tracking
Unidentified Object	1	2
Planned Object	2	2
Object of Opportunity	3	1

The SPARK system then provides an azimuth and elevation of where to acquire the space object to the TeleTrak system. The Teletrak system stops processing any tracking if a higher priority task comes in, if not, then checks to see if a telescope is available. When a telescope is available then the system slews to the azimuth and elevation provided by SPARK and begins target acquisition, tracking and image collection. Image collection is accomplished through a Webcam or StellaCam inserted in the eyepiece and data is transmitted to a computer. Tracking and imaging continues till the object is approximately fifteen degrees from the horizon due to light pollution around the telescopes at a lower elevation. Once complete with the collect the telescopes slew to the next target or return to a pre-determined location.

2. Methodology

A twelve step process proposed by J. Banks and others was used in developing the simulation model. This method provided a structured analytical approach to be applied during development. The twelve steps are[3]:

(1) Problem Formulation, (2) Setting of Objectives and Overall Project Plan, (3) Model Conceptualization, (4) Data Collection, (5) Model Translation, (6) Verified?, (7) Validated?, (8) Experimental Design, (9) Production Runs and Analysis, (10) More runs?, (11) Documentation and Reporting, (12) Implementation.

A seven step process as described by D. C. Montgomery is used to further enhance the design of experiment aspects in the simulation creation process, mainly in the areas of Data Collection and Experimental Design steps, but also in the Problem Formulation and Setting of Objectives and Overall

Project Plan. The seven steps are[4]:

(1) Recognition of and Statement of the Problem, (2) Selection of the Response Variable, (3) Choice of Factors, Levels, and Range, (4) Choice of Experimental Design, (5) Performing the Experiment, (6) Statistical Analysis of Data, (7) Conclusion and Recommendations.

The steps (1)-(8) for the twelve step simulation process and steps (1)-(4) in the seven step DOE process relate to actions and analysis that are accomplished during a Pre-Experimental phase while the remaining steps will be defined as Experimental/Post-Experimental Phase. This allows for discussions on what has occurred so far in the study and what actions will occur after additional work is accomplished.

3. Pre-Experimental Phase

3.1. Problem Formulation

The problem is to model a combined SPARK and TeleTrak system to allow for identification of possible system specifications, and to determine the optimal telescope azimuth and elevation return point after a collection to facilitate the acquisition of the next space object to track and image. Possible system specifications are: identify the maximum length of time the SPARK system has to compute an azimuth and elevation initial condition to pass to the TeleTrak system, and the minimum view time an item would need to have to attempt tracking of that object if the TeleTrak system was already tracking an object and for it to be a benefit.

3.2. Setting of Objectives and Overall Project Plan

The objectives are to produce analysis in order to develop statements of system specifications. In order to achieve the objective several tasks were needed to be accomplished over a period of ten weeks, and they are broken out in the overall project plan. The first five weeks were to be focused on learning about design of experiments and using the simulation software EXTENDSIM 8^{TM}. Selection of simulation software was based on prior use, and its robustness to handle several different simulation methods. In the sixth week, determine if the simulation is appropriate to achieve the objectives and formalize the problem statement with stakeholders. In the seventh week, develop a simple representation of the system to use as a base to grow the model in complexity as additional work or insight into the system is obtained. The simple representation would consist of random space object crossing the space fence, the SPARK system developing azimuth and elevation for TeleTrak system to begin target acquisition, the Teletrak system begins tracking and imaging object using two scopes geographically located away from each other. In the eighth week, expand the model to allow ability for scopes to independently track objects of opportunity and revert to using two scopes on one object for planned or unidentified objects passing through the space fence. Also, during the week develop a function to model the azimuth and elevation of the scope when an object exits or is interrupted, so calculations can be made on the amount of time required to slew the telescope to the new object. In the ninth week add the capability to use Two Line Element sets (TLEs) from a database or accomplish data collection to allow modeling which would enhance object generation to more accurately reflect real world conditions. Towards the end of the ninth week accomplish verification and validation of model using factorial design if needed. In the tenth week accomplish simulation runs, then use a Monte Carlo analysis to determine azimuth and elevation optimal locations and system requirements for minimum initial conditions of object to view given time required to slew scope, and finalize simulation work by writing a report.

Before going into model conceptualization it is beneficial to discuss the three types of simulations available (continuous, discrete-event, and discrete-rate) and the reasoning behind selecting discrete-event for modeling. The different methodologies[5] are: In a continuous model the time step is evenly spaced from each other, and interactions of the model occur with changes in time. In a discrete event simulation the system changes only when an event occurs, and is not dependant on time. Finally, in a "discrete rate simulation ... [the discrete event and continuous models merge to] ... simulate the flow of stuff rather than items; like discrete event models they recalculate rates and values whenever events occur[5]." A discrete event simulation was selected, because the telescopes would only be looking at a single item at a time, the system would change whenever an object crossed the space fence (event) or begins tracking with the telescope(s) (event). Also, the slew times could be approximated in the model as an activity with a processing time, and flight times could be simulated by a queue that releases objects if they have been waiting for awhile.

3.3. Model Conceptualization

Currently the SPARK system is able to identify where and when an object crossed the space fence, however orbit propagation is not possible as of yet. The model assumes that when the system is implemented this issue has been resolved and the determination of the object against the TLEs happens in an instantaneous manner. Another assumption is with the reliability of the TeleTrak system. The model assumes 100% reliability for the system on acquiring and tracking the desired object autonomously, but currently the system requires human input for minor corrections to have reliability in tracking an object. Another assumption is that any and all objects would be able to be viewed by the telescopes, which may not be the case depending on the size and brightness level of the object.

The length of the simulation will be for a single night of two two-hour periods to simulate the available collection periods due to space objects not able to be viewed using an optical telescope if the object falls in the shadow of the Earth. All activities use a normal distribution to represent when satellites are generated or accomplish an activity until data collection has been performed to more accurately represent the physical realities for the system. Queue blocks use a timer to release items after four minutes to represent the object is constantly moving in the system and therefore able to be a missed opportunity to collect on the target.

3.4. Data Collection

A large part of the any simulation is in data collection and if troubles did not arise within the model translation part of the process, additional data collection would have resulted. Preliminary data collection comes from screen captures of data showing the expected upcoming objects as illustrated in Figure 1. This representative screenshot is typical of number of objects in view at any given time along with the amount of time available to be able to view the object.

The slew time activity for the scope was represented by an Equation(I) block knowing the slew speed from the telescope manual and the last position of the telescope.

Therefore, using the screenshots again, a determination was made that using a normal distribution would suffice for now with a mean of seven minutes and a standard deviation of two minutes.

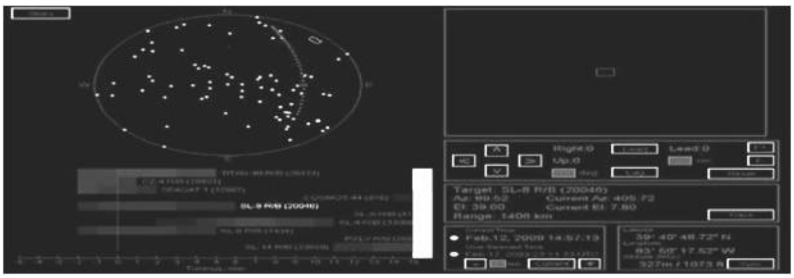

Figure 1: Satellite/Space Object Tracking Screenshot

The values and concepts were then used to develop the simulation model using EXTENDSIM 8™. Difficulties arose dealing with the pre-empt function of the activity block in order to simulate the priority of what object is to be tracked in the system. The authors discovered and confirmed with technical support there is a computer code problem with the software. They did make a suggestion on a possible fix with an Equation(I) block to force a timing check for the preempt signal. Developing code to make the proposed change has made the system disregard any higher priority items entering the modeling for the telescopes. Also, issues with resource pools apparently allowing more resources then what were allowed was quite troublesome, but a solution was finally found using gates down the separate paths for the telescopes.

3.6. Verified?

At this point in time, the model is failing verification, because tests showed increasing numbers of higher priority objects entering the TeleTrak system. This however, allowed for identification of issues with items of the same priority causing software errors. A good use of DOE could be used at this step to develop test scenarios on different functions as they are built into the system and used again when another change occurs to the model.

3.7. Validated?

With the model not getting out of the verification step it is difficult to validate the model. However, it has been demonstrated that queue blocks just using a timer to determine if an object should just exit the system is not the best solution. A method to enhance validity in this area is to develop an Equation Queue block factor in the stamped view time attribute for a specific item and push the item out if it meets a to be determined threshold.

3.8. Experimental Design

Again since a working model of the system does not exist it can only be discussed in terms of the proposed Experiment Design. Statistics show that for thirty runs of a test in an unknown population a normal distribution curve to model the data could be used. Since the model takes a relatively short amount of time to run, thirty runs of the simulation would be run to collect data on slew time with the telescopes free to move from their last location. This data would then be analyzed to determine which distribution (normal, lognormal, beta) to use on where to "home" telescopes before the next collection. Thirty runs of the simulation would then be run using the home location to slew from and the analysis compared. The expected results are a longer time to collect on target, but would also likely decrease the number of objects tracked over the course of the night.

4. During/Post-Experimental Phase

The final steps (Production Runs and Analysis, More Runs?, Documentation and Reporting, and Implementation) were not examined in depth, because of unsuitability of the simulation model in its current form. If implemented the results of the analysis would be presented during SPARK and TeleTrak team meetings to discuss implications of the system, and state requirements for the system beyond "do the best you can with what you can get."

5. Conclusions

The main objectives of developing a working simulation that would model the "to-be" architecture and optimal starting location for the telescope were not realized. However, the goal of learning design of experiments and simulation modeling were achieved. The twelve step simulation and seven step DOE processes provide a firm foundation for further work within these important realms. Key points as a takeaway from what has been accomplished so far are:

(1) Although the project plan as scheduled allowed for achieving stated goals, additional time must be allowed to learn how to use a simulation tool if advanced modeling behavior is required.

(2) Use an incremental approach in simulation as it is done in software, by only doing small portions at a time then testing to see if the expected model works.

(3) When designing for experiments, ensure that a sampling of representative cases is used to test a simulation or in collecting data for the model. A test case for the simulation involved having conditions within the system related to what priority was in the system. In collecting a sample for slew time, it was seen that the system would alternate slew directions, so even if the next target was a few degrees azimuth to the right and it was just collecting on an object while slewing to the right, the telescopes would take the time to spin nearly 360 degrees before tracking the object before it started tracking the object.

(4) Move to another aspect of the model if a particular process or logic is not working in the model. Seek help early and from experts when these circumstances occur. The help will eventually arrive or another solution might reveal itself, but at least another portion of the model will be completed.

(5) Use a simulation when variables are unknown, and understanding of the system is only partly understood. If a system can be represented in a logical model (equations), use that method to describe the behavior.

(6) When using a simulation, particularly discrete event, the timing of when an event occurs is crucial. Depending on how an object is connected and when it was created might force the timing of the calculation to occur too late in the process.

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