Proceedings of the 2005 Systems and Information Engineering Design Symposium
Ellen J. Bass, ed.

US ARMY EMPLOYMENT OF UNATTENDED GROUND SENSORS

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ABSTRACT

Army research initiatives include research and development of unattended ground sensors (UGS). UGS will improve the ability of tactical units to collect information and are expected to play an increasingly important role. Sensors are of several types, including acoustic, seismic, magnetic, electric field, and imaging. It is expected that deployed sensors will be self-organizing to form a sensor field. Because of power and communication limitations, it is anticipated that the sensor field will be required to process data locally, and report only the results of this analysis. Given detection, the report will include the classification or identification of an object transiting the field, as well as the field's self-assessed level of confidence in the estimate.

This study examined the level of confidence required before a decision maker would reallocate resources based on the report. Combat arms officers were provided a tactical situation and the sensor field level of confidence required before commitment of forces was elicited. A computer model was then used to investigate what sensor mixtures and densities were required to meet this threshold. The impact of correct and incorrect decisions for a tactical situation was examined using a high-resolution combat model. Additionally, the responsible unit level and doctrinal employment were examined.

1 INTRODUCTION

1.1 The Problem

Army initiatives include research and development into unattended ground sensors. Unattended ground sensors will improve the ability of tactical units to collect information. The design characteristics of UGS are not yet fixed. For example, UGS may be constructed so that each is an inexpensive uni-modal sensor that functions in one domain (e.g., acoustic, seismic, magnetic domains only). Multimodal sensors would be more expensive but have more refined ability to detect, classify, and identify targets. Additionally, the quantity, type mix, responsible unit level, and doctrinal employment are part of the trade space to optimize sensor value. This study, undertaken for the Signal, and Imaging Division, Sensor and Electronic Device Directorate, Army Research Lab (ARL), will examine these issues to determine the optimum choices, their robustness, and costs in order to facilitate deployment of UGS to the force.

1.2 Background

Unattended Ground Sensors (UGS) were first designed in order to provide information access to remote and denied areas in tactical surveillance zones. They are designed in order to give the commander a source of information where they can track enemy movements. By tracking the enemy and receiving early warnings from UGS the commander can be better ready to deploy his or her troops as needed. The sensors can include the following types of sensors, acoustic, optical, chemical, seismic, and other possible types.

UGS are typically battery powered with a signal or multiple sensors. This allows sensors to be used for many different types of projects. They can also be deployed in many different ways, such as artillery, hand, and air dropped.

There are currently several UGS systems already in use today. Canada has a sniper location system called GUARDIAN, which uses acoustic sensors to detect sniper fire. In addition, in France, they have another sniper system that uses acoustic, IR, and lasers to detect the location of snipers. In Denmark, acoustic and seismic sensors are used to estimate ground vehicle movement and where explosions take place. Germany has a system called BSA, which has the capability of detection, classification and type identification of personnel and ground vehicles. The UK has a system called HALO, which uses sensors to monitor artillery fire. The U.S. has used sensors in the early 1970's in the Remote Battlefield Acoustic and Seismic System (REMBASS) and the improved REMBASS (IREMBASS) more currently. In the 1980's wide area munitions (WAM) was developed in the U.S. WAM uses acoustic and seismic sensors to detect and kill a target at it closest point.

1.3 Assumptions

Our group consolidated the follow list of assumptions.

- Do not worry about enemy counter-measures such as jamming, spoofing, triangulating,
- The sensors are reliable.
- The data is processed in the sensor field.
- Sensors can be deployed by many platforms, using current system form factors.
- A user interface will be available to view the data.
- Sensors can self organize once deployed.

1.4 Recommendation

We currently do not have a recommendation. As we continue with our project and run simulations, we will be able to provide a recommendation for ARL.

2 PROBLEM DEFINITION

2.1 Needs Analysis

Our client is Army Research Lab (ARL). Through discussions and the problem, definition above we set off on a research question of what is the best way to use unattended ground sensors (UGS) in the tactical Army?

2.1.1 System Decomposition

In looking at sensors, we categorized them into three different categories, high, medium, and low. We saw the high-level sensors as the sensors that are used mostly by the intelligence community. This project focuses on the medium level of sensors; these are the sensors that will be used by combat arms platoons, companies, and battalions. The low levels of sensors are the disposable sensors that still need to be better developed. The following are a list of functions of the system:

Functions:

- Deploy sensors (could be any variety of means, from hand placement to volcano)
- Activate sensors/network (Self-organizing? Manual activation and networking?)
- Sense contact (acoustically, seismically, visually, or by whatever means the sensor works).
- Identify Contact (this processing may take place at a node rather than with the sensor)
- Compile overlapping information from multiple sensors to form best picture (part of processing and identification)
- Track contact (as long as in sensor range)
- Transmit information from sensor to node (if there are nodes)
- Transmit contact report to data collection point
- Transmit contact report down to the soldiers or others who need that information (if data goes to them directly this step would not be necessary)

Types of Sensors:

- Acoustic
- Seismic
- Passive Infrared
- Magnetic

Components:

- Structural – Air Emplaced, Air Deployed, Hand Deployed
- Operating – Gateway, Tripwire Nodes, Imaging Smart Nodes, Non-Imaging Smart Nodes
- Flow – Disposable Sensors

Structure:

- Super-system- Military Tactical Units, Army Officers,
- Lateral system- Other methods of collection including radar, UAV, Scouts, other current techniques of data collection.
- Sub-system- Data Display, sensors, receivers and transceivers (orange and blue), power supply, processor.

States:

- Radios: Sending, Receiving, Sleeping, Active, Off, Destroyed
- Sensors: Active, Dead, Sleeping, Off, Destroyed

2.1.2 Stakeholder Analysis

In order to gain insight on how to best use unattended ground sensors in the tactical Army and how to best integrate them into the existing force, we surveyed a group of officers, most of them captains and majors who had experience as platoon leaders and company commanders. In addition to a little demographical data, we focused mainly on how they think sensors should be used and at what unit level they should be employed. We also asked them how they think it would be best to emplace the unattended ground sensors and what sort of data they would like back from them. In addition to this, we attempted to find out what confidence would be necessary from the sensors in order for these officers to take action by giving them a scenario as well as asking them to validate our value hierarchy. For the most part, the feedback we got was directly pertinent to answering our question of how to use these unattended ground sensors in combat.

2.1.3 Scenario

In order to force our stakeholders to make a decision based on the information from the sensor field we came up with a simple scenario. This scenario forced the stakeholder to make a combat decision based on what information was coming back from the sensor field. This allowed us to determine the level of confidence that the stakeholder needed to receive from the sensor field in order to reposition his or her troops. After conducting the interview with the stakeholder, we hoped to gain a better insight on what information the leaders need to receive from the sensor field in order to influence their tactical decision.

Mission: Defend company sector to prevent the enemy from moving south

Enemy: Reinforced platoon of insurgents. Dismounted and using commercial vehicles

Troops: Reinforced mechanized infantry company

Terrain: Two avenues of approach are available to the enemy

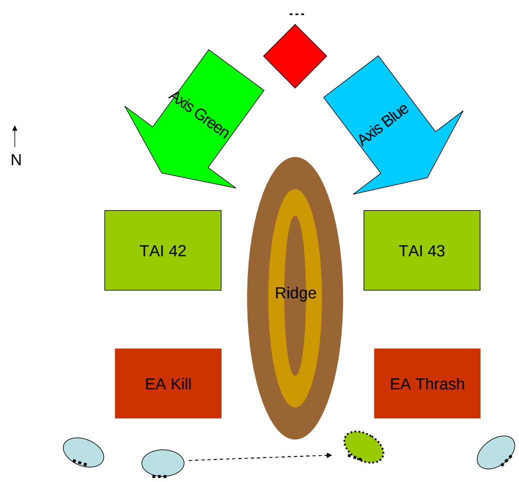

Figure 1: Tactical Situation

Situation:

- Intelligence has told you that the enemy is mostly likely to advance on Axis Green.
- The enemy is 35 minutes away from you position.
- It takes you 30 minutes to reposition your troops.
- TAI 43 is giving you detection in its sensor field.
- What level of confidence do you need from the sensor field in TAI 43 in order to weight coverage of EA Thrash?

Interview Results:

Our group interviewed nine different combat arms officers and two combat arms NCOs. Below is a histogram that shows the desired confidence that each stakeholder expressed. This confidence level is the level where the commander trusts the information sent back to the commander is a level where he will move his troops. When analyzing the results we found the mean to be 72.3, the median to be 70, and the Range as 50-90. Throughout the interview process, we noticed several trends. These trends are the focus of our project.

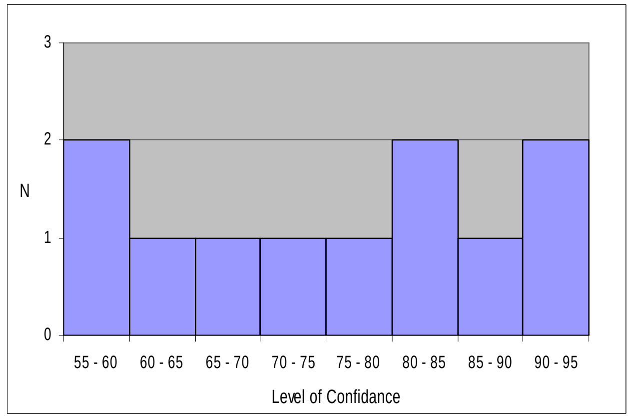

Figure 2: Interview Results

The first area of discussion is the employment level. This area addresses what level of command should control the deploying of the sensors and the results that the sensors send back to the user. The majority of the stakeholders believe that the sensors be given only to company and above for intelligence gathering, and in the defense. The reason is that below that level it is too much information to provide to platoon levels and below. Information available to higher levels will be given to the lower levels when the information deals with their area of operation. However, some of the stakeholders feel that if the sensors are used for local security then the platoon level should be giving the sensors as a tool.

The next topic of importance was the deployment technique. The consensus was that the sensors should be owned by the unit. Control of the deployment should rest with the local commander and his soldiers. This encourages either hand emplaced or use of mortars. The reason being is that the units would not have to be concerned with priority of fires from artillery or close air support.

The final topic of importance is the disposal of the sensor. Each stakeholder expressed a concern with anti-handling device. If they are disposable then the sensor should be able to destroy themselves after their useful life so the enemy will not be able to exploit the sensors so they may be used against us.

2.2 Value System Design

2.2.1 Value System Modeling

Our method of developing the functions of the sensor field was affinity diagramming. Our group wrote out every function that was important to consider. Then we organized the functions and kept the functions that were important to the stakeholders. Our first hierarchy was reviewed over by ARL and they told us what to eliminate and retain. The function that was deleted was the communication with the user. This is because the sensor will be added to whatever current communication system is currently be used.

2.2.2 Value Hierarchy and Evaluation Measures

We created a hierarchy of what would be the important functions of the sensors. We described six different primary functions that should be focus on when developing sensors. There are survivability, duration, communication, programmable, data collection, and deployment. Survivability is a function that encompasses the sensors ability to avoid detection and has a measure of height off the ground, and the sensors ability to survive in any environment was given a measure of what environment category it can survive. The duration is how long the sensor can survive in the field and has a measure of time for duration. Communication is the ability for sensors to communicate with each other; it has a measure of range distance. Programmable is the ability to alter the sensors parameters once deployed into the field this has a binomial measure. Collection is divided into four categories: Detection, classification, identification, and tracking. The first three of these functions have a measure of probability of detection and probability of false alarm rate. Also included in the collection section is the ability to track moving forces, which has a measure of accuracy. Lastly, the deployment function is the way in which the sensor will be placed in the field whether it is hand employed, artillery or mortar, or other method.

2.2.3 Weighting

In order to evaluate how valuable a sensor is to the users we will use value analysis. Through this method, we are able to take the wants of the users and quantify them. We first conducted a survey with various stakeholders from different combat arms branches. We then asked them to rank order their wants and needs. We then asked them how much more important each item was in terms of the importance relative to the least important item. We were then able to take the numbers solicited from each stakeholder and weight each of the characteristics of a sensor. This allowed us to see which of the characteristics were most important to the stakeholders and which were not as important. Our next step is to input these weights into our decision matrix in order to show our decision maker what the stakeholders feel the most important characteristics of a sensor field are. After ordering and defining the key functions in terms of the least important, we calculated the relative weights by normalizing their sum to one.

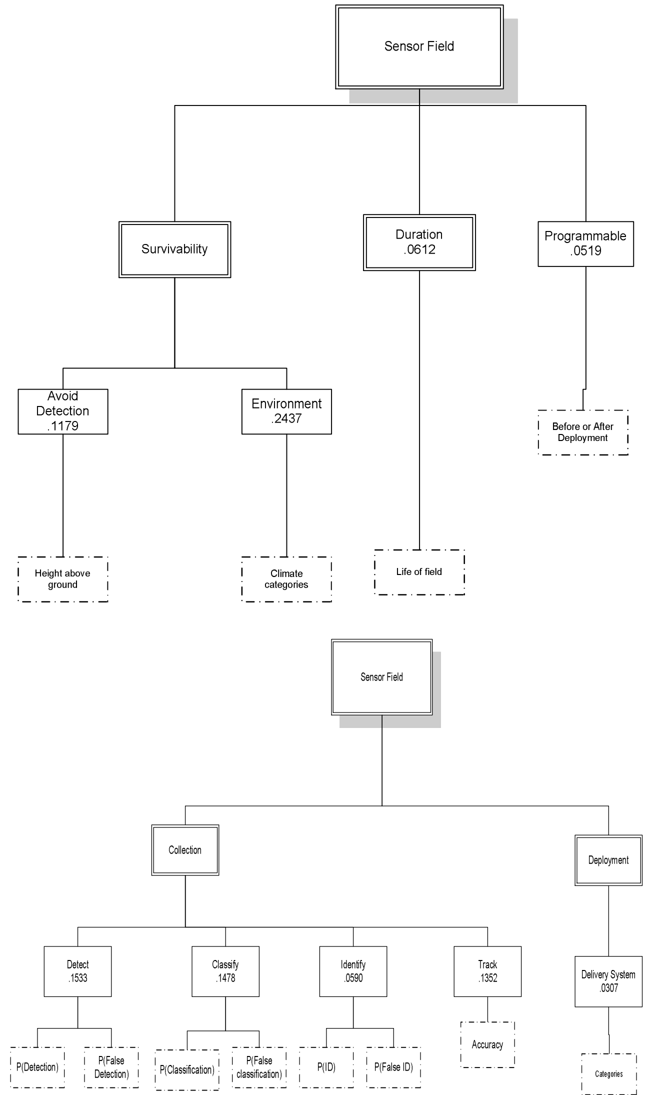

Figure 3: Value Hierarchy

3 DESIGN AND ANALYSIS

3.1 Alternatives Generation

3.1.1 Development of Alternatives

Ideation Process: Due to the variety of issues surrounding this problem, our alternatives only exist as general ideas consisting mainly of discussions of what level should control the use of unattended ground sensors, what density and mix of sensors should be used, and what other doctrinal issues should be considered when deploying them.

3.1.2 Feasibility Screening and Recommended Alternatives

Following the development of a comprehensive list of alternatives and constraints, we used Feasibility Screening Matrix to illustrate whether or not each alternative is feasible under our constraints. The alternatives, which are feasible, will be recommended for further analysis and these are the alternatives we model in the modeling phase.

3.2 Modeling and Analysis

3.2.1 Systems Modeling and Analysis

The next major step in our examination of the problem statement will be to develop models of unattended ground sensors to determine both how they should be best implemented and employed by the current force as well as to show how sensor data could affect the performance of the force. In order to accomplish this we will develop two models. The first will be a model of the sensor field itself, looking at different types of nodes at different densities to determine how well a certain type of sensor field will perform under different conditions. The two models we will use are Sensor Network Optimal Operations Simulator (SNOOPS) and Joint Conflict and Tactical Simulation (JCATS), both of which will simulate different elements of the problem.

3.2.2 SNOOPS Model

The SNOOPS model is a simulation designed by LTC William Bland, one of the members of the Systems Engineering Department at West Point, which, by providing the cumulative density functions of detection and of false readings, can effectively model the sensor field itself. We will use the results we outputted from this model to attempt to determine a true probability of detection for movement within a sensor field, given a field of a certain type of sensor at a certain density. SNOOPS provided for us a grid area and then develop a probability map that shows us the probability of enemy being in that grid based on the information from the sensors. We will be able to get the density of sensors needed in order to achieve the confidence that officers want to see. We will also be able to get the appropriate mix of sensors we will need and the best emplacement patterns for the sensors. We will give SNOOPS a rule to report back to the unit the highest probability of enemies and what grid they are in so that the leader can be informed of where the enemy most likely is. The rule for this model is SNOOPS will take the largest probability from all the trials and find the mean. The goal is to find a combination of type and density that will provide us with a confidence of 0.7.

In our project, we are analyzing four types of sensors: seismic, magnetic, acoustic, and passive infrared. The goal is to design a sensor field utilizing as many or as few sensors as possible in order to maximize the probability of detection and classification of an object moving through the sensor field. We have forty-four different simulations that we will run for our project, all of which will include acoustic sensors. The simulations are divided into two categories; one in which the sensor locations are determined randomly and the other in which they are determined by a fixed pattern.

We decided to use the SNOOPS program for the simulation part of our analysis. SNOOPS, written by Lieutenant Colonel William Bland, Department of Systems Engineering, United States Military Academy, wrote and designed to simulate the use of a sensor field. SNOOPS takes data including the type of the sensors, number of sensors, density of sensors, placement of the sensors and individual sensor detection capabilities, and runs a simulation of the sensor field as it attempting to detect moving objects. The output of this simulation is the probability of classification of the enemy that is entering the sensor field. The results give us the probability that our sensor field will correctly identify and classify the object it senses moving through the field.

A strength of SNOOPS is that it is capable of running hundreds of simulation runs in a matter of seconds. Since the output of the SNOOPS simulation is a probability, we developed a decision rule that made our results more accurate. Instead of only running five or ten iterations of a particular simulation, we chose to run five-hundred iterations of each simulation. Running a greater number of simulations makes our data more accurate by taking into account possible outlier probabilities that would not be considered if we only ran five or ten iterations. If we had simply run five to ten iterations of each simulation, we would have had to develop a decision rule to average the output probabilities and gain an overall probability of the simulation. In essence, running more simulations makes our data more reliable.

3.2.3 Joint Conflict and Tactical Simulation (JCATS)

Joint Conflict and Tactical Simulation (JCATS) is a simulation, which allows a detailed combat scenario to be modeled with a great deal of accuracy and control over the many factors and probabilities of combat. It is one of the latest software packages to be used in combat simulation and is an excellent tool. We used this software to model the specific outcomes, which are likely to occur based on different decisions, which would be influenced, by a sensor field. By having real decision-makers make decisions based on a scenario and simulation data, we can then simulate, using JCATS, the effect of their decision and the possible consequences. See Figure 1 for a diagram of the tactical situation. Each decision will have at least four possible consequences: where the decision was made to adjust based on sensor data and the sensors were right, for example if the enemy advances on Axis Green and the sensors in TAI 42 indicate this; where the decision was made to adjust based on sensor data and the sensors were wrong; where the decision was made to not adjust and the sensors were right; and where the decision was made to not adjust and the sensors were wrong. In two of the four cases, the decision made was the correct one—however, by modeling the effects of each of these four situations, one could make the call as to when sensors are trustworthy based on the impact of Type I and Type II errors.

After setting up each of these scenarios in JCATS and performing twenty runs of each scenario, we had our results. In the scenarios, which focused on the situations where the enemy went left, the model behaved in a predictable manner. The average amount of casualties of the blue forces, which were in the defense and were the users of the notional sensors, was one when the sensors did not work properly and 1.7 when they did. The average enemy (red force) casualties were 2.75 when the sensors did not work and 5.5 when they did. The increased number of friendly kills is likely a factor of the increased number of friendly units being exposed to the enemy. In addition, it should be noted that in JCATS units do not always see one another, as seems to have been the case every time in this scenario since at no point was all the units in one force destroyed. When the sensors worked, we did get more blue casualties. However, the loss exchanges ratio (red/blue) when the sensors did not work was 0.36. When they did work, it was 3.24, an order of magnitude improvement. For each of these statistics a two-sample t-test was applied and it should be noted that the sample mean of blue force kills is significantly larger (at 0.01 alpha level) when the sensors are used and function correctly and the sample mean of red force kills is significantly larger (also at alpha=0.01) when the sensors are used.

In the case where the enemy went right, the results also seemed to be biased by the fact that more friendly units were under fire when the sensors worked properly (because they had been reinforced). The mean number of enemy kills when the sensors work was 11.85 and was 12 when they did not work, two number which, when at t-test is applied, are not significantly different at even a 70% confidence level. However, the number of blue force kills increased at a statistically significant level (p=0.001) when the sensors were used from a mean of zero to a mean of 0.75 friendly casualties. In this case, it would appear that in all but one case, all of the units were able to encounter one another and each time the red force was wiped out. However, when more blue forces were added their casualties increased at a statistically significant level. It is apparent that although the scenario was arranged with twelve BMP-1s assaulting four M-2 Bradley's when the M-2s (the blue force) was not reinforced; the Blue Force was still able to destroy the enemy with no casualties without fortifications and against 3 to 1 odds.

JCATS, in this case, seems likely to have biased the results in several ways. First, because it does not image the terrain at a high resolution (or large amount of contour lines) for scenario planning, but takes into account changes in elevation and terrain when it runs the scenario, it would seem apparent that not all units were able to come into contact with one another, even though they should have been in range and facing the correct way. This, very likely, caused some of the discrepancies in kills. The fact that there was no point where the red force was able to defeat the blue force negates using the number of red kills as a unit of measurement. Ultimately, because of these biases, this scenario would tend to show that the blue units perform better not only without sensors, but also with fewer numbers of soldiers.

4 DECISION MAKING

The purpose of this section is to describe the methodology for scoring the various alternatives to prepare a recommendation for the decision maker. We will develop and explain our Multi-Objective Decision Analysis while converting our data into a decision matrix. The matrix will include the solicited weights for the value hierarchy, the cost per unit, and the density of sensors that need to be on the battlefield. Based on the sum product of the values and the weights of the criteria we will come to a conclusion of what kind of sensors the Army should be building for the future.

4.1 Alternative Scoring/Value Scores

Our main objective in evaluating our alternatives is not yet based off value scores. At this point, we have not been able to develop our scenario into a value model because such a model is difficult to assign to Unattended Ground Sensors. We have thus far used mainly our Stakeholder Analysis in scoring our alternatives.

4.2 Decision Matrix

We will develop our Decision Matrix when our simulations are complete.

4.3 Sensitivity Analysis

We have not yet developed our Sensitivity Analysis.

4.4 Decision/Recommendation

At this point in our analysis, our decision will be based off our Stakeholder Analysis and our understanding of how to best implement the Unattended Ground Sensors in the

Military. We know the military has sensors already at their disposal and that they use them sparingly to detect enemy presence near their defense or area of operations. At this point, we would recommend that the sensors should be hand deployed and should be available at either the battalion or the company level. Sensor performance also bears on our decision, and we recommend that the Military needs a 70 percent probability of accurate identification before the sensors can be fully trusted to do their job. This is based on the solicited weights from the stakeholder analysis of a mean of 72%, median of 70% and a range of 50%-90%. The values showed the value of accuracy of identification that the combat leader needs to see from the field before they will act on the information.

4.4.1 Cost Estimates

One of our objectives from the beginning was to minimize cost, hoping that sensors could be developed as small and as cheap as possible. The cost data is in the form of per unit for each type of sensor. Based on the performance of each sensor type we will use sensitivity analysis to find whether the extra performance is worth the addition of cost per unit. The client has not yet provided cost estimates.

In order to evaluate our different types of sensors we also considered cost. By considering cost, we will be able to show the decision maker how expensive a sensor field will be that meets all of the stakeholder's needs. We will use an equation given to use by the Army Research Lab (ARL). This part of the project will be done once we have received all of our simulation results.

4.4.2 Recommendation

We recommend that sensors, with the right probability of accurate detection, should be developed for further use in the military. Our recommendation will include the optimal mix of sensors and the amount a unit would need to reach the desired certainty within a given perimeter. Based on the value hierarchy Army Research Lab now has the ability to see what criteria do combat leaders desire the most.

For future research, we would change the JCATS scenario by perhaps using varied terrain, larger enemy forces and different enemy unit types.

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