Human Factors Assessment of Three Commercial Interior Positioning Systems

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Abstract

Interior Positioning Systems (IPS's) are being used to track equipment and people in many different settings commercially, including hospitals, university libraries, and museums. IPS's are functionally indoor equivalents to GPS tracking systems (which use a different technology and are only functional outdoors). This research consisted of an earth-based evaluation of three commercially available IPS's for potential use on future space missions. The best performing system resulted in an error rate of approximately 18%, but was difficult to implement. The worst performing system resulted in an error rate of approximately 80%, but was easiest to implement. None of the systems meet NASA requirements at this time.

1 Introduction

NASA astronauts rely heavily on mission operations personnel and other experts on the ground in order to achieve their objectives, and remain healthy and productive during the mission. Space flight in the future will require astronauts to be more independent, since it will be impractical, if not impossible to quickly return to earth in the event of an emergency. The hazards of long-duration space flight are real; and thus, in order for humans to participate effectively in long-duration missions and continue the exploration of space, systems must be developed that ultimately support astronauts and their health. Future missions, including the mission to Mars, will rely on the integration of telecommunications technologies, information technologies, and medical care technologies for the purpose of enhancing healthcare in space flight. Systems will minimally rely on mission control, and so must support crew independency. This paper discusses one in the list of many potentially required systems for crew independency: Interior Positioning Systems (IPS's).

Interior Positioning Systems (IPS's) are being used to track equipment and people in many different settings commercially, including hospitals, university libraries, and museums. While similar to Global Positioning System (GPS) tracking devices, the specific technology used is different. IPS's are functionally indoor equivalents to GPS tracking systems that are only functional outdoors. It is envisioned that IPS's would support crewmembers in three primary fashions: (1) allow crewmembers to find one another, especially in an emergency; (2) collect data for assessing environmental exposure assessment (e.g., radiation exposure); and, (3) collect astronaut location data that could be used by space architects in the design of future spacecrafts. This project took the initial step to assess the usability of such technologies by conducting an earth-based evaluation of three commercially available systems for potential use on future space missions. Systems were evaluated from both an engineering implementation and functional use perspective.

2 Method

Three commercial systems (A, B, and C) were subjected to the same testing environment, and evaluated using two

[1] This project was accomplished while the author was a 2004 NASA Faculty Fellow at Johnson Space Center, Houston, TX.

different functional measures of performance including: errors and subjective evaluation by participants. System A is designed to detect a sensor within a predefined logical area (defined by receiver placement), while systems B and C are designed to detect at a room level only. It should be noted that a room could be composed of more than one logical area. Dividing a room into smaller logical areas allows a system to be more accurate about the location of an individual or piece of equipment within that room.

2.1 Participants

A total of 10 (4 male, 6 female) individuals from NASA's workforce served as evaluators of the system. A total of five participants were used for the individual tests as described below, and six pairs of individuals were used for the team evaluation described below. Individuals participated in one or both of the tests. Since the systems, and not the participants were being tested, participants served only as a means of moving the transmitters through the test facility in a realistic fashion.

2.2 Experimental Environment and Apparatus

This study was conducted in the Advanced Integration Matrix (AIM) facility located at NASA's Johnson Space Center. AIM is a reconfigurable mock-up facility that can be used to emulate the physical environment of a spacecraft or planetary habitat. The facility consists of 6 large metal cylindrical modules joined in the center by an open hallway. The facility is currently a shell structure (not outfitted). Two modules are split level, attached with a metal stairway. Three areas in the module were used for this evaluation, including a split-level area. The AIM facility has video cameras located throughout that were used to record the participants traversing the facility. Transmitters were carried or worn by participants in this study. When using system A, participants carried a Hewlett Packard iPaq Pocket PC Personal Digital Assistant (PDA) with a compact flash wireless fidelity (Wi-Fi) card. For system B, participants wore a battery operated radio frequency (RF) badge, and for system C, participants wore a battery operated radio frequency/infrared (RF/IR) badge.

A dedicated laptop computer was used to monitor the personnel traversing the AIM facility, and also used to capture the location data. This laptop was configured with each system's software as provided by the three vendors in their evaluation packages. Prior to the evaluation, systems were tested by placing the particular transmitter on predefined points in the same orientation to ensure the system would recognize the transmitter independent of people transporting the transmitter. NASA personnel performed the installation and calibration for all systems per the vendor instructions in the evaluation kits.

2.3 Experimental Task

Participants were given an overview of the testing being conducted, signed a consent form approving video recording of the session, completed a demographic survey, and received a safety briefing so as to avoid any potential tripping hazards within the AIM facility. In addition, participants completed a walkthrough of the path they were to follow so that they were aware of the paths and stopping points in the facility. Colored numbers on the floor represented points to which participants were asked to walk during the evaluation. A different color was used to represent each walking condition participants were asked to complete. The three walking conditions included: Individual: a single individual traversing the facility; Pairs: two persons walking side-by-side through the facility; and Opposite: two persons walking from opposite ends of the facility and passing one another. Participants completed these tasks for each of the three systems independently. Once a system was enabled, the participant was either given the PDA to carry, or had the receiver attached to their clothing. In either case, all participants carried the PDA or wore the receiver in the same position. Participants were told when to begin walking to the first point based on the computer clock used by the systems to timestamp their location. The participant would stop at each point for a period of approximately 15 seconds, and advance to the next point based on a verbal command given through the AIM intercom system. Participants continued the walk until the last point on the path was reached.

In addition to the three walking evaluations, the systems were tested in several static conditions, including: (1) badges hidden in clothing and bags; and (2) badges hidden behind obstacles within the facility. During this testing, a single individual was used to carry the transmitter in all conditions.

2.4 Measures of Performance

Two different measures of performance were identified for evaluation of the three systems in the walking conditions: number of errors and subjective evaluation by participants. Each measure is described in Table 1. For evaluation in the static conditions (hidden badge and obstacle badge detection), the findings consist of a measure of whether or not the transmitter was detected.

Table 1: Measures of performance for walking conditions

Measure	Description of Measure
Number of Errors	An error could be of two types: failure to detect (Miss), or detection of the participant in one location when they were actually in another location (False Alarm). An error occurred whenever the system failed to detect the person correctly while standing at a point for a period of 15 seconds, or failed to detect them upon arrival at a new point. This method of counting error follows the Signal Detection Theory (SDT) method as developed by Green and Swets (1966).
Subjective Evaluation by Participant	Each participant completed a questionnaire. Question topics ranged from comfort with using the tracking device, to their views on privacy and the use of the location tracking system.

3 RESULTS

The results will be discussed by looking at each of the performance measures.

3.1 Number of Errors

System A was prone to minor fluctuations (1 -2 seconds) in its detection of a participant (i.e., the system would sometimes flip between areas when the participant was actually standing still on a point). The reason for this is currently unknown. Because of these fluctuations, the initial analysis of system A showed an error rate of over 100% when each fluctuation was counted as an error, since the number of errors exceeded the number of points. Since the fluctuations lasted only 1-2 seconds, a decision was made to exclude the fluctuations from the error count for the analysis. Figure 1 displays the error rate (without fluctuations) for system A at both the logical and room levels. Figure 1 also shows the error rates for systems B and C at the room level.

As shown in Figure 1, system C had the lowest error rate among the systems tested, and system A, by both logical area and room level, had the highest error rate. When one transforms errors into the amount of time a system was able to correctly identify an individual, System C was correct 96.5% of the time. System A had the lowest percentage time correct, 41.45%. System B was correct 79.31% of the time.

To assess the severity of the errors received, each of the errors was classified into one of three categories: (1) Adjacent – system identified the individual in a location adjacent to their actual location; (2) Nonadjacent – system identified the individual in a location non-adjacent to their actual location; and, (3) Different floor – system identified the individual on a floor different than where they were located. Because of the uniqueness of the AIM facility (i.e., the open second floor and total metal structure) as compared to facilities in which these systems are typically implemented (e.g., hospitals), the authors felt it was important to understand the types of errors that occurred. Table 2 provides a percentage breakdown of the types of errors encountered.

3.2 Subjective Evaluation by Participants

The feedback received from the participants of the study was consistent across all three of the systems, with the exception of one comment on system A. Users found carrying system A's PDA implementation uncomfortable, and thought it would potentially impair their ability to complete hands-on tasks. For systems B and C, the devices were completely acceptable; although, there was some concern about securing the badge to clothing. Several attitudes emerged regarding the wearing of a tracking device: a few participants felt very strongly that they did not want to be tracked and would refuse to wear a tracking badge; and, almost all participants wanted some degree of control over where and how often the system tracked them, as well as the ability to turn off the tracking or change how often or where they were tracked. Once told the potential benefits of IPS's, most indicated that they would be willing to wear one at work.

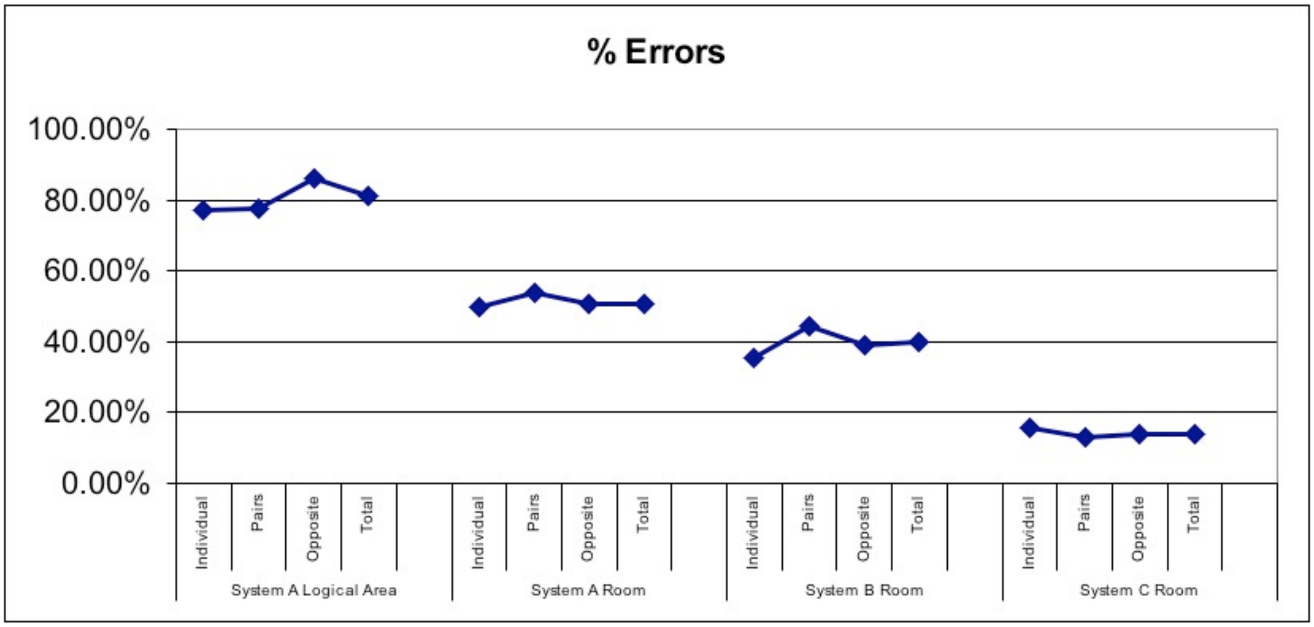

Figure 1: Percentage of error by system and by condition

Table 2: Types of errors as a percentage of the total error rate

System	Adjacent	Nonadjacent, Same Floor	Different Floor	Nonadjacent, Different Floor
System A	42.70%	0.00%	53.93%	3.37%
System B	54.17%	9.72%	19.44%	16.67%
System C	63.64%	0.00%	13.64%	22.73%

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3.4 Hidden Badge Detection

A single participant was used for this evaluation. The transmitter for each system was placed in different types of clothing, and a computer bag to evaluate whether it would be detected. Five situations were evaluated including: (1) in pocket of coat (light colored); (2) under light colored/sheer shirt; (3) under dark colored/thick shirt; (4) in jeans pant pocket; and (5) in a computer bag. Systems A and B were detected in all locations. System C was detected in only two conditions. It was not detected in the following cases: (1) under dark colored/thick shirt; (2) in jeans pant pocket; and (3) in a computer bag.

3.5 Obstacle Badge Detection

Several different obstacles were evaluated to determine if reception would be impacted/blocked. Physical objects including wood/fiberglass and insulation panels, approximately 4 feet by 8 feet, were used as obstacles. In general, all three systems were able to detect the person/transmitter behind the insulation panels. System A had the most problems with the physical objects. Typically, system A would detect the individual, but in another room or logical area. In one case, it detected the person on a different floor of the AIM facility. Thus it was the most prone to object interference. Systems B and C were able to detect the individual in nearly all the obstacle locations. In a couple of cases, they were slow in detecting the individual; however, both systems ultimately detected the individual. Since system C relies on *line of sight* because of its IR configuration, the authors were surprised it was able to detect the individual behind obstacles. However, because of the AIM's metal hull, perhaps the light signal was able to reflect off the facility walls and ultimately find the individual. There was only one condition where system C did not find the individual: when the individual was placed behind a heavy piece of machinery.

4 DISCUSSION

As this was a preliminary study, only a small sample of participants was used for the study, and no statistical analysis was conducted. In addition, the system setups were not performed by the vendors, but by NASA personnel, so there is a possibility that the systems weren't optimized. Finally, the AIM environment was very unique and not the target environment for these commercial systems; the hollow metal environment could have contributed to poor system performance. Nevertheless, this study established a solid procedure for evaluating these types of systems, and allowed for the collection of some preliminary data on these three systems.

When all three systems are compared on their ability to identify an individual's location within a small area, system A was the only system tested that provided this capability. The other two systems (B and C), only allowed for evaluation at the room level. Of course, system A could only identify the individual correctly approximately 41% of the time. Thus while system A was the only system that could provide tracking at the logical area, its performance was very poor. System C has the ability to identify people within smaller areas, however, this configuration was not available at time of testing.

When all three systems are compared at the room level, system C outperforms the other two systems. System B comes in second, with system A in third in terms of performance. Even with system C as the best performer, approximately 10% of the time system C has the individual identified in the wrong location. Thus, even the best performer is not without its limitations.

5 CONCLUSIONS

Several conclusions can be drawn from the evaluation conducted, but in summary it is clear that none of the systems provides a complete solution in meeting the tracking and technology integration requirements of NASA. In terms of functional performance (i.e., system meets user needs), system C performed well on all performance measures as compared to systems A and B. However, the system only provides tracking at the room level, and thus does not provide the level of fidelity required for tracking NASA assets or personnel. As described above, changes to the system may provide the additional fidelity required, but more testing will be required.

From an implementation perspective, system A is far simpler to implement than the other two systems because of its Wi-Fi design (e.g., no required cable runs). Since the other two systems do use TCP/IP protocols, it seems they could be integrated into existing networked systems. It should be noted that this was not tested and was not clear from company websites. Additionally, it may not be feasible to add them to existing networks for various other reasons.

While all three of these systems have been successfully implemented in commercial applications (e.g., hospitals), NASA's environment is very different than the environments traditionally using these applications. Further study is required to evaluate the feasibility of such commercial systems for space applications.

REFERENCES

Green, D. M. and Swets, J. A. (1966) *Signal detection theory and psychophysics.* New York: Wiley.