The Application of Human-Systems Integration: Designing the Next Generation of Military Global Positioning System Handheld Devices

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The effectiveness of systems and their users can be greatly enhanced by the application of human-systems integration (HSI) as an integral element of systems engineering. The current military handheld Global Positioning System (GPS) device exemplifies a case where HSI was not adequately considered. The current GPS device performs the necessary functions; however, usability issues impart burden and workload to the user, making the use of the handheld GPS device difficult. In support of the U.S. Air Force Space and Missile Command GPS Directorate and the Military GPS User Equipment (MGUE) program, APL applied a systems engineering approach to creating designs for the next-generation handheld GPS devices, incorporating HSI into the process of defining requirements and prototyping potential user interfaces. Feedback from initial user testing was extremely positive, and continuing this systems engineering approach should help ensure that the next GPS devices will better meet users' needs, resulting in more efficient task performance. This article describes the HSI activities that supported the MGUE project.

INTRODUCTION

The market for and features of commercial Global Positioning System (GPS) devices have been rapidly expanding, and as a result, the warfighters' expectations of the capabilities of a GPS device have also increased to include functionality beyond simple position, navigation, and timing (PNT). Military troops regularly purchase commercial devices for basic navigation use in theater because of their ease of use compared with current military handheld GPS systems.[1] Several suppliers of commercial handheld GPS devices even showcase feedback from military personnel describing the service members' satisfaction with the utility and usability of the vendor's product.

The lack of adaptability of current military handheld systems to newer and more capable technology is a significant challenge, and this is one of the drivers causing the military to purchase commercial GPS devices for their operational needs. A modular system architecture would better support the rapid adoption of new mobile device technologies into operational use. Additionally, access to a more secure PNT signal may be a decisive advantage in future conflicts against adversaries with more advanced electronic warfare capabilities. M-code is a new military GPS signal that will improve the secure access of signals and protect against jamming.[2] Thus, the need exists to provide an M-code-capable military GPS handheld device with an architecture that can adapt to changes in technology.

In support of the U.S. Air Force Space and Missile Command GPS Directorate and the Military GPS User Equipment (MGUE) program, APL applied a systems engineering effort that fully incorporated human-systems integration (HSI) expertise to identifying and articulating handheld navigation requirements based on warfighter needs. APL was tasked with providing MGUE requirements for a device that would be the follow-on to the Defense Advanced GPS Receiver (DAGR), the current handheld PNT system.

The project included the involvement of HSI engineers throughout the development of the requirements and prototypes. HSI is a system-wide comprehensive program for integrating user requirements as part of an overall system solution.[3] HSI examines seven core areas—manpower, personnel, training, human factors engineering, survivability, safety, and health hazards—in order to reach high-level goals such as improving user acceptance, reducing life-cycle costs, and reducing training time and costs.[4] Traditional systems engineering activities are largely concerned with mechanical, hardware, and software elements and do not fully address the end-user needs because it is assumed the user will automatically embrace new and improved technology. However, new technology often does not reach maximum potential because of an incongruity between the technology and unforeseen human limitations. This incongruity could be avoided if the users' needs and abilities were considered in the system design and users were involved throughout the entire system development cycle.

To ensure that the system requirements fully represented the user needs, a holistic systems engineering effort was executed. This effort had leads in both systems and HSI. The main activities of the project are represented in Fig. 1. The activities were primarily led by either a lead systems engineer or a lead HSI engineer and involved support across both teams.

APL started the holistic systems engineering process by collecting operational requirements from various sources, including the MGUE Capability Development Document, the Army Universal Task List, operational doctrine, and interview data. Interview data that captured operational needs were collected using a semi-structured process in which a broad range of military users were interviewed at several military installations. The operational requirements and interview data were used to develop user profiles and scenarios. These were then analyzed to define operational activities and system functions, as well as to support the development of user interface prototypes. Additionally, the interview data were analyzed and translated into formal user requirements. Finally, to elicit feedback on the design concept, a design concept walk-through of the prototypes was conducted with an additional set of users.

USER REQUIREMENT INTERVIEWS

User interviews were conducted to understand the current operational tasks, procedures, and environment related to GPS devices. The pervasiveness of handheld GPS devices in the military required the interviews to cover a large base of users. Discussions with subject-matter experts at APL generated an initial list of potential user communities. All military branches were considered, but the Army was found to be the largest user of handheld GPS devices. The initial plan was to interview five people in each of the following areas of the Army:

- Maneuver
    - Infantry
    - Aviation
    - Armor
- Maneuver support
    - Engineer
    - Military police
    - Chemical
- Effects
    - Information operations
    - Air defense artillery
- Fires
    - Field artillery
- Special Operations Forces (SOF)
    - Special Forces
    - Psychological operations/military information support operations
    - Civil affairs
- Operations
- Signal
    - Signal
    - Telecom systems engineer
- Military intelligence
- Foreign area officer
- Functional area branch
- Space operations
- Force sustainment
- Logistics
    - Transportation
    - Ordnance
    - Quartermaster
    - Logistician
- Medical services

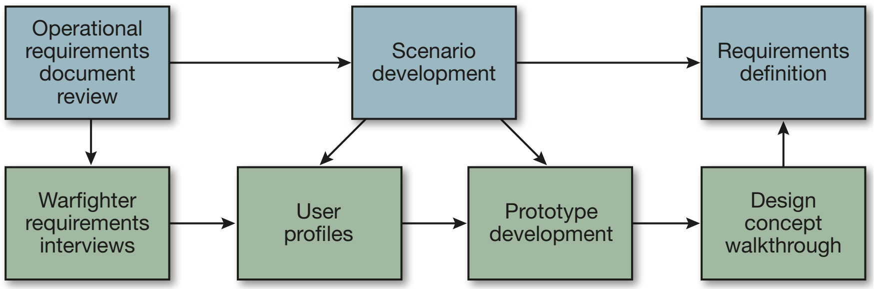

Figure 1. Identification of major tasks, showing how the systems engineering and HSI teams worked together to develop requirements. Blue tasks were led by the systems engineering team, and green tasks were led by the HSI team.

The interview structure was based on cognitive task analysis, existing doctrine, and training material.[5] This structure established the question areas and ensured that those functions and tasks anticipated to involve GPS were adequately investigated. The questions fell into five major areas:

1. Operational roles: covered questions concerning the user's responsibilities and history with GPS devices
2. Goals and tasks: focused on operational tasks that required the use of a GPS device
3. Information requirements: studied the information necessary to plan and make decisions about navigation and location tasks; questions were asked to determine the type of information used, how it was retrieved, and what the user did with the information
4. Decisions: looked at what key decisions the user made and what triggered the decisions; the goal was to understand any rules in the decisions and to explore potential decision aids
5. Commercial devices and smartphone applications (apps): determined whether interviewees used commercial devices and smartphone apps for military purposes

Interviews generally lasted 90 min and were typically with small groups consisting of two to five warfighters.

In the end, 99 warfighters were interviewed throughout the continental United States and across a range of operational communities. Table 1 describes the breakdown of the users interviewed. All attempts were made to obtain a fair representation of the user community, but some areas have users with more flexible schedules than other areas and were subsequently represented with a larger number of interviews. However, after the accumulation of numerous interviews, no new additional information was gained. Thus, the research team determined that most user communities had been interviewed and the majority of new insights had probably been collected.

USER REQUIREMENTS DEVELOPMENT

After completion of each interview session, the HSI team analyzed all the comments to provide information

Table 1. Description of users interviewed to define requirements

User	No. interviewed	Tasks
Maneuver		Neutralize the enemy and threats
• Infantry	17	
• Armor	6	
Maneuver support		Survey and breach obstacles
• Engineer	1	
Fires		
• Air defense artillery	1	Defend ground from air threats
• Field artillery	2	Place guns
SOF (U.S. Air Force)	2	Neutralize the enemy and threats
Special Forces (U.S. Army)	3	Influence the enemy and population by using nonlethal means
Military intelligence	3	Provide intelligence to commanders
Operations support		Provide communications support
• Telecom engineer	7	
• Space operations	6	
Logistics	11	
• Transportations	24	Drive vehicles
• Ordnance	1	Weapon supply and maintenance support
• Quartermaster	1	General supply support and delivery
• Logistician	11	Oversee maintenance and supplies
• Maintenance	2	Repair telecom equipment
Medical services	1	Provide medical services

Ninety-nine warfighters having a variety of backgrounds and experiences were interviewed.

for developing requirements and designing a prototype. Of those interviewed, many had used the DAGR in the field, including in Iraq and Afghanistan. Some of the participants used the DAGR in vehicles, whereas others used it dismounted. Many complained that the DAGR was too bulky and difficult to use and said that they preferred commercial devices because they were light and intuitive. Most users were not aware of all the capabilities of DAGR. DAGR is often used in vehicles to provide position information to the Blue Force Tracker (BFT), which is a computer/GPS-based system that provides individual soldiers and commanders with friendly military location information. The drivers who used the DAGR in their vehicles to connect to the BFT often left the DAGR in the vehicle because it was too difficult to reconnect to BFT after disconnecting the device and taking it outside the vehicle, and the specialized cables required to reconnect would often break when manipulated.

Warfighters desired that a number of capabilities and features be included in a robust GPS system. Themes extracted include two-way communications, situational awareness data, and better routing features. Many warfighters mentioned the desire for a device with two-way communication both for voice and data. The warfighters expressed a desire to text and receive route and hostile force information. The ability to send and annotate images was often mentioned. They want situational awareness relative to a specific location and its surroundings, not just abstract map coordinates. Location is most important in relation to other items of interest (i.e., improvised explosive devices, avoidance areas, etc.). Additionally, warfighters want seamless integration with a BFT that allows them to view BFT information on maps on their handheld devices. They expressed a need for route tracking so routes traversed could be repeated at a future point in time and so that they could use route information during mission debriefs.

Ultimately, the majority of warfighters said ease of use was the most important requirement for the new device. They do not have additional time to learn a new device, and if they get frustrated with the device too many times, the device becomes ignored, especially when they can easily use a commercial device instead. The new device must be able to compete with the commercial GPS world and perform multiple functions like the current smartphones.

Interview Analysis

Comments were categorized as either related to specific requirements of a handheld GPS device or a general comment unrelated to the specific requirements. Each statement was also assigned a general topic. Topic areas were developed from the bottom up, with new areas added as needed after each interview session. With this organization, similar comments from multiple users could be grouped together. Table 2 gives a description of each high-level topic in requirements-related statements and Table 3 gives a description of each high-level topic in general comments.

Each requirement-related statement and general comment was imported into Vitech's CORE tool. CORE is a model-based systems engineering tool that supports requirements management, multiple modeling notations, integrated simulation, architecture analysis, verification and validation, as well as documentation generation. This process helped the systems

Table 2. Definitions of each topic area for the requirement-related statements

Topic Area	Description
Communications	Ways in which warfighters would like to communicate, such as texting, sending pictures, e-mail, and emergency calls
Environmental considerations	Requirements for the operating environment, including changes in pressure and underwater operations
External interfaces	Systems warfighters would like the GPS to connect to or be compatible with, such as FalconView; also requirements related to how devices should connect
Form factor	How the device should be mounted, carried, and powered; descriptions of the device's size
Information collection	Data the warfighter would like to collect, such as images and voice recordings; ways to annotate data
Navigation	Features necessary for basic navigation such as turn-by-turn directions, route updates, and quick satellite acquisition
Situational awareness	Information about locations of nearby units and convoys, detailed ground-level images, satellite images, distances to targets, and landmarks
Security	Need to be able to quickly clear data and transmit data securely
Training	Requirements concerning embedded training and reducing training time
User interface	User interface should have a color display, and be simple, user friendly, and customizable

Table 3. Definition of each topic area for the general comments statements

Topic Area	Description
BFT	Descriptions of the current BFT, how they use it, and any issues
Current issues	Issues with the current military GPS devices such as the DAGR and precision lightweight GPS
Environment	Discussions about using GPS indoors and in open terrain
Equipment and data	Current uses of navigation data and tools such as FalconView and commercial GPS devices
Experience	Descriptions of the warfighters' roles and experiences with GPS
Maintenance	Requirements to reduce repair time
Missions and tasks	Descriptions of GPS-related tasks and missions, descriptions of how warfighters communicate, and descriptions of planning tasks
Smartphone apps	Ideas about current apps or new apps that could be useful to the military in a navigation context

engineering team organize the systems by linking together items such as operational activities, functions, and requirements. The tool was also used to build diagrams to visualize the links and aid in developing requirements.

In order to prioritize the requirements-related statements and determine which ones were applicable to the scope of the project, statements were rated as critical, important, useful, marginal, or special-purpose. Critical requirements were ones that, if not incorporated, would render the system unusable or unacceptable. Important requirements were those that would result in less effective performance of user functions if not incorporated. Useful requirements were ones that would enhance performance if incorporated but were not required for function performance, and marginal requirements would not affect performance of user functions. Finally, special-purpose requirements were ones that might be used only by a small population of the user community but would be critical to that community.

Figure 2 depicts the development of device requirements. Organized user interview data, operational doctrine, the Army Universal Task List, and the MGUE Capability Development Document requirements were used to develop user scenarios, operational activities, and top-level system functions. This analysis fed into the definition of the lower-level functional and mock-up requirements.

PROTOTYPE DEVELOPMENT

In this project, requirements development was aided by demonstrations of conceptual prototypes to representative end users. This allowed the end users to interact with system concepts and design criteria in a realistic

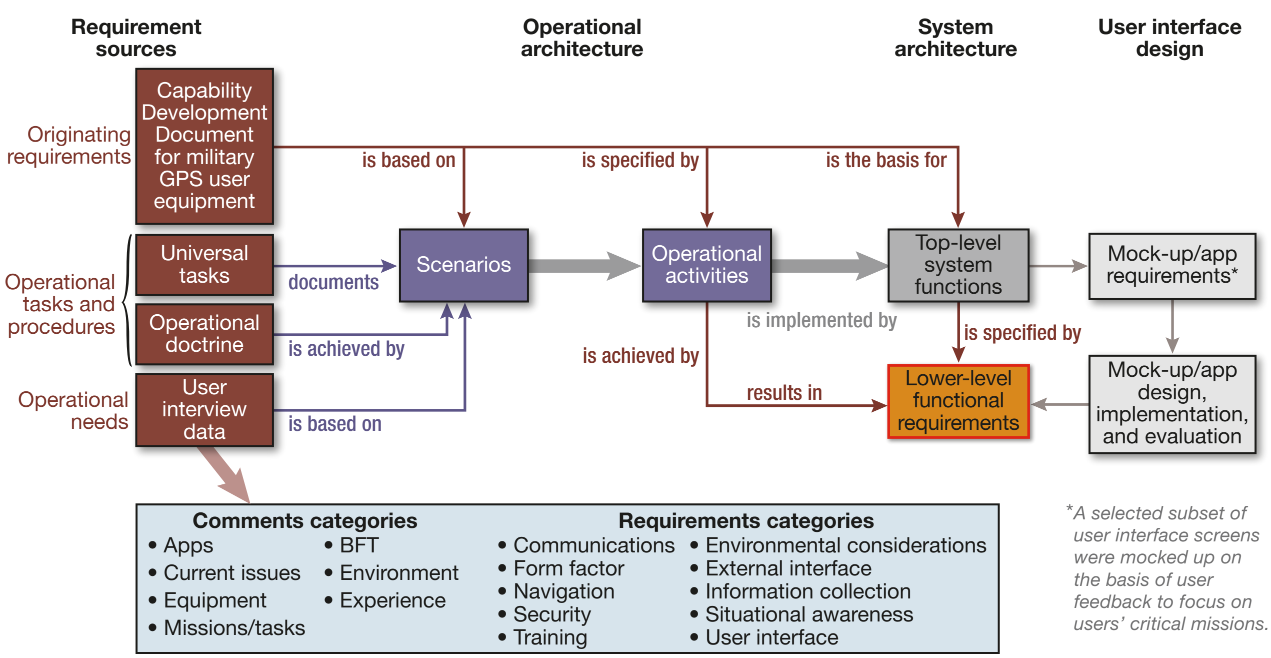

Figure 2. Development of the requirements, including the work by both the systems engineering team and the HSI team. High-level requirements and user data helped develop scenarios, operational activities, and top-level functions, which then helped define lower-level requirements.

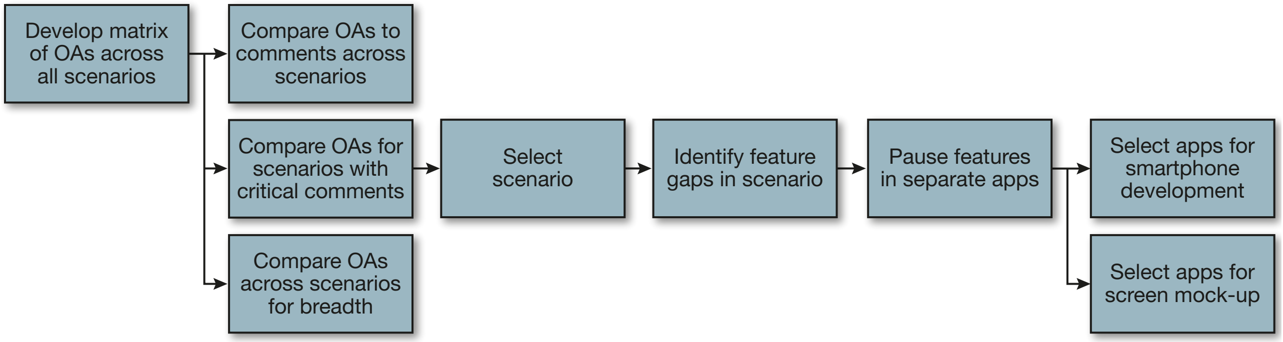

Figure 3. The process of selecting a scenario to drive prototype development. OA, operational activities.

manner early in the acquisition process. Feedback was obtained to help validate capability requirements and get preliminary usability data in the form of subjective comments. The first step in developing requirements for the prototype was to ensure that the intended users were identified and defined. User profiles were developed in order to better understand and organize the user community. Based on internal subject-matter experts' knowledge and analysis of data collected in interviews, user profiles were written for the users of handheld GPS devices. These users included infantry soldiers, technical engineers, combat engineers, field artillery soldiers, indirect fire infantrymen, and communication, engineer, and weapons sergeants of the Army Special Forces. Each user was studied for major PNT duties, training, and any advanced duties.

In addition to the user profiles, the systems engineering and HSI teams developed 25 operational scenarios. These scenarios assisted the systems engineering team in developing requirements and the HSI team in focusing the prototype. Because of timing and funding constraints, the HSI team decided to focus on one scenario in order to showcase a subset of features of the GPS device. The HSI team analyzed each scenario for the number of operational activities it contained so that the prototype would be developed based on a scenario that addressed the broadest set of operational activities and GPS features possible. The selection process is shown in Fig. 3.

The "Collection of Geo-Intelligence Data by SOF" scenario was selected by the HSI team to be the design reference scenario because it covered most of the functions that warfighters would need the MGUE handheld device to support. The scenario involved covert operations to collect geo-based intelligence information in support of a larger mission. During the scenario, the GPS devices are jammed, and the SOF team must navigate without GPS information. Additionally, the scenario required off-road route planning with integrated situational awareness information, which is currently available in commercial applications and highly desired by the warfighters. The scenario's operational activities were analyzed to determine the major user tasks that involved the GPS device, and these tasks were grouped into high-level functions to facilitate design of the prototype and user interaction with the prototype. Figure 4 depicts the flow of the major user tasks in the scenario.

Because of the flexibility of smartphone devices and the Army's high interest in using smartphones,[6] smartphone apps were determined to be the best way to prototype the features. The identification of the scenario's major tasks (described above) helped determine which smartphone apps should be built. Tasks and apps were

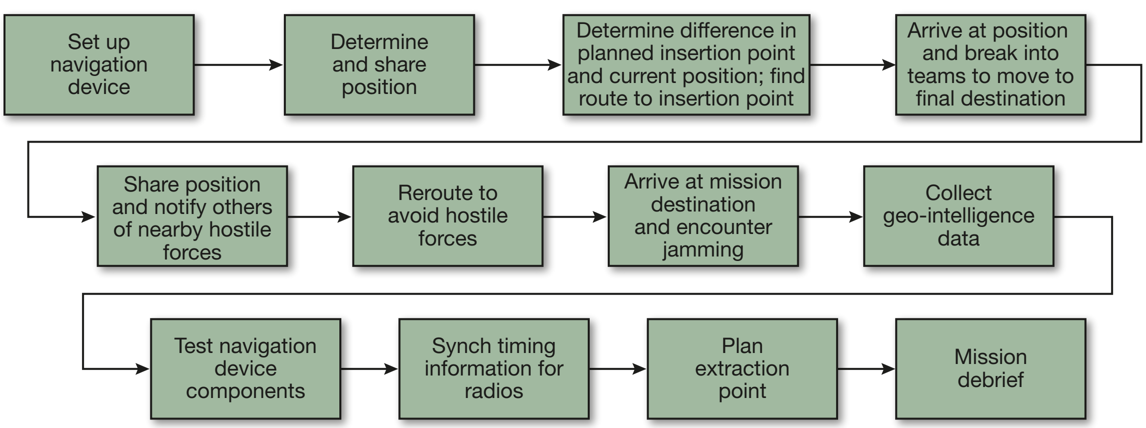

Figure 4. The 12 major tasks in the Collection of Geo-Intelligence Data by SOF scenario.

not mapped one to one, but instead tasks were grouped into apps that would work best with the user's mental model of smartphone devices. Eight apps were identified:

1. Navigation: plan routes and mark obstructions
2. Messaging: send messages about collected data, routes, images, improvised explosive device alerts, and other necessary information
3. Data collection: mark points of interest and hostile areas, annotate images and video, use measurement tools with images
4. Settings: select GPS precision mode and communications mode
5. Data loading: load mission data such as plans from FalconView or other mission-specific maps to be stored and viewed
6. SOF radio: use the smartphone as a radio
7. Compass: follow a particular route or heading
8. Counter jamming: detect jamming and geo-location of the jammer

Navigation App

The navigation app applied to a wide variety of users and best correlated to the objectives of the MGUE handheld project. As such, the navigation app was chosen to be fully developed for both an iPhone and a Samsung phone with the Droid operating system. Because of timing and funding constraints, all other apps were developed as a user interface prototype, as described in the next section.

One of the issues with the current commercial devices is that they do not work well in areas without roads. However, the military is very interested in being able to plan off-road routes, especially on the fly. APL chose to implement an app that provides the warfighter with the ability to perform off-road route planning using the commercial off-road planning service provided by Primordial. Primordial has developed Ground Guidance, which provides both a web service and a software development kit to support off-road planning.[7] The planner can input avoidance areas, select the mode of transportation, specify maximum slope, and select route priority such as fastest, shortest, or most concealed. The APL-created navigation app used the Ground Guidance as a web service, but in the future the app would use the software development kit so that warfighters could plan offline.

One of the other major desires mentioned in the user interviews was BFT. Warfighters need situational awareness to know who and what is around them so that they can then respond appropriately when situations deviate from the plan. BFT was implemented in the navigation app as a web service. Each mobile device continually sends its position to the server, and that server pushes position updates of all registered devices to all other registered devices. Figure 5 is a screenshot from the Samsung phone that shows the user measuring the distance to the nearest friendly unit being tracked.

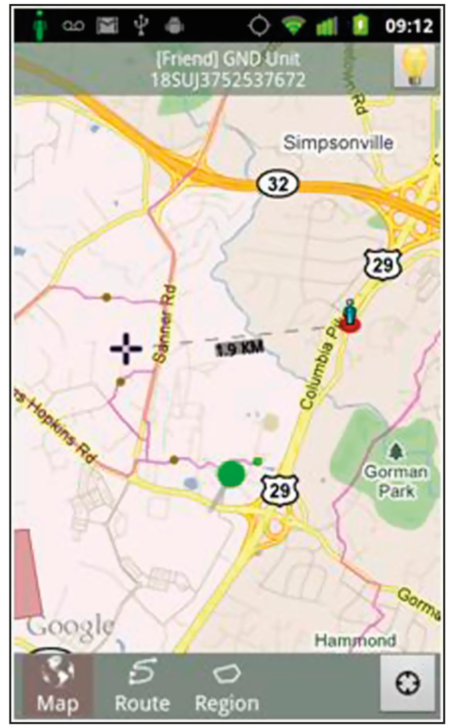

Figure 5. A screenshot from the Samsung phone that shows the user measuring the distance to the nearest friendly unit.

The other major feature of the navigation app was the ability to geo-tag pictures and view all pictures around a certain waypoint. In a future version, any device could send images to the central server, and then all other devices could view the images.

Interactive Mock-up

Because of funding and timing constraints, the other mobile apps were assimilated into a user interface mock-up prototype. One of the challenges of building the prototype was selecting the most appropriate prototyping tool. The HSI team conducted a trade study with 15 tools and rated them in the criteria determined most applicable to the MGUE project (Table 4).

None of the tools met all of the criteria, but Microsoft's Expression Blend and SketchFlow tool met almost all of the criteria. Additionally, it fully met the most important criterion of building fully interactive designs. Many tools have clickable prototypes only such that the user is able to click buttons to advance through prototype screens. However, the Expression Blend and SketchFlow tool allows extensive animation, which makes the working prototype feel very real to user.

The messaging, data collection, settings, data loading, SOF radio, compass, and counter-jamming apps were all prototyped using the Expression Blend and SketchFlow tool. The bulk of the prototyping effort

Table 4. Trade study matrix of user interface prototyping tools and criteria for selection

	Design							Review									
Mock-Up Toolsets	**Ability to draw on prototype**	**Custom component**	**Initial component library**	**Learning curve**	**Reusable component**	**Task workflow generation**	**Collaboration**	**Designer annotations**	**Interactive mock-ups**	**User feedback annotations**	**User testing statistics**	**Distributed review**	**Extensibility**	**Code generation**	**Documentation generation**	**Import code**	**Price ($)**
Adobe Flash Catalyst	X	X	X	3	X				X			X		MXML			399
Axure RP by Axure Software Solutions		X	X	2	X	X	X (maintains history)	X	X			X			X		589
Balsamiq Mockups by Balsamiq Studios	Limited		X	1	X					With confluence		X					79
Eclipse by the Eclipse Foundation		X	X	3	X				X		X	X		Java	X	X	Free
ForeUI by EaSynth Solution Inc.		X	X	2	X			?	X			X					99
Harmonia LiquidApps			X	2	X	X	X		X	Future	Future	X		Java, C++	X†	Maybe	400/year‡
iRise Studio	?	X	X	2	X	Yes*	?	?	X	X		X			?		
Justinmind Prototyper		X	X	2	X	X		X	X			X			X		495‡
Microsoft Expression Blend with SketchFlow	X	X	X	3	X	X		X	X	X	X	X		C++, XML	X	X	599
Microsoft PowerPoint	X			1				X	X	X							149
Microsoft Visio	X		X	2				X		X		X					559
Microsoft Visual Studio		X	X	3	X				X		X	X		X		X	Free for Express/ 549 for Pro
Pencil by Evolvus		X	X	1	X							X					Free
Pidoco	X	X	X	2	X		X	?	?	X		X			X		29/month‡
ProtoShare by Site9, Inc.	?	X	?	2	X		?	?	X	?		X			?		49/month‡

*No linking, but can link to requirements.
†Requirements (only in enterprise edition).
‡May not include all features.

was for the data collection app, which demonstrated tools to estimate distance, size, and angle in an image, to annotate videos, and to enter data about hostile forces. Figure 6 shows an image of the angle-measuring tool (left) and an image of data about a particular point of interest (right).

User Feedback

Members of the HSI team led the design concept walk-through. A total of six U.S. Army SOF instructors and one 112th Signal Battalion Science and Technology Officer served as participants. The participants covered the areas of Army SOF intelligence, engineers, and shooters. During the walk-through, the facilitator stepped through major functions in the scenario and the users were instructed to interact with the mock-up and smartphone prototype apps. At the conclusion of each of the 12 tasks (Fig. 4), the facilitator of the mock-up asked the participants a series of probe questions. The following is a sample of the probe questions:

Figure 6. Screens from the data collection app, which were included in a mock-up built using Microsoft's Expression Blend and SketchFlow tool. The angle-measuring tool (left) estimates the slope of an object in an image. Data about a particular point of interest, including geo-tagged images, are shown on the right.

- Was there information you needed to do this task that was not provided to you? If so, where would you expect to find this information?
- Is there any information that you ignored? If so, why?
- What mode are you currently in? Is it easy to determine the current mode?
- Were the actions you were asked to perform realistic, and what you would normally do?
- What are your thoughts on the ease of using this app?
- Does performing this task in this way fit in with your standard operating procedure and how you would expect to perform this task? If not, what is different?

Overall, the feedback was extremely positive. The warfighters were excited by several features of the apps:

- Single device capable of performing multiple functions
- Tracking and display of nearby forces
- Ease of use
- Tools to measure objects and angles in pictures
- Display of nearby pictures around waypoints
- Ability to merge collected data with data of others

They also discussed some additional features. The following are some of the features that were discussed in the initial requirements interviews as well as during the design concept walk-throughs but were not feasible within the scope of this project:

- Voice recognition
- Voice recording
- Master GPS device to control other GPS devices

Changes that were more feasible included the following:

- Ability to switch between angular mils and degrees on a compass
- Transparent overlay of a compass on a map
- Feedback of processing status

The comments were analyzed to determine whether they were statements about modifications that would be feasible for the remainder of the project. Some changes were incorporated into the iPhone, Samsung, and mock-up prototypes.

SUMMARY

HSI is critical to the success and acceptance of technological improvements. Warfighters tend to prefer using commercial GPS devices largely because of human-factors issues associated with the military device such as a confusing user interface, bulk, and fragility of components. New satellite M-code is being deployed for GPS, and new military receivers need to be developed to take advantage of the new capability. APL was tasked with defining requirements and prototyping aspects of the next-generation GPS handheld device.

From the beginning of the project, APL executed a holistic systems engineering approach that included human performance considerations. This included conducting user interviews to gather requirements, designing prototypes to embody requirements, and eliciting user feedback. The feedback was rolled into changes to the prototype.

Although the widespread effects of the systems engineering approach with HSI involvement cannot be seen completely at this stage of the project, HSI proved to be effective in defining requirements and developing prototypes that were well received by the user community as well as the GPS U.S. Air Force Space and Missile Command GPS Directorate. A verified draft of the functional requirements was successfully delivered to support acquisition of future M-code GPS receivers that are consistent with warfighter expectations.

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