Situation Awareness for Teams of Dismounted Warfighters and Unmanned Vehicles

Mark A. Livingston[a], Simon J. Julier[b], and Dennis G. Brown[a]

[a]Naval Research Laboratory, Washington, DC
[b]ITT Advanced Engineering and Sciences, Alexandria, VA

ABSTRACT

Changes in military operations in recent years underscore changes in the requirements of military units. One of the largest underlying changes is the transformation from large-scale battles to quick-reaction mobile forces. There is also pressure to reduce the number of warfighters at risk in operations. One resultant need of these two factors is the increased need for situation awareness (SA); another is the use of unmanned vehicles, which increases the difficulty for the dismounted warfighter to maintain SA.

An *augmented reality* (AR) system is a type of synthetic vision system that mixes computer-generated graphics (or annotations) with the real world. Annotations provide information aimed at establishing SA and aiding decision making. The AR system must decide what annotations to show and how to show them to ensure that the display is intuitive and unambiguous.

We analyze the problem domain of military operations in urban terrain. Our goal is to determine the utility a synthetic vision system like AR can provide to a dismounted warfighter. In particular, we study the types of information that a warfighter is likely to find useful when working with teams of other warfighters. The problem domain is challenging because teammates may be occluded by urban infrastructure and may include unmanned vehicles operating in the environment. We consider the tasks of dynamic planning and deconfliction, navigation, target identification, and identification of friend or foe. We discuss the issues involved in developing a synthetic vision system, the usability goals that will measure how successful a system will be, and the use cases driving our development of a prototype system.

Keywords: synthetic vision, augmented reality, situation awareness, dismounted warfighters, unmanned vehicles

1. INTRODUCTION

Changes in military operations in recent years underscore changes in the requirements of military units. One of the largest underlying changes is the transformation from large-scale battles to quick-reaction mobile forces. There is also pressure to reduce the number of warfighters at risk in operations. One resultant need of these two factors is the increased information requirements of each military unit – according to some, down to the level of individual warfighters.

The term *situation awareness* (SA)[1] embodies the idea that a warfighter knows what has happened, is happening, and is likely to happen within the environment that can affect him and his ability to achieve his objectives. Clearly, as the battlespace becomes more dynamic due to faster-moving, smaller military units (among both friendly and enemy forces), SA becomes harder to acquire and maintain.

Military operations are not planned to be performed by lone individuals. They encompass a coordinated set of actions by a number of warfighters, commanders, and support specialists. All of these actions complicate the battlespace and increase the possible number of outcomes and reactions to a single action or series of events sparked by a friendly or enemy course of action (COA). Knowing what is likely to happen becomes especially

Further author information: (Send correspondence to Mark A. Livingston)
Mark A. Livingston: E-mail: mark.livingston@nrl.navy.mil, Telephone: 202-767-0380
Simon J. Julier: E-mail: simon.julier@nrl.navy.mil, Telephone: 202-767-0275
Dennis G. Brown: E-mail: dennis.g.brown@nrl.navy.mil, Telephone: 202-404-7334

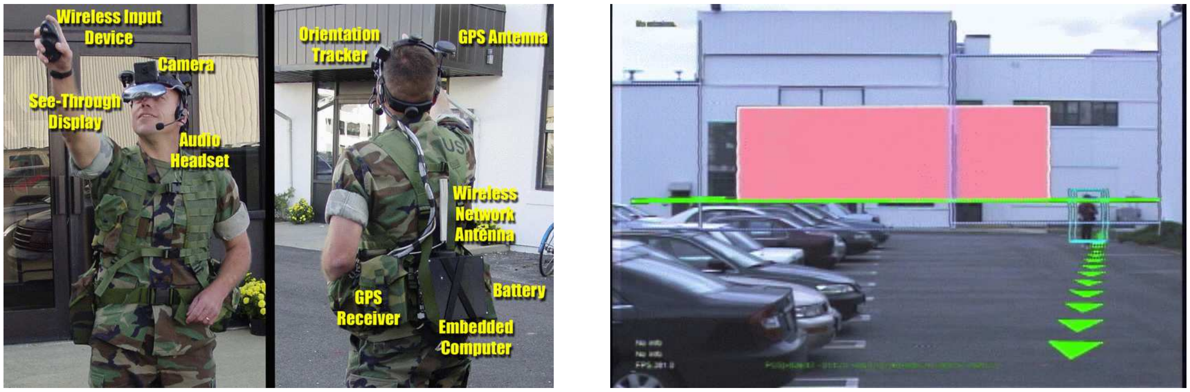

Figure 1. At left is a recent implementation of the BARS wearable prototype. At right is an image captured from a video-based implementation of the system. In this image, a remote user is both visible and highlighted by the blue box at right for illustrative purposes. The image also includes the remote user's path and an occluded building (center). GPS coordinates and compass data appear at the bottom.

difficult in urban operations, where line of sight contact with even friendly forces is unlikely to be maintained for long periods of time.

An *augmented reality* (AR) system mixes computer-generated graphics (or annotations) with the real world. The annotations can provide information aimed at establishing SA and other information to assist combat decision-making. The design of the user interface of a mobile AR system presents a unique set of technical challenges. An AR system must be capable of automatically deciding what annotations need to be shown. Furthermore, the characteristics of those annotations (such as appearance, size, and drawing style) should be chosen to ensure that the display is intuitive and unambiguous.

Providing such a display is the goal of the Naval Research Laboratory project entitled "Visualization and Interaction for Wearable Head-up Displays" (VIeWHUD). This project extends the results from the Battlefield Augmented Reality System (BARS),[2] which developed methods to provide information for a single dismounted warfighter and network the mobile system with a command center and other users (Figure 1). The BARS user interface includes a sophisticated but disjoint set of functions that assist the warfighter in understanding the surrounding environment, including an information filter to annotate the most important or nearby objects, a set of representations of occluded objects, alerts to information passed from networked users, and multi-modal input techniques. To transform the system from a single-user SA tool to a shared team SA tool requires extending the user interface functions to incorporate roles within collaborating teams and information about how an individual warfighter's actions might affect the rest of the team.

The first step in this transformation process is a domain analysis, detailed in Section 2. The output of the domain analysis leads to a list of design principles (Section 3). Section 4 presents a set of use cases that will inform the system development.

2. DOMAIN ANALYSIS

Domain analysis consists of four main steps: establishing user profiles, performing a contextual task analysis, setting usability goals (both qualitative and quantitative), and listing the platform capabilities and constraints. The analysis is in one sense simply asking the question that AR designers and developers have asked for quite some time now, namely "What is AR good at helping users accomplish?" While this question is obviously necessary, the formalism of the domain analysis process can help place it in the proper context.

2.1. User Profiles

The basic idea of creating user profiles is to identify the types of people who might use the system. Characteristics such as knowledge and experience, specific skills, distractions or other challenges, structure and frequency of their tasks, and even physical characteristics (e.g. color blindness) are identified. This stage is difficult for an

AR system, because it is somewhat radical compared to current tools available. But the tasks of dismounted warfighters are highly structured, so we can tap into this knowledge to understand roles. This point is crucial for success, because one of our goals is to enable customization of the AR system to specific tasks. There is a limit to customization, however. The amount of training each user receives will be significant. The warfighter is expected to conform to the equipment much more so than an office worker.

BARS chose to focus on Marine Corps tasks. Most Marine officers and all Marines sent into battle are male. This leads to a concern in designing the user interface about the potential impact of color blindness. However, there are standard military color schemes in use; these should be adopted as much as possible. Those who did not grow up with computers as part of their daily lives are likely to be less familiar and comfortable with computers and non-traditional computer interfaces. Also, all the military users are likely to be using the proposed system in environments of extraordinary stress. Simplicity is thus an important goal for all aspects of the user interface. It will promote ease of learning, user acceptance, and ease of use when it matters.

We can draw from other application areas to learn some important lessons about how users will arrive at their SA. A study of pilots and air traffic controllers found that individual differences can make a huge impact on how different people use the same information.[3] One person may be more willing to take risks, leading him to assess a situation differently than someone who prefers a more conservative approach. People who share the same physical space but have different responsibilities will have different goals and thus may place different values on different pieces of data. A study focused on aviation take-off and landing surprisingly found that experience of the pilots did not have a statistically significant effect on their decisions, although overall, the consistency of decisions was rather low. This finding suggests that training has a strong effect, but goals and personal preferences can play large roles. The study further studied the effect of three types of conflicts. Conflicting plans were easily resolved. Conflicting information was resolved about 78% of the time. However, conflicting evaluations of the situation were very difficult to resolve (26% of the time). This type of conflict forces people to rethink their professional judgment, which proved difficult. A final observation was that having completely shared knowledge was not essential; in fact, alternate perspectives may be beneficial.

The following user profiles were suggested through discussions with officers at Marine Corps Systems Command (MARCORSYSCOM) and Training and Education Command (TECOM) and through readings of Marine Corps Doctrinal Publications.

2.1.1. Command and Control

Command and control (C2) organizes a military operation. Commanders are responsible for analyzing information, making decisions, allocating resources, planning COAs, communicating instructions and information, coordinating activities, supervising execution, and monitoring the results. During the operation, they will respond to requests to deviate from the operational plan, according to observations reported from the battlefield.

These activities in fact take place at every level in the hierarchy; however, we will reserve this term in our domain analysis for commanders who are not in the field with their units. This is a somewhat arbitrary distinction from a military point of view, but from the perspective of the technology developer, it is significant. C2 units by this definition are not mobile, which is a crucial platform constraint to be handled later.

Commanders at this level will be experienced leaders and military analysts. Most will have significant field experience as unit commanders before rising to this higher level in the command structure. As these commanders will tend to be older, this implies (for the short term) that they are less likely to be familiar with computers and interfaces. C2 commanders will be able to use their hands, but voice commands may also be favored. C2 personnel will have a significantly broader array of information available to them than the team leaders in the field with whom they are communicating.

2.1.2. Unit Commanders

The units we consider range from fire teams (generally four Marines) through companies (over 100). They will implement the decisions of C2 commanders (as defined above) or unit commanders higher in the command structure; their job is thus much the same as the C2 officers, just on a smaller scale. They will also report back on the results of their efforts to a higher-level commander, who will either make a decision as to what to do or relay the information up the chain of command and await a decision from a superior officer.

The further down the chain, the fewer people there are under the commander and the less experience that commander may have. These commanders are likely to have more experience with computers, especially "first-person shooter" games that are sometimes used to teach military strategy and techniques. They will be mobile; however, these users will be in the battle and thus carrying a weapon. They will have been trained to use a protocol of voice and gesture commands to communicate with their team members. Thus voice and gesture interaction techniques are likely to be favored over traditional desktop interfaces. Tablet-based interfaces are in use and may be a good compromise.

2.1.3. Pilots and Drivers

Pilots require that their attention be on the environment in front of them, which led to the development of HUDs that project information normally found on the dashboard onto the windshield. Pilots generally have a wide view of the environment, which may make details difficult to see. They are often engaged in the battle by providing support for ground operations, by definition a collaborative effort with friendly forces that they may not be able to see. Various aircraft (notably helicopters) are used to insert forces into the operational area and extract forces from the field. These special tasks that require close collaboration distinguish the roles of pilots.

Pilots are heavily trained in the operation of their aircraft before taking part in an operation in that capacity. However, pilots are still generally on the younger end of the age spectrum. They are selected for this type of duty because they exhibit skills that are considered valuable for a pilot, such as spatial reasoning and maintaining spatial orientation. Indeed, the early psychological tests on these skills were developed for the military for evaluating the suitability of candidates for pilot training. It should be noted that pilots obviously have their hands occupied by their primary task; what percentage of the time they might have a free hand is a question that should be resolved.

Vehicle drivers perform many tasks similar to pilots, such as insertion or extraction of forces. Driving is a skill that most people in the United States learn at a relatively early age, but HUDs are rarely offered on consumer vehicles. (That may be in the process of changing, however.) Their ground-borne points of view, however, make their information requirements rather different from pilots' requirements. Drivers do not often have the luxury of a wide field of view in urban situations, although one could argue that this would be a considerable advantage if an AR system were able to provide such a view. Drivers are not likely to be quite as heavily trained as pilots and will likely be younger and less experienced. Drivers have their hands occupied for their primary task but frequently have a hand free for other tasks.

2.1.4. Medical Personnel

Medical personnel often need to respond by coming to the assistance of a wounded warfighter. They may need to know how to safely navigate to an arbitrary location in the AO. They may also want to have physiological status monitoring capabilities such as those envisioned in the Land Warrior program.[4] These capabilities would enable them to have advance knowledge of the warfighter's health before arriving at the scene, telling them what particular equipment they may need. Medical personnel have a very specific task, and aside from this, their only concern is for their own safety. That concern implies that they must stay out of the way of units who are engaged in the operation, so the coordination with active units is an important part of their role, despite not likely being in active communication with most units. Other units, it follows, must be aware of the routes that medical personnel are taking, so that they can avoid conflict or provide protection, as appropriate.

2.1.5. Unmanned Vehicles and Vehicle Operators

While unmanned vehicles are currently not sufficiently autonomous for them to perform tasks without direct operator control for more than a few moments or on a single task, researchers expect to increase their capabilities to enable them to handle more complex tasks. Thus we should include in our user profiles not only operators of autonomous vehicles, but also the envisioned autonomous vehicles. Currently, most unmanned vehicles require one or more human operators per vehicle. In the future, researchers expect one operator to command large numbers of vehicles.

Currently, unmanned vehicles can navigate a programmed path accurately so long as no significant obstacles intervene. Obstacles may be impassable, avoidable, or temporary. For example, some terrain may be impassable for the vehicle in the best of circumstances — for example, deep water for a wheeled vehicle. Other obstacles, such as a mound of debris, might block the planned path, but would allow the vehicle to navigate around. A temporary obstacle might be consist of a manned vehicle (friendly, neutral, or even enemy) that takes no notice of the unmanned system. The first type of obstacle requires operator intervention. The last two require a modest amount of sophistication in the control program of the robot (and perhaps a map of the environment). With sufficient data and control programs, these obstacles can be handled without direct operator control. This problem also serves well to illustrate the capability levels of current robotic systems. Some older systems would be confounded by all three, but new prototypes should (soon) handle the last two levels.

Future systems are envisioned to handle higher-level tasks. Take, for example, the task of clearing a building. A robot with sufficient navigation capabilities (perhaps to include the ability to climb stairs) could methodically build a map of the building and check for the existence of enemy forces or non-combatants within. Of course, the robot may be disabled, should it find an enemy position. This level of mechanical and control sophistication is envisioned within such a modest time frame that it merits our consideration of the potential of such systems.

Unmanned systems carry an array of sensors, notably imaging devices (visible light, infrared, or thermal). They may carry chemical and biological sensors to provide early warning of airborne agents. Receiving this data is critical to benefiting from the use of unmanned systems. Thus we must also think about the bandwidth and connectivity available, which are currently quite low. Imaging devices provide data that is often of low resolution or low quality (for a variety of reasons), which limits their utility. This data generally comes with some degree of certainty that is less than 100%. Knowing the likelihood of the data to be accurate (due to difficulty in obtaining accuracy at the source and/or time passed since the collection of the data) can be of great import when making decisions using that data. Finally, the team must be able to interpret data quickly in order to make the best use of it in a dynamic environment, which in turn requires useful and usable interfaces to the data. Some data may be interpreted by the vehicle operator without the need for informing commanders, whereas other data will be relayed on to commanders to integrate it into the team SA. UAVs operators benefit from having a wider field-of-view than the camera that shows the view from the UAV cockpit.[5]

One study of the use of hand-held tablets[6] found that a number of radio messages concerned the status of unmanned vehicles (UAVs in the test). Being able to have a status monitor would help reduce radio traffic while still keeping the information available – immediately – to anyone who needed to know. Status information should include not only whether the vehicle were functional, but its location and route as well. There were a number of problems with video from a UAV not being useful (e.g. blurry) that required the field commander to interact with the UAV operator repeatedly to achieve the desired result of getting surveillance on a target. Thus, the image quality could be analyzed on a basic level and this information included in the status as well.

2.2. Contextual Task Analysis

The goals in contextual task analysis are for the system designers to understand the mental model that the warfighters have, the language they use, and the behavior they exhibit – consciously or subconsciously – while they perform their tasks. This analysis will lead to a set of scenarios describing tasks for which we will extend BARS to help them. The following tasks and characteristics were analyzed in discussions with officers at MARCORSYSCOM and by observing training for military operations in urban terrain (MOUT), the general use case anticipated for BARS.

Strict command protocol within the military dictates that information and decisions are disseminated down the chain of command and reports are sent back up the chain for changes needed. A unit leader may have parameters within which he can make adjustments without consulting higher officers, but these are strictly defined as part of the operational plan that defines each unit's responsibilities.

One study conducted a domain analysis[7] and made the following the observations relevant to the intended use of AR for establishing SA.

- There are no mature models for communications in the urban environment.
- There are also no models that coherently integrate the effects of terrain, weather, oceans, space, etc. for joint urban operations.
- Units need to be able to communicate within the unit and with adjacent units.

- Tracking of individual friendly forces within urban clutter, including inside buildings, was judged to be an important feature.
- User customization of the common operating picture (COP) helps.
- Ideally, the process of retrieving information would be automated so that people get the information they need according to their priorities and roles.
- Small units need to feed corrections and changes to the map and database.
- There is a need for 3D information within buildings and underground.
- Information should be stamped with the time of its collection.
- The display must help a user find objects of interest in a cluttered view, according to mission requirements.

The analysis identified further research needs that are relevant to AR as well, such as the formation of effective dynamic networks of people, how cultural differences affect planning and decision-making, creation of the COP for personnel with widely different roles and goals and dynamically updating the plans, and seeing personnel in "urban canyons."

With the user profiles from the previous section and the principles above in mind, we analyze some common tasks and consider the contributions an AR system for SA can make.

2.2.1. Dynamic Planning and Deconfliction

Friendly units should not have routes or lines of fire that intersect with those of other units unless there is a specific plan to do so. In urban battles, where the routes available can change dramatically and quickly (e.g. roads blocked by damaged buildings or vehicles), this becomes very difficult, in addition to being extremely important, in any situation.

The initial plan made by a C2-level strategist avoids conflicts between units. However, all units must adapt their actions to the reality on the ground. No plan can perfectly foresee all enemy responses and necessary countermeasures. Thus some or all units will need to change their respective COAs; these changes must avoid putting units in conflict with each other. Plans frequently come with alternatives to which a mission might switch based on what happens on the ground; these overlays need to be available in order to choose the best option. For example, fields of fire from other units are important to a unit that may need to change its direction to a route outside the parameters of the initial plan.

An extremely important issue is the length of routes. In one study,[6] routes and directions communicated during an operation were generally quite short (a few hundred yards). Close contact was encouraged among dispersed teams, and the commander had a hand-held tablet that was updated with live map locations of teams. When teams must refrain from communications, the duration and (potentially) distance of routes grows, complicating the deconfliction task.

2.2.2. Navigation

Navigation is a basic task for military units. However, the trend in military planning has been to move away from precise route following, which implies a strict hierarchical control of troop movements, to allowing individual units to determine the best route to get to a desired destination. However, this task still requires that the units be able to maintain their orientation to the environment, and as noted above, avoid conflicts with the routes of other units. These two requirements are more difficult to fulfill in urban terrain than in open terrain. Also, routes can be more complicated and dynamic in their availability.

Control measures are a feature of operational plans that coordinate movements between units. One example relevant to navigation is a phase line, an imaginary line across which all units move simultaneously. In MOUT, in can be especially difficult to know whether a set of movements is staying in proper synchronization. Seeing phase lines and relevant unit locations, along with automatic cues that indicate whether a unit is ahead or behind the pace of others, could be a powerful tool in precise operations.

Another aspect of navigation is the ability for a rescue crew to get to a fallen warfighter. The system can report a location and potential routes to get there, taking into account known information about the availability of pieces of the route. Also, because urban environments can have buildings that are hard to distinguish, having an objective location measurement such as GPS automatically relayed to friendly forces and shown from their point of view is likely to reduce errors in position reporting.

2.2.3. Target Identification

Many targets are pre-planned for a particular mission. However, targets of opportunity are likely to arise during the course of a mission. Enemy positions may have changed since intelligence was gathered, requiring an adjustment in the targeting once the operation begins. This type of information is often known by forward observers, but must be effectively communicated to other units. If this communication is not efficient, the pace of the operation slows down, sacrificing the advantage that comes with swift advance.

Unambiguous cross-referencing of the environment from two locations that do not have line-of-sight contact and may not even see the same objects is a difficult task. Current maps are two-dimensional and do not show height information. But urban environments are full of three-dimensional targets, such as windows and doorways, that are hard to pinpoint on a map.

2.2.4. Identification of Forces

Identification of friend or foe (IFF) is an extremely important issue for military units. Knowing whether a person or vehicle that is approaching or that suddenly appears poses a threat or not is vital to reducing fratricide and casualties among non-combatants. Our current AR work supports identification of friendly forces with a simple icon. The effectiveness of this icon in various situations remains to be evaluated. It currently works for an individual or a vehicle; it should be extended to be indicate teams and convoys as well. This identification can then be combined with planning information as described above. Thus by looking through the AR system at a friendly convoy or dismounted unit in the distance, a warfighter can learn who they are and where they are going.

Related to identification of units in the battlespace is knowing the logistical and inventory information about units. How much supply do they have? Where is their resupply stored? When will they need their reserves? How can the reserves be brought to them safely and efficiently? Systems of RFID tags have been proposed for maintaining accurate inventories; perhaps BARS could be tied to such a system to provide alerts to low supplies and help plan resupply missions.

2.2.5. Surveillance

A common task performed by unmanned vehicles is surveillance. UAVs and UGVs are both used for such tasks. If the vehicles must avoid detection, UAVs may fly high at the cost of reducing the effective resolution; UGVs may have to be restricted from open areas. As noted, unmanned vehicles can follow planned routes with reasonable accuracy, but may need strategies such as hiding from potential enemies or navigating unforeseen obstacles. Thus, current UGVs must be monitored quite closely by an operator. UAVs operate with more autonomy and don't generally require close supervision to maintain a route. However, if changes are desired or needed in a route for any unmanned vehicle, the information must be communicated to the vehicle. Ideally, a ground-based commander could give such an instruction to a UAV as naturally as to another dismounted warfighter, such as by drawing on a map (and specifying an altitude for a UAV) or specifying actions taken at certain landmarks. These capabilities would be natural extensions of current hand-held communication devices, which enable ground-based units to share maps of the environment.

2.3. Usability Goals

The usability goals for a variety of users are discussed somewhat in the user profiles. We will first reiterate a few key points and discuss related characteristics of the task at hand. From these, we can list qualitative usability goals. These then get refined into specific quantitative usability goals.

The environment in which users shall operate the system is expected to be high stress, which argues for having a qualitative goal of a simple user interface in terms of both operation and ease of understanding the presentation. We have previously embarked upon a program of creating intuitive graphical representations for understanding relative depth among graphical and real objects,[2,8] as have other researchers.[9–11] Such intuitive representations are important towards reaching our goal of having a system that can be used in time-pressured, stressful environments.

It follows that the amount of information desired may change for certain tasks. When a high-priority task begins, such as a medic coming to the assistance of a wounded warfighter, general information such as a target's location is not relevant, whereas navigation cues such as unsafe areas (which may coincide with targets) remains important. For command and control personnel, details at the fire team level may serve only to clutter the display rather than inform. However, when a discovery of enemy positions is made, details from a particular warfighter may be the most important thing for a short time.

We noted earlier that some users will have their hands occupied, whereas some might have their hands free at least some of the time, and users in upper levels of the command and control structure are likely to be working with systems that resemble desktop or laptop machines. Thus another qualitative goal is to have free hands most of the time.

Based on the tasks discussed above, we can set performance goals for certain tasks. One way to test the system usability on these tasks is to deploy them in training environments and see whether the warfighters' performance with the AR system is at least equivalent to that without. The level of performance leads to specific, quantifiable goals for a number of metrics. We would hope to see improved performance on at least some of these tasks. An internal study generated the following list of quantifiable metrics.

- amount of radio traffic

  Designating objects in the environment is a common type of communication between units in the field; anything that can reduce the need for radio traffic or otherwise speed up these types of communications is a benefit.
- location error and time required during report creation
- location error and time required during report reception
- ability to plan on the move (Independent discussion of this is above.)
- individual or squad reporting to headquarters
- headquarters tracking and mobile user tracking
- level of detail of georeferencing information required
- similarity of coordinates

  Two units may have different grids established for specifying coordinates. If these grids are not registered properly to each other, errors will follow, such as units misinterpreting coordinates as referring to them when they do not, or vice-versa.
- nighttime operation (amount of light required)

Based on the contextual task analysis, we add the following items.

- successful deconfliction in dynamic planning
- correct identification of responsibility for targets of opportunity
- arrival at phase lines in synchronization
- time and success rate for path planning
- accurate IFF in the AO
- success at maintaining adequate supplies for all units, or resupplying successfully

2.4. Platform Capabilities and Constraints

The greatest technical challenge for BARS is mobility, which constrains the power available to run the system. We anticipate that hardware manufacturers will continue to reduce power required by components such as mobile computing platforms, displays, and tracking systems. We assume that they will also improve features and decrease the size and weight of mobile devices such as those that will be components of final versions of BARS. The limits of accuracy of some of these component systems, such as GPS and inertial tracking systems or speech and gestural input devices, will always be a constraint on the capabilities of the system. We hope to overcome these limitations with well-designed software that understands these limitations and produces the best responses in the face of errors from the various devices. The need to use the systems in various levels of ambient light from bright sunshine to darkness requires the display to have a wide, controllable range of brightness.

3. DESIGN PRINCIPLES

There are many characteristics which affect the efficacy of collaboration. In arriving at design principles from our user profiles and task analysis, we want to keep in mind the following issues regarding the nature of the collaborative efforts.[1]

- Collaboration characteristics
  Considerations: time of collaboration (synchronous or asynchronous), predictability of collaboration (scheduled or unscheduled), place of collaboration (co-located or distributed), degree of interaction (ranges from low to high–military combat is high).
- Tool characteristics
  Considerations: recordable/traceable (audit, bringing missing team members up to date), identifiable (Can users be reliably identified by other users?), structure (Specific and predetermined communications or unstructured and varying types of information can be exchanged.)
- Information types
  Considerations: verbal, textual, spatial/graphical (maps or drawings), emotional (fatigue, workload, competence, anxiety), photographic, video
- Collaborative processes
  Considerations: planning, scheduling, tracking information, brainstorming, document creation, data gathering, data distribution, shared SA

Adapting a plan to the situation as an operation unfolds is a basic function for every warfighter. Marine doctrine lays out the following notional structure for the use of intelligence during an operation.[12]

1. Define the Battlefield Environment
   Identify characteristics of the battlefield that will influence friendly and threat operations. Establish limits of the area of interest (AI). Identify gaps in current intelligence briefings.
2. Describe the Battlefield's Effects
   Focus on general capabilities of each force until COAs are developed. Assess terrain, weather, geography, infrastructure, et al. Geography includes data such as politics, civilian press, local population, and demographics. Infrastructure includes facilities, equipment, and framework needed for the functioning of systems, cities, or regions.
3. Evaluate the Threat
   Use historical data and threat models to determine how the threat normally conducts operations. If the threat is not well known, this step includes collecting data and developing the threat models concurrently.
4. Determine Threat COAs
   Using the results of the previous three steps, identify the options available to the threat and assign a likelihood that the threat will choose each. Prepare event templates and matrices to guide intelligence collection and reduce the uncertainty in this process.

Everyone in the military conducts some form of analysis. Two examples are given in the doctrine manual.

- A rifleman in an infantry fire team considers the possible actions of the enemy soldier he is about to engage. He also considers how the local terrain and weather affect both himself and his adversary.
- An armor company commander considers the possible actions of the enemy battalion that he is about to engage. He also considers how terrain affects the enemy's COAs and the accomplishment of his own mission.

Sometimes the battle will progress in a direction unanticipated during the initial analysis and wargaming. The enemy is following his own plans and timelines; those determined during staff wargaming are only estimates. Therefore, staffs should ensure they use analysis, wargaming, and intelligence synchronization as dynamic tools rather than as one-time events. As the operation unfolds and the enemy's intentions become more clear, reinitiate the SA and decision making processes as needed. This process requires key members of the staff to conduct "mini-wargaming." During these sessions, the intelligence staff officer reviews and modifies the initial assessment, and the battle staff makes new decisions and writes new COAs.

Not all information should be displayed in all situations. When targeting, for example, the team leader should have a mental map of the location of friendly forces, so that if he receives hostile fire, he doesn't need to think about the map to know the situation and be able to react. However, on patrol during a peace-keeping mission, the location of friendly forces would be much more dispersed and more dynamic, so that no single team could know the map. When fire is heard, having that map could be critical in reacting promptly and properly.

4. USE CASES

By providing information that enables a dismounted warfighter to achieve SA, an AR system can enable better decision-making in these types of dynamic situations. We surveyed potential users at the C2 level (but who had significant experience at unit command levels) and identified the following candidates for display in a head-up view of the world. Figure 2 shows an image with information specified by a user in our survey.

- GPS coordinates and cardinal directions
- heading to objective
- locations of friendlies or directions to their locations
- labels on features of the environment (especially for urban environments)
- a timer or clock
- radio frequencies in use
- optional personal notes (such as intelligence about personnel movement patterns)

One clear choice was the desire to have all information displayed only on demand. Connecting to allied forces was listed as a desirable goal as well. The study, as well as anecdotal evidence from demonstrating early prototypes of our AR system, identified the overhead map view as among the most popular features possible with an AR system. The ability to tie directly to indirect fire support was cited as a potential benefit as well, making the call for fire more efficient. This feature could also be applied to a vehicle gunsight, even if the vehicle is not remote. Again, this ability could save valuable time in communicating a target's location and could perhaps help reduce friendly-fire incidents. Having fire result in the placing of an enemy icon on the map is useful, but the corollary is the need to remove such icons when targets are neutralized or even mis-identified.

Based on the domain analysis up to this point, we present the following scenarios that are representative of military operations. These use cases will guide the development in the VIeWHUD project.

4.1. Dynamic Planning

Team Alpha receives an objective from the field commander when a spotter sees something suspicious in UAV video. Team Alpha broadcasts its planned route to all teams. Team Bravo's leader sees that route in his AR display and notes that it crosses his line of fire. He responds with a message to the field commander that includes a new proposed route he quickly composed in the system. With AR, he can create this new route without taking his eyes off the battlefield. The field commander accepts the new route and designates it to Team Alpha.

4.2. Target Identification

Two teams are en route to their objectives. Team Alpha encounters fire and must hold their position. They can identify the direction from which the fire is coming, but are unable to pinpoint an exact location. They note this direction with a gesture through their AR view of the world. Team Bravo sees the direction indicated as a line through the environment, which they can see in a map view. This information enables them to identify likely locations for enemies along the line from which Team Alpha is taking fire. They plot a route to investigate the potential target and are able to neutralize the threat. Both teams then continue to their objectives, with Team Bravo's route recomputed from their current location.

Figure 2. An image, with user annotations, from our survey of use cases for BARS. All text and lines are indicated by the user as possibly useful information. This scenario asked the user to act as a spotter for a team on an urban hostage rescue operation.

4.3. Emergency Assistance

A variation on the previous scenario would occur if a member of Team Alpha were hit and required medical assistance. Suppose that another member of the team neutralized the threat. The team leader calls for help and specifies his location and the enemy location on the map. The field commander dispatches a medical team to that location, taking into account all previously planned routes and the discovered enemy location. These routes are relayed to all teams, so that each is aware of the new arrangement of friendly forces.

4.4. Forward Observer

A forward observer locates targets for the artillery, which does not see the target. After he calls in initial coordinates and sees the point of impact, he then gives instructions for adjusting the fire. Adjustments are nearly always necessary due to weather, enemy countermeasures, or other factors. In order to call or adjust fire, the forward observer must perform a map analysis and terrain association, then determine the distance and direction to the target from his location. The artillery computer calculates the firing parameters. The forward observer must first locate his position on the map grid. With modern GPS and an AR system, this can be computed and displayed to him on demand. The orientation of the terrain with the map may be assisted by overlaying the map in his view of the environment. This feature makes the forward observer's initial tasks much more efficient. When targets have been hit, the observer can instruct the system to record the coordinates and associate a new feature in the environment with that location. With an AR system, he could do this with an action as simple as gazing at the target and a voice command to the system.

4.5. Unmanned Vehicle Operation

A unit commander sends a team of UGVs to perform reconnaissance in the AO. One UGV encounters an obstacle blocking a road. It proceeds to enable an inspection routine that searches for space around the obstacle. When it finds none, it reports the road as blocked to the commander, who uses this information to redraw routes for other teams. We also envision a scenario in which the obstacle is not physical, but the presence of a chemical agent detected by sensors on the UGV. In either case, the commander identifies a new objective for the UGV, a rendezvous with a team that will retrieve the UGV for fast extraction from the AO.

5. SUMMARY

The domain analysis process refines the design of an application so that it directly serves the needs of the intended users in a way that makes the system easy to use. For military applications, with their changing nature over the long-term and dynamic operational contexts, this is a particularly challenging goal. However, by analyzing the users and their tasks, we can envision potential benefits of an AR system for providing SA. We have observed that a number of military users and tasks already benefit from having access to dynamic information in order to maintain SA. We believe that seeing this information in a head-up display, integrated with the environment, can further promote the fast incorporation of new information to SA.

When teams of warfighters and unmanned vehicles move through an environment, maintaining SA becomes a significant challenge. The environment places severe restrictions on the computing equipment and leads to a set of design principles that emphasize intuitive information display and interaction. Ultimately, user evaluations will determine whether the resulting AR system actually helps users in real tasks. However, by identifying the important considerations and designing use cases, we can focus our efforts on real problems that face warfighters and give ourselves the best chances of solving those problems.

REFERENCES

1. C. A. Bolstad and M. R. Endsley, "Tools for supporting team SA and collaboration in army operations," tech. rep., SA technologies, Mar. 2002.
2. M. A. Livingston, L. J. Rosenblum, S. J. Julier, D. Brown, Y. Baillot, J. E. Swan II, J. L. Gabbard, and D. Hix, "An augmented reality system for military operations in urban terrain," in *Interservice/Industry Training, Simulation, and Education Conference*, Dec. 2002.
3. J. Orasanu, "What needs to be shared in shared situation models?," in *DoD Human Factors Engineering Technical Adisory Group Meeting 54*, Nov. 2005.
4. Natick Soldier Center, "Operational requirements document for land warrior," June 2003. `http://www.natick.army.mil/soldier/WSIT/LW_ORD.PDF`.
5. G. L. Calhoun, M. H. Draper, M. F. Abernathy, F. Delgado, and M. Patzek, "Synthetic vision system for improving unmanned aerial vehicle operator situation awareness," in *Proceedings of SPIE: Enhanced and Synthetic Vision*, **5802**, pp. 219–230, May 2005.
6. E. Bowman, "Human factors analysis of C4ISR on the move testbed 2005 experiment," tech. rep., Army Research Lab, Feb. 2006.
7. R. Mahoney, K. R. Carson, H. R. Last, C. M. Patterson, R. H. V. Atta, and M. S. Vassiliou, eds., *Joint Urban Operations Workshop on Command and Control and Net-centric Environment Science and Technology*, Institute for Defense Analyses, Mar. 2005.
8. M. A. Livingston, J. E. Swan II, J. L. Gabbard, T. H. Höllerer, D. Hix, S. J. Julier, Y. Baillot, and D. Brown, "Resolving multiple occluded layers in augmented reality," in *IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2003)*, pp. 56–65, Oct. 2003.
9. C. Furmanski, R. Azuma, and M. Daily, "Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information," in *Proceedings of IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2002)*, pp. 215–224, Sept. 2002.
10. N. Sugano, H. Kato, and K. Tachibana, "The effects of shadow representation of virtual objects in augmented reality," in *IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2003)*, pp. 76–83, Oct. 2003.
11. R. Bane and T. Höllerer, "Interactive tools for virtual x-ray vision in mobile augmented reality," in *Proceedings of IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2004)*, pp. 231–239, Nov. 2004.
12. "Intelligence preparation of the battlefield." U.S. Marine Corps Field Manual 34–130, July 1994.