Dynamic Information Needs Analysis: Understanding User Information Needs in Subterranean Warfare

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In this practice-oriented paper for human factors research, we describe our experiences piloting an exercise to understand how a moment-by-moment input device can be utilized to help understand soldiers information needs while conducting subterranean (sub-t) warfare and facilitate development of Augmented Reality (AR) displays for sub-t use. We created a sub-t environment using the Unity game engine and utilized students as subjects to facilitate experiment setup and validation. Little research is being done on what information soldiers need in a subterranean environment. Here we begin to investigate these *information needs.*

Introduction

Subterranean (sub-t) warfare takes place in a high-risk operating environment that has been primarily the realm of Special Operations Forces (SOF). This is changing as conventional forces carry out military operations in urban terrain (MOUT). Conventional forces must now be prepared to conduct sub-t warfare when they encounter it, and the most likely places they will encounter sub-t challenges will be in cities with features such as tunnels, subways and sewers (Tucker, 2018). Conventional forces could also face the possibilities of sub-t warfare in places such as North Korea (DPRK), where sub-t terrain might include false tunnels, booby traps and explosives (Murray, 2014).

In order to enhance warfighter effectiveness in the sub-t environment, a critical capability will be providing the right information at the right time. The sub-t environment denies many sources of information that would be available above ground, including GPS positioning and satellite imagery (Morris, et al., 2005). The physical terrain also limits routing, retreat options and restricts the transport of bulky weapons and equipment. Given these factors, one of few methods of gaining a tactical advantage is through superior information gathering, sharing and display (McGeorge, Kane, & Muller, 2019).

We envision that information gathering will be made possible through the deployment of robotic platforms that conduct autonomous reconnaissance operations. Such platforms are potentially able to collect vast amounts of information, including video data, lidar point clouds and identified features (such as enemy positions, CBRN hazards, etc.) (Defense Advanced Research Projects Agency, 2019). A significant challenge will be to pare down this data, so that warfighters receive actionable information and little clutter.

At present, a major research question is what information soldiers need to be effective in a sub-t environment. While typical unit tasks such as bypass, neutralize, control, contain and clear exist in both the terrestrial and sub-t domains, it is substantially more difficult to scope and coordinate a sub-t operation. For instance, one issue in the sub-t environment is the lack of terrain landmarks that units can use as reference points for coordination. Another issue is the three-dimensionality of sub-t environments, which are difficult to intuit as tunnels may extend in any direction to any depth, with non-intuitively situated caverns, warehouses, factories, WMDs, C2 nodes and any other number of features (as illustrated in Figure 1).

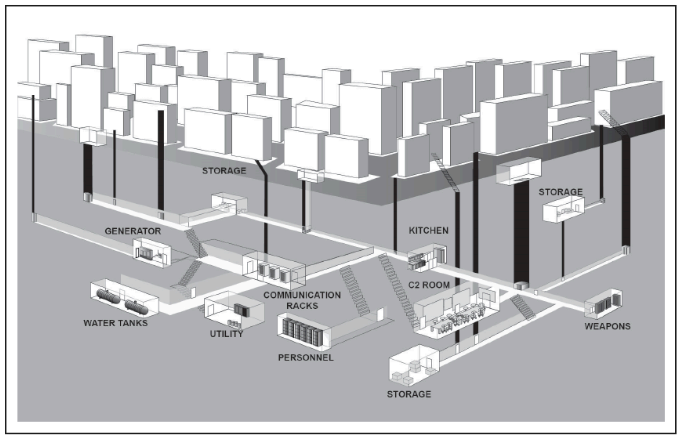

Figure 1 - Tactical Tunnel System in Urban Environment (U.S Army, 2019)

There is a potential for augmented reality (AR) to help soldiers conduct these types of missions in a way that was not previously possible. We hypothesize that sub-t environments are naturally constrained, so that AR gear may be less intrusive than in conventional environments. Furthermore, tools that are used in urban missions, (e.g., digital maps on tablets/handheld screens, paper maps/charts, laptops, etc.) may prove too cumbersome in a sub-t environment. In this sense, equipping soldiers with AR for sub-t operations seems a particularly good fit – sub-t environments are typically more limited in terms of information and decision opportunities. AR provides the tactical user an ability to display relevant information that is critical to understanding the battlespace.

Again, the question remains as to what information should be displayed by the AR interface. AR opens up the possibility for soldiers to understand the sub-t environment much like a soldier can intuitively understand a building by observing it from the outside and relying on a preexisting mental model for a building. Buildings are finite in space, have a limited number of floors and follow typical building patterns. Sub-t environments do not follow similar patterns so a mental model would not exist. AR could help bridge this gap. AR sub-t visualizations and information could be provided in near real time to enhance soldier lethality and effectiveness.

Whereas AR research conducted to this point has focused primarily on above ground operations, the constraints of sub-t mean the data required may not be the same (You, Zhang, Ma, Deng, & Yang, 2018). Grid coordinates and GPS routes are not available, yet soldiers will still need to navigate and know where they are going (Morris, et al., 2005). How do soldiers want this data presented, and do they even want this type of data? Can point cloud data collected from drones and robotics be presented to soldiers using AR in a meaningful way? What would routing information in sub-t look like in an emergency? Could AR provide visualizations of green and red zones to keep soldiers out of danger areas they may not realize exist? These are all questions that can be explored using AR in virtual reality (VR) simulations such as the one developed by this team.

Practice Innovation

To address the questions presented above, we started with a basic information needs analysis and set up an exercise to see if this type of data could even be collected. We want to understand *what* information users want and if they want it shown in an AR display as they move through a sub-t environment.

Reviewing the literature and considering the sub-t operating environment, we quickly realized that information needs will be dynamic (Penix, Swift, & Trusty, 2019). Not only will the information needs change with respect to time and environment, but we hypothesize that they will also change based on individual role and the type of information (e.g. navigation, position, sensor, etc.). Due to the dynamic and time variable nature of the data, a device was desired to measure a subject's moment-by-moment information needs.

We built a dial feedback device with an Arduino microprocessor at its core (Figure 2). The device acquires "in the moment" feedback and sends the data to a host computer. The easy-to-use dial makes it simple to engage participants in the environment and assess the degree of their information needs at any time. Additionally, literature shows that moment-by-moment ratings can facilitate researchers in identifying significant events that triggered information needs (D'Ambrosio, 2019; Penix, Swift, & Trusty, 2019). Detail about these information needs can be solicited after participants have completed the trial.

Methods

To understand information needs, we first needed a test environment. The Unity Game Engine provided a rapid way to build a complex set of sub-t features. Using free or low-cost assets available from the Unity Asset Store, various subterranean elements were used to build a complex realistic environment.

We configured our Arduino-based device to collect data from a subject immersed in the Unity simulation. To synchronize data, accept user inputs and display the sub-t environment, MATLAB based software called CARMA (Girard, 2014) was modified to accept Arduino inputs (Figure 3).

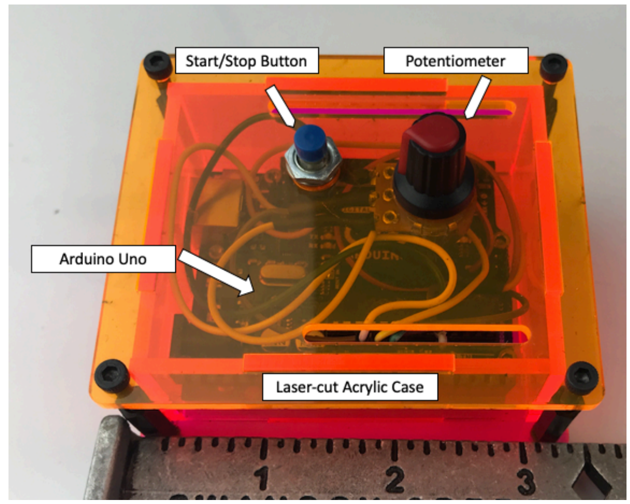

Figure 2 - Moment-by-moment Data Capture Device

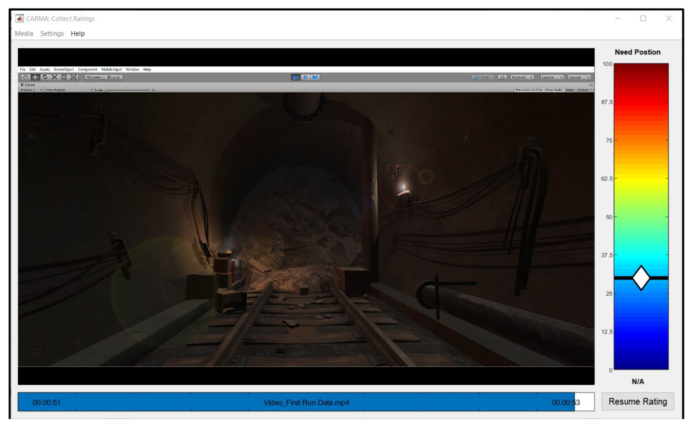

Figure 3: Modified CARMA Software *(Girard, 2014)* with Arduino Input Capability

A pilot exercise was conducted to evaluate the function of the data collection system. During the evaluation, the software was operated by twelve student users. The main goal of the exercise was to confirm that our system is capable of capturing data that will be useful in the future for characterizing information needs.

We ran the exercise on four different days in two locations, but followed the same procedure for all exercises. The same equipment and software was used on all exercises. The students were shown a video of the Unity sub-t world in CARMA (Girard, 2014). The avatar was navigated through the environment along a predetermined path. Students were given a brief overview of what they were looking at and the role they were playing.

The participants were instructed they were a soldier moving through a sub-t space and to "Please use the dial to indicate how much you WANT information that could be displayed in an imaginary AR field of view based on what you are viewing at that moment." There were two types of information we requested users to ask for in separate exercises: navigation information or enemy location information. The range of the dial was zero to 100. While watching the video, participants could turn the dial clockwise to indicate they wanted information at that point of the simulation and then turn the dial back to zero once the need had passed. We did not quantify what "amount of information" was during these exercises; it was subjective to the individual user. We were more interested in seeing when users wanted information and what features (intersections, piles of rubble, lights, etc.) drove the desire for information.

Findings

In this pilot experience, we provide numbers *only* to guide other researchers wishing to replicate this type of activity with a larger number of participants. Our sample was small, asymmetric and there are potential confounds. The experience we were exploring was whether or not we could utilize moment by moment data to determine information needs of users in a dynamic and changing sub-t environment (Coyle & Vaughn, 2008).

There were some interesting trends noted when looking at the pilot exercise feedback. First, as expected, decision points such as junctions, piles of rubble and obscura drove the need for information, which the moment-by-moment inputs revealed. However, when looking at navigation information needs vs. enemy position information needs, we observed a distinct phase shift of the enemy position data. In other words, when approaching the same decision points users wanted to know where potential enemies were earlier than they wanted navigation information. Applying traditional data collection methods (e.g., focus groups, think aloud protocols, interviews) researchers may not see this slight variation in information needs. However, by utilizing a moment-by-moment data collection device, possible insights such as this could be teased out during studies.

Another interesting finding which warrants further study was users indicating a desire for information when there were extended periods of darkness with no decision points or visual stimuli. There is a section of tunnel in the simulation that shows complete darkness for approximately nine seconds. Every user indicated some desire for information between four and six seconds into the complete darkness. When asked about this desire after the exercise, users had similar responses. That they felt like they wanted to know "something" since they had no idea what was ahead of them in the darkness after what seemed to be an extended period of time. This indicated to us that when users are in a dead reckoning type of navigation mode, they desired a course correction after some period of time just because they felt like they needed it. Again, if traditional data collection methods were being utilized, users may have been reluctant to provide feedback during these types of event, but utilizing a moment-by-moment collection device allowed this information need to be captured.

The data collected was time series in nature (as illustrated in Figure 4). The figure shows the average of all data collections over time for each information need (e.g. navigation and enemy position). The red lines represent the averages while the gray lines are the individual users moment-by-moment data. They y-axis represents a hypothetical magnitude of users information needs based on the 0-100 scale of the knob turn. Since the information needs were subjective to the users feelings, as well as the rate at which they turned the dial, there were some difficulties encountered in trying to apply statistical methods to further analyze the data. Users trials could be averaged within each type of information need (e.g., navigation, enemy position) and provide an overview of points in the simulation that drove information needs. However, it proved difficult to apply other analytical methods to the data that were useful.

Figure 4: Time Series Moment-by-Moment Data

Discussion

The use of a dial to collect moment-by-moment data was a conducive exercise for prospective research. While we could not use statistical methods to glean more information at this time, further refinement of the data collection software and additional standardization in the scenario could eliminate this problem.

As stated above, we saw compelling trends in the data by using this device such as the slight phase shift in information needs and the desire for information in area of complete darkness. We determined that this methodology could be used as a starting point for further research. Using the moment-by-moment data, researchers can look at what features drive information needs in a simulation; repeat experiments with the same features in varying scenarios could be analyzed for similar resulting inputs from users.

There are a few ways we could enhance the experimental design for this scenario. First, we limited the pilot experience to available students. Future experiment results could differ from the pilot experience if individuals with military training were utilized. The second way we would refine our experimental design would be to conduct trials within different sections of the sub-t network with similar features to see if similar results were achieved. For example, comparing data from exposure to repeated features such as dark tunnels within the same simulation. Our pilot experience was limited to a single section of the sub-t network in our Unity simulation.

Finally, we utilized a screen captured video of the sub-t network displayed in CARMA (Girard, 2014) to show the simulation during trials. In future iterations, it would be preferable to utilize a virtual reality (VR) headset and show the simulation in Unity using waypoints to guide the avatar. We could also possibly provide a better methodology to capture data by interfacing an Arduino device directly with Unity.

Practitioner Take-aways

Employing a moment-by-moment data collection device did provide insights into information needs that could not have been gleaned from other collection methods.

● **There is currently no standardized, instrument driven way to collect information needs**. Information needs can vary from user to user, and are typically collected by survey, focus groups, user research, think aloud studies or interview type activities (Wilson, 1981). However, in the context of a simulation being shown to a user, it may not be the best approach to interrupt a user to solicit feedback. On the other hand, trying to utilize retrospective recall to collect such data could present its own issues. Individual abilities to recall details vary and interactions may differ which could cause relevant details to be overlooked (Penix, Swift, & Trusty, 2019). Using a knob like device to collect information needs only appears in a few pieces of literature (D'Ambrosio, 2019; Penix, Swift, & Trusty, 2019). There is a commercial company that provides knob based feedback devices for audience and media feedback; little research has been done incorporating the use of this device related to information needs (Dialsmith, 2020).

● **Utilizing a low cost instrument, it is possible to understand user information needs prior to engaging in costly and time consuming research to develop AR displays.** In this exercise, we tried using an inexpensive moment-by-moment data collection instrument to better understand what environmental features, decision points or other stimuli drove the information needs a user would want in a sub-t AR display. With the insights gained form this device, future development can be done to provide users with the correct AR data at the precise moment they desire it. This could help eliminate lengthy questionnaires, usability testing and interviews to get a desired AR outcome.

● **Other areas of research could benefit from moment-by-moment data collection to explore information needs.** In the literature, examples were found for using dial based moment-by-moment data collection devices (D'Ambrosio, 2019; Penix, Swift, & Trusty, 2019). However, most looked at user sentiment, emotional responses and user engagement. There were three examples found that looked at information needs, however, they were not looking at information needs in support of AR (D'Ambrosio, 2019; Mcgraw, 2016; Penix, Swift, & Trusty, 2019). All examples used a commercial off the shelf device that is expensive and requires specialized software to conduct the data analysis (Dialsmith, 2020). In our pilot setup, we were able to utilize inexpensive parts from around the lab to develop a device at an almost negligible cost. The data analysis was also done inexpensively by utilizing open-source software and adapting it to our needs (Girard, 2014).

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