Extending Intelligent Tutoring Beyond the Desktop to the Psychomotor Domain

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ABSTRACT

Today, Intelligent Tutoring Systems (ITSs) are generally authored to support desktop training applications with the most common domains involving cognitive problem solving tasks (e.g., mathematics and physics). In recent years, implementations of game-based tutors based on the Generalized Intelligent Framework for Tutoring (GIFT), an open-source tutoring architecture, provided tailored, militarily-relevant training experiences in desktop applications (e.g., Virtual Battlespace and Virtual Medic). However, these game-based desktop tutors have been limited to adaptive training for cognitive tasks (e.g., problem solving and decision-making), whereas the military requires adaptive training to extend beyond the desktop to be compatible with the physical nature of many tasks performed by soldiers. This paper examines how commercial smart glass technologies could be adapted to support tailored, computer-guided instruction in the psychomotor domain for military training *in-the-wild*, locations where no formal training infrastructure is present. We evaluated the usability and system features of 10 commercial smart glasses including Atheer One, CastAR, Epson Moverio BT-200, GlassUp, Google Glass, LaForge Icis, Laster See-Through, Meta Space Glasses, Optinvent ORA-S, and Vuzix M-100. Smart glasses were selected as the focus of this study over handheld mobile devices to promote a hands-free experience during a training task where the hands are needed to accomplish the task (e.g., climbing and maneuvering over uneven terrain). Each set of smart glasses was evaluated not with respect to each other, but with respect to their capabilities to support adaptive instruction in-the-wild and at the learner's point-of-need. We examined a wide range of smart glass features and capabilities, and evaluated their compatibility with a representative military task, land navigation, to answer the question: what system design features (e.g., usability and interaction) are needed to support adaptive training for this individual psychomotor task beyond desktop applications so it can be taught anywhere (in-the-wild)?

ABOUT THE AUTHORS

Dr. Robert A. Sottilare leads adaptive training research within the US Army Research Laboratory where the focus of his research is automated authoring, automated instructional management, and evaluation tools and methods for intelligent tutoring systems. His work is widely published and includes articles in the Cognitive Technology Journal, the Educational Technology Journal, and the Journal for Defense Modeling & Simulation. Dr. Sottilare is a co-creator of the Generalized Intelligent Framework for Tutoring (GIFT), an open-source tutoring architecture, and he is the chief editor for the Design Recommendations for Intelligent Tutoring Systems book series. He is a visiting scientist and lecturer at the United States Military Academy and a graduate faculty scholar at the University of Central Florida. Dr. Sottilare received his doctorate in Modeling & Simulation from the University of Central Florida with a focus in intelligent systems. In 2012, he was honored as the inaugural recipient of the U.S. Army Research Development & Engineering Command's Modeling & Simulation Lifetime Achievement Award.

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INTRODUCTION

Intelligent Tutoring Systems (ITSs) provide adaptive training where the instruction is tailored to support the specific needs of an individual learner or a team of learners (Sottilare, 2013). ITSs are generally authored to support adaptive desktop training applications with the most common domains involve cognitive problem solving tasks in mathematics and physics (Cossairt and LaViola, 2012; Cheema and LaViola, 2012). In recent years, implementations of game-based tutors (e.g. reconnaissance task training in Virtual BattleSpace and combat casualty care training in VMedic) using the Generalized Intelligent Framework for Tutoring (GIFT; Sottilare, Brawner, Goldberg, & Holden, 2012; Sottilare, Holden, Goldberg, & Brawner, 2013), an open-source tutoring architecture. Each game-based tutor (Goldberg, Sottilare, Brawner, & Holden, 2012) demonstrated adaptive training techniques for military training tasks in a desktop environment. However, these tasks were largely cognitive in nature and the military requires adaptive training tools and methods for frequently performed psychomotor tasks (e.g., marksmanship, reconnaissance in urban environments, and land navigation) involving both cognitive and physical aspects and occurring outside of locations with formal training infrastructure (e.g., Joint Readiness Training Center).

In order to support effective, adaptive instruction at the point-of-need, this paper examines how commercial smart glass technologies could be used to support instruction beyond the desktop for military training *in-the-wild*. We evaluated the usability and system features of 10 commercial smart glasses including Atheer One, CastAR, Epson Moverio BT-200, GlassUp, Google Glass, LaForge Icis, Laster See-Through, Meta Space Glasses, Optinvent ORA-S, and Vuzix M-100 (Figure 1). Smart glasses were selected as the focus of this study over handheld mobile devices to promote a hands-free experience during a training task where the hands are needed to accomplish the task (e.g., climbing and maneuvering over uneven terrain). Each set of smart glasses was evaluated not with respect to each other, but with respect to their capabilities to support adaptive instruction in-the-wild and at the learner's point-of-need. We evaluated the range of smart glasses features capabilities, and their compatibility with a representative military task, land navigation, to answer the question: what system design features (e.g., usability and interaction) are needed to move adaptive training for a psychomotor task beyond the desktop to individual soldiers in-the-wild? This paper examines how commercial smart glass technologies could be adapted to support tailored, computer-guided instruction in the psychomotor domain for military training *in-the-wild*, locations where no formal training infrastructure is present.

Figure 1. Sample of Smart Glasses Evaluated (L-R: Atheer One, GlassUp, and Optinvent ORA-S)

Point-of-Need Training Capability Requirements

The primary gap to be addressed under this Army requirement is the lack of an easily accessible, persistent, cost-effective, and low-overhead training environment (U.S. Army Training and Doctrine Command, 2011). A capability is needed to bring training to Soldiers instead of Soldiers going to fixed training locations. This point-of-need training capability would be easily distributed, web-based, and built upon open-enterprise architecture in the cloud. Army training and educational opportunities would be available on demand anywhere and anytime. However, it should be noted that the delivery mechanism (e.g., laptop computer, mobile device, and smart glasses) for adaptive training is critical in determining the limitations of the domain model scope and complexity. For example, it may be extremely difficult to train all the complexities of a psychomotor task in a desktop computer setting.

The major connection between point-of-need training and domain modeling is the practicality of extending adaptive training beyond the desktop. Low-cost commercial tools (e.g., smart glasses) must be investigated to determine their suitability to support the same kinds of tutor-user interaction afforded in static desktop applications. The cloud architecture to support adaptive training and education will be required to operate with and without internet connectivity depending on the location of the learner and their access to the network. For example, if a soldier decides to take a two hour training course while traveling and knows that internet connectivity will be intermittent, he might decide to download the course to his device and take it offline. The architecture must be able to track the soldier's progress and upload results when connectivity is again available.

A Representative Military Training Task for In-the-Wild Adaptive Training

The representative military training task we selected was land navigation. We selected this task because it requires the use of both cognitive and physical skills outside of the traditional classroom environment in a psychomotor task domain where adaptive training techniques have not been previously applied. This task was also selected because it is likely that GPS capabilities will not be available in a large scale conflict and soldiers must be able to navigate without the use of GPS. However, GPS capabilities are prevalent in smart glasses. While we might not want the soldier to have access to GPS during training, we do want the GPS to be able to provide a ground truth measurement of the soldier's position from the GPS in order to assess the soldier's land navigation skills in real-time. The smart glasses we chose were evaluated with respect to their ability to efficiently and effectively support adaptive training in-the-wild for a land navigation task.

According to the US Army Field Manual 3-25.26, the land navigation task involves map reading, route selection, terrain association, and squad tactical movement. The ability to recognize representative colors, symbols, and topographic lines to determine terrain features (e.g., hills, valleys, waterways, saddles, and ridges; see Figure 2) on a map, and plan a navigable route are pre-requisites to the navigation of real terrain. The squad leader must be able to determine grid north using the sun and stars as navigation aids. He must be able to determine direction and distance (e.g., grid azimuth) on real terrain based on a planned azimuth on a map. He must be able to recognize terrain features identified on a map and associate them with features in the real terrain while in route to a destination.

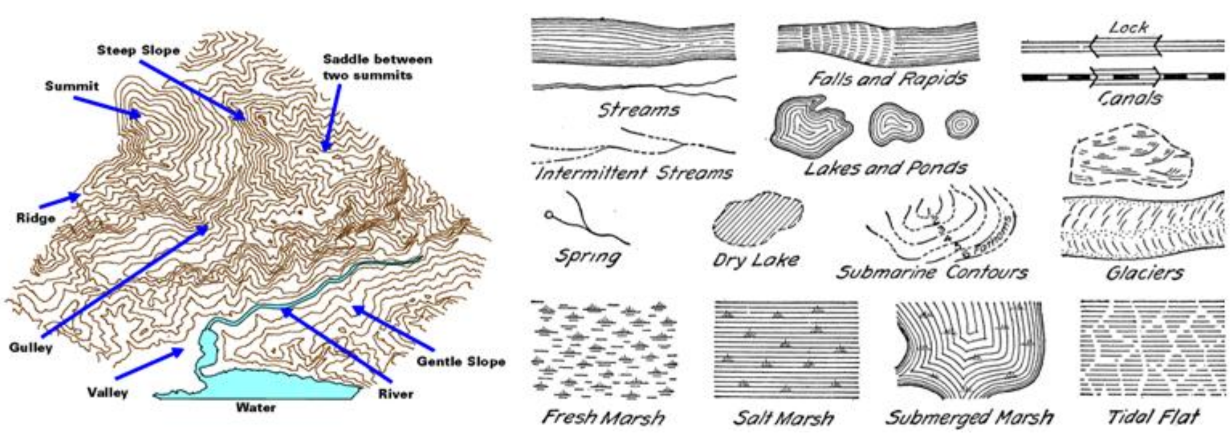

Figure 2. Representative Terrain Features for Map Reading in Support of Land Navigation Tasks

METHODOLOGY FOR USABILITY EVALUATION

Adaptive systems (e.g., ITSs) provide one-to-one computer-guided learning experiences which are tailored to each individual learner's needs and capabilities. The application of smart glass technologies to adaptive training and educational domains in-the-wild is new so we began by identifying criteria in the context of our representative military task, land navigation, and usability analysis based largely on Nielsen's usability heuristics (1994) which are summarized below.

Criterion: Information Availability and Visibility

The system should always keep users informed about what is going on, through appropriate feedback within a reasonable amount of time to allow for effective user response. The system should use visuals, alerts, and icons which are simple and consistent. Only important information should be displayed. Examples of system status indicators are battery meters, dashboards, maps, compasses, and mouse-over screen tips for system objects. Menus should not contain information which is irrelevant or rarely needed. Every extra unit of extraneous information in a menu competes with the relevant units of information and diminishes their relative visibility. Ideally, smart glasses supporting tutoring in-the-wild must be able to support development of new menus and interfaces to allow user interaction in a variety of domains. It must also be able to provide information to the user while not obscuring the user's view of environment.

For our land navigation task, content presented via smart glasses may be used to augment the learner's memory and reduce cognitive workload with prompts while in-the-wild. For example, the user might be prompted to identify terrain features in the live terrain when they veer off course, and then be asked to identify where they believe they are on an electronic map displayed by the smart glasses. This interactive dialogue with the tutor will allow the learner to recognize the error on their own. For more detail see the *error recognition and prevention* heuristic below.

Criterion: Consistent User Interfaces and Standards

The system's user interfaces should be consistent with the users' language and use terms, phrases and concepts which are familiar to the user. The system interface should be consistent with established norms for the task(s) to be accomplished (e.g., land navigation). Real-world conventions should be used to make information appear in a natural and logical order. The system should avoid the use of system-specific terms, phrases, and concepts in order to reduce cognitive workload and promote automaticity as the learner progresses with training. Users should not have to wonder whether different words, situations, or actions mean the same thing. User interfaces should maintain consistent language across menus.

For example, in our land navigation task, common terms used are "grid north", "azimuth", "back azimuth" and "magnetic azimuth". Using synonyms for these terms may be confusing to the learner and detract from efficient task execution during the planning phase. Prior to training and when necessary during training, it is important to assess the learner's knowledge of common terms to ensure they understand and can recall these common terms. Therefore, smart glasses should be able to deliver and score assessments and provide appropriate feedback, support, and remediation during planning and tutoring in-the-wild.

Criterion: User Control

Users, especially novice users, may choose system functions by mistake. The system should support *back* and *home* functions along with *undo* and *redo* functions to allow users to quickly escape when they select a function by mistake. For example, during route planning for our land navigation task, the user should be able to change their plan quickly and easily based on more in-depth evaluation of the terrain features in order to develop an optimal route in relationship to time and effort.

Criterion: Error Recognition and Prevention

In most cases, we want the system be able to recognize errors and provide error messages. These messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

However, while good error messages are an important element of adaptive system design, error prevention may be more important in some cases. It may not be efficient to allow planning of a route which cannot be navigated (e.g., across a wide river or up steep terrain. Ideally, we would like the user to discover these errors on their own during planning through a reflective discourse with the tutor rather than just allowing the system to identify the error and suggesting an alternative route. For example, the discourse for our land navigation task might look like this:

> **User**: "*I have completed my route planning.*"
> **Tutor**: *"Analysis of your route indicates the time to completion at more than four hours. The best expected time to navigate from your starting point to the end point is about 2 hours. Is there anything you can do to improve your route?"*
> **User**: "*I planned a route with the straightest path possible given the terrain features. I could examine the terrain features again to see if there is an easier route.*"
> **Tutor**: *"Good, what terrain features might be causing the increased time to navigate?"*
> **User**: *"My route takes me over a saddle, but it is still uphill from my starting point."*
> **Tutor**: *"Okay, let's try some alternative routes to see if we can reduce the navigation time."*

The reflective discourse continues as the user evaluates the terrain based on their new knowledge. Once planning is completed and an efficient route has been planned, the tutor will guide the user through the actual navigation of the real terrain. Again, this guidance is provided indirectly as the user veers significantly off course:

> **Tutor**: *"Let's stop here… identify the features in each ordinal direction."*
> **User**: *"There is a large hill to the west… a smaller hill to the east… I am moving downhill toward a valley, and I just crossed a small stream."*
> **Tutor**: *"Please identify your current position on the map on your heads up display."*
> **User**: *"I appear to be off course. I should have taken the path down the hill to the east."*

Criterion: Comfort, Durability, Ease of Use, and Flexibility

As the hardware element of the adaptive tutoring system in-the-wild, smart glasses should be comfortable to wear over the time required to execute the training task. Lightweight, durable materials which can be worn in varying weather and lighting conditions are desirable. In order to minimize the user's memory load, the system should make objects, actions, and options visible to the user so they do not have to remember where to find them. The user should not have to remember information from one part of the user interface to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate. In the case of our land navigation task, we might want the map to pop up in the heads-up display based on a voice command in order to keep the user's hands free for other tasks. Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation on demand. Documentation should be easy to search, and focused on the objects, actions, and options available to the user at the time of the query. The user interface should be flexible and allow for accelerated actions (e.g., shortcuts) for more advanced users to speed up interaction. The smart glass interface should support both inexperienced and experienced users and allow users to tailor frequent actions.

RESULTS OF SYSTEM FEATURE AND USABILITY HEURISTICS EVALUATION

Tables 1 and 2 provide system specifications for the ten smart glasses evaluated as part of this study. Table 1 specifications include: what the images are able to be projected on (glasses or real-world surfaces in the environment); whether information is displayed within the learner's field of vision or outside (i.e., side, above or below); the display type (e.g., 2 or 3 dimensional); the display resolution; battery life, field of view (FOV); weight (grams), and whether a software developer kit is available. A discussion of the specifications related to Table 1 follow including feature descriptions, their range, their relationship to usability heuristics, and their potential impact on our goal: supporting tailored, computer-guided instruction in the psychomotor domain for land navigation, a military training task, *in-the-wild* which include locations where no formal training infrastructure is present.

Table 1. Smart Glass System Specifications (Part 1)

Smart Glass	System Specifications							
	Project Images To	Display in Field of Vision	Display Type	Display Resolution	Battery Life	Diagonal FOV	Weight	Developer Kit ?
Atheer One	glasses	within	color, 3-D Stereo	1024 x 768	6 hours	65 degrees binocular	70 g	not public
CastAR	glasses and real-world	within	color, 3-D Stereo	1280 x 720	1 day	65 degrees binocular	100 g	yes
Epson Moverio BT-200	glasses	within	color, 2-D and 3-D stereo	960 x 540	6 hours	23 degrees binocular	88 g (glasses) + 124 g (controller)	yes
GlassUp	glasses	side	monochrome 2D	320 x 240	1 day	NA	65 g	yes
GoogleGlass	glasses	above	color, 2D	640 x 360	1 day	14 degree monocular	50 g	yes
LaForge Icis	glasses	side	color, 2D	800 x 600	6 hours	NA	80 g	yes
Laster SeeThrough	glasses	within	color, 2D	800 x 600	6-8 hours	40 degrees monocular	55 g	yes
Meta Space Glasses	glasses	within	color, 3D	960 x 540	32 hours via pocket computer	23-35 degrees	180 g (glasses only)	yes
Optinvent ORA-S	glasses	within and side	color, 3D	640×480	4-8 hours	24 degrees monocular	80 g	yes
Vuzix M-100	glasses	within	color, 2D	428 x 240	6 hours	monocular	85 g	yes

Display Features

Display features include display modes, presentation of information in the field of the user's vision, display type, resolution, and diagonal field of view (FOV) per display. Projection modes may either mirror the displays of tethered devices (e.g., smartphones) or support independent menus. Virtual images may be within or outside the field of the user's vision (i.e., above, below or to the side of the user's field of vision) within the smart glasses or projected onto an external surface.

Related to the usability heuristic *information displays and visibility* is the need to keep users informed about system status. While it is important to have information about battery status and other system data available to the user, placing information directly in the view of the user at all times could cause safety issues by occluding all or part of the real world view. In support of our land navigation task, we recommend a schema to place information to the side, above or below the user's vision unless the information is an alarm or other time critical information. The user should also be able to move information and images into and out of their field of vision at will. Of the ten smart glasses evaluated, only the ORA-S provided the option to present data both within and below the user's field of vision. An adaptive tutor could provide alerts through text messages to Bluetooth-enabled smart glasses. The location of text alerts could be displayed outside the user's field of vision and moved within the field of vision to gain attention. A text messages could also be translated to a voice message to eliminate clutter and reduce cognitive overload by providing feedback through a second sensory channel.

Display types were primarily color and supported 2-dimensional projections which is suitable to provide maps and augmented labels for helping to identify terrain features. However, the size and detail of map data available to the user may be limited by the display resolution which varied widely, but was as low as 320 x 240 pixels. Given diagonal resolution as low as 14 degrees, FOV may also be a limiting factor in presenting anything more than simple 2-D images without interfering with the user's field of vision of the real world.

Battery Life

Battery life for the evaluated smart glasses ranged from 4 to 32 hours. From a practical perspective, the learner in our land navigation task should not have to worry about the battery life of their smart glasses during adaptive training experiences. We recommend battery in our notional adaptive training system provide at least one day of uninterrupted power, provide unobtrusive methods for recharging the battery (e.g., solar battery charger) or provide additional battery storage (e.g., Meta Space Glasses pocket computer).

Weight and Comfort

When we discuss system weight, we are primarily talking about user comfort. The glasses evaluated ranged from very light (50 grams or about 1.8 ounces) to light (180 grams or about 6.3 ounces). Review of these glasses reveals that they can be worn for long periods of time (over four hours) without significant discomfort. Of consideration is how the glasses rest on the bridge of the nose and the ears. Binocular glasses tend to balance the weight more evenly across the nose and ears, and are therefore recommended over monocular models. Another consideration is whether the glasses move around significantly when the user runs, climbs or changes direction or posture.

Software Development Kits

Nearly all of the glass sets reviewed had a compatible, publicly available software development kit (SDK) to support authoring of unique applications. While this might have minimal impact on our relatively simple land navigation task, it is desirable to be able to present information to the user in a variety of formats during the adaptive training process, and this requires the development of new menus and user interfaces. The usability of smart glass-based ITSs largely depends on the ability of the user to interact with the system.

Table 2 specifications include information about: onboard computing power, memory, and storage; wireless connectivity; photo and video capabilities; sensors, and other interface features (e.g., touchpads and wands). A discussion of the specifications related to Table 2 follow including feature descriptions, their range, their relationship to usability heuristics, and their potential impact on our goal: supporting tailored, computer-guided instruction in the psychomotor domain for land navigation, a military training task, *in-the-wild* which include locations where no formal training infrastructure is present.

Table 2. Smart Glass System Specifications (Part 2)

Smart Glass	System Specifications						
	CPU	Memory and Storage	Connectivity	Photos	Videos	Features	Sensors
Atheer One	via smartphone (Android)	provided by smartphone	WiFi, Bluetooth	8MP	NA	gesture support	gyroscope, accelerometer, compass, proximity sensor, capacitive touch sensor, ambient light sensor, GPS
CastAR	via smartphone	provided by connected devices	WiFi, Bluetooth	NA	NA	wand controller	120 Hz absolute tracking with sub millimeter precision; 1000 Hz Inertial tracking
Epson Moverio BT-200	onboard	1 GB RAM; 8 GB (32 GB with SD card)	WiFi, Bluetooth, and via Android device	VGA	VGA	touchpad (on controller), Dolby Digital plus sound, projectors	camera, GPS, compass, gyroscope, accelerometer, microphone
GlassUp	via smartphone	NA	Bluetooth	NA	NA	touchpad on glasses, real-time information feeds (read-only)	accelerometer, compass, ambient light sensor, precision altimeter
GoogleGlass	onboard	1-2 GB RAM; 16 GB	WiFi, Bluetooth	5 MP	720p	touchpad, voice control	camera, accelerometer, gyroscope, magnetometer, ambient light sensor, and proximity sensor
LaForge Icis	onboard	1 GB RAM	Bluetooth and via Android device	5 MP	720p	IambicFLO™ directional speaker	gyroscope, accelerometer, touchpad
Laster SeeThrough	via smartphone	provided by connected devices	Bluetooth	NA	NA	text, email, phone, music	GPS, 10 DOF head tracker, gyroscope, accelerometers, compass
Meta Space Glasses	via pocket computer	4 GB RAM; 128GB (via pocket computer)	WiFi, Bluetooth	5 MP	720p	Dolby 3D surround sound, 2 microphones	3D time of flight camera, color camera, 9-axis Integrated Motion Unit: accelerometer, gyroscope and compass
Optinvent ORA-1	onboard	1 GB RAM; 4 GB	WiFi, Bluetooth	5 MP	1080p	touchpad, voice control, control buttons, speaker	camera, 9-axis motion sensor, ambient light sensor, proximity sensor, GPS
Vuzix M-100	onboard	1 GB RAM; 4 GB	WiFi, Bluetooth	5 MP	1080p	4 control buttons, remote control app, voice navigation and gestures	3 DOF gesture engine (L/R,U/D,N/F), ambient light sensor, GPS, proximity sensor, 3-DOF head tracking, 3 axis gyro, 3 axis accelerometer, and 3 axis mag/integrated compass

Processing Power and Connectivity

Some level of onboard processing, memory, and data storage are a must for supporting data manipulation, learner state classification based on behavior and/or physiological measures, and archiving of learner actions and states for after-action-review (AAR). Real-time assessment of learner states is critical to real-time feedback and the management of adaptive instruction per the learning effect model (Sottilare, 2012; Sottilare, Ragusa, Hoffman, and Goldberg, 2013). The ability to store/retrieve maps and planned routes on demand is critical to our land navigation task.

Half of the smart glasses reviewed provided onboard processing power while the remaining glasses offloaded processor tasks to a smartphone or other device (e.g. Android tablet or pocket computer) via Bluetooth. Wi-Fi-enabled devices were also common among the glass sets evaluated, but unlikely to be useful for our land navigation task in-the-wild based on the low availability of Wi-Fi. The processing power and connectivity features of these devices directly affect the effectiveness of smart glasses as a mechanism to support adaptive training in the wild.

Camera and Sensors

Seven of the 10 smart glasses included a camera and 6 of 10 included video. The capture and display photos and video could support data collection for an automated AAR provided via the smart glasses. Significant artificial intelligence (AI) would be needed to support individualized, automated AARs, but the data capture could be driven by interaction between the computer-based tutor and the learner. For example, the global positioning system (GPS) sensor could be used to compare the user's current location to a planned route. Variation from the planned route could be used to trigger interaction with the learner and instructions to capture pictures of terrain features at their current position. Common errors by learners navigating the terrain could also be captured in video for display during the AAR.

GPSs, compasses and inertial tracking capabilities might be used to support performance measures during our land navigation task. Voice controls will be important to support improved usability and hands free interaction. The user's voice can be used to activate menus and support easier data input (e.g., text input or identifying perceived position on a map). Sensors to support gesture recognition for pointing and selecting from menus will also reduce the user's workload. A few of the systems reviewed included touch pads on the glasses (i.e., Glassup, GoogleGlass, and Optinvent ORA-S). The Epson Moverio provided a separate touchpad. Each of these devices provided limited menu navigation capabilities, were awkward to operate, and seem to be less much less efficient than voice control. Much the same as texting while driving is distracting and potentially dangerous, we found that using touch pads external to the smart glasses tended to draw the user's attention away from the display during input and could result in safety issues in areas with uneven or steep terrain. Finally, the ambient light sensor is critical to adjusting displays during the operation of most of the smart glasses we reviewed.

RECOMMENDATIONS AND FUTURE RESEARCH

The evaluation of ten commercial smart glasses identified recommended best practices for adaptive tutoring in the wild. For displays, we recommend the option to present data within and below the user's field of vision where the tutor and the user can move text and graphical data into the user's field of vision based on the criticality of the information. As in all portable systems, battery life was deemed critical for long duration tasks (task exceeding the normal time for a training class; more than one hour) to keep the user from having to constantly focus on whether their battery will last through the training experience. Weight and comfort were identified as something already provided by commercial smart glasses, but we recommend maintaining the glasses at 50 grams or less to maximize comfort over long duration exercises. Tinted and prescription glasses are also recommended to support long wear in bright sunlight and for user's who have corrected vision.

Connectivity via smartphone (Bluetooth) is recommended to allow for real-time interaction with the adaptive tutor and to support other service calls to the cloud (e.g., learner state classification algorithms). As a backup, onboard processing power is a must to support local classification of learner states (e.g., frustration, surprise, boredom). Cameras and sensors, especially GPS, can provide needed data to the adaptive tutor to assess the performance of the learner in real-time in the wild. Finally, software development kits (SDKs), while prevalent in commercial smart glasses, may not provide the flexibility needed to support presentation of all the training material and graphics needed to support psychomotor tasks in the wild. Additional evaluation is needed across several military psychomotor tasks to determine the true extent to which current SDKs can support presentation of training content to the learner.

CONCLUSIONS

Our evaluation of commercial smart glasses identified several capabilities which are necessary antecedents to adaptive tutoring in the wild. We examined a wide range of smart glass features and capabilities, and evaluated their compatibility with a representative military task, land navigation, to answer the question: what system design features (e.g., usability and interaction) are needed to support adaptive training for this individual psychomotor task beyond desktop applications so it can be taught anywhere (in-the-wild)?

Smart glasses were a technology of choice in lieu of smart phones based on the need for hand-free operation to support psychomotor tasks (e.g., land navigation) where information exchange with the adaptive tutor could guide learning and present instructional content while still maintaining safe interaction with the real world environment.

This evaluation was not intended to compare and select a pair of smart glasses, but instead to provide an understanding of the range of available capabilities in order to operationalize requirements for adaptive tutoring in the wild. The evaluation was also conducted to provide identification of gaps where capabilities in commercial smart glasses could not currently support adaptive tutoring in the wild.

The results of our evaluation revealed strengths and weaknesses for all of the smart glasses examined. Not one provided the range of capabilities and usability required to support our candidate military task, land navigation, but each possessed salient characteristics which could be used to drive requirements for future smart glass design to support psychomotor tasks.

Clearly, for a land navigation task, display resolution is a critical factor and most of the devices analyzed do not have high enough resolution to support map reading when significant detail is required. The one pair of smart glasses that has reasonable resolution is the CastAR system. However, this device requires special retro-reflective material, making it impractical for "in the wild" use. In addition, these smart glasses all have relatively small FOV, which can be a problem when images need to be superimposed over a large range at any one time. All the devices do have a variety of different sensors that, when coupled together, can provide tracking at reasonable accuracy levels (Welch and Foxlin, 2002). This represents a strength of the different smart glassed we examined.

The next step in exploring ITSs in the wild requires both improved hardware and software to support high resolution displays with wide FOVs. Currently, proof of concept exploration of this area could be accomplished with a smart glass device such as the Meta Space Glasses, given they have several sensors which may be used to properly acquire a 3D scene in real time and to support simultaneous localization and mapping (SLAM)-based tracking (Hu et al., 2012). Although the FOV is small, work is currently being done to expand the FOV. As an example, Maimone has developed a pair of smart glasses with a 100 degree FOV (Maimone, et al, 2014).

Another recommendation for future research is to explore other methods to improve display resolution and FOV by combining depth cameras and HD web cams with commodity HMDs such as the Oculus Rift. This combination would support 1080p resolution at 100 degree FOV. Of course, the device would be heavier than most smart glasses and would also need computational power greater than the amount supported by the smart glassed reviewed. Given hardware that is "good enough" to support proof of concept prototyping, further research involves the best way to present tutoring information to a trainee and to examine the most appropriate methods for having the trainee enter information into the ITS. There are a variety of different possibilities including 3D user interfaces, tablets, and voice communication. All of these methods need to be explored not only from a technological perspective but also from a user experience and pedagogical perspective as well.

Our last recommendation for tutoring *psychomotor tasks* is to expand the number and type of tasks which might be included within our *in-the-wild* taxonomy. Our definition of in-the-wild pertains to locations where no formal training infrastructure is present. This definition opens up the possibilities that in-the-wild tutoring does not only include tasks performed in outdoor real-world locations, but might also include tasks performed indoors where there is no formal training infrastructure to provide immersive experiences or track individual trainee behaviors. These training tasks might include medical, maintenance, or planning for tactical operations domains (Figure 3) where cognitive (thinking) processes and physical (doing) processes merge. Additional research is needed to explore the idiosyncrasies of these domains and to understand the interaction and usability needs for various classes of tasks.

Figure 3. In-the-Wild Psychomotor Tasks for Medical, Maintenance, and Tactical Planning

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