Iterative Interface Design for Robot Integration with Tactical Teams*

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Abstract. This research investigated mobile user interface requirements for robots used in tactical operations and evaluated user responses through an iterative participatory design process. A longitudinal observational study (five sessions across six months) was conducted for the iterative development of robot capabilities and a mobile user interface. Select members of the tactical team wore the mobile interface and performed operations with the robot. After each training an after-action review and feedback was received about the training, the interface, robot capabilities, and desired modifications. Based on the feedback provided, iterative updates were made to the robotic system and the user interface. The field training studies presented difficulties in the interpretation of the responses due to complex interactions and external influences. Iterative designs, observations, and lessons learned are presented related to the integration of robots with tactical teams.

Keywords: Human-robot Interaction · Mobile User Interface · Human Factors · SWAT · Robot Integration

1 Introduction

The focus of this paper was to iteratively design and evaluate a mobile interface for control and communication with ground robots for use in law enforcement tactical team operations. This was investigated through the research efforts of Mississippi State University's Social, Therapeutic, and Robotics Systems (STaRS) Laboratory and the Starkville (Mississippi) Special Weapons and Tactics (SWAT) team. The research team was given access to monitor the SWAT team's activities and incorporate the use of the

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robot within the team's monthly training exercises. Select members of the tactical team wore the mobile user interface to perform different operations using the robot. After each training session, the team members completed an after-action review and provided feedback about the training, robot, and the mobile user interface. Based on the information provided by the team, modifications were made to the interface and/or the robot prior to the next training session and then reevaluated.

The members of law enforcement tactical teams have one of the most dangerous civilian occupations. Their tasks are challenging because of the need to operate in dynamic, unpredictable, and often unknown environments. The primary purpose of SWAT teams is to ensure safety and to save lives in a systematic approach in different high-risk situations, such as engaging with active shooters, subduing barricaded suspects, rescuing hostages, and similar incidences [1]. They want to take all possible actions to minimize danger during their mission responses.

The background and motivation for this paper is presented in Section 2. Related work is presented in Section 3. The methodology for the research is included in Section 4 of the paper. Section 5 includes details regarding the design and development of the iterative user interfaces using a participatory design process. In Section 6 challenges and lessons learned are presented, followed by conclusions and future work in Section 7.

2 Background and Motivation

Robots such as unmanned ground vehicles (UGV) are ideal for integration with tactical teams such as SWAT. The United States, Department of Defense (DoD), defines a UGV as "a powered physical system with (optionally) no human operator aboard the principal platform, which can act remotely to accomplish assigned tasks" [2]. UGVs can be programmed extensively to operate semi-autonomously in different terrains [3]. The U.S. Army's 30-year unmanned ground systems (UGS) campaign plan is expected to decrease the workloads on warfighters both physically and cognitively as well as increase their combat capabilities [2]. The same statement applies for SWAT teams, who have to operate in the civilian environment. For the rest of the paper, the term *robot* will be used specifically instead of UGV for ease of reading.

Historically, robots are imagined as ideal for jobs that have one or more of the three Ds: dirty, dull, or dangerous [4]. Takayama et al. state that this simplistic notion has changed over time in the last ten years [5]. Their analysis indicates that people now consider robots for jobs where memorization, strong perceptual skills, and service-orientation are key factors. Human-robot teaming is the collaboration between humans and intelligent robots to perform specific tasks. Woods et al. point out that in such teaming both the human and the robot contribute unique qualities [6]. While a robot may be equipped with advanced sensing capabilities superior to a human, today's robots require human intervention to understand and act on the information.

SWAT officers envision the possibility that robots may be able to make their jobs safer. However, they do not have a good understanding of the strengths, weaknesses, and operational requirements needed to incorporate robots into their activities. Robots could be a significant addition to SWAT and increase their capabilities. One of the most significant benefits of integrating robots into tactical environments is the minimization of risk to the lives of the SWAT team members. Robots could be sent into the environment ahead of rest of the team giving them the ability to have "eyes" on the scene first before having to directly encounter potential threats. The following are some other benefits for integrating robots into SWAT operations:

i. For scouting to gain critical intelligence about the environment and potential threats.
ii. For guarding a specific room or hallway, while the team conducts slow and methodical searches in other directions.
iii. For diverting the attention of threats when encountered and providing team members with an advantage in these types of situations.

When a robot is used in SWAT operations, it is often considered as a camera on wheels [7-9]. Another common use of robots in law enforcement is for explosive ordnance disposal [10, 11]. How a robot could potentially be integrated as a member of the team instead of just another piece of equipment was initially explored in [12].

3 Related Work

In 1999, the Defense Advanced Research Project Agency (DARPA) was interested in research for tactical robots since it was evident that military conflicts would occur in urban areas with a large amount of building infrastructure and civilians [13]. Since this time, research has been conducted for the development of this type of robots and methods of communication with these robots. While the focus was on military operations, it also applied to other tactical teams such as SWAT teams, who have to operate in a similar manner in the civilian environment. Researchers have discussed with SWAT team members, issues related to the integration of robots into tactical environments such as SWAT operations [10, 14].

Over time, robots have been successfully integrated and used in different instances with law enforcement teams for explosive ordnance disposal [10, 11] or as remote cameras to provide intelligence [7, 9, 15]. While some of these robots are small in size, which helps operators maneuver the robots more easily, sometimes law enforcement teams prefer larger robots, because they feel these robots could provide improved protection and enhanced capabilities that may save lives. Hence, they are willing to compensate for the challenges that may occur with these robots (e.g., large size, battery life, sound generation, etc.).

There has been limited research in the area of integrating these robots as teammates instead of considering the robot as a tool for performing one specific task with tactical teams such as SWAT [10, 11, 14, 15]. When deploying a robot with a SWAT team, it is usually thought of as an adjunct to the team or a tool to operate remotely. The issue with this concept is the team member who is operating the robot is practically unable to perform his own tasks as he is now acting solely as an operator for the robot. A typical operator control unit (OCU) is large in size and often the person using it cannot perform any additional tasks that would be part of their typical responsibilities as a SWAT team member. Moreover, OCUs have a high associated cost from both the hardware and software perspectives. This is a challenge for any SWAT teams as they try to use minimal manpower to respond to most tactical situations. Also there are challenges associated with the use of robots with SWAT teams, such as the robots being considered a distraction to SWAT operations and potentially slowing down the team in specific types of responses, especially with dynamic entry [14]. Research has been performed to identify the potential roles a robot could fulfill within a SWAT team, serving as a team member, and the acceptance of a robot integrated as part of a SWAT team [12].

Over the years, researchers have come up with different user interface (UI) concepts to interact with robots [16-19]. Some of these interfaces would not be feasible for use in a tactical environment. Researchers also have explored the use of telepresence, multimodal displays, and the effects of temporal latency in the effort to create a better OCU for military environments [20]. Traditionally, these OCUs require larger hardware and expensive software, which makes the operating cost of the robots very high. As the overall budget for the U.S. DoD will be reduced by $489 billion over next ten years [2], DoD is investigating affordable, interoperable, integrated, and technologically advanced robots. The increasing popularity of low cost mobile devices and wearables in recent years has provided a great opportunity to use such devices as OCUs to communicate with different types of robots especially in tactical team responses. Moreover, the familiarity of using these devices among the members of the tactical response teams is a significant benefit. While mobile phones has been used previously as an OCU, it has only been considered as an alternative controller to joysticks [21]. Very limited research has been done to identify mobile interfaces as a completely viable OCU approach for implementation. The goal of the research presented in this paper is to identify the viability of using mobile interface to control and communicate with the robots in SWAT team and how an iterative design process could help with achieving this.

4 Methodology

The method used in this study involved the development of a mobile interface to control and communicate with a ground robot for use with SWAT teams. In SWAT trainings, a robot was deployed in different runs to perform different scenarios and training/response operations. The training sessions were held in different locations such as a large multi-story building, an abandoned house, open air police training facility, and a controlled testbed facility designed as a small two-bedroom apartment similar to locations commonly investigated in SWAT responses. Initially, a basic concept interface was designed and an ethnographic interview was conducted with one of the SWAT team leaders. Based on the input, a working prototype was built to use during future SWAT team trainings. Training was held approximately once a month at these locations. After each training an after-action review was performed and feedback was solicited about the training, robot, and interface, with a focus on requested modifications. Based on feedback from the officers, iterative modifications were made to the robot platforms and the interface prior to the next training, when additional feedback was requested.

4.1 Hardware

A Jaguar V4 robotic platform from Dr. Robot is used in this research [22]. Modifications were made and additional components were added to address the requirements of the SWAT team, such as cameras, LED lighting features, and a speaker system for distraction sounds. An Arduino board was installed inside the robot to control the lights and sounds. A Lenovo laptop was used to run the robot. A PicoStation from Ubiquiti Networks was used to increase the range for controlling and communicating with the robot from a distance [23]. Android smartphones (both Nexus 5 and Nexus 6) were used to serve as the operator control unit (OCU) for this robot and to activate the lights and sounds diversion device. Logitech game controller and Wii remote with Nunchuck controller were additionally used for teleoperation of the robot.

4.2 Software

The software architecture was designed as a distributed control system to support a high degree of modularity for adding and/or removing hardware and software control components as required for the control of the robot, sensors, and onboard distraction devices. It was implemented using the Robot Operating System (ROS). An Android application was developed to control and communicate with the robot. Over time, different iterations of this interface was introduced to address the requirements of the SWAT team. The following functionalities were implemented within the interface:

i. Display live streaming video feeds broadcasted from the robot.
ii. Toggle between the two different camera feeds on the robot: drive camera and top camera.
iii. Control the onboard strobe lights and diversion sounds.
iv. Drive the robot through the interface.

5 Iterative Interfaces

The traditional mechanism for driving the Jaguar V4 robot was using a laptop as an OCU, which was not feasible for use with the SWAT teams because of different factors such as size and weight. The use of a laptop strapped onto someone's chest and having him or her constantly looking at the screen completely negates any effectiveness of that member as part of the team. Other than operating the robot, the member would not be able to participate in the response operations at all. This is not ideal, because most SWAT teams are small in numbers and having a team member unusable because of the robot defeats the purpose of using a robot as a teammate to serve as a force multiplier and to increase the team's capabilities.

This prompted the researchers to develop a better solution that would allow the SWAT team to control and communicate with the robot effectively without compromising one of the team members. In the think aloud discussion with members of the team, they wanted a mechanism that would fit perfectly with their current equipment and would not be a distraction. Familiarity with the device and common interfaces and reduced learning curve were important to them as well. A smart phone strapped on their non-dominant arm with an armband (Fig. 4a) seemed a viable solution to this problem. This approach required significant development efforts on both the hardware and software aspects because there was no existing codebase for this robotic system that could be used as a starting point for the development of a mobile interface.

The researchers had to design and build the interface from scratch. As part of the process to develop a functional prototype, an ethnographical interview with one of the

SWAT team leaders to identify the requirements for this type of an interface was performed. Since the SWAT team members had not used this type of an interface before and their technical knowledge was limited in terms of the design process, the two main requirements was a) no glare from the screen if possible to minimize distraction and b) to perform operations as easily as possible. It was determined that the team members would wear the interface on their non-dominant arm and that the interface would stay in landscape mode only.

Driving in different directions, activating different lights / strobes and sounds, switch between cameras, etc. are defined as different operations that can be carried out through the interface. Similar operations were grouped together and considered as functionalities within the interface. The four functionalities were: driving the robot, activating lights / strobes, activating sounds, and switching between camera feeds. An iterative process of designing the mobile interface over time through a participatory design process was followed with feedback received from the SWAT team members after each training session. Three major iterations were performed and implemented during this six-month series of training exercises.

5.1 First Interface Iteration

For the first iteration the researchers decided to use a tabbed interface approach. The interface functionalities were in different tabs (Camera, Drive, Lights, and Sounds as shown in Fig. 1). The default view would provide the operator with a camera feed that could be toggled between different cameras with a single tap (Fig. 1a). For activating lights (Fig. 1c) or playing a sound (Fig. 1d), the operator could select the desired function and specific operation in the interface and it would activate immediately. To deactivate the operation, the operator would tap again the specific operation indicator. This was helpful as the officers could activate multiple lights and deactivate them using one action as long as the operator remained on the lights function panel.

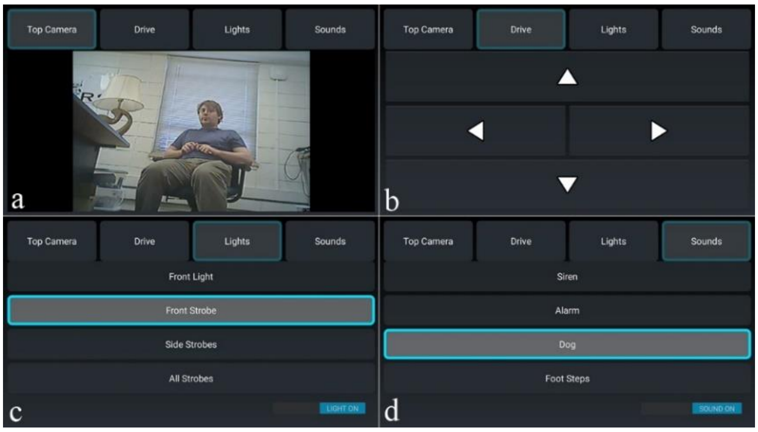

Fig. 1. First Interface Iteration: a) broadcast panel from top camera, b) drive controls panel, c) lights and strobes options panel, and d) diversion sound options panel.

The researchers then tested this interface in two training sessions and while the officers' responses were positive overall, their most requested change was to be able to perform operations while simultaneously being able to watch the video feed from the onboard cameras. This feedback directed the researchers' efforts to develop a second iteration of the interface.

5.2 Second Interface Iteration

As requested by the SWAT team, the researchers redesigned the interface to be able to broadcast the video from the cameras while having the ability to perform other operations. This interface resulted in a three-pane system: (1) the left pane contained all of the available functionalities, (2) the center pane contained the video feed(s), and the right pane contained the operations, such as lighting, sound, and drive commands (refer to Fig. 2). It was natural to put the video pane in the center, for the other two panes the researchers did a heuristic evaluation for usability inspection [24]. Since the team members would often wear the interface on their left arms, it was easier to access needed buttons and features on the right side of the interface compared to the left as that would a further reach and closer to the body limiting access. In general, it was determined that Operations would be performed more frequently compared to selection of basic functionalities. Hence, the researchers designed the pane setup using this approach.

The researchers also wanted to test incorporating another function and set of operations – access to additional sensors on the robot and as a placeholder for a future expected enhancement. To accommodate this addition, the lights and sounds functionalities were combined and assigned in the interface to a button named Utilities. This added an extra layer of required actions forcing the team members to select the utilities panel, select desired operations, and activate specific buttons for the desired lights (Fig. 2c) and sounds (Fig. 2d) to activate them. An improvement from the previous interface iteration was the ability toggle between the cameras on the robot without having to change the current operation pane.

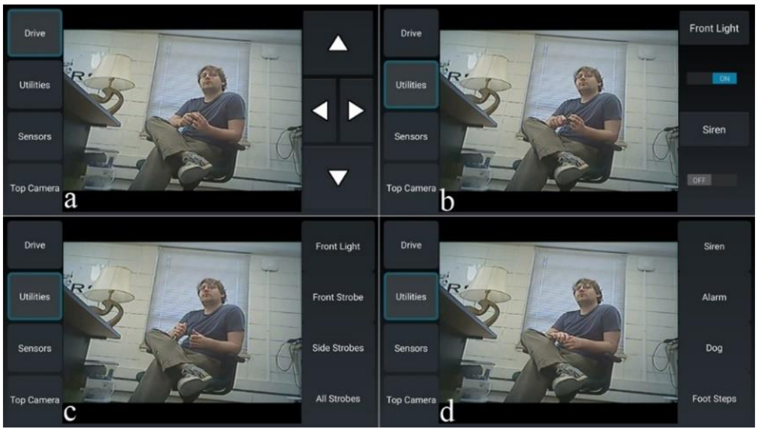

Fig. 2. Second Interface Iteration – camera broadcast always visible: a) drive controls, b) light and sound control as utilities, c) lights and strobes options, and d) diversion sounds options.

The researcher tested this iteration of the interface during the next two training sessions. The overall response from the SWAT team was more positive compared to the response to the first interface iteration. The team was happy to be able to view the video feed and simultaneously access specific operations. The researchers also queried the SWAT team about their thoughts on having the functionalities on the right side of the interface and the operations on the left with a minor adjustment to the screen. Most of the team members stated they preferred the current setup in the second interface iteration that located the functionality buttons on the left and the operation buttons on the right. The biggest disadvantage they revealed in this iteration was having to perform additional actions to activate the lights and sounds when needed and while under high stress. Their feedback was to accomplish a desired task with fewer required actions and in a more informative way if possible. This led the researchers to design and develop a third interface iteration, which is the current version used in training.

5.3 Third and Current Interface Iteration

The researchers tried to address the concerns expressed by the members of the SWAT team and developed the current (third) iteration for the interface. Since, there was no actual additional sensory data to show in the interface at this time, it was decided to return lights and sounds functions to individual buttons on the functionality pane of the interface and to remove the Utilities and Sensor functionality buttons from this version of the interface (see Fig. 3). This change allowed the lights (Fig. 3b) and sounds (Fig. 3c) functions (buttons) to be activated through direct operations. All of the operations were set as toggle buttons that allowed the SWAT team to be able to activate and deactivate any specific light or sound by tapping once when the appropriate function panel was selected. This reduced the number of actions required to activate an operation by 1. Toggling between cameras (see Fig. 3d) was modified to indicate which camera would be displayed on activation of the button.

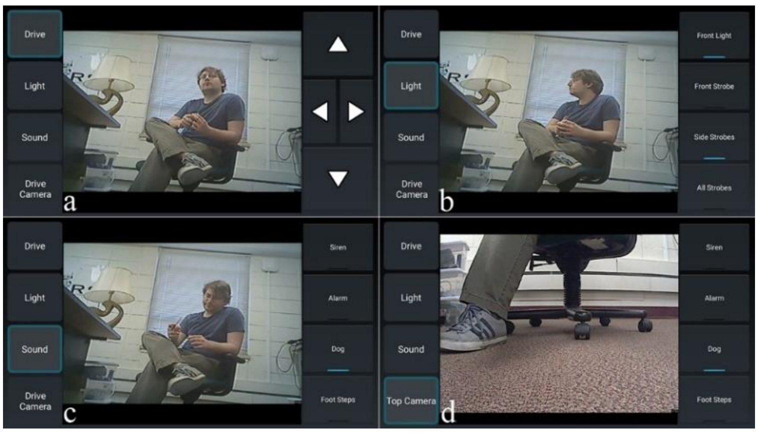

Fig. 3. Current Iteration – camera broadcast always visible: a) drive controls, b) lights and strobes options, c) diversion sounds options, and d) toggled camera showing drive camera

The researchers evaluated the current (third) interface iteration over the next three training sessions and it seems the SWAT team really likes how the operations are more intuitive now. As possible minor modifications, the researchers explored the idea of being able to view both of the camera feeds at simultaneously by having them side by side or up and down in the center pane of the interface. The responses from the team were not supportive of this approach. They preferred the single camera view as it was easier to obtain scene understanding with the single video feed instead of the small frames displaying the two camera feeds. The size of display was an important factor in this decision.

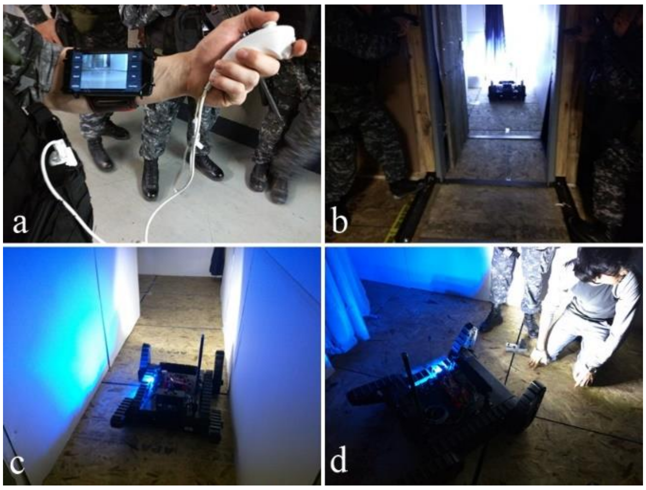

Fig. 4. Use of current interface in SWAT training a) team member with the interface b) robot entering the apartment, c) robot checking the hallway with activated strobe and sound, and d) robot assists in capturing the suspected threat.

During each iterations, the researchers explored the use of different controllers as well as virtual controller within the interface for teleoperation of the robot. This was to identify the acceptability and usability for teleoperation. SWAT officers seem to prefer physical controller in compare to virtual one. Moreover, Wii remote with Nunchuk was preferred compared to Logitech game controller as it can be operated with just grabbing and with the thumb. The researchers still exploring different mechanisms for teleoperation of the robot.

The researchers continue to evaluate and integrate small updates to the current iteration of the interface. The SWAT team has been using this iteration of the mobile interface to control and communicate with the robot in their training sessions (see Fig. 4).

6 Challenges Faced and Lessons Learned

The initial discussion of system capabilities and requirements was limited by a lack of experience with the proposed system. In some cases, this is inherent in the early stages of design: a potential user cannot interact with a system that does not yet exist. In the researchers' case, the law enforcement officers initially had limited experience with controlling the robot and little to no knowledge of the robot's capabilities. This led to difficulty in identifying concrete requirements for the user interface.

The initial mobile device (Nexus 5) selected had a 4.95" screen with a 1920 x 1080 resolution. This provided limited space for the display of camera feeds and buttons for the activation of available operations. The subsequent mobile device (Nexus 6) has a 5.96" screen with a 2560 x 1440 resolution. While the increased size improved the available space for the camera display and controls, it has also negatively affected comfort. There is a clear tradeoff between comfort and the effectiveness of the display area, which is directly impacted by the size of the device. To accommodate all of the desired operations, we explored hierarchical menus in the second iteration to discover that the tradeoff of an increased number of actions per operation versus the total number of available operations. In the current case, the SWAT team members did not consider this to be an effective solution.

In addition to difficulties with providing effective access to light and sound operations, using digital (on/off) buttons to drive the robot was not effective. During the evaluation of the interfaces, the SWAT team members were also provided an external controller based on a Wii Nunchuk to provide analog control of the robots movements. This provided the team members with a single-handed controller that was well received and allowed for better control of the robot. It was able to be attached to their current gear and did not impede the performance of tasks by the officers.

Training was performed in a number of different scenarios that revealed different types of challenges for the SWAT team members. The variation in scenarios affected officer responses to the robot and the provided interfaces. While it would be tempting to control the scenario, the current study sought to observe integration in a range of training scenarios defined by the officers to understand the complexities of designing a user interface that would be effective in many scenarios commonly faced by law enforcement. A custom interface or robot for each scenario is not a practical solution for robot operations in law enforcement. The iterative design process provided the SWAT team members with repeated exposure to the robot and interfaces leading to increased experiences with the robot and increased understanding of robot and interface capabilities. This, in turn, significantly improved the quality of feedback and the ability for the SWAT team members to provide effective recommendations for modifications needed in the interface.

7 Conclusion and Future Work

The development and evaluation of a mobile interface for use as an OCU with tactical teams has not received significant attention from the research community. The importance of such interface is significant because it could help with the integration of robots with SWAT teams without the need to sacrifice a team member to serve as a dedicated robot operator. The process was challenging because the officers must function in different types of responses that require different capabilities in the robot and functionalities in the interface. The ability to provide an interface that can be easily used by officers operating in high stress environments, requires significant participatory design to develop both high usability as well as a positive user experience. Through a process of multiple training and three interface iterations, we have developed an interface that meets the current needs of the officers.

Because lives are dependent on the robot and the interface working to meet the needs of the officer, the involvement of the officers in different training exercises was critical to this project. It was discovered that what may work in one scenario (e.g., slow and methodical building searches) may not work for another scenario or response type such as fast, dynamic entry. It is important to consider what functionality is needed when an officer is in a safe location versus in immediate threat of danger. It is also important to consider what happens when the officers must work in low-to-no light conditions versus a daytime response. An immediate concern related to the latest version of the interface is backlighting the officers due to the ambient light from the display in a low-to-no light response, the officers could be placed in danger because they would be the focus of attention. This research will be ongoing and will continue to enhance all aspects of the robot functionality in addition to the necessary changes required in the interface to support tactical operations that include the integration of robots into tactical teams.

The focus for future work in this research is to collect and analyze data from two different user studies that address the usability and the acceptability of the mobile interface developed while continuing the iterative process of development for the interface. Two large studies have already been developed and performed in spring 2016. Future interface enhancements may include the use of tactic buttons or interfaces that do not require ambient lighting and may be safer and provide a better user experience.

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