Discoveries from Integrating Robots Into SWAT Team Training Exercises

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***Abstract*—**This research discusses the results of two field evaluations associated with the integration of a ground robot within SWAT team operations. The results indicate that officers preferred having the robot in a *Point* (first man in) role to having the robot located in the *Rear-Guard* (last man in) role. The results indicate that the officers reported the robot to be more appealing, trustworthy, cooperative, and helpful in the *Point* role. They also expressed that they felt less stressed and pressured when the robot was in this role versus having the robot following the team. The robot serving in the *Point* role was viewed as more integrated with the team and the team liked the robot more than when it was in the *Rear-Guard* role. The survey results indicate that there were no differences in responses when comparing two different ground robots in the *Point* role; however during debriefing discussions and from anecdotal comments made by SWAT team officers, a strong preference was expressed for the more rugged, reliable, slower paced Husky A200 robot.

***Keywords*:** *law enforcement, SWAT, robotics, human-robot interaction, team integration, assessments, human factors.*

I. Introduction

Law enforcement officers encounter dangerous, challenging, and unknown environments and situations as part of their responsibilities. This is even more evident for members of Special Weapons and Tactics (SWAT) teams. These specialists are highly trained and are called in to handle the most challenging of law enforcement operations that fall outside of the responsibilities of a regular officer [1]. They are typically called out to serve high-risk arrest and search warrants, to subdue barricaded suspects, to engage with active shooters that may be heavily armed, to rescue hostages, and other similar operations. They are trained to resolve high-risk situations with a minimum loss of life, injury, or property damage [1, 2].

SWAT team officers are trained and equipped with specialized gear that may include assault rifles, breaching equipment, riot control (less-lethal) agents, stun grenades, and sniper rifles. These teams are composed of mostly volunteers, and they operate with the minimum number of members needed to complete the operation (eight to nine members for typical teams with larger agencies having multiple teams) [1].

Robots could become a significant force multiplier if SWAT team members are trained with robots and learn their capabilities. When a robot has been used in SWAT operations it is often considered a camera on wheels [2-5]. The other common use of robots in law enforcement has been for explosive ordnance disposal [1, 6]. This research project investigated ways in which robots could be incorporated into a SWAT team as a member of the team and not just another piece of equipment. The project explored potential roles of the robot working with the team and how it could be incorporated in with their existing team model and operations. Additionally, the research evaluated if there was a preference for one ground robot to another.

With a robot acting as a member of the team, it can assist with providing reconnaissance information, it can provide cover by the noise it makes, and it can be a distraction to allow officers to enter an unknown, unpredictable, and dangerous environment. The paper discusses surprises discovered from the observation and integration of robots with SWAT team training sessions over the past year with the Starkville City Police Department, Choctaw County Sheriff's Office, and Mississippi State University Police SWAT teams.

II. Related Work

The use of robots by law enforcement is not a new concept; however the uses have been very limited and focused. Robots have been successfully adopted and used in law enforcement for the purpose of explosive ordnance disposal [1, 4, 6]. These robots are not without challenges, (e.g., large size, battery life, maneuverability, etc.) but the law enforcement community finds value in these types of robots for protecting lives and is willing to compensate for the challenges encountered during use.

Robots are used as remote cameras to provide intelligence information to law enforcement prior to entering into an unknown or dangerous situation. These robots are small in size, highly maneuverable, and are tele-operated [2, 3, 5, 7, 8].

Small robotic platforms have both benefits and challenges during deployment. Some benefits are that they can be placed in locations that might be too small or dangerous to enter and the robot can provide critical intelligence about the situation prior to entry via visual feedback displayed on an operator control unit (OCU). Due to their small size, these robots are often tethered causing issues with tangling of wires and limited distance of exploration. Alternatively, the robot may have batteries and be operated wirelessly, which limits operation time and the exploration distance due to signal strength issues [2, 3, 5, 7, 8]. For some robotic platforms, there may be issues with obstacles such as stairs, boxes, and items found in the environment.

There is very limited research in the area of deploying a robot along with a SWAT team [1, 6, 8, 9]. Field deployments typically, have the robot operated remotely and it is considered a tool or an extension of the team. The robots are usually tele-operated requiring one member of the team to be taken out of the fight to operate the robot. This is a challenge for SWAT teams that are typically using minimal manpower to respond to an incident [1]. Additionally, the use of robots in SWAT operations has met several challenges including officers reluctant to accept the robots due to the possibility of the robots being a distraction and a potential safety issue if they are not able to keep up with the team's movements and the demands of the response [9].

The goal of the research presented in this paper, is to determine if there is a role that a robot can fill within a SWAT team as a team member and not just as a tool? Will a SWAT team accept, trust, and work with a robot as another team member or will the robot be considered another piece of equipment in their tactical toolbox for use during a response?

III. Tactical Needs Assessment and Issues

Tactical teams are trained to respond to many different types of incidents. Planning and assessment for each incident needs to be conducted to determine the best possible response and the timing of the response. It is important to determine what manpower is needed, and what type of specialized equipment may be necessary for the response. It is difficult for SWAT teams to assess the needs for an incident response primarily because the situation, environment, and/or location could rapidly change and what might be appropriate in one moment may be drastically different the next. Based on discussions with officers and observations of training activities with SWAT teams, it was determined that the needs assessment for a SWAT response typically focuses in two primary areas: (1) mission scope and (2) operational speed necessary for the response [1, 9]. If robots are incorporated into SWAT team responses, the platform and capabilities will need to be factored into the needs assessment.

A. Mission Scope

It is critical to any mission to understand what has already happened (*context*) and whether it is changing (*dynamics*), known as the mission scope. Officers need to understand how fast will they have to respond to any changes. The team members always need to be prepared for surprises during incident responses.

1) Dynamics – Mission dynamics may include a situation that is quickly changing or could have periods of inactivity followed by immediate action (e.g., hostage situation, active shooter). The incident may have short bursts of activity (e.g., an apartment drug raid), or it could involve a long, methodical sweep and clear of a large, complex environment (e.g., a school building). The SWAT team may or may not have adequate time for sufficient planning depending on the urgency of the situation and whether there are lives in danger. The teams often face uncertain environments, with a lack of maps of the area, they may have faulty or limited intelligence, and they are often dealing with contaminated (e.g., chemicals associated with drugs) and/or cluttered environments. All of these make incident response challenging for SWAT teams.

2) Context – The context of the incident is an important factor in the planning of a response. SWAT team members must respond to any event that has the appearance of a threat and/or victim. Once a threat has been identified there are many contextual factors that need to be considered as part of planning and mission scope. The SWAT team needs to take into account the presence of a weapon and the lethality of that weapon, the stance and motion of the suspect, any audio information they can obtain, and visual cues of the emotional state of the suspect.

B. Operational Speeds

The speed at which a SWAT team responds depends on the mission scope. There are two fundamental types of operational speeds involved in an incident response: (1) *dynamic entry* and (2) *slow and methodical entry*.

1) Dynamic Entry – occurs when the response requires quick action and an element of surprise (e.g., a drug raid). The pace is fast, and requires rapid decision making by the team. The team movements are fast, fluid, continuous, and precise. They are careful not to block one another and follow a pattern of movements similar to approach, stop, turn, check, turn, check, and then resume. The team has shared knowledge of the plan and necessary actions for the response. The focus is on the speed of the response. This type of team response requires significant training for officers to inherently react to the situations encountered. Due to the speed of this type of response it is not conducive to having a robot as a member of the team. A robot will block or impede the officers; it would be distracting, and more detrimental than helpful.

2) Slow and Methodical Entry - this type of entry occurs when there is knowledge of a suspect in a large or complex environment (e.g., an office building or school). Intelligence may be limited and requires the officers to methodically search, clear, and secure multiple areas of the facility. The pace for this type of response is moderate. The focus is on security. The team focuses on communication, attention to details, and methodically searches for victims and/or suspects or threats. Communication signals are conveyed via gestures, verbal, and touch. The team stays in close contact with each other and may physically reach out and touch their fellow team members to keep all members of the team safe and alert. It is the slow and methodical entry in which the robot may become a useful member of a SWAT team.

C. Ground Robots

If ground robots are to become integrated members of a SWAT team, it is important to know and understand their capabilities and how they will be operated during the mission.

1) Capabilities – Robots are equipped with different capabilities. Most mobile ground robots have some type of vision system (e.g., RGB camera, night vision, thermal imaging, RGB-D*,* stereovision, etc.) in order to provide visual feedback and mapping of the environment. This visual information can be critical for intelligence gathering to assess the environment. The vision system can provide SWAT team members with target identification, locate threats, and provide information regarding the location of victims, hostages, and/or suspects [1, 6]. The robots may be equipped with visible lighting, infrared illuminators, and/or audio capabilities to provide cover for the team members [1, 6]. Depending on the type of robot, it may be able to carry equipment or even be used to assist with the evacuation of victims or injured officers [10].

2) Robot Operation – Traditionally, the robots that have operated in SWAT environments have been tele-operated. This requires one officer to be trained and essentially taken out of the fight to operate the robot. This trained operator remains at a distance and directly controls the movements of the robot. There is a limited range of operation from the operator to the robot (limited either by wireless signals or by a tether). The visual feedback from the robot comes to the operator on a small screen on the OCU. There is limited situation awareness of the environment unless the robot remains within line of sight. The visual perception is limited by the onboard camera viewpoint, known as the keyhole effect [11]. An alternative to tele-operation is supervisory control of the robot [12]. The robot operates autonomously for obstacle avoidance and responds to certain visual cues in the environment (e.g., hand signals from officers, targets identified by the vision system) using pre-determined protocols based on scene understanding [13-15]. The robot would convey its intentions for movement to one or more officers in the team. A robot operation officer would be equipped with a method to override the robot's next movement command(s), to supervise the robot's movements and then return control back to the robot as needed. Supervisory control requires that one or more officers be trained and equipped to provide direction to the robot, particularly when selecting between available actions in the course of the mission (e.g., determining which direction to pursue for search when more than one choice is available). However, supervisory control uses autonomy to offload much of the workload allowing the officer to perform his/her duties in the mission response while occasionally providing direction to the robot [12].

IV. User Studies and Training Exercises

The Mississippi State University research team was invited to observe and participate in monthly team training sessions with the Starkville City Police, Choctaw County Sheriff's Office, and the Mississippi State University Police Departments' SWAT teams for the past year. For the first six months of training the research team observed the SWAT team members performing their typical and required training. It was important to learn the process and the models/methods they used for communication and interactions among the team members. As a result of these observations, two roles were highlighted for their importance in team performance, and those were the roles of *Point* (first person in) and *Rear-Guard* (last person in). It was these roles that seemed the most interesting to explore whether a robot could provide support or fulfill these roles as part of the team. Additionally, an evaluation was performed to determine if one particular ground robot would be preferred over another.

A. Roles Evaluated

The hypothesis (H1) for the evaluation of roles integrated in with a SWAT team (for human team members the roles are *Point, Member of the Stack,* and *Rear-Guard*), it was expected, based on comments from prior training exercises that the robot in the *Point* role would be preferred to the robot in the *Rear-Guard* or *Member of the Stack* role[1].

1) Point Role – In this role, the SWAT team member or the robot would be the first "man" in the room. The officer in this role leads members of the team into a room and serves as the forward "eyes" of the stack. When entering a room, this officer will capture the attention of any occupants in the room. In the case of the robot, it would take the attention away from any of the human team members attempting to enter in behind the robot. The robot would provide "eyes" and possibly "ears" in non-secure locations without endangering the officers. The robot could provide communication with victims, hostages, and suspects. It would serve as a guide to the SWAT team and establish the

Figure 1: Husky A200 Robot from Clearpath Robotics, Inc.

[1] Due to the time limitations available for training only the *Point* and *Rear-Guard* positions were evaluated with the robot. The *Member of the Stack* position was not evaluated in this training exercise.

pace for the team upon entry. Additionally, if the robot is equipped with high intensity lights during night operations it could provide a visual shield to blind suspects and to protect the officers from detection, keeping them safer during entry into unknown and/or dangerous environments. The noise from the robot would also provide cover for the movements of the team. In the *Point* role, the robot moves in advance of the team and, while the noise will alert a suspect that a search is taking place, the robot's position between the suspect and the team allows the noise from its movements to mask the noise from team movements and potentially draw the suspect out of hiding well ahead of the team.

2) Rear-Guard Role – This role provides cover behind the team. The *Rear-Guard* is the last officer in the room and makes sure that secure areas remain secure. An officer trained as a sniper often covers this role. In this role for example, the robot could serve as a "pack mule" for the team carrying essential equipment, gear, and/or supplies. It would follow the team at a distance of three to six meters into a facility. Depending on the capabilities of the robot it could assist with casualty evacuation [10]. The robot in this role could potentially reduce the load team members must carry, which in turn could improve team performance. A concern with having the robot in the *Rear-Guard* role is that it would no longer provide cover for the movements of the officers. If the robot is in a role that follows the team, then the team will be placed between the suspect and the robot. Due to the noise produced by the robot it will be evident that a search is taking place, and the suspect may be more alert to sounds that the team may make on approach. If a suspect should investigate the noise produced by the robot, the team will be more vulnerable being placed between the source of the noise and the suspect.

B. Robots Evaluated

As part of this research, the MSU research team evaluated the responses of SWAT team members to two different unmanned ground robots. The first robot was the Husky A200 from Clearpath Robotics, Inc. (See Figure 1) [16], and the second robot was the MMP-30 built by the Machine Lab (See Figure 2) [17] and customized by Clearpath Robotics, Inc. [16]. The Husky A200 robot is a differential drive wheeled robot that weighs approximately 110 pounds with payload and has a top speed of 1.0 m/sec. The MMP-30 is a differential drive tracked robot that weighs approximately 50 pounds with payload and has a top speed of approximately 1.2 m/sec. During training exercises it was discovered that the Husky A200 was capable of pulling a 200-pound SWAT officer in full gear down a hallway, so it is expected that this robot could potentially perform casualty evacuation.

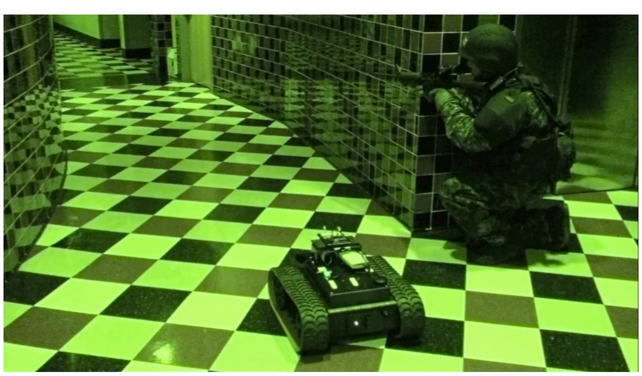

Figure 2: MMP-30 robot from the Machine Lab customized by Clearpath Robotics, Inc.

One aspect of the current research is to evaluate how differences in characteristics of the two robot platforms (i.e. size, speed, and maneuverability) mediate acceptability of a platform in the two selected roles: *Point* and *Rear-Guard*. The hypothesis (H2) for this evaluation was that the SWAT team members would prefer the MMP-30 robot (due to its smaller size, faster speed, and maneuverability) to the Husky A200 robot for integration as a SWAT team member.

C. User Study and Evaluation During Training Exercise

A study was conducted with two unmanned ground robots at the Center for Advanced Vehicular Systems (CAVS) located on the Mississippi State University (MSU) campus. The study involved the lower level of the facility and the officers trained on *slow and methodical entry* incorporating robots in with the team (See Figure 3). Role players were used as suspects during the search. *Note:* Six of the SWAT team members had previous interactions with the Husky A200 in two prior training sessions held in a different location on the MSU campus. The results from the prior robot trainings will not be presented as part of this paper.

1) Participants – The participants for this user study were members of the Starkville City Police and the Mississippi State University Police Department SWAT teams. A convenience sample of nine officers was present for the field training exercise and agreed to provide feedback on the robot platforms. The teams were integrated, as they often assist each other during incident responses and train together. This data collection was not a formal laboratory experiment, but rather it was a field study in which the research team was permitted

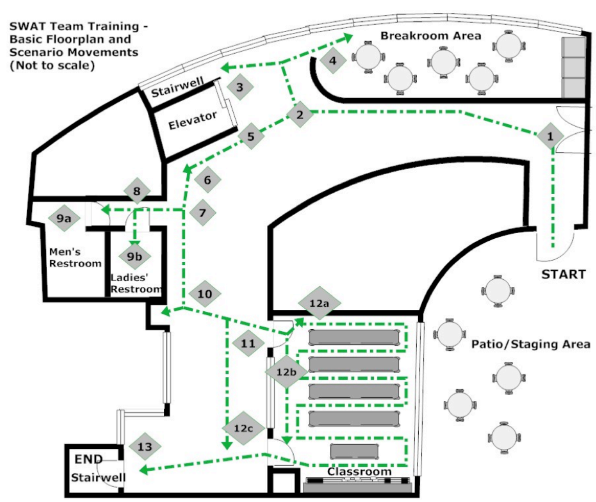

Figure 3: Floorplan of SWAT Team Training Scenario

to integrate robots in with an existing training exercise. Proper IRB approval was obtained for this field study data collection.

2) Methods and Evaluation – For this study the research team performed two different evaluations. The first evaluation used the Husky A200 robot and compared SWAT team members' responses for the robot operated in the *Point* role with the robot in the *Rear-Guard* role. In the second evaluation the SWAT team members were asked to compare the Husky A200 robot with the MMP-30 robot both operating in the *Point* role. SWAT team members completed a questionnaire after each scenario. After the evaluations were completed a debriefing discussion session was conducted with the officers to obtain their thoughts regarding the use of the robots and the integration of robots as part of the team.

a. Evaluation 1 Procedure (Roles Evaluation) – SWAT team members performed a slow and methodical search of the downstairs space at CAVS (See Figure 3). The nine officers allowed the Husky A200 robot to take the *Point* role in the team. The team was not responsible for operating the robot during the exercises. The robot was tele-operated in a manner that would emulate autonomously programmed behaviors. The team was aware of and could observe the tele-operator during the exercises, but had no input on the behaviors the robot performed. The operator was placed in a location that was analogous to where a SWAT officer operating the robot would be located. Since the team was aware of the tele-operator, it is not clear if that impacted how comfortable the team was with the robot or whether they would have responded differently if they believed the robot was truly operated autonomously. This would require further investigation.

The robot and team members slowly and methodically followed the path indicated in Figure 3. The Husky A200 was capable of pushing open heavy doors; however the officers would open the doors for the robot when needed. The Husky robot, because of its size, was not able to navigate the aisles of the classroom (locations 11-12 in Figure 3) to search and clear the room. Instead it waited at the exit point until the team to caught up after clearing the classroom. The same procedure was repeated with the Husky A200 robot serving in the *Rear-Guard* role. The behavior patterns for this scenario were essentially the same; the primary difference was the location of the robot. The robot followed the team members and maintained a three to six meter distance from the trailing team member.

Following each of the slow and methodical entry and search scenarios, each team member completed a questionnaire with their evaluation of the robot in the role it performed (e.g., *Point* or *Rear-Guard*).

b. Evaluation 2 Procedure (Robot Evaluation) – SWAT team members completed the slow and methodical search with first the Husky A200 robot and later with the MMP-30 in the *Point* role[2]. As discussed in the *Evaluation 1 Procedure,* the robot was tele-operated as if operating with autonomous behaviors and SWAT team members were not responsible for controlling the robot. Team members were aware that the robot was tele-operated and could observe the tele-operator. The officers were not able to provide any input into the behaviors of the robots.

The same scenario from the *Evaluation 1 Procedure* was used for this evaluation. The Husky A200 robot spent more time maneuvering in the hallway to provide cover for the team movements. The motors and tires from the skid steering provided more noise to mask team movements. The Husky A200 robot was able to open doors for officers in all but one instance where it hit the door at an angle the prevented it from pushing the door open. The procedure was repeated with the MMP-30 robot in the *Point* role. The MMP-30 robot moved more quickly and was much quieter than the Husky A200. The MMP-30 had more difficulty with opening doors due to its lighter weight and tracks. The tracks caused the MMP-30 to crawl up a door rather than push the door open; therefore after this happened once it was no longer used to open doors for the officers. The MMP-30, because of its size and speed was capable of thoroughly searching each aisle in the classroom for suspects. During this process, the SWAT officers waited in the hallway until it was deemed safe to enter and then carefully searched, cleared, and secured the room using their own search procedures following the robot's search.

Following each scenario, each team member completed a questionnaire with his evaluation of each of the robots in the role of *Point.*

3) Results – For the evaluation of the Husky A200 robot in the *Point* and the *Rear-Guard* roles, team member survey responses indicated that they would work with the robot but that the team members preferred the robot in the *Point* role (100% of respondents). These results support hypothesis H1 that the officers would prefer the robot operating as the *Point* role. Figure 4 depicts the mean responses to specific items on the questionnaire. Team members rated the robot in the *Point* role as more appealing (*Point:* M=5.78, SD=1.2; *Rear:* M=3.89, SD=1.4; t=3.005, $p < .01$), more helpful (*Point:* M=6.00, SD=1.0; *Rear-Guard:* M=3.33, SD=1.4; t=4.619, $p < .001$), more trustworthy (*Point:* M=5.67, SD=0.9; *Rear-Guard:* M=4.56, SD=0.9; t=2.697, $p < .05$), and more cooperative (*Point:* M=5.78, SD=1.1; *Rear-Guard:* M=4.33, SD=0.9; t=3.108, $p < .01$). Team members also reported that they liked the robot more (*Point:* M=6.33, SD=0.7; *Rear-Guard:* M=4.11, SD=1.7; t=3.636, $p < .01$) and were marginally more attentive to the robot (*Point:* M=4.89, SD=0.6; *Rear-Guard:* M=4.11, SD=1.1; t=1.923, $p < .10$) in

[2] Due to time limitations, the robot order was not balanced. Also, this was not a formal laboratory experiment but rather the research team was permitted to integrate robots into an existing field training exercise.

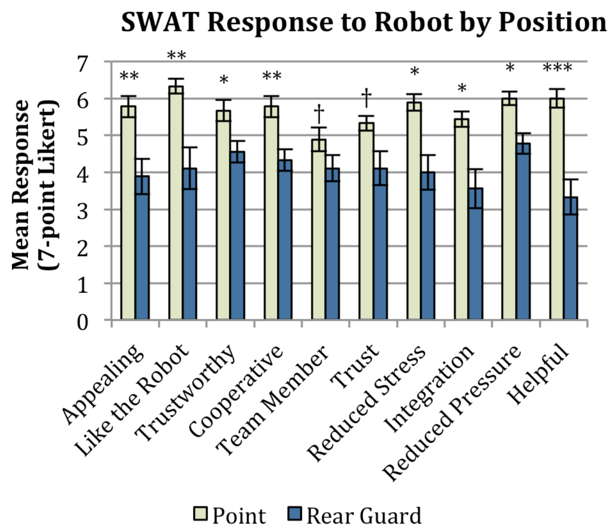

Figure 4: Significant results of the survey of SWAT team members for the Husky A200 in the *Point* and *Rear-Guard* roles. *** $p < .001$; ** $p < .01$; * $p < .05$; † $p < .10$.

the *Point* role compared to the *Rear-Guard* role. Team members perceived the robot in the *Point* role to be better integrated with the team (*Point:* M=5.44, SD=1.1; *Rear-Guard:* M=3.56, SD=1.6; t=2.905, $p < .05$) with less stress (*Point:* M=5.89, SD=1.4; *Rear-Guard:* M=4.00, SD=1.4; t=2.884, $p < .05$) and pressure (*Point:* M=6.00, SD=1.2; *Rear-Guard:* M=4.78, SD=0.8; t=2.475, $p < .05$) as a result of the robot's presence.

Perceived ruggedness (*Point:* M=6.00, SD=1.1; *Rear-Guard:* M=5.22, SD=1.1), comfort level (*Point:* M=4.33, SD=1.9; *Rear-Guard:* M=4.33, SD=1.1), robot attentiveness (*Point:* M=5.00, SD=1.2; *Rear-Guard:* M=4.11, SD=1.1), and safety (*Point:* M=5.11, SD=1.8; *Rear-Guard:* M=3.67, SD=1.8) were not significantly different across the two roles. In both roles, team members indicated that they perceived the robot's speed to be sufficient or slightly slower than they would prefer (*Point:* M=4.78, SD=0.8; *Rear-Guard:* M=3.89, SD=1.9).

For the evaluation of the Husky A200 and the MMP-30 in the *Point* role, there were no significant differences in team member responses to the survey questions by robot platform. These results do not support hypothesis H2, which stated that the MMP-30 would be preferred to the Husky A200 robot. However anecdotal comments provided during the debriefing discussions indicated that officers did have a preference for the Husky A200 robot.

V. Discussion

A candid group discussion with the nine officers during the post-study debriefing session provided surprising insights that were not revealed through the survey data.

1) Surprise Factor – As a group, the officers commented that they felt the noise of the Husky A200 robot provided excellent cover for team movements and felt safer having the robot serving in the *Point* role. The noise of the robot was louder than the noise made by the officers. The robot in this role would move between the suspect and the officers and with the robot noise it would not be evident to the suspect the movements of the officers. The robot movements and sounds masked the sounds made by the officers. This provided an additional layer of protection between the suspect and the officers. Also, if the suspect investigates the sounds of robot the officers will then learn the location of the suspect.

This effect of the robot's movements and sounds was highlighted when one of the officers decided to hide in a stairwell at the end of the hallway to listen to what the Husky A200 robot would sound like as a suspect hiding. His comment was "I would not want to be the suspect hiding from that robot." He expressed that the sounds resulting from the Husky A200 movements were intimidating because it would be unclear what was coming and it masked the sounds of the team moving. If the team was between the suspect and the robot then the teams' movements could be heard over the robot movements because the team would be closer to the suspect than the robot. There was a strong preference by all nine of the officers to have the robot serving in the *Point* role because the robot would be placed between the suspect and the team and provided a masking noise and distraction to provide an additional level of protection for the team.

2) Robot-Team Integration – Although the survey data did not indicate a preference between the two robots tested, during the debriefing discussion, at least three of the officers commented that if they could only choose one robot it would be the Husky A200. This was surprising as the MMP-30 robot was smaller, was better able to search confined and cluttered spaces, moved more quickly, and was more maneuverable during team integration.

There are three factors that may have contributed to this surprising discussion regarding how the team perceived the two robots: (a) predictability, (b) toughness/ruggedness, and (c) reliability. Traditional human-robot interaction focuses on the agreement between the capabilities of the equipment and the needs of the operators. Task analyses, interface design, prototyping, and field validation activities are all geared toward verifying that the system design is appropriate for the tasks at hand [18, 19]. The primary goal is to design a robotic system that an operator can interact with seamlessly while maintaining awareness of both the robot performance and the current situation status.

From a tactical operations perspective, a slow and predictable response seems to be preferred over a fast but less predictable response. There are a number of potential factors in play:

a) Agreement between robot movement characteristics and the movement dynamics of the team. In a tactical operation the pace of the team is set by the *Point* role. This might explain why the Husky's slow and precise movement patterns would be preferable to the MMP-30's faster and more erratic movements. Fast and erratic movements within a SWAT team are considered undesirable to the team and they train extensively to overcome this movement response often attributed to the adrenaline released during these types of operations. The Husky A200 sets a slower and more predictable pace for the team. A primary purpose of integrating robots into this field training was to determine if there would be a preference between two different robots with different capabilities. The movements of the robots were not choreographed and matched between the robots because it was important to showcase the differences in capabilities between the robots for the team.

b) Perceived ruggedness and robustness of the robot in a support role. The Husky A200 is a noticeably larger and more rugged robot, which is more congruent with the SWAT team identity and personality. One of the officers commented on the ruggedness of the Husky A200 because it was able to pull a fully geared SWAT officer down the hallway in a previous training exercise and that was part of the debriefing discussion on one of the differences between the robots. One of the officers also commented on the Husky A200's ability to push open the doors on its own, requiring less officer assistance. SWAT teams identify with being tough and rugged, able to endure many challenges, and the Husky A200 robot personified this for the team.

c) Perceived reliability of the robot in field operations. A slower robot motion profile may be preferable because it allows more effective time-sharing between the tasks of monitoring the robot response and clearing the room – the predictability of the robot's movements allow for less frequent checks of the robot's path (i.e., supervisory control), so that more cognitive resources are available for securing the environment [12, 20]. Limitations in maneuverability may be less apparent when team members are more focused on the current situation. A faster-moving robot that is less predictable may require re-orientation to the robot's current location, increasing stress and cognitive demand on team members (and potentially a hazard to team mobility; see also [21], for other interaction examples).

VI. CONCLUSIONS

The primary observation from the current project was that a robot could be perceived as a SWAT team member and not merely a piece of equipment. The SWAT team members, consistent with the computers as social actors theory developed by Nass *et al.* [22], strongly identified with the robots and assigned personality characteristics and names to the robots. One of the officers named the Husky A200 robot "*Hefty*" because of its ability to pull an officer down the hallway and because of how rugged it was during operations. Another officer named the MMP-30 robot *"Jonesy"* because it reminded him of a high-energy fellow officer he worked with closely. Within a few minutes all of the officers were calling the robots by these names and most commented that the names were fitting. These characteristics in turn impacted how the team members viewed the robots' performances – the robot that best fit the pace and style of the team was preferred, even when that robot was anticipated to have greater mobility limitations in a mobility-critical environment. This effect did not appear to be impacted by the person that was tele-operating the robot but were directly related to the characteristics attributed to the robot and mentioned in anecdotal comments by team members during the training and in the debriefing discussion.

The second observation was that regardless of the robot used, the *Point* role is preferable to a *Rear-Guard* role, even when the robot may be well suited to a support role (e.g., casualty evacuation). Having the robot be the first 'man' in has several advantages: distraction, cover, and reconnaissance, and it also allows the team to monitor the robot's movements more effectively than if the robot is behind them and the primary threat is ahead.

It should be noted that in these instances, the robot determined the speed of engagement, even the more mobile of the robots slowed team response time. Given the emphasis on security (and on training), this was not a major concern for the team members. However, the potential for increased time stress in actual field operations should be considered prior to introduction in field deployments.

The results of this research could be applicable to other tactical operations, such as observed in military operations [15]. The use of ground robots in this manner could be helpful in any tactical operations in which the robot could provide extra cover through the use of lighting and sound, in addition to visual feedback to users. The use of ground robots in this manner may also be helpful in disaster response, especially in cases of terrorist attacks if the suspects may still be in the area of the attack. The use of supervised autonomy with search and rescue teams would also be beneficial for use in disaster response. The robot would take the lead to identify potential dangers and allow the rescuers to focus on finding and assisting victims.

The focus of future research efforts is the development of the supervised autonomy components. Additionally, there is a need to develop visual systems for detecting and interpreting SWAT team movements and gestures in challenging environments (e.g., low-to-no light, smoke-filled rooms, etc.) [15]. There is ongoing research associated with conveying the robot's intent to officers during covert night operations through the use of infrared lighting signals visible with night vision goggles and with audible messages communicated through Bluetooth communications. This research was beyond the scope of this paper and will be presented in future publications.

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References

[1] C. Lundberg and H. I. Christensen, "Assessment of Man-Portable Robots for Law Enforcement Agencies," presented at the 2007 Performance Metrics and Intelligent Systems (PerMIS'07) Workshop, Gaithersburg, MD, 2007.

[2] K. Schreiner, "Operation: Microrobot," *IEEE Intelligent Systems and their Applications,* vol. 14, pp. 5-7, Jan/Feb 1999.

[3] M. Fielding, J. Mullins, B. Horan, and S. Nahavandi, "OzBot - haptic augmentation of a teleoperated robotic platform for search and rescue operations," presented at the IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR2007), Rome, Italy, 2007.

[4] J. Kumagai, "Techno cops [police robotic and electronic technology]," *IEEE Spectrum* vol. 39, pp. 34-39, 2002.

[5] L. Yue, H. Qiang, H. Yuancan, Z. Liancun, G. Junyao, and T. Ye, "A Throwable Miniature Robotic System," presented at the 2011 IEEE International Conference on Automation and Logistics (ICAL), Chongqing, China, 2011.

[6] H. G. Nguyen and J. P. Bott, "Robotics for Law Enforcement: Applications Beyond Explosive Ordnance Disposal," in *SPIE International Symposium on Law Enforcement Technologies*, Boston, MA, USA, 2000.

[7] I. Burt, A. Drenner, C. Carlson, A. D. Kottas, and N. Papanikolopoulos, "Impact Orientation Invariant Robot Design: An approach to Projectile Deployed Robotic Platforms," presented at the IEEE International Conference on Robotics and Automation (ICRA 2006), Orlando, FL, 2006.

[8] L. J. Blitch, "Semi-autonomous tactical robots for urban operations," presented at the Intelligent Control (ISIC), 1998. Held jointly with IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA), Intelligent Systems and Semiotics (ISAS), , Gaithersburg, MD, 1998.

[9] H. L. Jones, S. M. Rock, D. Burns, and S. Morris, "Autonomous Robots in SWAT Applications: Research, Design, and Operations Challenges," presented at the 2002 Symposium for the Association of Unmanned Vehicle Systems Internations (AUVSI '02), Orlando, FL, 2002.

[10] G. Gilbert, T. Turner, and R. Marchessault, "Army Medical Robotics Research Report," U.S. Army Telemedicine and Advanced Technology Research Center (TATRC), Fort Detrick, MD. 2007.

[11] M. Voshell, D. D. Woods, and F. Phillips, "Overcoming the Keyhole in Human-Robot Coordination: Simulation and Evaluation," presented at the Proceedings of the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando, FL, 2005.

[12] G. Taylor, R. Fredericksen, J. Crossman, M. Quist, and P. Theisen, "A Multi-Modal Intelligent User Interface for Supervisory Control of Unmanned Platforms," presented at the 2012 International Conference on Collaboration Technologies and Systems (CTS), Denver, CO, 2012.

[13] M. Manigandan and I. M. Jackin, "Wireless Vision Based Mobile Robot Control Using Hand Gesture Recognition Through Perceptual Color Space," presented at the 2010 International Conference on Advances in Computer Engineering (ACE), Bangalore, Karnataka, India, 2010.

[14] K. R. Konda, K. Achim, H. Schulz, and D. Schulz, "Real Time Interaction with Mobile Robots Using Hand Gestures," presented at the Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction, Boston, Massachusetts, USA, 2012.

[15] S. M. Fiore, N. L. Badler, L. Boloni, M. A. Goodrich, A. S. Wu, and J. Chen, "Human-Robot Teams Collaborating Socially, Organizationally, and Culturally," presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2011.

[16] Clearpath. (2012, September 21). *Clearpath Robotics - Husky A200*. Available: http://www.clearpathrobotics.com/husky

[17] MachineLab. (2012, September 21). *MMP-30 Mobile Robot Platform*. Available: http://www.themachinelab.com/MMP-30.htm

[18] W. Fastenmeier and H. Gstalter, "Driving Task Analysis as a Tool in Traffic Safety Research and Practice," *Safety Science,* vol. 45, pp. 952-979, 2007.

[19] D. O'Hare, M. Wiggins, A. Williams, and W. Wong, "Cognitive Task Analyses for Decision Centred Design and Training," *Ergonomics,* vol. 41, pp. 1698-1718, 1998.

[20] T. B. Sheridan, "Supervisory Control," in *Handbook of Human Factors and Ergonomics* G. Salvendy, Ed., ed New York, NY: Wiley, 1997.

[21] N. A. Stanton, R. Stewart, D. Harris, R. J. Houghton, C. Baber, R. McMaster, P. Salmon, and e. al., "Distributed Situation Awareness in Dynamic Systems: Theoretical Development and Application of an Ergonomics Methodology," *Ergonomics,* vol. 49, pp. 1288-1311, 2006.

[22] C. Nass, J. Steuer, and E. R. Tauber, "Computers are Social Actors," presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'94), Boston, MA, 1994.