Squad-Level Soldier-Robot Dynamics: Exploring Future Concepts Involving Intelligent Autonomous Robots

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Abstract. Future U.S. Army robots are developing capabilities to better "see" (e.g., scan and recognize objects), "think" (e.g., recognize implications and decide on a best course of action), and "act" (e.g., execute actions). This report describes systematic feedback gained from active duty Soldiers with dismounted squad level experience, to identify preferences and levels of trust with regard to squad level robotic capabilities, roles, and tactics. Soldier-based feedback will inform ongoing programs of research regarding U.S. Army Autonomous Squad Member (ASM) capabilities, through validation of mission scenarios, information requirements, and tactical maneuvers.

Keywords: Army robotic systems · Ground robots · Autonomous systems · Squad performance · Squad tactics

1 Introduction

Robotics in general enable U.S. Soldiers to see, hear, touch, and/or manipulate objects from a distance. Army robotic applications include many thousands of assets deployed for diverse combat missions such as reconnaissance, logistics (e.g., carrying materiel), and retrieving the combat wounded [1, 2]. Remotely controlled ground robots have saved the lives of numerous Soldiers in explosive ordnance disposal missions [3]. Robots will soon play key roles in Army dismounted squads, and they are the focus of several DoD programs of research with regard to enhanced human-robot communication and autonomous capabilities [4]. For example, DARPA's [5] Legged Squad Support System is a "pack animal" controlled by spoken commands, that can follow a Soldier through rough terrain, and the Marine's Ground Unmanned Support Surrogate can sense and avoid obstacles while navigating user-provided paths [6]. The Army's Safe Operations in Urban and Complex Environments [7]; their Robotic Collaborative Technology Alliance [8] and ONR's [9] Maneuver Thrust Programs have focused on perception and intelligence technologies to enable robots to work more closely with humans (e.g., "follow the human," "follow these waypoints") for a mission's duration.

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The sheer number and diversity of U.S. Army robotic assets pose a challenge to human factors specialists to design systems that are simpler and easy to use [10, 11]. Ease of use is crucial to the warfighters who use these systems while maintaining awareness of their surroundings [12]. Designers must understand warfighter missions, task, and information requirements [13].

Robotic assets are evolving to become more autonomous and intelligent [14]. Future concepts include the transition from robots as tools to robots that can play a more intelligent and autonomous role within a squad [13]. This includes cognitive concepts such that the robot would, to some degree, be better able to "see" (e.g., scan and recognize objects), "think" (e.g., recognize implications and decide on a best course of action), and consequently, "act" [15]. As these more autonomous assets accompanies one of the teams, they need to perceive and label static elements of the environment (e.g., roads, trees or buildings), detect, and predict the activities of nearby humans. Ultimately, the goal is to develop robots that can be expected to interact with Soldiers, executing tactical actions as planned, yet able to act autonomously, or suggest changes in plans, when the situation requires it. Robots will be considered as partners to Soldiers, much as military working dogs are considered as a working unit with their handlers. Indeed, current and future scenarios include dyads and triads that integrate military working dogs, robotic assets, and human "handlers" [16]. For vehicle-based missions, autonomous assets include the concept of a vehicular armed robotic "wingman".

To further progress towards these goals, a research collaboration was initiated, drawing together researchers from the Naval Research Laboratory (NRL) and directorates of the Army Research Laboratory (ARL), within the Advanced Research Program Initiative (ARPI). ARL's Robotic Collaborative Technology Alliance (RCTA) supports this effort, and contributes by focusing on perception, detection and classification of objects [17, 18], and activities in the environment [19]. NRL provides advanced research on gesture and natural language interpretation. The overarching goal is a system that will use locally sensed and externally supplied information (e.g., maps, observations, and status reports) to populate its world model and to make inferences about its state and the state of its squad or team. The robot reasons about goals and appropriate actions which are then executed. An important action is to communicate relevant information to its squad mates.

2 Mission Scenario-Based Tactics and Requirements

As part of this research team, ARL Human Research and Engineering Directorate (HRED) outlined the means to validate a mission scenario to be used by ASM research teams, identify core tactics, and collect Soldier feedback pertaining to information requirements for each event that occurs within the scenario. During this effort, Soldiers were asked about robotic capabilities that would be most useful within the scenario, and within squad-level operations in general [20]. These interviews also served to explore issues of Soldier-robot dynamics within an operational context, in order to identify opportunities for robotic assistance. The interviews were based on specific mission scenario events, to elicit Soldier feedback on information requirements and robot/sensor capabilities.

24 Soldiers participated in these interviews and provided detailed feedback with regard to information and capability requirements, priorities of use, and recommendations for robot roles and responsibilities particularly with regard to how the Soldier would use an advanced robotic platform during each event. They were asked to consider in detail, mission events as they unfold, in order to capture experience based feedback with regard to questions such as “what information would you need now,” “what is likely to go wrong,” “what would you do next,” etc. These interviews resulted in feedback that identified priorities in robot capabilities, operational issues in robot deployment, and suggestions to developers [20]. The investigation was conducted in 2 phases. In Phase I, 12 junior enlisted Soldiers were recruited for the experimentally based assessment. In Phase II, 6 senior noncommissioned officers (NCOs) were recruited for the assessment.

2.1 Interviews

A scenario-based cognitive task interview approach was applied [21, 22]. For each interview session, the interviewer began with an explanation of the research goals, then introduced a scenario-based questionnaire, where specific events were described. The investigator probed for feedback with regard to each event pertaining to realism and likelihood, the typical reaction of squad members if faced with the scenario event, the type of information they would likely need or seek out, and the possible contributions of an ASM to that event. The interviewer encouraged discussion and captured Soldier comments with regard to refining, informing, or augmenting scenario content; and ASM capabilities and design considerations.

The questionnaire items were structured to poll the Soldiers on their opinions on the concept of employment for the ASM to include the following: location during the mission; actions by the squad leader, squad members, and the ASM during each of the trigger events; the ASM’s level of understanding of common military hand and arm signals and verbal commands; and the level of trust (from none to complete trust), that Soldiers had in the ASM to perform mission-related tasks. These questions also served as a precursor to the interview questions by establishing a foundation on which to base the ASM capabilities and employment considerations.

The interview questions were structured to poll the Soldiers on their opinions for key ASM capabilities and task performance to include the following:

- Top 3 capabilities for successful mission accomplishment
  - Top 3 capabilities or functions that would be nice to have
  - General concept of an ASM
  - Command and control of an ASM
  - Mission status, and general and specific capabilities, sensors, and mission tasks that should be considered for future ASM design and employment.

2.2 Junior Enlisted Responses

Trigger Events

Soldiers were asked a series of questions pertaining to what actions the squad leader (SL), the squad, and the ASM would take when a specific event occurred during the

Table 1. Trigger event 1: react to mortar attack, junior enlisted

Position	Summary of tasks or actions to be taken (Consensus of participants/General conclusions)
Squad leader	Yell incoming. Move self and squad out of impact area as quickly and safely as possible
Squad	React to SL commands and move out of impact area in direction given by SL
ASM	Follow squad. Try to identify direction of mortars. Scan area for safe route and alert squad
SL actions to reorient squad	Regroup in covered position. Check or verify status of personnel and equipment
Reorient ASM	Scan area for enemy. Determine alternate route to continue with the mission
ASM relocation choice	Equally split between not moving it to another position in the squad to moving it based on the situation and what task it is to perform

Table 2. Trigger event 2: react to sniper fire, junior enlisted

Position	Summary of tasks or actions to be taken (Consensus of participants/General conclusions)
Squad leader	Give order to take cover (move out of kill zone if necessary). Try to determine where sniper fire originated from
Squad	Take cover. Determine where sniper fire is coming from. Provide suppressive fire on sniper's location
ASM	Scan area and detect sniper's location
SL actions to reorient squad	Eliminate sniper if tactically feasible. Continue mission on planned or alternate route as necessary
Reorient ASM	Determine route to engage sniper or to continue mission. Notify higher echelon of situation. Continue to scan for enemy threats
ASM relocation choice	ASM should move out of danger area to protect itself. Could be used as cover for squad if necessary

conduct of the mission. Follow-up questions were then asked on what actions were necessary to reorient the squad and the ASM to continue the mission. Tables 1 and 2 provide a summary of their responses to 2 events: Mortar attack and Sniper fire.

Trust in ASM to Conduct Tasks

Soldiers were asked to identify what tasks they had complete trust, some trust, and no trust in for the ASM to conduct. Soldiers had complete trust in the ASM to scout or check routes, check for IEDs, and know its location via GPS. Soldiers had some trust in the ASM to evacuate casualties. Soldiers had no trust in the ASM to engage the enemy if the ASM had a weapon system, without human intervention. The complete lists of responses to the areas of trust are tabulated in Appendix C with many single responses for most tasks identified without a general consensus among Soldier.

ASM Capabilities: Priorities

The following table provides the top three capabilities listed by junior enlisted for ASM squad level robotics (Table 3).

Table 3. Necessary and nice-to-have priorities, junior enlisted

Priority	Necessary	Nice to have
1	Navigation of terrain	1. Capability to transport supplies and equipment 2. Weapon system
2	1. Identification of targets and scanning for enemy 2. Night vision/thermal instrumentation	Carry first aid supplies and evacuate casualties
3	Load carrying ability	1. Transport litters and casualty evacuation aid 2. External power source for recharging batteries

ASM Concept

Eleven of the 12 Soldiers felt that the ASM was a good idea. The dissenting Soldier based his response on the lack of trust he had in it to complete tasks and stated he was not a fan on technology. Soldiers liked the idea of reducing their load by offloading it to the ASM. Providing additional security was also indicated as an asset. Seven of the 12 Soldiers indicated that the ASM should understand verbal commands as the primary means of maintaining command and control of it. Soldiers were nearly unanimous (11 of 12) that the ASM should provide a reminder of the mission objective after an interruption of the mission occurred, feeling that this could be helpful to a task saturated squad leader. 11 Soldiers agreed that the ASM would be an aid if it informed the squad of reaching phase lines, lines of departure, etc. on time. This would confirm that the mission was proceeding on schedule and the squad was in the right location. Nine Soldiers indicated that they would like the ASM to have a weapons platform mounted on it. Seven of those nine Soldiers indicated they preferred another Soldier to be "in the loop" for conducting the actual engagements with the weapon system. Eight of the Soldiers preferred a remote device for weapon system control, primarily to prevent a Soldier from being exposed to friendly fire. Soldiers did not trust the decision making capability of the ASM to provide autonomous engagements for fear of fratricide, out-of-range engagements, and safety. Soldiers were nearly unanimous (11 of 12) that the ASM should be configured for casualty evacuation. Eight of those 11 Soldiers indicated that the ASM should not evacuate the casualties alone to the casualty collection point because a human would be necessary to accompany the ASM to return fire and protect the casualty. Eight of the 12 Soldiers felt that the ASM should have a smoke-producing capability with seven of those preferring a dispenser to a generator-based capability. Soldiers were unanimous that the ASM should have a chemical detection or alarm system. They saw it as being able to provide real-time warnings and reporting since Soldiers do not continuously monitor for chemical threats. Soldiers were unanimous that the ASM should have a shot detection capability that provides the location, distance, and azimuth to the shooter and caliber of the weapon fired.

2.3 Noncommissioned Officer (NCO) Responses

Six senior enlisted Soldiers were recruited for this phase of the experimentally based assessment. The Soldiers completed a demographics questionnaire initially to determine their military background and experience. They had an average age of 29 years with an average time in service of 9.5 years. There was 1 E-5 promotable and 5 E-6 s and all were MOS 11B. All of the senior enlisted Soldiers had at least 1 deployment (3 to Afghanistan, 4 to Iraq, and 4 to Kuwait). Four of the 6 deployed Soldiers had experience with robots during their deployments (3 in Afghanistan and 1 in Iraq) in an Infantry unit.

Trigger Events

Soldiers were asked a series of questions pertaining to what actions the Squad Leader the squad, and the ASM would take when a specific event occurred during the conduct of the mission. Follow-up questions were then asked on what actions were necessary to reorient the squad and the ASM to continue the mission. The following tables provide summary responses for two events: Mortar attack and Sniper fire (Tables 4 and 5).

Table 4. Trigger event 1: react to mortar attack.

Position	Summary of tasks or actions to be taken (Consensus of participants/General conclusions)
Squad leader	Determine new course. Provide squad with a distance and direction to move. Continually assess the situation
Squad	Move to rally point given by the squad leader (distance and direction of movement). Maintain security during movement
ASM	Try to identify direction of mortars. Scan area for safe route and move with the squad
SL actions to reorient squad	Regroup in covered position. Check with team leaders. Reorganize and consolidate as required
Reorient ASM	Follow directions of squad leader and continue movement with the squad
ASM relocation choice	Four of the 6 favored moving it to another position based on the situation and what just happened on the mission

Trust in ASM to Conduct Tasks

Soldiers were asked to identify what tasks they had complete trust, some trust, and no trust in for the ASM to conduct. There was no consensus in any of these areas and the most common responses are cited as follows. Soldiers had complete trust in the ASM to carry the gear and evacuate casualties. Soldiers had some trust in the ASM to conduct reconnaissance and send some reports. Soldiers had no trust in the ASM to engage the enemy if the ASM had a weapon system, without human interface and to completely move and think on its own.

Unlike the junior enlisted Soldiers, the senior Soldiers were less positive in their support for an ASM to augment the squad and did not see the potential to reduce the Soldier load, increase lethality, and provide location and route information without

Table 5. Trigger event 2: react to sniper fire

Position	Summary of tasks or actions to be taken (Consensus of participants/General conclusions)
Squad leader	Take cover. Try to determine where sniper fire originated from. Report situation to higher
Squad	Take cover. Determine where sniper fire is coming from. Maintain security
ASM	Determine sniper's location
SL actions to reorient squad	Eliminate sniper if tactically feasible via fire and maneuver. Continue mission on planned or alternate route as necessary
Reorient ASM	Continue to scan for enemy threats. Move to appropriate position
ASM relocation choice	Four of the 6 felt that the ASM should move out of danger area to protect itself and then scan for potential targets

committing a dedicated operator for command and control of the ASM. The senior enlisted Soldiers shared similar opinions with the junior enlisted Soldiers that for the ASM to be considered helpful and not a burden to the squad, it must demonstrate reliability, navigational capability, and be available at all times to conduct a mission from start to finish. Similarly, the two groups of Soldiers agreed that the ASM operation and sensor packages must conform to noise and light disciplines encountered by forces operating in all geographic terrain and mission contingencies.

3 Soldier Analyses of Map-Based Information

Additional questions were developed to gain detailed feedback from Soldiers with regard to operational relevance, information requirements, tactical options, and decision processes that can be inferred through map-based information, to enable programmers to strive towards robot-based inferences of the same information. Given the background and map-based information, Soldiers were asked to identify information contained in the map that would guide tactical decision making. This information will drive more autonomous robot-based decision-making and response.

3.1 Participants

A total of 12 Soldiers were recruited for this experiment. The Soldiers completed a demographics questionnaire to determine their military background and experience. They had an average age of 37 years with an average time in service of 15 years. They ranged in rank from E-5 through O-3 and had one of the following military occupational specialties (MOS): 11A, 11B, 11C, 19D, or 19K. These MOS reflected an Infantry officer (1), Infantryman (7), Mortar man (1), Cavalry Scout (2), and an M1 armor crewman (1). All of the 12 Soldiers had been deployed. They collectively had 14 deployments to Afghanistan, 21 deployments to Iraq, and 6 deployments to Kuwait. Five of the Soldiers had experience with robots during their deployments, with three associated with an Infantry unit, and two in reconnaissance units. These robots were used to scan for possible improvised explosive devices (IEDs), detonate IEDs, Raven recovery, and for overhead surveillance. Additionally, one Soldier was involved with the testing of a squad ground robot while at Ft. Bliss.

3.2 Interviews

After each Soldier completed the informed consent and demographics forms, they were given a detailed description of a route reconnaissance scenario, a map depicting the route (Fig. 1), a written specification of key events, and completed a detailed questionnaire without relating it to an autonomous squad member (ASM). After each Soldier completed the questionnaire, they were given a detailed description of selected contingency missions (Fig. 2) to determine key capabilities and tasks without and with an ASM in order to support a successful mission.

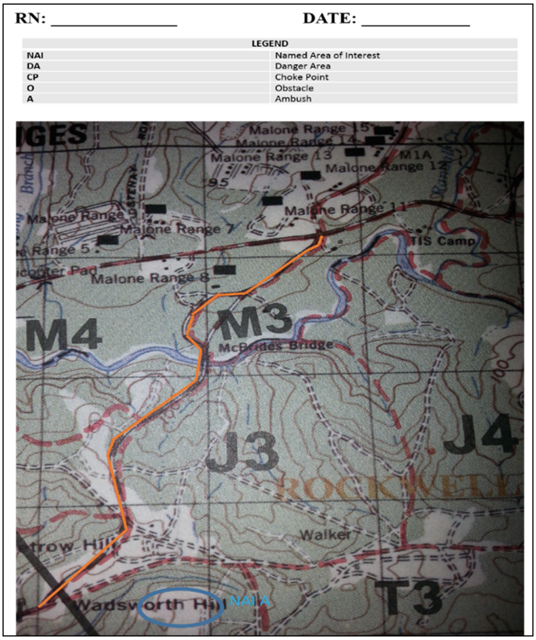

Fig. 1. Mission planning map

Soldiers provided specific feedback regarding map-based information, and identified information that should also be provided, along with implications of information. Given information provided, they specified implications and conclusions with regard to route selection, danger areas, choke points, obstacles, ambush areas, and squad formations. The following section summarizes the results.

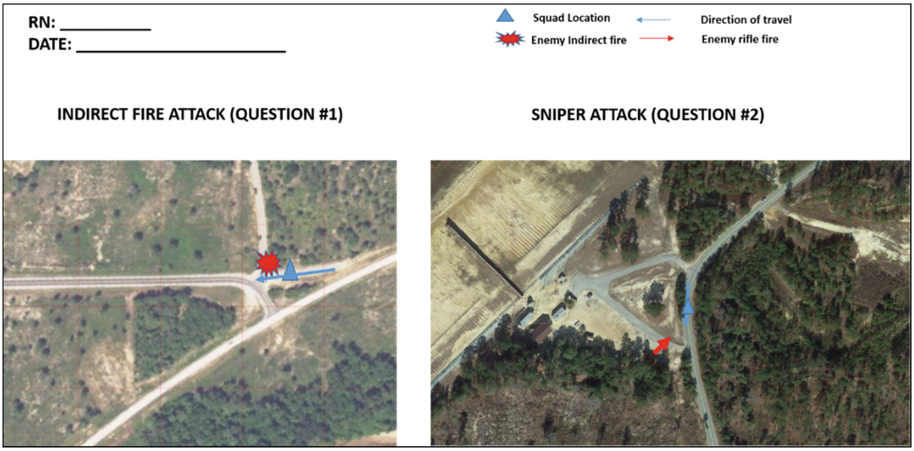

Fig. 2. Contingency missions maps

3.3 Mission Planning

ASMs can support mission planning through access to operational information. Soldiers emphasized the need for current information on IED attacks, locations, detonation techniques used, and the types of IEDs used. This information would be useful to identify the current threat in the area and also identify previous attack locations so that security could be more effective in those areas. Additional support such as air support, medical evacuation (MEDEVAC), and fire support available was also of major interest. MEDEVAC support available was identified as needed in order to plan for casualty evacuation and casualty collection points. Similar to IED intelligence, Soldiers wanted recent information about enemy activities in the area, past ambush sites, and rules of engagement. This information was important for planning the route and what type of formation to use in danger areas. Soldiers would ask the platoon leader for information pertaining to: aerial reconnaissance assets available and past reconnaissance information, rally point locations, target reference points (TRPs), and other items pertaining to the commander's intent.

4 Conclusions

A key difference between junior and senior enlisted Soldiers is the degree of trust in more autonomous robotic systems. Based on the lack of trust, especially with the senior enlisted Soldiers who will be the decision makers within the squad, new equipment training could be used to increase the trust in the ASM. The training will have to be thorough, put the ASM through its paces, and demonstrate the ASM's full range of capabilities for the Soldiers to accept it as "an additional squad member" and use it in an autonomous role or mode to its full capacity.

- The ASM must be dependable and reliable to accompany the squad on any mission for it to be totally accepted as a squad asset by all squad members. Otherwise, there will be a tendency to leave it in the rear.
- The ASM should be modular in design and capabilities with the ability to quickly mount and remove sensor packages and accessories without special tools to make it adaptable and efficient for any mission.
- Actions of the leaders, squad members, and ASM for each of the trigger events and interview results identified in the body of the report should be useful as insights for the computer programmers to define squad actions for those and similar trigger events.

Soldier feedback converged on the following primary capabilities or characteristics of the robots as contributing factors to the robot's successful mission accomplishment:

- Maneuverability
- Speed of traversing the route
- Sensor packages
- Capability to negotiate any type of terrain

Other characteristics identified of lesser importance included: ability to lift or carry objects, weight/transportability, size, and load carrying capability.

The nearly unanimous choice of the Soldiers for a combination of tele-operated and autonomous operation indicates a definite concern about allowing the intelligent robot always to take actions on its own. As autonomy increases there is an increase in the necessity that their operator, supervisor, or teammate have an accurate understanding of autonomous agent's actions, environment, reasoning, projections, and uncertainty calculations [23]. Soldier insights and recommendations in general are consistent with sound military judgment, and it should be noted that the Soldiers of this rank and experience will be the leaders and unit trainers of the end users once an ASM is fielded. They will directly influence their subordinates about the capabilities and limitations of any system that is a squad asset. Issues identified in this report directly relate to issues currently being investigated regarding the development and distribution of more autonomous robotic systems for Army operations [24].

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