FIELD REPORT

Long-Term Study of a Portable Field Robot in Urban Terrain

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The armed forces have a considerable amount of experience in using robots for bomb removal and mine clearing. Emerging technology also enables the targeting of other applications. To evaluate if real deployment of new technology is justified, tactical advantages gained have to be compared to drawbacks imposed. Evaluation calls for realistic tests which in turn require methods dictating how to deploy the new features. The present study has had two objectives: first, to gain a comprehensive view of a potential user of man-portable robots; second, to embed a robot system with users for assessment of present technology in real deployment. In this project we investigated an army company specialized in urban operations performing their tasks with the support of the iRobot Packbot Scout. The robot was integrated and deployed as an ordinary piece of equipment which required modifying and retraining a number of standard behaviors. The reported results were acquired through a long-term test ranging over a period of six months. This paper focuses on the characteristics of the users and their current ways of operation; how the robot was implemented and deployed. Additionally, this paper describes benefits and drawbacks from the users' perspective. A number of limitations in current robot technology are also identified. The findings show that the military relies on precise and thoroughly trained actions that can be executed with a minimum of ambiguity. To make use of robots, new behavioral schemes, which call for tactical optimization over several years,

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are needed. The most common application during the trials was reconnaissance inside buildings with uncertain enemy presence when time was not critical. Deploying the robot took more time than completing the task by traditional means, but in return kept the soldiers out of harm's way and enabled them to decrease weapon deployment. The range of the radio link, limited video feedback, and the bulky operator control unit were the features constraining the system's overall performance the most. On the other hand, did properties of the system, such as ruggedness, size, weight, terrain ability, and endurance, prove to match the application. The users were of the opinion that robots such as the Packbot Scout would be a valuable standard feature in urban intervention.

1. INTRODUCTION

Mobile robots, also referred to as Unmanned Ground Vehicles (UGVs), have been used extensively for Explosives Ordnance Disposal[1] (EOD) and mine clearance operations for quite some time. Military, police, fire brigade, and rescue services have recently started to evaluate robot technology as an aid to remove humans from unnecessary harm, to perform more efficiently or at lower cost, and to enable missions unsuitable for humans. The question of when to acquire new technology for real deployment is complex and interdisciplinary. Possible advantages have to be weighed against costs for acquisition, integration, training, and maintenance, as well as mission efficiency and reliability. The work presented in this paper addresses the cost-benefit analysis from the perspective of a selected end user—military in urban intervention. Issues investigated have been such that the chosen users were competent to respond to. This has excluded the evaluation of, for example, costs in economical terms[2] or valuing the humanitarian and political benefits of avoiding casualties.

Examining the pros and cons experienced by users, first of all, requires access to their arena. This might, due to reasons of safety and security, be a delicate matter when targeting high-risk work-groups. Second, user assessment demands a thorough knowledge of the users and their current work schemes as this constitutes the baseline for comparison. Evaluating new features calls for the development of methods for deployment. Since current methods are highly optimized, users need to be adequately trained for the new behaviors before comparison can take place.

The present study has had two objectives. The first has been to gain a comprehensive view of a potential user of man-portable robots. This includes task analysis, investigation of user characteristics, and identification of limiting factors of today's methods. The second objective has been to embed a robot system with the chosen user for assessment of present technology in real deployment. This includes identification of suitable robot missions, evaluation of usability, and comparison of pros and cons that robot deployment involves. Emphasis has been placed on performing the study under as realistic circumstances as possible. Only technology that could be operated by the end users in their ordinary environment was regarded since the validity of users' opinions concerning what could be tested in reality differs vastly from speculations regarding features that might be included on future versions.[3] Analogously, the results of the study were divided into two groups:

1. Results based on methods and technology that were tested during the trials. Achieving such results demands both having hardware that can represent the investigated feature in a realistic way, and that the feature is used often enough to be studied with validity.
2. Results concerning technology or methods which were not evaluated in depth. The reason for this could be either that the technology was not yet available, or that the feature in question was not deployed often enough to be statistically verified with adequate confidence.

This paper primarily presents the results which fall into the first category. Initial findings within the second category have been previously reported (Lundberg, Reinhold & Christensen, 2007b).

As this was the first step in the investigation of

[1] Removal, disarmament, and destruction of explosives.

[2] Soldiers and officers in the field are not aware of costs for acquisition, training, logistics, or maintenance.

[3] The same applies to speculations about what is needed by other types of users than those who actually participated in the tests.

robot deployment amongst the selected users, the approach for research has, to a large extent, been performed through methods of anthropology such as *observation* and *interviews*. Quantitative data mainly derived from a *questionnaire* at the end of the trials. The three data collection methods triangulate[4] the outcome of the study which, to a large extent, is qualitative rather than quantitative. Some of the conclusions drawn primarily verify what has been an apparent problem in the arena for a long time. In other cases we believe to have proved that available technology is now able to match the users' requirements.

The present work is intended to assist technical researchers and developers of field robots by providing a holistic view of a user with high expectations of what can be achieved with robots. Further, this work is directed towards those dealing with acquisition and tactical development concerning robots for high-risk work forces. The work performed will also serve as the necessary basis for the design of coming in-depth experiments.[5]

This project has been a joint initiative between the Royal Institute of Technology (KTH), the National Defence College (FHS), the Swedish Defence Materiel Administration (FMV), and the Royal Life Guards (LG) of the Swedish Armed Forces. An infantry company, specialized in Military Operations in Urban Terrain (MOUT), constituted the user group for the study. The company provided full access for research while using an iRobot Packbot Scout on their training maneuvers during a period of six months.

The remainder of the paper is organized in the following way: Section 2 contains a discussion of related work. Section 3 presents a description of the robot, the user, the test facilities, and how implementation and research was performed. Section 4 contains the results, divided into three categories: Subsection 4.1 presents characteristic of the users while Subsections 4.2 and 4.3 describe the tactical and the technical findings of robot use, respectively. Section 5 gives a discussion of the project, the research methods, as well as the main results.

[4]Triangulation of data see (Silverman, 2006).
[5]One such experiment has already been performed to compare manual mapping with teleoperation mapping (Lundberg & Christensen, 2006).

2. RELATED WORK

Various studies have previously investigated high-risk workers deploying field robots. The most common application, bomb destruction or removal, has been successively refined since the first attempts in Northern Ireland in the beginning of the 1970's (Birchall, 1997). Today this is a well-established robot niche with several mature systems available as demonstrated at the European Land-Robot Trial 2006 (Schneider, 2007). Other areas of robot deployment shared by the police and military and given substantial investments are security, surveillance, reconnaissance, and tactical support (Carroll, Nguyen, Everett & Frederick, 2005; Jones, Rock, Burns & Morris, 2002; Kumagai, 2002; Barnes, Everett & Rudakevych, 2005; Ebert & Stratton, 2005; SPAWAR, 2007), although much of the research is not published in detail (Ashley, 2006).

The task of chemical, biological, radiological, and nuclear (CBRN) contamination control is about to be addressed as sensor payloads are maturing for deployment on EOD-robots in daily use, such as the Packbot, Talon, Wolverine, & URBOT (Smith-Detection, 2007; Foster-Miller, 2007; Gardner, Treado, Jochem & Gilbert, 2006; SPAWAR, 2007). Rescue robotics, and especially Urban Search and Rescue (USAR), is one of the field robot areas currently receiving the most attention in research studies. Countermeasures against, and preparedness for terrorist attacks and earthquakes have invigorated efforts to push robot technology into use (Murphy, 2004; Hisanori, 2002; Matsuno & Tadokoro, 2004; Scholtz, Young, Drury & Yanco, 2004; Yanco & Drury, 2004).

Human-robot interaction outside the scope of high-risk field workers has been evaluated in long-term tests as well. An early example is the integration of the SURBOT (White, Harvey & Farnstrom, 1987) for mobile surveillance in a nuclear power plant. More recent examples consist of testing of the robot seal Paro amongst elderly (Wada, Shibata, Saito, Sakamoto & Tanie, 2005), of the fetch-and-carry robot CERO by a partially impaired person (Hüttenrauch & Eklundh, 2002) and a number of long-term tests of tour guide robots such as the RoboX9 at Expo02 (Tomatis, Terrien, Piguet, Burnier, Bouabdallah, Arras & Siegwart, 2003). By now space applications have also been trialled substantially through NASA's deployment of rovers on Mars (Leger, Trebi-Ollennu, Wright, Maxwell, Bonitz, Biesiadecki, Hartman, Cooper, Baumgartner & Maimone, 2005).

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PRE-STUDY	MAIN STUDY	POST-EVALUATION
Documentation study Observation Formal interviews Informal interviews Exploratory testing Participation	Observation Informal Interviews Exploratory Testing Testing Participation	Formal Interviews Questionnaire
Y 2004/2005	Y 2005/2006	Y 2006

Figure 1. The various data collection methods deployed during the three phases of the test.

The above-mentioned examples have in common the implementation in a realistic setting over a period of time. Despite the similar aim of these projects, approaches may vary significantly depending on objective, resources, and type of application. For example, evaluation amongst elderly will differ vastly from evaluation with search and rescue personnel. Likewise, technical requisites to enable testing vary greatly between, for example, deployments in a museum and on Mars. Hence, there is no obvious and uniform way to evaluate the deployment; established research methods may not meet the requirements to evaluate the telepresence, dynamics, or autonomy of mobile robots (Scholtz et al., 2004). Traditional methods—developed for other fields such as human-computer interaction, home electronics, social anthropology, or psychology—need to be tested, perhaps also modified and merged, in order to facilitate evaluation of robotics (Thomas & Macredie, 2002). The application targeted in this project is distinguished from previous work on risky applications by its highly dynamic and responsive target.[6] From this perspective it has more in common with more casual applications such as service robotics. The project has fielded a commercially available robot in an arena that is, for reasons of secrecy, more frequently researched than published. Research taking a comprehensive view of robot deployment within MOUT has not been previously reported.

3. METHODOLOGY AND SETTING

3.1. Outline of Study

A pre-study initiated the project with the purpose to investigate the user and to explore in which ways they could benefit from using robots (Lundberg, Christensen & Hedstrom, 2005). The pre-study implemented and performed exploratory testing of the robot during five military training maneuvers January to March 2005. The robot was deployed by conscript soldiers and tested within squad level during four maneuvers. On the final maneuver, one of the researchers, who is also an officer, operated the robot in order to deploy on company level. Pre-study data was gathered through military manuals, field observation, formal and informal interviews, and participatory observation (Figure 1).

The pre-study led to a decision to implement long-term testing on a larger scale during the following year. A selection of standard procedures was redesigned to include the robot. Once mastered by the operators, the new procedures were demonstrated to the rest of the company. It was thereafter up to the commanders of the company to use the robot as they considered appropriate in their training maneuvers.

3.2. User Group

The Swedish Armed Forces are based on conscription of 18 to 24 year old males. The Army uses conscript soldiers in positions up to second platoon commander. Higher positions are held by professional officers. Women can volunteer to do military service, and all positions within the Swedish Armed Forces are open to both genders. Basic military training service ranges from eight to fifteen months. Standard units such as the company in our study are trained in one-year cycles.

The appointed MOUT-company consisted of 200 soldiers, 7 professional officers, 16 Armoured Personal Carriers[7] (APCs), and 10 logistic vehicles.

[6] Enemy soldiers or civilians instead of artifacts such as bombs or hazardous chemicals.

[7] Tracked vehicles, armed with 20 mm cannons, capacity to carry 11 people (Hägglunds Vehicle AB, PBV302).

About three percent of the company members were female. Ten additional officers served as instructors. Soldier training initially targets individual behaviors; complexity of training is gradually increased on squad, platoon, company, and, finally, battalion level. Lower-level training receives more time as higher-level training requires larger logistical, personnel, and organizational resources. MOUT-units further require access to urban surroundings suitable for training. This includes moving entire units nationwide, or even to neighboring countries, in order to access appropriate exercise areas.

Performing tests on a specific organizational level calls for the framework of at least one level higher, i.e., testing squad behavior requires the framework of a platoon, and platoon assessment in turn calls for a realistic company setting. For example, the majority of participants provided the context for the test rather than interacting with the product.

During the six month test period, the company acted as a cohesive unit on five training maneuvers which included 200 to 6000 soldiers and lasted for three to six days.[8] The maneuvers were set up with an initial phase of political conflict, mobilization, and handover of tactical responsibility to the company. The robot had no role during these initial phases which, generally, lasted for one-half to one day. The robot, however, entered the scene during combat for a total of 16 days.

The company under study is a highly specialized unit which directs about 90% of its training towards urban intervention. Ordinary troops have an opposite distribution with open terrain as their primary area of operation. Many current conflicts, however, take place in urban environments, and a corresponding redirection of armed force training is ongoing.

3.3. Test Facilities

All tests were carried out in facilities regularly used for military training. Deserted and partly demolished industrial and residential buildings offered an environment similar to those expected during combat operations (Figure 2). During the tests no adaptations or adjustments were done to the environment. The test period spanned from autumn to spring and temperatures from −15°C to +15°C.

Figure 2. One of the test environments, a deserted steel factory complex in Fagersta. To *seize* such a building is a typical task for a company.

3.4. Robot System

The iRobot Packbot Scout[9] (Figure 3) used in the study was equipped with a number of accessories. The same Direct Fire Weapon Effects Simulator (DFWES) that is used for combat training was mounted on the robot (Saab BT46). The system includes a laser mounted on the firearms, and a sensor suit worn by the soldiers. Adding the fire simulation system enabled the soldiers to engage the robot with their firearms during training.

Two more payloads were developed; a flashlight

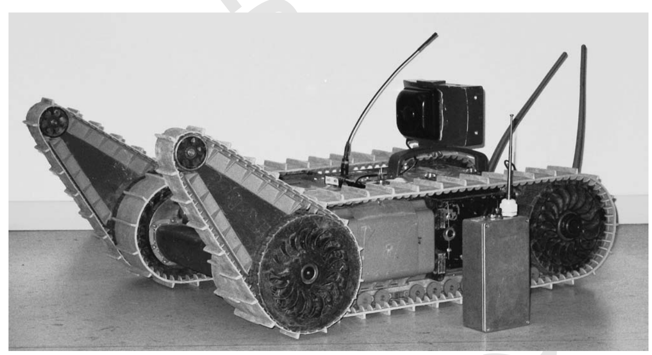

Figure 3. The Packbot Scout equipped with the Claymore mine (top), and the Direct Fire Weapon Effects Simulator. In front, the remote control for payload operation.

[8] The maneuvers took place in Fagersta 1–4 Nov. 2005, Enköping 8–9 Nov. 2005 (Demo 05), Marma 5–9 Dec. 2005, Fagersta 6–9 Feb. 2006, Jordberga 5–7 March 2006, Norrköping/Stockholm 20–26 March 2006.

[9] See (Lundberg et al., 2005; iRobot, 2007) for a description of the Packbot Scout.

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for illumination in dark premises and a blank Claymore mine, both triggered by remote control. A siren on the robot simulated detonation of the Claymore mine. The choice of weapon was not a result of detailed consideration. A Claymore mine, which is a standard weapon for infantry troops, would most certainly destroy the robot if detonated. The mine might also be a much too powerful weapon for indoor use or while in the vicinity of our own personnel. It does not, however, have to be aimed very accurately. Nonlethal weapons such as flash-bang grenades might be a more suitable option for initial implementation.[10]

Along the course of the test, the system also incorporated extra batteries, chargers, basic spare parts, a rope for lowering the robot into premises, a carrying system, and protective cases for all components. A telescopic rod, which could be attached vertically to the robot to detonate trip-wired explosives, was also included.

3.5. Robot Implementation

During the pre-study, the robot had not been in company hands except during the individual trial appointments. For the main study test, except during modifications and repairs, the robot was kept by the company. All transports, maintenance, and charging was carried out with the test groups' ordinary resources in order to expose the system to realistic stress. The users were instructed to treat the robot as a standard piece of equipment and they were told that damage and wear was considered an expected side effect of the study. The robot's robustness was stated to be comparable to the users' radios or optical equipment.

In agreement with the Commander of the Royal Life Guards, one officer and two soldiers were trained to operate the robot during the main trials. Unfortunately, one of the soldiers was released from duty due to medical reasons after two months. The operator task was performed according to the regular rules and demands of the unit.

No military tactical concepts of robot deployment existed when the robot was first introduced to the company, nor did the users have any well-defined opinions about how the system could be implemented. This was the first acquaintance with robotics for most of them. The delegated operators had no previous experience with robotics, but were accustomed computer users and had some experience with RC-crafts.

Three levels of operator training were defined: 1. *Basic Level*, 2. *Map and Search Level*, and 3. *Tactical Level*. Training for the *Basic Level* followed the scheme developed during the pre-study. This included briefing about the robot, basic driving, and familiarization with the appearance through video feedback. After the basic training, which took one day, the operators were able to perform simple missions and continue to practice on their own. Since the higher level behaviors were not yet defined, the higher level training was, to a large extent performed concurrent with exploratory testing. The *Map and Search Level* incorporated the ability to sketch explored premises and to search for persons or Improvised Explosive Devices (IEDs).

After having acquired personal skills in robot control, the operators were trained to execute missions in conjunction with others, i.e., the *Tactical Level*. Initially, this was done in pairs, where the operator and an assisting soldier were trained to act as a team (Figure 4). After approximately seven days of practice,[11] the pair was integrated into group, squad, and platoon level, and performed their tasks synchronized with other mission activities (Figure 5). While the two first training levels only included the operator and the assistant, the third level also required adaptation of the group in which the robot operated.

Once the operators had acquired the necessary skills, demonstrations were done for one platoon at a time and included a briefing about the system, safety issues, and a demonstration of an exploration mission. It was emphasized that the robot use was a test and that some aspects could not be expected to reach full effectiveness until after some time of tactical development and training. After the demo the company was free to use the robot system as they pleased. During the training maneuvers, either the DFWES-system[12] or the training officers could determine the robot had been neutralized; if so, the robot was returned to the transportation vehicle from

[10]The use of armed robots is not a new occurrence. EOD-robots have been equipped with disruptor guns for more than three decades (Birchall, 1997), and attempts to use robots for explosive deliverance date as far back as World War II (Chamberlain, Doyle & Jentz, 1993).

[11]As a comparison, the basic operator course for EOD-technicians lasts five days (Lundberg, Reinhold, & Christensen, 2007a).

[12]See Section 3.4.

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Figure 4. From left to right: the Packbot Scout, the robot assistant, and the robot operator. The robot is about to move up the staircase to the left; meanwhile, the assistant is ready to act in the most hazardous direction, in this case considered to be the staircase. The operator controls the robot from a previously secured area. Observing the robot in line of sight provides better situational awareness than having to rely on the user interface. The assistant, therefore, supports the operator with voice commands as long as he has the robot in sight.

Figure 5. From the left: the platoon leader, the robot operator, the group leader, and thereafter the private soldiers. The platoon leader is using the robot-system to perform exploration around the corner. The group leader is observing the neighborhood and the soldiers are ready to act in hazardous directions.

where the operator could retrieve it as a new robot. There was no set limit for how many times this could be done, i.e., the company had a fictitiously unlimited resource of robots. The company had access to one robot system on all maneuvers except for the 2006 final maneuver when two systems were deployed in parallel.

Prior to testing with conscripts, military safety regulations required the system to be reviewed by the Armed Forces Safety Board, which identified the risk of the robot falling onto a person situated below as the largest hazard. All participating personnel were informed about robot safety prior to every training maneuver.

3.6. Data Collection and Analysis

Military training manuals and videos proved valuable tools to get familiarized with the users' circumstances, their terminology, and their work schemes (Figure 1). In addition, participating in one national[13] and one international workshop[14] on urban warfare presented the opportunity to investigate areas of tactical development.

Observation, with video and photography documentation, was an essential research method for the project. The users are accustomed to the presence of instructors and visitors during exercises. Armlets are used to distinguish observers from participants, which allowed for full access observation during the maneuvers. For safety reasons, hearing protection and protective goggles had to be worn by military personnel as well as civilians while indoors during the firing of blank ammunition. Radio communication between the platoon leaders and the company commander added an alternative method of observation. This is an established way for training officers to stay informed about the units' overall progress. Observing the process from the enemy side

[13]The annual MOUT-development workshop of the Army Combat School, Borensberg, 10 May 2005.

[14]Trilateral workshop on Urban Warfare, The Ministries of Defence of Germany (FhG-INT), The Netherlands Defence Research Institutes (TNO), Swedish Defence Research Agency (FOI), and Swedish Defence Materiel Administration (FMV), 18–19 May 2005, Stockholm.

provided a beneficial alternative point of view. Researchers also took the place of robot operator for participatory observation purposes.[15]

Three types of interviews were conducted during the project. First, two officers were interviewed before the long-term test regarding what applications they thought might be feasible for robot implementation. The results were verified by the respondents after transcription. Second, participants were interviewed about their established procedures and their experience working with the robot. These interviews were done spontaneously at appropriate times in the field, and were held in an informal manner. In some cases these interviews were documented with video or notes, but mostly the data was written down at a later time. Finally, after the long-term study, four soldiers and six officers were chosen for in-depth interviews regarding their experiences from using the robot. An anthropologist who had not participated in the field studies was recruited to perform the final interviews. These interviews, which lasted anywhere from 30 min to one hour each, were recorded and transcribed.[16] The topics explored in the final interviews were aligned with the topics of the end-of-trial questionnaire. The semi-structured interviews provided the opportunity to extend and modify the questions for in-depth investigations.

The 41 most experienced participants (36 soldiers and 5 officers) were selected for the questionnaire study. The inquiry contained 14 main questions which were either statements to be rated on a five point scale, or open-ended questions. The respondents were given the option to add alternatives they believed to be missing. Participants took from 20 to 60 min to complete the questionnaire. The post-evaluation (interviews and questionnaire) was designed to document which robot missions had been performed, explore the opinions about the robots efficiency/functionality and its significance compared to other equipment, probe ideas for future development and ethical considerations, and investigate whether acquisition was recommended.

[15]Just as during the pre-study, one of the researchers acted as operator during one maneuver when the trained operators were unavailable.
[16]Each interview took eight hours on average to transcribe and about as long to analyze.

4. RESULTS

4.1. User Characteristics

Military operations in urban terrain might be one of the most challenging team tasks performed. Complexity, lack of information, personal risk, fatigue, and time pressure in possible combination with limitations in experience make the work environment highly demanding. Forces deployed in peacekeeping and peace enforcement missions might also be pressured by cultural differences, media, and ethical doubts. Compared to missions in field settings, missions in urban terrain often tend to be more fragmented without clear borders between civilians, enemies, and allies (Krulak, 1999). The numerous possible hideouts and the difficulty to overview urban areas call for a large number of personnel to control an area even against small enemy forces. For example, to *seize* and secure a building such as the one displayed in Figure 2 would be a typical task for a MOUT-company.

A company can be described as the smallest self-sufficient army unit in the sense that it has medical resources and supplies to last a couple of days, can handle vehicle towing and field repairs, and is given tactical responsibility for a defined area. Command is carried out by two captains with six to ten years of experience. Only one is the formal commander, but in urban operations they often work in unison, one leading the soldiers moving on foot while the other manages the Armoured Personnel Carriers (APCs). A MOUT-Company consists of three fighting platoons and a Staff/Supply platoon. Each platoon is commanded by a lieutenant with three to six years of experience who is assisted by a conscript sergeant. The platoon leaders and the assisting sergeants carry radios for communication with the company commanders and the APCs. Each MOUT-platoon consists of four squads, each with an APC. Each soldier has an area of expertise such as squad leader, machine gunner, sharp shooter, demolition expert, combat medic, APC-commander, APC-gunman, or APC-driver. When moving on foot, the soldiers perform in pairs (*buddy-system*) in order to provide mutual protection, assist during obstacle passing, and so on. Tasks that have to be solved in exposed settings are executed according to strict routines. For example, soldiers having a weapon malfunction calls out "malfunction" and drops low in order to take cover as well as to visually inform the

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others about the inability to solve the current task. Meanwhile, the soldier's "buddy" positions behind him or her as a lookout in order to offer protection until the problem has been resolved.

For transport in urban terrain the troops have the option to use the APCs. In case of hostile encounters the soldiers leave the vehicles and continue their movement on foot through buildings to be sheltered and hidden. From then on all the necessary equipment has to be carried, which requires all gear to be compact, light, and rugged. Only the most necessary equipment and limited amounts of supplies can be brought along. Soldiers are, however, already fully loaded and forced to leave important gear, supplies, and water behind.

The combat vehicles are often left behind because they have limited mobility and constitute a relatively obvious target which, despite their armor, cannot withstand the firepower of modern portable anti-tank weapons and mines. Normally a driver, a machine-gunner, and an APC-commander remain in the vehicle in order to perform medical evacuation, fire support, outflanks, etc. While moving on foot the soldiers have to be able to traverse obstructions, climb through windows and onto roofs.

Most indoor operations are carried out in dusk or darkness with either helmet-mounted night vision goggles or powerful flashlight illumination. Both have their drawbacks. The night vision goggles cognitively impair the wearer by limiting the field of view and eye movement, removing stereo vision, and obstructing rifle deployment (Sandberg, 2003). A flashlight, on the other hand, reveals the position of the user. One possible solution, which takes the pros and cons of both into account, is to use the night vision aids for stealth *reconnaissance*, and white light for armed action during which the ability of perception and speed is prioritized.

Communication and distribution of information is limited during urban operations. First, the circumstances for voice communication are often poor due to physical factors and the necessity to operate in silence. Second, there is an aggravating factor due to the high stress level on the personnel. Third, the organization is strictly hierarchical so all information transfer and most of the decisions are handled through the chain of command. In addition, some of the leaders have to communicate on two different networks, one for subordinates and the other for superiors. However, units or individuals cut off from communication will continue to act according to the commanders' outline plan.

To improve the information distribution, tests are currently done to equip every single soldier with a radio for inter-squad voice communication. The radios have proved to eliminate many of the communication problems related to the deliverance of verbal messages, but much of the information is spatial and difficult to present through speech. The use of sketches is common when communicating face to face, and basic sign language is used for line of sight communication. Trials are also made to equip soldiers with wearable computers for GPS-positioning, digital maps, aerial photographs or satellite images, digital cameras, and radio data networks for information sharing (Hoving, 2003).

Despite communication difficulties the units are expected to perform swiftly and in synchronization. Predefined tactics help the soldiers anticipate how their own forces will act in situations when planning or communication is lacking. All basic military behaviors have been thoroughly defined and trained in order to minimize reaction times, optimize efficiency, and minimize the risk of fratricide. For example, on squad-level it is defined in detail what equipment each soldier carries, which task each soldier performs, how the squad moves, who opens doors, who is the first to enter, how communication is carried out, and so on. Established routines are not static but are continuously evaluated and refined. The evolution is, however, an incremental process performed over many years. Examples of predefined key behaviors relevant when considering UGVs are:

- *Reconnaissance*–Gathering of information through remote observation or by entering the specific area. Enemy encounter is avoided.
- *Combat reconnaissance*–Same purpose as for *reconnaissance* but with the aim to pursue into *attack* in case of enemy encounter.
- *Attack*–Offensive action through maneuvering and firing of weapons in order to hold, neutralize, or force the enemy to surrender.
- *Seize*–Taking control of an area with or without enemy encounter. This includes ensuring that the area is free from enemies and establishing a defense.
- *Search*–Defensive way to perform *seize*. Sol-

diers go through a building room by room without using any firepower. *Search* can be performed silently.

- *Cleanse*–Offensive way to perform seize. Soldiers go through a building room by room with preventive use of hand grenades and rifle fire, i.e., throwing grenades and shooting into the next room before entering or even observing it. *Search* often precedes *cleanse* until enemies are encountered.
- *Break-in*–More or less aggressive action to enter a building. Obvious entrances such as doors are avoided due to the risk of IEDs or ambush. Ladders or vehicles are regularly used to enter above-ground floor (Figure 6). Armored vehicles can be used to breach through walls and provide massive fire support to soldiers on foot. *Break-ins* are initiated from a *safe spot* and are considered completed once the troops are in control of a *safe room* inside the building. Performing a *break-in* is a task for an entire platoon and is considered to be a very risky operation that has to be performed with rapid intensity. *Break-ins* are regularly preceded by diversions.

In addition to predefinition and training of fixed behaviors, the MOUT-doctrine strongly emphasizes that only one task is conducted at a time. Individual soldiers or units are given only one objective at a time to avoid any ambiguity or mishaps due to mental overload. The high risk, uncertainty, and time pressure has further brought the MOUT-troops to be very conscious about reliability, a phenomena also observed among police SWAT-teams (Jones et al., 2002). Being able to execute a task according to plan is favored over attempting something more advanced that might not work. Failure to carry out an outlined plan is considered a major tactical setback since one of the foundations of the military doctrine is to be proactive rather than reactive to the enemy's actions. In fact, reliability along with the desire to move and respond to new situations swiftly, is often considered more important than reducing risk (at least during training maneuvers). Often a task is so time-constrained that if it cannot be solved within certain limits, it does not need to be performed at all.

Figure 6. *Break-in* performed through a window to avoid ambush or IEDs. One squad is entering (right), one is ready to go (center), and another is being briefed (left) by the platoon leader (pointing). The first goal after entering is to establish a *safe room*.

For international missions the enemy is expected to be technically less well-equipped and trained but possibly more experienced. Recent conflicts show an increased use of asymmetric measures or means violating international law, e.g., deploying snipers and suicide bombers, resorting to terror actions, and targeting civilians (Krulak, 1999). It is a well-established tactical fact that a defending force is better motivated and more willing to take risk, and also holds the advantage to fortify which renders a power balance of approximately one to four compared to the attacking force.

Likely tasks in international missions differ from those performed during soldier training. Despite a serious attitude and sometimes even frightful realism during exercise, it is hard to reconstruct the true impact of casualties. The aim during training is to get the most possible out of available resources and time. Training is, therefore, directed towards complex tasks, such as offensive, high-paced, and full-scale battles performed in order to engage and, thereby, train, as many soldiers as possible. Routine duties such as surveillance or low-intensity conflicts receive less attention. During the study the examined MOUT-company normally trained two rather offensive *seize* missions per day, each rendering 5–30 of their own wounded or killed (Figure 7). This is not a likely level for international missions. Troops participating in international missions are reluctant to risk their own or civilian losses; a phenomenon that has also been pointed out in other countries (Sion, 2006). The need for training with less aggressive behaviors and nonlethal weapons is recognized.

The observed training maneuvers did not deal with the dilemma of IEDs or anti-personnel mines to any large extent; although such threats might be a

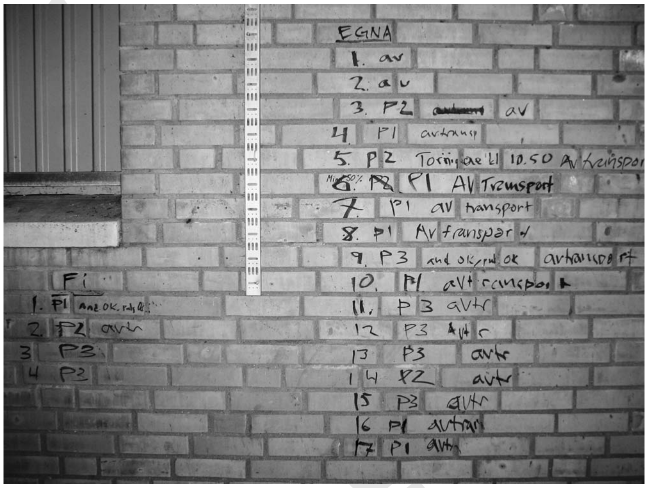

Figure 7. A medical log written on a wall in the *safe room*. This was the outcome of half a day of training maneuvers, the ones in the left column are the enemies, the ones in the right are their own. The log keeps track of the priority for evacuation of the wounded. Abbreviations: P1–very urgent, P2–urgent, P3–not urgent, P4–dead or mortally wounded, av/avtr/avtransporterad–evacuated.

significant problem in international missions. High ambitions to obey international law during soldier training might be the reason for this.[17]

4.1.1. User Characteristics in Summary

MOUT are complex team tasks that require high levels of coordination. Time is often a critical issue and means of communication are sparse. The methods of the troops are highly defined and thoroughly practiced in order to enable synchronized actions even when coordination is absent. The troops regularly leave the APCs and continue their movement through buildings on foot. Alternative entrances such as windows are preferred to avoid ambush or IEDs. Weight is a critical issue as the soldiers are already heavily loaded. The units are expected to perform their tasks no matter the type of premise, level of destruction, weather conditions, or time of day. Massive weapon deployment and rapid action is used to *seize* premises that are known to, or suspected to be, held by enemies. This increases the risk for civilian casualties. Nonlethal weapons and methods are desired although the training maneuvers are performed more aggressively and at higher pace than what is expected in international missions. Tactics are typically refined through small iterations over long periods of time. The main user characteristics are also summarized in Table I.

[17] Learning how to neutralize IEDs would also mean learning how to rig them.

4.2. Tactical Findings

4.2.1. Organization and Command

After the trials 83% of the users were of the opinion that every MOUT-platoon should be equipped with one Packbot[18] (i.e., three systems per company). Having the robot systems as a standard part of the platoon, instead of as a resource allowed access to from time to time, largely influences execution efficiency. It was considered that a MOUT-robot has to be accessible within a few minutes; the tactical window of opportunity does not allow for longer delays. The information gained with the robot is of

[18] *How many systems do you believe to be appropriate for a MOUT-company? ☐ One per company? ☐ One per platoon? ☐ One per squad?*

Table I. User characteristics in summary.

Areas of concern	Main features
Timeframe	Often a very critical issue
Communication and synchronization	Challenging conditions; behaviors are therefore, predefined and well practiced
Operational conditions	Day and night, all weather and climate
Environment	Mainly urban, likely in destruction
Properties of gear	Rugged, man-portable, light weight
Operational characteristics	Today's tactics are characterized as either rather defensive (prior to interception) or highly aggressive (post-breakout of violence); nonlethal alternatives are desired

most value to the soldiers about to enter the explored area.[19] As soon as any of the team members enter the premises, they will gain a better control through their own senses and means (weapons) than with the robot. Any information about enemy presence is typically only valid for a short period of time, as revealed enemies are bound to change their position. The robot operator needs to be at the site of exploration to grasp the overall setting in order to physically handle the robot and be able to pass on the information quickly.

Operating and handling the robot system proved to be a two-person task due to both physical and mental workload issues. To a large extent, the mental workload imposed isolates the operator from the surroundings; this can, just as for other mentally demanding tasks, be handled through the *buddy-system*. While the role of an assistant can be performed by any soldier given some additional training, the operator requires at least one week of individual training.[20] The operator needs to have the tactical and verbal skills of a squad leader in order to understand the tactical situation and to communicate gained information to others.

The number of persons required to deploy a robot is often considered in the evaluation of system efficiency (Murphy, 2004). As mentioned, the military is accustomed to tasks that have to be performed in support of others, so the ratio of two persons per robot does not seem to be of critical concern. On the contrary, the MOUT-doctrine states that only one task should be solved at a time; accordingly, it is not applicable to have one operator deploying several systems simultaneously as is often suggested in research concerning autonomy (Jones & Lenser, 2006).

The robot was one of the heavier pieces of equipment handled; though occasionally, one soldier drags or carries another wounded soldier who weighs at least four times as much. The robot's weight and size reduces the ability to perform dynamic moves such as running and jumping. The extra weight and size also cause problems while passing narrows and crawling in cover. Furthermore, falling over with the extra weight increases the risk of injury. The robot crew needs to be physically stronger, more motivated, and more alert than the average soldier while moving on foot. Although the robot and the Operator Control Unit (OCU) could be carried by one person, a pair moves with speed and endurance corresponding better to the rest of the troops. The size and weight of the Packbot approached the acceptable limit of MOUT; any weight reduction would be beneficial.

Similar to other company-shared resources, the commander set a standard to submit the robot-system to the platoon momentarily having the highest demand. Platoon leaders in charge of the robot system most commonly assigned it to one of the squad leaders, who in turn acquired the information; alternatively, the leaders had the soldiers about to enter the explored area cooperate with the robot operator directly. After fulfilling a platoon's needs, the system was released and relocated to the company's post for medical evacuation to await the next mission. Having the robot, and the operators, assigned to varying units also involved having them transported by different APCs. This proved to cause logistical problems since the vehicles were already fully loaded with gear and supplies. Being able to transport and preferably launch the robot from the outside of the APCs would be valuable.

4.2.2. Specification of Tactical Behaviors

A MOUT-scout robot needs to be closely integrated with the deploying unit. Leaders on all levels, as well as the individual soldiers, have to adapt and train their tactics to accommodate robot deployment. Experience is required in order to accurately decide to which situations the UGV should be deployed; how the mission should be conducted; how long a robot mission will likely last; what terrain the robot can handle; and what information the system is capable of rendering. The trials meant to specify the robot operation in as much detail as other MOUT-behaviors. This included defining the operator's tasks as well as working out how squad-, platoon-, and company commanders should reason regarding when and how to deploy the robot. The level of detail is indicated by the following examples:

- *Operator level*–Robot exploration should be done along walls that provide a reference for navigation. Deviations from walls should be done in a perpendicular pattern; the compass

[19] Compared to, for example, UAVs, which in many cases are operated by others rather than those taking part of the information gained by the system.

[20] Covering the *1-Basic Level* and *2-Map and Search Level* described in Section 3.5.

can be used for support although the risk of local deviation due to metal has to be considered. The point at which the wall is temporarily abandoned should be memorized to facilitate return. This methodology is especially vital when exploring larger areas.

- *Squad level*–Since time will only allow for one report, the exploration should be completed before passing on information; however, in case immediate progress is necessary, be prepared to interrupt the exploration to report current findings.
- *Platoon level*–The robot can be deployed for tasks that are normally performed with backup from the rest of the platoon. This enables exploration beyond the point when all soldiers are tied up guarding already seized areas.
- *Company level*–The robot can be used for high-risk *reconnaissance* or for situations in which *cleanse* is not feasible due, for example, to the possible presence of civilians.

4.2.3. Executed Scenarios

During the training maneuvers the robot was deployed on two–ten occasions per day. Figure 8 displays the distribution of the different types of missions according to the post questionnaire.[21] The missions reported most frequently were: reconnaissance inside of buildings 37%, investigation of *break-in* points 24%, and mapping 21%. The flashlight and Claymore payloads were deployed 8% and 7%, respectively. When considering this distribution, it has to be taken into account that the payloads were not available until the two last maneuvers.

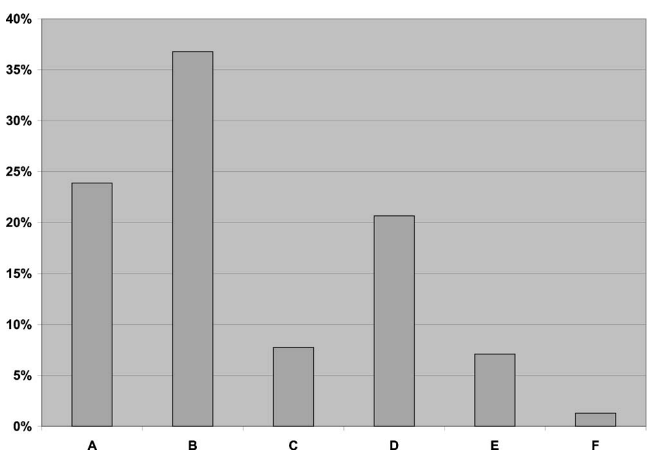

Figure 8. The distribution (%) of the different scenarios reported in the questionnaire (see footnote 21).

4.2.4. Methods for Deployment

Robot reconnaissance was typically initiated from a *safe spot* where the squad could make a short stop in cover. From the *safe spot* the squad or platoon leader ordered the operator to perform the search with specifics on what area to explore, available time, and whom to report to. It was beneficial to have the operator attend the company and platoon briefings to gain general insight into the tactics. Attending the briefings also enabled the operator to suggest how to deploy the UGV.

Robot exploration was done short steps at a time to avoid losing radio contact and to ensure the acquired information was up to date. The tentative exploration also enabled the commanders to keep up the momentum; additionally, it reduced the need for soldiers to memorize large amounts of information. The successive method was also motivated by the commanders' desires to perform immediate action towards enemies encountered, thereby minimizing the forewarning effects of the robot. Consequently, exploration was done one or two rooms ahead and ideally rendered a suitable safe spot for the soldiers to advance to.

Handing over spatial information is an important part of using the UGV for reconnaissance and mapping. The operator displayed sketches of all but very simple premises on a small whiteboard, which was attached with Velcro on the lid of the OCU laptop. The sketching was best done incrementally, 1–3 walls or doors at a time. Attempts to keep too much information in mind easily led to information loss. In the interest of time and clarity, only very basic information, such as walls, doors, and windows,

[21]*Describe the different scenarios you have experienced during the UGV-trials…Select the type of scenario out of the following…: A. Reconnaissance of Break-in point, B. Reconnaissance in rooms or corridors, C. Illumination with flashlight, D. Mapping, E. Deployment of Claymore mine, F. Surprise or mislead.* (The response-fields were: Scenario type (A–F), number of times, which exercise area, course of event, pros and cons.)

were depicted. When showing the sketch, the operator added a few keywords describing the character of the environment and any people observed. Sketching also helped the operator better grasp the layout.

Nonoperators taking part of the image from the robot had difficulties assimilating the context of the explored region. One likely reason is that passive observers do not have the operator's motor motion of the joystick commands. Constant attention had to be given to the robot's camera view in order to understand the spatial layout; this became clear during trials with multiple OCUs within the squad. If the operator explained the robot's current position with the sketch, however, the camera view could be used to point out specific observations. Unfortunately, the interface design did not allow for snapshot images to be taken and stored for later viewing.

In the event of likely enemy encounter, the entering team received more detailed information from the robot operator. If interference was not expected, the squad or platoon leaders were satisfied to know that nothing suspicious had been observed. Thus, it is initially of more interest to identify threats such as enemies or IEDs than receiving a spatial outline. The soldiers did not always follow the path of the robot, both for physical and tactical reasons. For example, the robot could be used to enter through openings too narrow for a person; or, if moving between stories, the robot could be lowered with rope or use another set of stairs. When the platoon decided to advance in another direction, the robot could be used for continued exploration of the excluded region. According to MOUT-doctrine, a platoon only expands one direction at a time to avoid fratricide and maintain a focused strike force; the robot thus allowed for a change in doctrine.

If given enough time, the operators were able to make fairly accurate observations of the areas explored with the robot (Figure 9). Areas indicated but not open to exploration, such as rooms behind closed doors, however, tended to be neglected and forgotten. A separate experiment showed robot mapping, on average, to require 70% more time and result in 44% more errors compared to manual mapping (Lundberg & Christensen, 2006). From a tactical aspect the approximate layout and character of the premise is of main interest; dimensions do not need to be highly accurate. Other information of interest include appropriate positions for cover and strategic fire, influenced, among other things, by the material

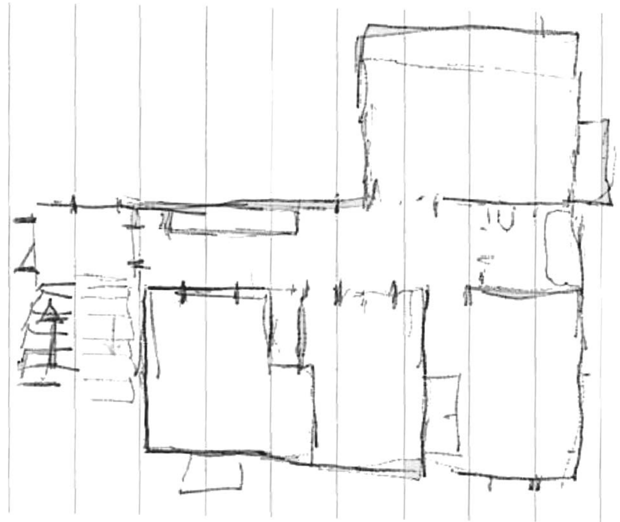

Figure 9. The operators were able to make fairly accurate sketches of areas they explored with the robot, in this case a two-bedroom apartment. While it took the robot operator 18 minutes to do this sketch, it would only take the soldiers a couple of minutes to perform the *search* manually.

and thickness of walls, doors, windows, and other objects in the area. The true effects of ammunition and scatter are diminished during training with blank ammunition. Soldiers tend to seek cover behind objects which would in reality not withstand small arms fire and shrapnel. Improvements in the Direct Fire Weapon Effects Simulator system is currently under implementation (by equipping buildings with sensors and actuators) in order to model this aspect with more accuracy. Training facilities are also being equipped with video and position tracking devices for soldiers and vehicles. It is important to also integrate these systems on robots as the user, at least in this case, spends more time practicing than performing live missions.

Hostile encounter probably means loss of the robot in return for decreasing personal risk. The soldiers not only concluded that the robot could decrease danger, but also argued that it could be used as an alternative to hand-grenades and rifle fire during a *cleanse* operation—an ability that would decrease the amount of required ammunition and minimize accidental harm to civilians and infrastructure. One of the platoon leaders pointed out that the robot could spare enemy lives by opening for inter-

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action in situations traditionally handled with brute force. Voice communication through the robot would enable for alternative solutions to hostage situations, threatening crowds, and assisting wounded personnel.

The tactical significance of the robot dramatically changed when given lethal ability; turning it into a tool for breaking up entrenched situations or directing action against enemies encountered during exploration. Making the robot lethal also added the possibility to use it for deterrent, threatening, or misleading purposes. Correct identification of friends, foes, and civilians is a crucial aspect during weapon deployment. This was a demand that could not be met with the quality of video feedback provided from the Packbot Scout. The Claymore mine could, therefore, only be deployed in areas certain to hold solely enemies.

The flashlight-payload was used to evaluate the benefit of personnel not having to hold the light themselves. The system was deployed on a few occasions, but never during enemy encounter. The UGV was not deployed to trigger anti-personnel mines or trip-wired devices as this threat was not included in the maneuvers. Trials were, however, made to visually identify IEDs during individual operator training. IEDs on floor level could occasionally be identified from within a few meters. Higher placed objects were harder for the operator to spot.

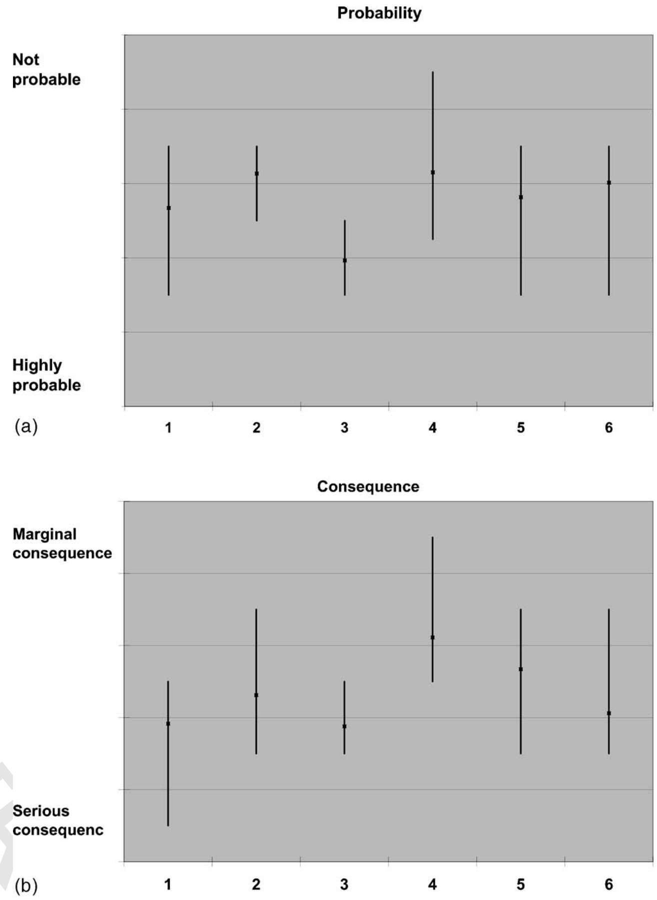

Figure 10. The ratings of probability and consequence given for six disadvantages from robot use (see footnote 22). A combination of probability and risk shows that alternative 1 and 3 are considered the most critical. Alternative 6 was also rated a serious risk. Dots indicate mean value and whiskers show the interquartile range.

4.2.5. Drawbacks

The test disclosed two main perceived risks, namely that the robot might create delays in situations when timing is crucial and that it could reveal the unit to enemies[22] (3 and 1, respectively, in Figure 10). It was also considered possible that having access to a robot could make the soldiers reluctant to put themselves at risk and thereby decrease the performance of the unit (6 in Figure 10). Throughout the trials the commanders generally chose not to deploy the robot if they felt a rapid action would be beneficial; however, during the interviews they stated that the prioritizing of tactical benefits on behalf of increased risk was probably not feasible to such an extent during real missions. The time constraints are fundamentally different in MOUT than compared to, for example, EOD. EOD-robot missions are to a large extent performed by a small specialized team, requested to come and act independently on a prespecified and static target within an area seized and defended by another unit. While EOD-robots are considered to decrease time-on-target, the MOUT-robot will not reduce the operational time (Lundberg et al., 2007a).

[22]*Value the disadvantages the robot might convey. Estimate both the probability of the event and the consequence to the unit deploying the robot…, 1. Robot operations reveal own unit, 2. Robot exposes operator to increased risk compared to other soldiers, 3. Using the robot delays the unit during high ambition missions, 4. Using the robot delays the unit during low ambition missions, 5. A plan has to be changed because the robot fails, 6. The availability of the robot makes the soldiers less willing to take risks and thereby decreases the capacity of the unit.* (Replies were given on a five point scale.)

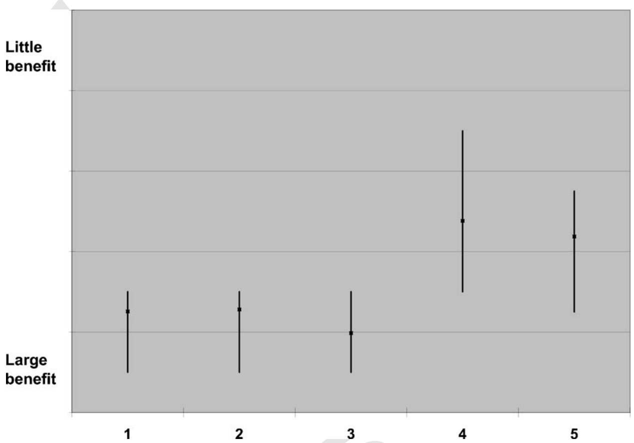

Figure 11. Estimated benefits for scenarios tested (see footnote 26). Dots indicate mean value and whiskers show the interquartile range.

4.2.6. Benefits

Multi-role capabilities are desired to enable frequent deployment. This in order to justify the added workload the robot entails to the MOUT personnel. The complexity of payloads spans from simple solutions such as two-way audio or fire circuits,[23] to payloads requiring real-time data processing, or high speed data transmission to the user-interface. The trial period did not enable a complete development, training, and evaluation of the targeted scenarios. The respondents were therefore asked to estimate the benefit of the tested scenarios given that full implementation would have been performed. 85% believed that the system could be deployed 7–10 times or more during a company attack of the type performed during training.[24] None of the respondents expected the robot to be used less than four times per attack.[25]

Figure 11 displays the estimated benefits from a UGV in the tested missions.[26] Weapons deployment, together with reconnaissance, were the applications regarded to be of most benefit. None of the respondents reported a strong opinion against using robots as weapons.[27] On the contrary, 79% replied that they had no objections to doing so; none of the respondents replied being strictly against. Ten out of the 41 respondents did, however, comment that their opinion only applied as long as the fire command was executed by a human (not autonomous/automatic).

The tests were performed on maneuvers intensified both in risk and time. To explore the offset, the test participants were asked to value the benefits for different types of operations likely for military forces of the European Union (Ortega, 2005).[28] Of the four types, the attended training maneuvers mostly resemble the first. The first, together with the second, were also the ones believed to be most suitable for UGV deployment (Figure 12). The final question of the questionnaire asked for general comments. Eleven people replied. Seven of these commented on the importance of tactical development and training of UGV-behaviors; five were positive remarks about the UGV.

4.2.7. Over-all Valuation

The users' impression of the UGV's overall costs and benefits was investigated by asking them to compare the value of the robot to two other systems also being tested by the unit–inter-squad radios[29] and night-vision goggles.[30] The robot was rated to be as valuable as the night-vision goggles (mean 2.9 on the five point scale), and slightly less valuable than

[23]A fire circuit is a standard feature on EOD-robots that enables the operator to control a binary switch on the robot. The switch is normally used to fire the disruptor gun, but it might as well be used to turn on/off any other payload mounted on the robot.

[24]*Rate how many times per company attack the UGV-system could have been deployed if each platoon had one system in use. ☐ 0–3 times for the entire company, ☐ 4–6 times for the entire company, ☐ 7–10 times for the entire company, ☐ 11–15 times for the entire company, ☐ 16 + times for the entire company.* (Regularly two company attacks were performed per day during the maneuvers.)

[25]The outcome was 0%, 15%, 44%, 20%, and 22%.

[26]*Value what benefit the robot you have been testing would have in the following missions if the tactics for this were fully developed and trained…. 1. Reconnaissance and mapping of break-in point, 2. Reconnaissance and mapping of rooms or corridors, 3. Deployment of weapons such as Claymore mines, 4. Surprise or threat, 5. Illumination.* [The question handled 13 scenarios but only the 5 category-1 alternatives are included here (Section 1. Introduction). Replies were given on a five point scale.]

[27]*Do you think that using weaponized robots is unethical?*

[28]*Rate the value of the UGV for the following types of international operations…: 1. Separation of parties by force, crisis management, peace enforcing operations, 2. Conflict prevention, disarming, and confiscation operations, 3. Evacuation operation of combatants and civilians, 4. Humanitarian assistance, catastrophe support, and evacuation of refugees.* (Replies were given on a five point scale.)

[29]*How do you value the benefits of the UGV compared with the benefits of the Inter-Squad Radio?* (Reply was given on a five point scale.)

[30]*How do you value the benefits of the UGV towards the benefits of the Night-Vision Goggles?* (Reply was given on a five point scale.)

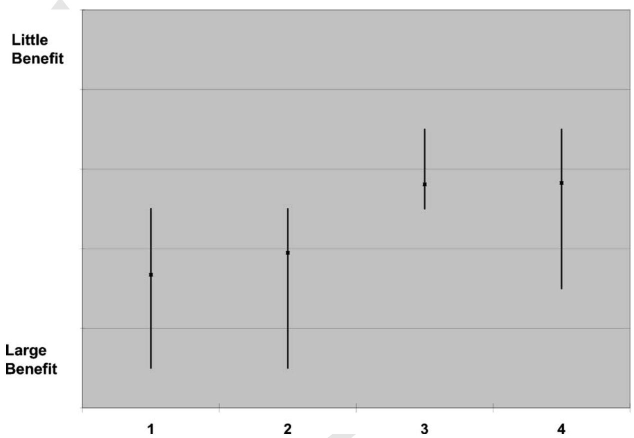

Figure 12. The value of the UGV in different types of operations (see footnote 28). Dots indicate mean value and whiskers show the interquartile range.

inter-squad radios (mean 3.5). However, the responses were rather dispersed (standard deviation of 1.3 for both). The end-users were also asked to suggest other equipment more important than a UGV. Ten people responded but none of the suggestions were reported by more than two people. A more distinct reply was given to the question of whether or not UGVs should be acquired for the Swedish Rapid Deployment Force going into service in 2008 (Nordic Battlegroup-08).[31] 76% replied full support for acquisition, 2% opposed strongly.

4.2.8. Tactical Findings in Summary

The most common mission was reconnaissance inside buildings with uncertain enemy presence, and minor time constraints. The main benefits of the system were risk reduction and decreased weapon deployment. Major tactical drawbacks were reduced pace and increased risk of detection by the enemy.

Deploying the Packbot in MOUT is a two-person task due to both physical and mental demands. The operator and the robot system need to be close to the front line to allow for rapid deployment. Size, weight, mobility, robustness, and endurance live up to the demands. Night vision capabilities are necessary since indoor illumination cannot be guaranteed. The users were of the opinion that units given high-ambition tasks should be equipped with one UGV per platoon. Additional sensors and payloads would increase deployment rate. Armament is desired and tactically significant. Table II further summarizes the main tactical findings.

4.3. Technical Findings

The questionnaire investigated technical issues out of two perspectives: the first included technical constraints,[32] the second the value of improvements.[33] The second included both properties which were assessed during the trials and such that were not (Excluded topics: robot armor, sensors, EOD-functions, autonomy).

Narrow field of view, poor image quality, and limited radio range were considered the most limiting features (Figure 13). Robot speed also stood out. The robot's top speed (4 m/s) was, however, observed to be limiting only in open spaces or outdoors. In most indoor settings the robot was able to go faster than the operator could control.

Automatic mapping (during teleoperation), two-way audio, and the possibility to crop images from the video feedback for later viewing, were the highest ranked improvements (Figure 14). In addition to the findings from the questionnaire, more descriptive information on technical performance was provided through interviews and observations.

4.3.1. Robustness, Packing, and Transport

Packing and ruggedness are the primary features that influence problems connected to bringing technical equipment into the field. Equipment sensitive to physical damage risks either breaking or not being used due to the negative impact on the opera-

[31]*Do you think UGVs should be included in Nordic Battlegroup-08…?* (Reply was given on a five point scale.)

[32]*To what extent do you regard the following properties to constrain the performance of the tested robot? 1. Speed, 2. Off-road ability, 3. Radio range/range of radio, 4. Low camera position, 5. Only having forward looking camera, 6. Quality of video feedback, 7. Power endurance, 8. Physical robustness, 9. Reliability, 10. Information transfer from the robot system to the persons needing the knowledge.* (Replies were given on a five point scale.)

[33]*Rate the benefit of improving the robot in the following areas…: 1. Weapons deployment, 2. Automatic mapping, 3. Two-way audio, 4. Having several OCUs within the squad, 5. Improved OCU (smaller, lighter, easier to use), 6. Acquire images, 7. Brighter LCD for use in bright daylight, 8. Decreased latency in video feedback and steer commands.* [The question handled 17 improvements but only the 8 category-1 alternatives are included here (Section 1. Introduction). Replies were given on a five point scale.]

Table II. Tactical findings in summary.

Areas of concern	Main features
Tactical feasibility of size and weight	Acceptable, although any decrease would be greatly beneficial. In addition to man-portability issues, fitting the robot into the vehicles is a limiting factor.
Robot handling	One operator and one assistant
Durability of information rendered with the robot	The informational value only lasts for a few minutes. As soon as the soldiers enter the area, they will gain better situational awareness.
Command and stationing	Positioning must allow for immediate access to the platoon commanders.
Number of robots in a MOUT-company	One for each platoon.
Prerequisites	Commanders on all levels must have knowledge about appropriate situations for use, time allowances, and expected quality of information.
Main disadvantages imposed by the robot	The robot may delay advance, reveal the own unit, and make soldiers reluctant to take risks of their own.
Primary application during training	Reconnaissance indoors, investigation of *break-in* point, and mapping.
Deployment frequency during training	The robot was deployed 2–10 times a day. Missions were generally short, with a specified objective in mind.
Deployment frequency once fully implemented	Estimated to 7–10 times a day when performing offensive attack.
Applications with the most potential	Reconnaissance, mapping, and weapons deployment.
Benefits of the robot	Decreased weapons deployment and reduced risk for own personnel, civilians, and also enemy personnel. The ability to provide an alternative to aggressive actions such as *cleanse*.
Relevant types of operation	Offensive operations such as separation of contending parties, or peace enforcement.
Outcome of enemy encounter	The robot is easy to spot and eliminate, and enemy encounter will likely lead to loss of the robot.
Lethal abilities	A weaponed robot has a large tactical influence. Reliable identification requires improved situational awareness. The military revealed few moral considerations regarding use of weaponed robots.
Comparison to other equipment	The robot was considered as valuable as night-vision goggles but less valuable than inter-squad radios.
Acquisition	Systems such as the Packbot ought to be acquired for international missions.

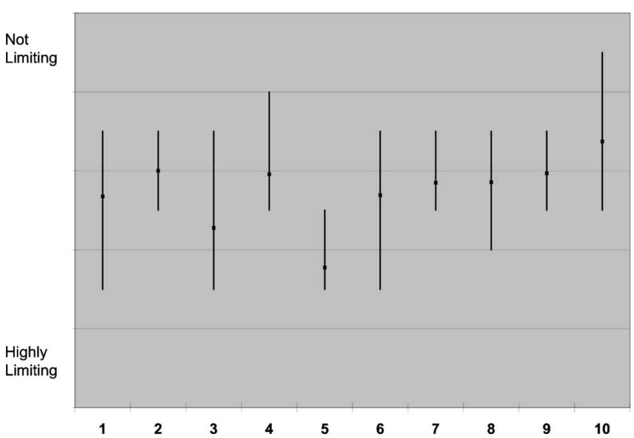

Figure 13. The ratings of the level of constraint different technical features imposed on the UGV's performance (see footnote 32). Dots indicate mean value and whiskers show the interquartile range.

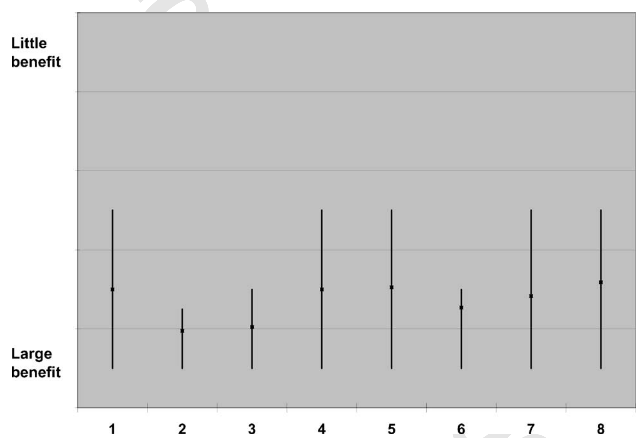

Figure 14. The benefit of technical improvement of features that were available for trial (see footnote 33). Dots indicate mean value and whiskers show the interquartile range.

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tor's ability to act in unison with others. Ruggedness needs to correspond to other equipment in use such as radios, weapons, or binoculars. The heavier or bulkier an object is, the more physical damage it has to withstand. Adequate carrying systems are especially important for heavy equipment. The military's uniforms and carrying systems are adapted to existing gear and cannot be expected to handle new items such as a robot or OCU without modification. Packing is needed not only for the robot and the OCU, but for all system components such as chargers, spare parts, and batteries. During one of the field studies, the spare batteries were found frozen in ice on the bottom of a 20-foot supply container; not an unlikely treatment of soldier gear, caused by harsh circumstances and time pressure in combination with fatigue, carelessness, or lack of knowledge.

The Packbot Scout managed the realistic stress levels of the trials fairly well. The camera covers for antennas, and the GPS receiver suffered the most damage, but connections and battery holders would also benefit from additional robustness. The *flippers*[34] are the most sensitive part of the propulsion system and risked damage if the robot rolled down a staircase or fell from a height over one meter. The Packbot was never submerged in water but it withstood rain and splashes from driving through puddles. Subzero temperatures (Celsius), aside from decreasing the battery performance, did not cause any problems. The army is accustomed to performing their abilities, with some variance in efficiency, regardless of weather conditions, time of day or year; equipment needs to withstand the same conditions, or they risk being viewed as inadequate. This stands in contrast to both manned and unmanned aviation for which weather limitations are tolerated.

4.3.2. Off-Road Ability and Audio

MOUT-soldiers are almost certain to encounter obstructions such as misplaced or broken furniture or demolished buildings. A robot with an inability to traverse obstructions such as steps or stairs will limit the number of possible applications to such an extent that the system is unsuited for military applications. The environment of MOUT will be more demanding than for service robotics is used, but not necessarily as tough as for search and rescue applications (Carlson & Murphy, 2005). During the test, ground conditions such as high grass, sand, and snow challenged the skid steering of the Packbot, but only on very rare occasions did the engine overheat or the tracks dislocate. Snow created the worst conditions for driving since snow gathered between the tracks and the driving wheels, which increased the track tension. In soft snow the Packbot easily got stuck because of snow piling up under its chassis. In some cases the robot could come unstuck by driving with the *flippers* folded down. However, snow had generally by then piled up on the ramp in front of the camera and blocked the view. The Packbot was not feasible for operation in more than five centimeters of soft snow.

The *flippers*, which are a key component of the robot's terrain ability, can be used to recover from roll-overs. They also enable the robot to pass stairs, steps, and other obstacles. Ascending stairs is easier than descending as the center of gravity in the front tends to make the robot slide when going down. Barbwire or other thin metal wire snags in the tracks and ultimately traps the Packbot. The friction in the transmission, which is normally high enough to keep the robot still while no steering commands are given, is unable to prevent the robot from moving down steep angles involuntarily. Such unintentional movement severely complicates driving in steep terrain (Lundberg & Christensen, 2007).

The soldiers, however, generally found the Packbot's capacity to pass obstacles to be sufficient (McBride, Longoria & Krotov, 2003). In many cases mobility was not limited by the properties of the robot but by the operator's inability to grasp the setting through the user interface. If stuck, the robot could often be retrieved as the operator could observe the situation in line-of-sight. Noise from the robot, such as from collisions or slipping tracks, helped the operator understand the on-goings. Multimodal feedback (visual, audio, and other such as tactile feedback of motor loads) would likely increase the operators driving performance significantly. The troops have hearing protection that electronically blocks loud noise. The headset can receive in-line audio from radios or other electronic systems and, thereby, enable the use of audio feedback even under noisy circumstances or stealth operations. Two-way audio is a standard feature on many EOD-robots which would be of tactical value also in

[34] Dual tracked arms in the front which are part of the robot's propulsion system (Figure 3).

MOUT. The robot was considered to be too noisy for stealth operation. In addition, booting the OCU operating system causes it to beep.

4.3.3. Operator Control Unit

In comparison to the robot, the off-the-shelf laptop with external joystick did not suit the application as well. The weakest point of the entire robot system was the USB-connection for the joystick. It was no more rugged than that found on a common laptop computer, which became especially critical since a reboot was required to regain contact with the joystick if the cable was momentarily disconnected. Both the USB port and the joystick were retrofitted with protective covers along with a carrying system allowing the operator to use both hands for climbing, crawling, and weapon deployment. The laptop served as a basis during the trials but does not reach the level of currently available portable or wearable technology (Hedström, Christensen & Lundberg, 2006). Major issues concern ruggedness, portability, daylight capacity of the LCD screen, and backlight for the control buttons to allow identification in darkness.

4.3.4. Power Supply

On a full battery set, the system could, in general, cover half a day's combat training.[35] Current Packbot design requires a Philips screwdriver for battery change; replacing the laptop batteries requires a coin.[36] Charging was done by the only 230 V AC source of the company, a gasoline-powered generator by the staff tent. The generator was not run continuously, but only when time allowed the staff tent to be put up. The generator went down every once in a while, causing the Packbot battery charger to enter drain mode if the power was lost and regained with the battery inserted. Only one battery charger per robot/laptop made charging time consuming. Lighter batteries or energy sources (instead of NiCd) would be beneficial since they constitute a large part of the system's weight. Extra batteries could not be brought along by the operators due to issues of weight. Attempts to keep extra batteries in the combat vehicles often failed since the vehicles tended to reposition continuously. The medical evacuation point, which should always be strategically centered and accessible to all units, proved to be a more suitable place for spare batteries and modular payloads. The advantage of having the robot and operator control unit run on military standard batteries would be immense. Seven batteries out of twenty stopped working and two were mechanically broken during the two years of trials.

4.3.5. Radio Communication

The capacity and range of the radio link greatly affects the usefulness of the robot system. The practical use of the system vanishes as the video frame rate drops below ten frames per second. The IEEE 802.11b link generally enabled the users to explore up to two hundred meters outdoors and up to two rooms away inside of buildings. Unfortunately, the distance between squad members was sometimes greater than the range of the robot's radio link. This prevented the operator from moving around within the range of his group, for example in order to brief the squad leader, while maintaining contact with the robot. The circumstances for robot deployment outside differ from inside. Outside, the distance between safe spots are greater which makes the limited range even more restraining than indoors. The range of two hundred meters was often too short for outdoor missions. Other radio-traffic on the 2.4 GHz frequency notably decreased the quality of the Packbot's radio link. In addition to a wider range, flexible solutions for dealing with jamming, national spectrum regulations, and other radio traffic are desired. Integration with the user's ordinary radio- and command-and-control system needs to be considered. A doubled radio range would increase the tactical performance in MOUT notably.

4.3.6. Sensors

Area surveillance is one of the most common military tasks and was therefore tested with the robot. Unfortunately, the current interface design made it impossible to perform in practice. To do visual surveillance using the 240×320 pixel image was simply too unstimulating a task for a human to perform over time. Acoustic feedback would have increased the operators chance to regain attention when

[35] The OCU-laptop was delivered with one battery and a floppy disk drive. Replacing the floppy drive, which was of no use, with another battery made the laptop and robot battery times correspond better to each other.

[36] It is standard to avoid the need of tools for basic operation of military equipment.

needed, but the obvious solution would be a motion-detection functionality. The limited resolution and field of view, in general, gave the operator a fair chance to detect human-sized targets in small rooms, such as apartments, and targets of car-size in larger rooms such as industrial buildings. The visual feedback did not enable a reliable distinction between friends and foes (for example, by distinguishing uniforms). The low placed cameras were easily blocked by obstacles. The low placement also made it hard for the operator to discover negative obstacles such as a staircase approached from above or edges of balconies. This became very clear in the industrial facilities, where handrails and fences are designed for adults only and, therefore, regularly leave the space closest to the ground unprotected. Basic knowledge about the robot's design makes it easy to anticipate and avoid its field of view. With the current sensor setup, the robot is more suited to gain spatial information rather than find moving targets.

The IR-camera (close to visible spectrum) was the more used of the two cameras onboard. The fisheye camera would be very useful as it gives a broader view which makes passing narrows easier; unfortunately, it requires normal indoor light. The poor light conditions prevailing during MOUT-operations made the IR-illuminator an important feature. Direct light, such as strong or low angled sunlight, blinds out both onboard cameras when, for example, in a dark room facing a bright opening; the IR-illuminator can to some extent compensate for glare in close range. It should be noted that the IR-illuminator, which is invisible to the human eye, can be seen through both the night vision goggles and the night vision mode of commercial camcorders. The Packbot renders a thermal profile that is as visible as a human when observed through a IR sight.[37]

The GPS did not provide any useful data indoors or near buildings. In open terrain the range of the radio link prevented the robot to operate from a distance, to make GPS-positioning a relevant feature.

4.3.7. System Perspective

From the users' perspective, a UGV system includes more than a robot, batteries, and an OCU; military out in the field are accustomed to being provided with all the bits and pieces required along the equipment lifecycle. This includes technical manuals in their native language, tactical guidelines, transport casing, special tools, spare parts, training courses, etc. Achieving this will require joint efforts from industry, third part developers, and users.

Successful integration of UGVs in the armed forces requires consideration of a broad range of issues, such as power supply, radio communication, maintenance, and command-and-control. The ongoing process of equipping each soldier with a wearable computer, sensors, and radio has to be considered in the design of future OCUs. A wide range of standards must be complied with. Some examples are: Environment–*MIL-STD 810*, System Safety–*MIL-STD 882*, Human Factors–*MIL-STD 1472F*, Certification for Deployment in Explosive Atmospheres–*ATEX Directive 94/9/EC*, Nonmagnetism–*Stanag 2897 Annex C*,[38] and Electromagnetic Interference: *MIL-STD 461/462*

4.4. Technical Findings in Summary

Increased visual feedback, longer radio range, and two-way audio are the most desired improvements. GUI features such as snap-shot and automatic mapping are valuable. Operations outdoors are restrained by radio range, robot speed, camera resolution, and glare. The robot operates more efficiently indoors. Transmission noise restrains advancement by stealth. Integration with other military equipment such as radios, command-and-control systems, and energy supplies largely influences future overall performance. Table III further summarizes the main technical findings.

5. DISCUSSION

5.1. Changing the Doctrine

The prevailing MOUT-doctrine has evolved through small iterations under a long period of time. The main tools in use such as assault rifles, grenades, armored combat vehicles, radios, mines, and anti-tank weapons have all been around for 50 years or more. EOD and mine-clearance robots are also used on a regular basis to solve well-defined tasks according to highly-developed methods. Robots in other applications, on the other hand, constitute an en-

[37] Such as the one on the man-portable anti-tank missile Bofors Missiles Robot 56 BILL.

[38] Nonmagnetism is a requirement for EOD tools.

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Table III. Technical findings in summary.

Areas of concern	Main features
Limiting technical properties	Narrow field of view, poor image quality, and limited radio range.
Desired features	Automatic mapping, two-way audio, and possibility to crop images.
Ruggedness and robustness	The robot managed fairly well, but the operator control unit needs to be adapted to portable field use.
Off road ability	With the exception of soft snow conditions, the robot managed fairly well off road.
Power endurance	Meet the demands well.
Sensing	The night vision capability proved to be very valuable, The GPS did not serve any purpose.
Stealth	Noise was the most revealing factor; the robot has an IR-profile comparable to that of a person.
Integration with other systems	Making use of military standard components such as batteries would simplify handling and maintenance of the robot. There are a number of procedural, environmental, and military standards to comply with.

tirely new functionality which sets aside many of the constraints that have shaped prevailing tactics. This project has shown that it is possible to change the well-established and highly-structured doctrines to incorporate new concepts, but that it will require a larger tactical development effort than what is normally accomplished with the users' development assets. The incorporation of new technology can be divided into two categories:

1. Tasks performed today for which robots could replace humans. This category, for example, includes the demanding and often time-consuming clearing IEDs or mines. The EOD-teams typically first try to use the robot in order to avoid personal risk. If this does not succeed, they will proceed to solve the situation manually under the protection of a bomb suite.
2. Tasks that are not performed today but that could be accomplished using robots. Again, IEDs and mines can be used as an example. According to current strategy, MOUT-troops do not attempt to disarm or pass encountered IEDs or minefields. Instead they try to find an alternative route or make a request for an EOD-team to clear a passage. Equipping also common units with EOD-robots could enable a complete change of some aspects in the current doctrine.

During the project it appeared that scenarios falling into the first category were more concrete and, therefore, best suited for initial implementation. It meant taking an established behavior in current use and modifying it to include the robot. If the new behavior were to fail, the traditional methods could be used for recovery. However, gaining insight into the full potential of new technology by including the second category would require a substantial redesign of doctrines, including identification of niches that might not have been targeted before. The opportunity to test previously nonexisting abilities might not occur during current test and training maneuvers as they are typically arranged to suit existing methods. Applications that fall into the second category would result in behaviors that lack traditional alternatives, which would make the user wholly dependent on all-new features. During the process of introducing new abilities, it should be kept in mind that traditional methods might be set aside, which calls reasoning about how to act if the new feature were to fail.

5.2. How to Implement

Previous experiments and demos have shown that soldiers and lower level officers in general are sceptical about robotics until they get to fully know the system abilities (Lundberg, Barck-Holst, Folkeson & Christensen, 2003; Lundberg, Christensen & Hedström, 2005). The hand-over of the robot system to the users rather than bringing it to each appointed trial, intended to give them a sense of responsibility and, thereby, increase their commitment in deployment. Still, the study showed that implementation of a robot required significant efforts in development and training of new behaviors. Specific support and coaching will be required to enable this; simply providing a user with hardware will not be sufficient to implement robots in teamwork applications requiring either human-robot interaction as well as organization-robot interaction.

In addition to the two conscripts, an officer was also trained in robot operation, simply because officers are accustomed to master all the skills of the soldiers. Having an officer trained denoted knowledge on a high level about the robot system's capacities during tactical planning and briefing. The trained captain was second company commander and, thereby, a key person in the company.

The participants in military maneuvers are constantly graded, and leaders who attempt to deploy new features, instead of using traditional methods, take an increased risk of failure. Establishing a tolerant, supportive, and rewarding atmosphere during future tests will increase the rate of deployment.

5.3. When to Test

Performing the tests in a relevant environment is of major importance. In this case the most realistic settings available were the large-scale maneuvers performed during soldier training. It should, however, be kept in mind that training maneuvers differ from real missions regarding mission profile and risk willingness.

A qualitative approach seems to be the best option while testing in a large and complex setting such as one where several hundred persons act individually and dynamically on a mutual task. Quantitative measures are hard to apply as the course of events cannot be controlled and as the sought occasion might not occur often enough to be valued by statistics, but rather have to be regarded through the opinion of experienced participants. Further, it is not possible to perform repeated trials in the same test environment with a single test unit because of the learning effect.

Regardless of what methodology is applied during the phases of research and development, most of the army's evaluation is done through *participatory observation*, i.e., an embedded researcher (the officers and soldiers) uses the tested gear on a daily basis and forms a personal subjective opinion. Hence, even if qualitative approaches might not be the most scientifically distinct, they correspond to how fielded products will be regarded by the end users.

In order to provide well-founded viewpoints it is crucial for the test-user to have some level of hardware knowledge as a base for reasoning. An important quality of long-term testing is the decrease of bias connected to the introduction of a new product. It also gives the test group time to modify their behaviors to the new circumstances and to develop a mature opinion. In the beginning of the test period, the views on the system's capabilities and possible applications differed vastly between users. The initial interviews with the two officers produced numerous suggestions of how the robot might be used in urban warfare. Most of these proved unfeasible during later trials. Similarly, the unstructured interviews made during the trial illustrated that many of the suggestions of how to deploy robots were unrealistic. Not until the end of the deployment phase, when the final interviews were conducted, were the users experienced enough to reflect over robot deployment with more unity.

The more developed the introduced system is, the more relevant are the rendered results likely to be; in conflict there is a need to perform testing in early stages of the product design. An early introduction also enables parallel development of the system and the tactics for use. If this includes changing well-established doctrines this process might require significant time. When considering when to perform user testing it also has to be regarded that the users incorporated in studies will inevitably form an opinion about the tested system. Unsuccessful trials might have an overall negative impact, which can be very hard to recover from; hence, the point of time when to perform testing is a strategic compromise. The Packbot Scout was found capable enough to serve as a basis for research concerning search for objects, exploration, mapping, and payload delivery. Issues regarding mobility, endurance, robustness, radio range, user interaction, tactics, organization, and ethics concerning arming robots could be successfully investigated. Upon request, the users had the ability to see past properties that restrained the system, for example, the bulky operator laptop. On the other hand, implementation of the Packbot did not give the users the ability to discuss topics like autonomy or sensor data fusion with the same level of accuracy. Nor did the end-users have enough background knowledge to value the system in economical terms. On the other hand, it seemed more natural for them to value the benefits of the robot in comparison to other equipment.

The project gave an opportunity to gain insights about the physical and mental recourses available amongst the users. It also proved to build a cooperation framework between the participating organizations and to serve as a suitable way to initiate the use of robotics in the addressed fields. Man-portable platforms were a suitable first step in the introduction of robots amongst the military. Dealing with larger platforms, potentially with autonomous functionality, will increase the demands for testing by orders of magnitudes due to safety regards, legislation, and practical issues such as transport, towing, fueling, training, and field repairs.

After the two years of trials, the officers of the company expect the robot activity to continue in order to keep the gained experiences up to date. Not proceeding might be regarded as negative by the personnel after their having identified robots as a tool with high potential.

5.4. Collecting Data

Manuals and instruction videos allowed access to basic users work procedures and terminology. As might be the case for many vocations, the documentation mainly covered the basics. Observation and participation were important means for gaining a holistic view of the users' work practice. Attending the briefings proved valuable to grasp the course of maneuvers. The opportunities for participatory observation proved to be very valuable for insights on the individual soldier's situation, as well as for establishing an informal setting for discussions.

The monitoring of a group as large as a company brought about a number of practical issues. The target of observation had to be constantly shifted in order to catch the overall situation. The frequent shifts together with the movements of the units in turn caused logistical demands such as bringing clothing, safety gear, supplies, and batteries for one or several days; arranging transport along with the combat vehicle convoys; and managing accommodation.

Circumstances during field studies made documentation difficult. Photography proved to be the most valuable out of note-taking, photography, and video. Taking notes in the field often proved unpractical while video imposed too high workload compared to the information gathered.

The unstructured interviews conducted during the maneuvers were important in getting to know the users and their activities. The short moments of conversations in the field, however, did not allow for reflections. The ten interviews at the end of the project served both as a recollection of the performed missions, and as a survey of the opinions about the system. Follow-up questions were used to verify the validity of the responses, which made it possible to evaluate in which areas the users had a well-grounded opinion. The respondents showed a high level of cooperation and willingness to share knowledge. Using an interviewer who had not participated in the field study decreased the risk of bias. The interviewer's little previous knowledge did not seem to cause friction with the respondents, but resulted instead in more detailed and descriptive responses, which opened the possibility for additional discoveries.

The questionnaire aimed to document the performed robot missions as well as to investigate the questions from the final interviews on a higher number of respondents. The questionnaire and the ten interviews were designed and performed in parallel. Both the final interviews and the questionnaire indicated which topics the users could answer with validity. A pilot-test of the questionnaire would have revealed this and enabled a more feasible survey design.

5.5. Delimitation and Outlook

The approach to have the end users deploy the tested product in a realistic setting limited the scope to technology that could be operated by privates and also have a fair chance to hold out in harsh environments. The authors' aims to motivate continued use of robots has favored applications that could show immediate success over applications which require more extensive reformation, even though the latter might have had a greater long-term potential. Increased radio range, new payloads, improved user interfaces, and tactical developments certainly hold potential for future progress; however, this article has not focused on speculations about technical improvements to come. The findings from current technology, though, are promising enough to justify implementation for a number of reasons. The Packbot Scout as a tool for MOUT imposes an acceptable load on the troops, while offering advantages for current uses. Even if the applications might not be the most commonly used in international missions, the benefits reaped from the Packbot proved signifi-

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cant enough to justify its presence in the toolkit for urban operations. Regarding possible future applications, a premature implementation of the robot would allow for tactical adaptations parallel to future technical developments. Early deployment would also enable a valid dialog between end users and developers.

6. CONCLUSION

The long-term approach in a realistic setting has enabled investigation of technical, tactical, ethical, organizational, and human-robot interaction issues out of the users' perspective. Gathered data became more uniform over time, indicating the validity of the end results and their ability to serve as a foundation for future work. However, it should be remembered that training maneuvers target the most engaging task rather than the most common in active duty missions.

The study has showed that the MOUT-units rely on precise and thoroughly trained actions that can be executed with high precision and a minimum of ambiguity. The importance of reliability increases with risk and uncertainty. Time is often a critical issue, and means of communication are often sparse. All MOUT-gear must be portable as many of the missions are performed on foot; ruggedness and weight are important issues. Equipment must function regardless of weather or time of day.

Deploying the Packbot in MOUT is a two-person task for both physical and mental reasons. The most common mission was *combat reconnaissance* in buildings when enemy presence was uncertain and time was not critical. The main benefits were reduced risks for own troops and civilians, as well as a decreased weapon deployment. The users were of the opinion that units assigned to high-ambition tasks in urban settings should be equipped with one UGV per platoon.

The range of the radio link, the video feedback, and the design of the operator control unit were the features constraining the system's overall performance the most. Other properties of the system, such as ruggedness, size, weight, terrain ability, and endurance did, on the other hand, prove adequate to the application. Trials with payloads indicated that the system has potential for more frequent deployment if extended with modular add-ons for enhanced sensing, voice communication, and weapons deployment. Integration with other military equipment must be a consideration for the future design of robots.

The question of beneficial deployment is, however, beyond just technical functionality. The introduction of robotics as a tool to infantry soldiers may be comparable to automatic rifles or portable radios. Implementing a device with such novel functionality will require tactical development beyond what is normally accomplished. Those who begin implementation now will not only gain the benefits of today's available systems, but also be able to perform tactical development parallel to ongoing technical development, and thereby shorten the time to deployment of the next robot generation with years.

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