Long Term Study of a Portable Field Robot in Urban Terrain

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***Abstract*— Military, police, fire brigade and rescue services need to evaluate robots as an aid to remove humans from risk, to perform more efficiently or at lower cost and to enable missions unsuited to humans. The benefits gained by using robots have to be valued against costs for acquisition, integration, training and maintenance as well as mission efficiency and reliability.**

This study has investigated the benefits and costs experienced by an Army company specialized in urban operations while solving their tasks with the support of a PackBot Scout robot. Established research methods such as observations, exploratory testing, interviews and surveys were used for documentation of the study ranging over a period of two years. During the entire process great emphasis was placed on keeping the users' working conditions as normal as possible.

This paper describes the methodology used during the test, i.e. how the robot was embedded into the users' everyday activities and how this was evaluated. Experiences from the performed tests and evaluation approaches are discussed in order to serve as support for future field robot evaluations.

It is concluded that the taken approach can be recommended to research projects with a robot prototype with reasonable capability to work in a realistic setting in order to test its relevance and readiness.

I. INTRODUCTION

Robots also referred to as Unmanned Ground Vehicles (UGV), have been in extensive use for EOD (Explosives Ordnance Disposal, i.e. removal, disarmament and destruction of explosives) and mine clearance operations for quite some time. Recently, the use of robot technology has aspired to be incorporated in a number of other types of operations. Military, police, fire brigade and rescue services seek to evaluate robots as an aid to remove humans from risk, to perform more efficiently or at lower cost and to enable missions unsuited to humans.

Search and exploration is one of the most investigated applications for the next generation of field robotics. The ability to traverse and perceive premises is moreover the base for most robot applications. However, it is still unclear if current technology is mature enough to justify further implementation. Benefits gained by using robots have to be valued against costs for acquisition, integration, training and maintenance as well as mission efficiency and reliability.

The aim of this project was to examine the advantages and disadvantages connected to the use of a scout robot on operator level as well as on higher levels in the organization. A long-term approach was chosen for the test, in order to diminish the initial bias connected with the introduction of a new product, give the test group time to modify their behaviors to the new circumstances and to form a mature opinion.

In this paper it is described how a PackBot Scout robot was implemented in an Army company and by what methods research was performed. The taken approach is discussed with the aim to serve as a support for further research with similar objective.

II. RELATED WORK

Various long-term user tests have been performed in the area of robotics previously. An early example is the integration of the SURBOT [1] for mobile surveillance in a nuclear power plant 1986. Later are the 17 month testing of the robot seal Paro amongst elderly [2], the 3 month testing of the fetch–and-carry robot CERO by a partially impaired person [3] and a number of long term tests of tour guide robots such as the RoboX9 serving for over 5 months at Expo02 [4]. The area of robot use in search and rescue has been subject to increased research since 9/11/2001, both in the USA [5] [6], and elsewhere [7]. Another example is the now substantial experience of long-term use of robots in space applications such as the NASA-rovers deployed on Mars [8]. Police SWAT-application has been analyzed regarding robot use [9], and finally, a considerable amount of work has been done in the military arena although it is not commonly published in detail [10].

The abovementioned examples have the implementation in a realistic setting over a period of time in common. But despite having the same overarching goal, the approaches may have to 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, there is a great variation on technical requisites to enable testing. The reliability demands are, for example, totally different if testing in a museum compared to deployment on Mars. Hence, it is not obvious how to evaluate mobile robots. Established research methods may not fulfill the tele-presence and dynamics of mobile robots [6]. Research methods from other fields need to be trialed and perhaps modified or redeveloped in order to facilitate evaluation of robotics.

III. METHODOLOGY

A. *Outline of Study*

The project was a joint initiative between the Swedish Royal Institute of Technology (KTH), the National Defence College (FHS), the Swedish Defence Materiel Administration (FMV) and the Royal Life Guards Regiment of the Swedish Armed Forces (LG). The cooperation between the involved parties was initiated as members of military acquisition (FMV) and academic research (KTH and FHS) in cooperation together addressed the issue of to what extent current UGV-technology could be of benefit in urban field applications.

The project started with a user study and a number of small-scale robot tests with the purpose to observe the user and explore in what way robots could be of benefit in the users' activity. This research was carried out during five military exercises under a period of four months from fall 2005 to spring 2006. Data was gathered through field observation, informal interviews and participatory observation (Fig. 1). The robot tests included implementing and performing exploratory testing of the robot within group level as well as by having one of the researchers, who is an officer, participate as robot operator while the robot was used within company level [11].

Based on the results from the first phase it was decided to perform implementation and long-term testing on a larger scale during the following year of service for drafted soldiers doing military service. A number of the users' standard procedures were redesigned to include the robot as an aid. Once mastered by the operators the new procedures were demonstrated to the rest of the company. It was thereafter up to the officers of the company to use the robot as they saw fit in their training maneuvers. During the test period the robot system was part of the company as any of their other equipment.

PRE-STUDY	INTER-STUDY	POST-STUDY
Documentation Study Formal Interview Observation Pre-Testing	Observation Informal Interview Exploratory Testing Participation	Formal Interview Questionnaire Analysis Workshop
FY 2004/2005	FY 2005/2006	FY 2006

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

B. *User Group and Test Facilities*

The user group consisted of an Infantry Company for Military Operation in Urban Terrain (approx. 200 soldiers and 15 Armored Combat Vehicles). In addition 10 training officers were affiliated with the company during maneuvers. The maneuvers in which the robot trials took place included 200 to 6000 soldiers and lasted between three to six days.

All tests were carried out in facilities regularly used for police, fire brigade and military training. These consisted of deserted and partly destructed industrial and residential buildings and offered an environment similar to what can be expected in real operations. During the tests no adaptations or adjustments were done to the environment. The test period spanned over all season including all weather and a temperature span from –25°C to +25°C.

C. *Robot System*

The IRobot PackBot Scout [11] used during the study was equipped with a number of accessories (Fig. 2). The same Direct Fire Weapon Effects Simulator that is used by the soldiers was mounted on the robot (DFWES-Saab BT46). The system consists of a laser mounted on the firearm and a sensor suit worn by the soldier. The system simulates direct fire when training with blank ammunition.

Two more payloads were developed, a flashlight for illumination in dark premises and a Claymore mine. The operator could trigger both by remote control. During the test the system also came to include extra batteries enabling a typical day's deployment, chargers, basic spare parts, a rope for lowering the robot into lower premises, a telescopic rod which could be attached vertically to the robot in order to detonate trip-wired explosives and protective cases for all the included equipment.

D. *Robot Implementation*

The long-term test started off with a handover of the robot system to the users. From then on, except during modifications and repairs, the robot was kept by the company during the 6 month test period. During the test all transport, maintenance and charging was carried out through the users' ordinary resources.

It was stated to the users that the robot system should be exposed to realistic stress and that any damage or wear due to normal use was a beneficial result to the study. The robots durability was said to be alike the users' radios or optical equipment.

In agreement with the Commander of the Royal Life Guards Regiment it was decided that one officer and two soldiers should be trained to operate the robot. They were previously non-practiced in robotics but were accustomed computer users and had some experience of RC-crafts. Unfortunately one of the soldiers was released from duty due to medical reasons after two months. Just as during the pre-study did one of the researchers act as operator in cases when the trained operators were not available. The original purpose of this was to increase the prospect of robot use but it also proved to be a valuable occasions to perform participatory observation.

Three levels of operator training were defined; 1-*Basic Level*, 2- *Map and Search Level* and 3- *Tactical Level*. Training for the *Basic level* was done according to the scheme developed during the pre-study. This included briefing about the robot, basic driving and familiarization with the appearance through the cameras onboard, as well as performing simple missions. After the basic training, which could be done in less than one hour, the operators were able to continue practicing on their own.

Since the higher-level behaviors were not yet defined the rest of the training was in large extend performed in parallel with exploratory testing. The *Map and Search Level* incorporated the ability to make a sketch of explored premises and to search for persons or IEDs (Improvised Explosive Devices).

After having acquired personal skills in robot control the operators were trained to act in conjunction with other soldiers, i.e. the *Tactical Level*. First, this was done in pairs, where operator and assistant were trained to act as a team where the assistant handled the close up safety, transport, robot revival etc. (Fig. 2). Subsequently, after approximately seven days of practice, the pair was integrated into group, squad and platoon level performing their tasks in synchronization with other mission actives (Fig. 3). The information transfer from operator to team proved to be a crucial issue. While the two first training levels only include the operator and the assistant, the third level also requires adaptation from the group in which the robot operated.

The robot system was demonstrated to the rest of the company once the operators had acquired the necessary skills. The demonstrations were done to one platoon at a time and included a briefing about the system, safety issues and a demonstration of a search mission. It was emphasized that the robot use was a test and that some aspects could not be expected to have full effectiveness until some time had been given for tactical development and training.

After the demo the company was free to use the robot system as they pleased. Robot missions evolved to be initiated in two ways. Either the company commander submitted the robot system to one of the platoons in advance of the missions or the platoon or squad leaders requested assistance of the system during mission realization.

The formal organizational position of the robot operator was in the Company Command Squad. But at the end of the test period the company commander had set as a standard to submit the system to one of the platoons. Most often to the platoon which were to perform brake-in into the targeted building. Once a platoon's need of the robot had diminished it was released and the operator relocated to the medical evacuation post, which is aimed to be reachable by the entire company all the time.

During the training maneuvers the robot could be determined to be hit either by the DFWES-system or by the training officers. If judged to be destroyed it was returned to the combat vehicle used by the operator. The robot operator could then retrieve it as if it was a new robot. There was no limit set for how many times this could be done, i.e. the company had a fictitiously unlimited recourse of robots. However, in reality there were one or two systems in use at the time. The same safety guidelines developed during the first test phase were deployed during the long-term test [11].

E. Data collection and Analysis

A number of data collection methods were deployed during the three phases of the project (Fig. 1). The initial step of the user investigation was to study the training manuals and

Figure 2. To the lower left the PackBot Scout robot, the robot assistant in the center and the robot operator in the upper right. The robot is about to drive up the staircase to the left, the assistant is ready to act in the most hazardous direction which is in this case considered to be the staircase. The operator is controlling the robot from a previously secured area.

Figure 3. From the left: the platoon leader, the robot operator, the group leader, and thereafter the 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.

instruction videos of the users. The researchers also participated in a national workshop and a NATO-workshop on urban warfare in order to deepen the knowledge in the field.

Observations were performed for two purposes. First, to gain knowledge about the users' environment and way of working. Second, to evaluate the use of the robot. These two processes were performed in parallel although the former was initiated at an earlier stage.

The users are accustomed to have both instructors and visitors amongst them during exercise. Armlets are used to distinguish observers from participants, which made it possible to have full access for observation during the maneuvers. For safety reasons hearing protector and eye protectors had to be worn. Documentation was done through video and photography.

An alternative way of observing the course of events was to listen to the radio communication between the platoon leaders and the company commander. This is an established way for the training offices to keep informed about the over all progress of the unit.

Participatory approaches were used when the trained operators were not available. This was possible since one of the researchers in the group is an army officer who was trained to operate the robot along with the operators from the company. During the participatory tests the researcher took the place of the operator soldier in obedience of regular rules and demands.

Three types of interviews were conducted during the project. From the start, and during the tests, participants were interviewed about their established procedures and about their experience of working with the robot. These interviews were done spontaneously whenever appropriate in the field and were held in an informal manner. In some cases these interviews were documented with video or notes but most commonly the data was written down at a later point of time.

Secondly, two officers were interviewed in advance of the long-term test regarding what applications they thought might be feasible for robot implementation. Notes were taken during the interview and the conclusions were verified with the participants within a couple of days.

Finally, after the long-term study, an even mix of 10 soldiers and officers were chosen for an in depth interview regarding their experiences from robot use. An anthropologist who had not participated in the field studies was recruited to perform the in-depth interviews. The interviews, which lasted a half to one hour, were semi-structured with one person a time held in one of the users classrooms. A number of topics were defined to be explored but the inquiry was open for modification and extension. Audio was recorded with an MP3-player and non-verbal cues etc. by notes. Each interview took six to eight hours to transcribe and another six to eight hours to analyze.

After the long-term test 40 of the most robot experienced soldiers (35) and officers (5) were selected for a questionnaire. The inquiry was designed to explore the participant's opinion about efficiency in different standard procedures, the robot's significance compared to other equipment, their ideas on possible future use and whether or not they supported acquisition. The questionnaire contained both open-ended questions and Lickert scale rated statements. It took the respondents between 20 minutes to one hour to fill in the form.

A number of issues have been investigated repeatedly through different methods along the project. An evaluation group has been organized to discuss and conclude the gained data. The group, which holds members from all the participating organizations, will conclude the outcome of the study in the fall of 2006.

IV. Discussion

A. Implementation

A number of factors have influence on the results of long time studies. Some of these can be controlled to a desired state while others cannot, and therefore have to be regarded as an influence on the results.

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. Still, these do not fully monitor all aspects of a real application. For example, the true impact of casualties is hard to reconstruct and considerations connected to these may be influenced. Further, the training maneuvers focus on the most difficult tasks rather than the most common in real missions, which is probable to offset the results. Despite these biases, a qualitative approach might be the best option while testing in large and complex settings such as operations including several hundred persons acting individually and dynamically on a mutual task. This, since there is no way such a complex setting can be kept constant enough to facilitate comparative quantitative measures or because the sought occasions do not occur with desired frequency.

Besides having a true test environment it is crucial for the user to have some kind of hardware-knowledge as a baseline. If the user is previously unfamiliar with robotics, his or here opinions will lack in relevance and realism.

An important quality of long-term testing is the decrease of bias connected to the introduction of a new product is diminished. 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 there were significant differences in the test persons' opinions of how the system should be used and what capabilities it could have. These anomalies were found to have decreased significantly during the test, which confirms the accuracy of the gained information.

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 enables parallel development of the system and the tactics for use, if this includes changing well-established doctrines it might be a process taking significant time. It also has to be considered that if the intended end users are incorporated in studies they will inevitably form an opinion about the tested system. Unsuccessful trials might have negative impact, which can be very hard to recover. Hence, the point of time when to perform testing is a strategic compromise. The PackBot Scout was found to be capable to perform well enough to serve as a basis for research around search, exploration/mapping and payload delivery. Issues regarding mobility, endurance, physical robustness, climate hardiness, radio reach, user interaction, tactics, organization and ethics concerning armed robots could be fruitfully investigated. The users did, if requested, have 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 an 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.

A long term study gives a good opportunity for extensive technical evaluation. Having the robot stationed with the Life Guard Regiment consumed eight PackBot batteries, an entire track system and an operator laptop. Wear, damage and breakdown has to be considered in the plan of the test. The project 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. It also gave an opportunity to gain insights about the physical and mental recourses available amongst the users.

Previous experiments and demos had showed the military often to have a curious but somewhat skeptical approach to robotics [11, 12]. The intention of handing over the system to the users (instead of bringing it to appointed trials) was to give them a sense of responsibility and thereby increase commitment to use the robot. Still, experience from the study shows that implementation of a robot requires 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 a sufficient measure for implementation in applications requiring qualified human-robot interaction.

The actual handover of the robot was not planned to be other than an informal delivery of the system. But the meeting turned out to be a kind of “kick-off” since more officers than expected attended, including the commanders responsible for the training of the concerned company. Also personnel from the Defence Material Administration and academia attended. The spontaneous meeting was beneficial to the project since it served as a starting ceremony for the trial. Performing ethnographic studies in large settings will call for a great deal of flexibility in order to perform tests and observations once the chance is given. In this case the users’ primary goal was to do conventional training of soldiers and officers. In several cases were planned robot trials cancelled or rescheduled. Being flexible and having backup plans will facilitate higher research efficiency. During the performed project few occasions were given to gather representatives from the concerned organizations. Occasions like the handover kick-off proved to be rare, but important for test management. The attention from the superior officers during the handover was valuable since the attitudes of superiors have a big influence in strictly hierarchical organizations. The attitude of the higher-level officers was continually enthusiastic during the project. The lower level officers, who were the ones actually having contact with the robot, showed a pending attitude until they got to fully know the system abilities.

For hierarchy reasons it was decided to also train an officer in robot operation, although operation, of the robot would most likely be the task of a soldier. This is because the officers in most cases possess all the skills of the soldiers. Having an officer trained in addition denoted the presence of knowledge about the robot system’s capacities during tactical planning and briefing. The trained Captain had the positions of Second Company Commander and was thereby a key person in the control and ordering of the company.

Just as Jones et al. concluded for SWAT-police [9] the military to a large extent uses predefined scenarios as starting points for their behaviors. This need emerges from the high demand to perform synchronized with small means of communication. A predefined scenario mediates how the co-workers are likely to act even if the arisen situation differs from trained scenarios. Any new routines introduced need to be defined and trained accordingly. The demonstration of the robot system to the company proved to be a vital component from the scenario aspect. It showed the soldiers and officers how the system could be used for exploration which turned out to be the most common mission to be deployed. It is believed that the other capacities, developed after the demo, would also have been favored if demonstrated in the same way. Unfortunately this was not feasible due to practical reasons, instead the newer capabilities were shown in a smaller scale during the maneuvers.

Safety and reliability were two important issues during the trials. On numerous occasions, have safety issues brought deployment of systems to long lasting halts. Besides being important for safety, reliability is also of major importance for the addressed users. Again, just as Jones et al. concluded for the SWAT-police [9], the military is not interested in the introduction of any additional uncertainties in their activity. The need for reliance, together with the desire to move and respond to new situations swiftly, is often considered more important than reducing risk (at least during training maneuvers). This conception proved to be very strong amongst the military but it is indicated by the test that the use of robots, which can be sacrificed, could decrease both own and enemy casualties and thereby justify a change of doctrine. Out of a methodical point of view the use of robots can be encouraged by conventional means such as information, training and demonstrations. But it should also be remembered that the participants in the maneuvers are constantly being graded and that officers deciding to deploy a robot take an increased risk of failure, which might influence their carrier. Establishing a tolerant, supportive and rewarding atmosphere during tests will influence the rate of deployment.

Military is currently in the process of drastically improving their way of evaluating the combat training. Video, GPS and increased use of weapon training systems (like DFWES-46) is being deployed. It is important for the robot developers to also integrate these systems since the addressed user, at least in this case, spends more time practicing than performing live missions.

B. Data Collection

Taking part of manuals and instruction videos was a good way to get to know the basics of the users' work procedures, learn their terminology etc. As might be the case for many vocations, the documentation did mainly cover the basics. The high-level skills were mediated by the officers once the soldiers had reached a higher level.

Observation and participation were important ways for gaining a holistic view of the user. It showed to be essential to attend the briefings in order to grasp the course of maneuvers. Observing the process from the enemy side was a beneficial way to get another point of view.

Monitoring 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 constant observation shifts and the movements of the unit 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.

The circumstances during the field studies made documentation difficult. Out of note taking, photography and video (including using a helmet mounted camera) photography proved to be the most valuable way for documentation. Real time note taking was often unpractical and video caught to little valuable information compared to the workload and distraction it imposed.

The initial interviews with the two officers did produce numerous suggestions of how the robot might be used in urban warfare. Most of these proved not to be feasible during the later trials. Similar was the case with the unstructured interviews made during the trial. Many of the rendered 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 unstructured interviews conducted during the maneuvers were an important way of getting to know the users and their actives. The short moments of conversations in the field did, on the other hand, not give much scope for deeper reflections.

The ten interviews in the end of the project served both as a recollection of the missions performed and for surveying the opinions about the system. Follow-up questions were used to verify the validity of the responses, which made it possible to examine in which areas the users had a well-grounded opinion. The respondents chosen for interview showed a high level of cooperation and willingness to share knowledge. Taking in an interviewer who had not participated in the field study decreased the risk of bias. The interviewer's lower level of knowledge did not seem to cause frictions with the respondents. Instead it forced the respondents to be detailed and descriptive, which enabled additional discoveries.

The questionnaire aimed to document the performed robot missions as well as to investigate the questions from the final interviews over a higher number of respondents. The questionnaire and the ten interviews were designed and performed in parallel. Alike the final interviews, the questionnaires too 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. The mission-documentation part of the questionnaire gave a statistical supplement to the more detailed descriptions received trough interviews.

V. CONCLUSION

It is concluded that the taken approach may well be used to investigate technical, tactical, ethical, organization and interaction issues concerning robot use in field applications. The ethnographic approach in combination with a long-term implementation rendered data that changed to be more uniform over time. It is reasonable to believe that the increase of unity indicates that end-result is valid and can serve as a foundation for future work.

Apart from producing valuable knowledge, the project did establish a cooperative relation between the involved organizations. It also served as the initial step in the introduction of robots for urban operations in the Swedish Defence, which is considered to be central for future robot implementation since military tactics need time to incorporate new technology.

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