The Use of Robots in Harsh and Unstructured Field Applications

C. Lundberg, H. I. Christensen, A. Hedstrom

Centre for Autonomous Systems (CAS),
Numerical Analysis and Computer Science (NADA)
Royal Institute of Technology (KTH)
S-100 44 Stockholm, Sweden
carl.lundberg@fhs.mil.se, hic@nada.kth.se, ah@kth.se

Abstract - **Robots have a potential to be a significant aid in high risk, highly unstructured and highly stressing situations such as experienced by the police, the fire brigade, rescue workers and military. In this project we have explored the abilities of today's robot technology in situations such as mentioned. We have done this by studying the user, identifying scenarios were a robot could be used and implemented a robot system in these. We conclude that highly portable field robots are emerging to be an available technology but that the human-robot interaction is currently a major limiting factor of today's systems. We also find that operational protocols, stating how to use the robots, have to be designed in order to enable the implementation amongst the users.**

I. Introduction

A. Motivation

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 demining operations for quite some time. Recently the use of UGV has been extended to a number of other types of operations. The main drivers for increased use of UGV systems in harsh field operations include:

- To further remove humans from high risk areas/tasks.
- To perform operations more efficiently and/or at lower cost.
- To enable missions that can not be achieved with use of robot technology.

A joint study is performed by the Swedish Royal Institute of Technology (KTH), The National Defence College (FHS), the Swedish Defence Materiel Administration (FMV) and Life Guards Regiment of the Swedish Armed Forces (LG). The primary objectives of the study is to assess current technology and provide demonstrations of how UGV technology can be integrated into typical operations. The study involves identification of key operational requirements, the key components for UGV systems, prototype development for applications, end-user studies, and definition of guidelines for future progress.

B. Related Work

There has previous work done in the field addressed by this project. E.g. Fong has examined small portable interfaces such as PDAs for robot control [1] as well as C. Lundberg et al. [2], H. Huttenrauch et al. [10], H. K. Keskinpala et al. [8], who also performed an objective data analysis. D. Perzanowski et al. have explored possibilities of PDAs and multimodal user interface approaches [9].

The Center for Robot-Assisted Search and Rescue at the University of South Florida has performed a number of studies on field robotics in harsh and unstructured environments. J. Burke et al. have conducted a series of studies of robots for military and search and rescue operations [3]. J. Burke et al. have examined methods for evaluation of robot use [4]. J. Burke et al. have investigated the user methodology for robot-use in field applications [5].

II. Project Description

A. The Robot System

The iRobot Packbot (Fig. 1) is small (70*50*20 cm) and light enough (18 kg) to be man portable. Thanks to the flipper arms, which can be rotated 360 degrees, it has significant off-road abilities for its size. The flippers also enable recovery from a flip over. The battery powered robot has a top speed of 3.7 m/s and operating time between 3 and 12 hours. In standard configuration the Packbot has a Fish-eye camera and an IR-camera, IR illuminator, GPS receiver, electronic compass, and absolute orientation sensors. The robot has five payload bays and double 802.11b radio links for communication with the operator control unit.

Fig. 1 The Packbot going down stairs while checking out the basement of a residential building block.

Fig. 2 The PDA running the graphical user-interface developed for the project.

Our previous tests revealed that a laptop computer, such as delivered with the Packbot system, is not suitable as a portable user interface for a lightweight field robot due to weight, size, not being rugged enough, and being too bulky with screen and keyboard folded apart. In search of other interfaces we developed and tested a number of concepts, including wearable computers and several tablet PCs and PDAs.

An off the shelf PDA was used for the tests described in this paper. The PDA, a IPAQ 5550 (Fig. 2), runs Pocket Linux, has an integrated 802.11b radio link, a combined 320x240 pixel TFT touch screen.

The graphical user interface (GUI) developed for the project shows the video from one of the two cameras onboard the robot, receives the operators drive commands, enables him to set different parameters on the robot such as IR-lights on/off, brakes on/off, frame rate of the video, toggle different display-alternatives and monitor battery power, motor temperature, current compass reading and GPS-position. The driving commands can be entered either by pressing the arrows overlaid on the video screen or by using the hardware buttons at the bottom of the PDA. Other attributes are set through drop down menus. Status information and warnings, such as low radio connection or low battery power, are displayed in the command window below the video screen. The flipper positions are illustrated graphically to the right in the command window.

B. *The Users*

6th Infantry Company (approx. 150 persons) for Military Operation in Urban Terrain (MOUT) at the The Life Guards

Fig. 3 The Reconnaissance squad robot-team using the Packbot to scout a residential block. The operator to the right, the squad leader in the middle and the first soldier to enter after the robot to the left. No doubt that the system is distracting the users general perception of the surroundings, at least initially.

Regiment (LG) of the Swedish Armed Forces was our main user group. In particular we user the reconnaissance squad consisting of 8 conscript soldiers between the age of 19 and 20 with a military training background of 8-10 months. Also the training officers and members of the LG MOUT-development group contributed in numerous occasions.

D *The Test Facilities*

All user tests have been carried out in facilities regularly used for police, fire brigade and military training. These consist of deserted and partly destructed industry and residential buildings and offer an obstructed environment similar to what can be expected in real operations (Fig. 4). During the tests no adaptations or adjustments were done to the environment. Except from the robot system only the users' ordinary equipment was used, apart from charging the batteries from the regular power supply network instead of from the vehicles.

E. *Test Methods*

The three main aims for conducting user testing were to:

1) Investigate and document the users, their workload, their current methods and behaviors.

2) Find key scenarios and develop methodology for how to use robots in these.

3) Evaluate available robot technology in field applications.

The tests were performed through a number of approaches:

1) User study: We started of by conducting a user study to gain a thorough knowledge of how the user operates, what physical and psychological loads are put on individuals and in which scenarios a robot system might be suitable. Initially information was gathered by studying the soldier instruction material such as manuals and video. Thereafter the users were observed during training and under maneuvers

Fig. 4 One of the test environments in a deserted steel factory complex, a large red brick building named "Red October".

2) Interviews: We interviewed personnel with extensive experience in the application-field (training officers and members of the MOUT-development group) to gain a deeper knowledge of their current strategy and to identify possibilities and limitations of their current methods to solve their tasks.

3) Exploratory tests: We conducted a number of exploratory tests to find out how to use the robot and to find new ways of solving tasks. The tests were done by having the robot crew perform iterative tests on the same task to find a suitable methodology. Since this was the users' first acquaintance with the robot-system it was done in parallel with them learning to handle it.

4) Validation tests: We used validation test approaches to verify the usability of our user-interface design. We also tried to perform validation-test for comparison of solving the same tasks with and without robots. But we found that we had not reached a high enough training level with the robot system to make a fair comparison. It also proved inappropriate to perform this kind of validations on large scale military operations since the surrounding circumstances could not be kept constant.

5) Ethnographic study: As one of the authors is an officer in the Swedish Armed Forces we were able to integrate him as robot operator into the maneuvers in order to extend the tests beyond the occasions when we had access to the trained robot crew of the reconnaissance squad (Fig. 6). In this way we provided a robot-system with a fairly well trained operator to the user organization. This also eliminated the conflict between serving the robot system and having other ordinary task to fulfill. Participating with a team member like this gives a very good understanding of the users situation and is a spontaneous way to interact with the users.

Fig. 5 illustrates how we found the above mentioned tests and studies contributed to three aims of user testing. The overall test strategy and test designs are adaptations from the guidelines of J. Rubins [7].

The tests were carried out on five military training

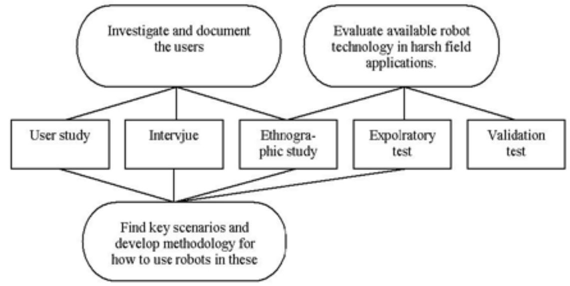

Fig.5 Illustration of how studies and tests contributed to three aims of user testing.

missions over a period of three months. The tests were fitted into the schedule whenever appropriate considering that the main purpose of the maneuvers was of course to train the units in their basic skills. In addition we arranged a number of specific robot-test runs with only the selected test persons involved.

We used digital video and digital photography as our main documentation aids during the field tests. When acting as observers and instructors we used handheld video cameras for documentation. During the ethnographic study a helmet-mounted camera was used for documentation (Fig. 6). Since the number of researchers participating in the field tests ranged only from one to three we often handed out video cameras to the instructing officers to increase our information gain.

The robot system had to be passed through an official System-Safety Review by the Swedish Armed Forces Safety Board before we were allowed to bring it to testing in the units. In advance of all test runs we were particular to inform both the units having the robot systems as an aid and the units acting as their enemy about the robot, the safety hazards it might impose and how to avoid them. We found that the risk of the robot falling or being dropped onto personnel constituted the largest personal danger. The robot risks to be damaged through falling or getting run over by other vehicles.

Fig. 6 To the right, one of the authors participating as Robot-operator during the Ethnographic studies during winter conditions. (Yes a 18 kg robot makes you sink deeper into the snow than everybody else). Documentations was done with a helmet-mounted DV-camera. To the left the company commander with his two radio operators.

III. Observations and Findings

In this chapter we start off by presenting observations and findings regarding the operator control and awareness (A). Thereafter we present issues regarding the abilities and hardware of the robot (B-E). Finally we handle matters concerning the organization and actives above the operator (F).

A. Operator Control and Situational Awareness

We found that the operators ability to teleoperate and take advantage of a robot system seems to pass along certain perceptual stages. Although the sequence of these stages is not strictly sequential, the earlier steps generally have to be mastered before and during the next.

The first stage contains the mere handling of the user interface controls and basic operation of the robot within line of sight. This is often referred to as teleoperation. Normally, the user starts by teleoperation the robot within line of sight, which is beneficial since it shows how the robot behaves according to the controls.

Next, the operator can start to teleoperate the vehicle. During teleoperation the operator has to take use of the video feedback provided by the user interface. Of course, the quality, size, number of frames per second and latency influences the prospect of good perception. The human interpretation of the video feedback is carried out to different depth.

The primary step while teleoperating the robot is to realize the extension of objects shown through video in order not to collide with them. If a difference between the given drive commands and the video feedback is occurring the system is either malfunctioning or the robot is stuck. With some experience and use to the systems ability the driver can realize this and work on getting the robot freed. Likewise, contextual clues such as objects appearing up side down can be interpreted by the user as that the robot has flipped over.

The following perceptual step for the operator is to continuously track the surrounding and relate it to the motion of the robot to create a mental map model of the environment around the robot (a human version of Simulations Localization and Mapping, SLAM). We call this telenavigation.

Finally, the video can be interpreted to give an understanding of what is going on around the robot i.e. gaining situational awareness. E.g. a bulging wall is merely an obstacle but an indication of that the building might be about to collapse.

We argue that the demands on the human robot interface increases further up along the perceptual stages. Hence driving a robot in line of sight does not require a lot of support or feedback from the user interface whereas teleoperation increases the demands and telenavigation puts even more load on the interface performance, and so on.

Analogously we found that the demands on the user depend on the knowledge about the surroundings explored with the robot. A prior known environment is less demanding than an unknown. This seems to yield not only for actual knowledge, but also for the ability to anticipate it. The users could more easily anticipate the layout of residential buildings and make progress in them than in industrial facilities.

We found that operating the robot tended to visually and attentionaly isolate the user from the surrounding, which is of cause not beneficial in high risk situations. To address this we decided to have the robot system served by two persons. The acting in pairs is any way a common methodology amongst our users. The person not operating the robot could then handle the close up defense and safety, sketch the area explored by the robot, lift and carry of the robot when needed, open and close doors etc.

Further we found a need to define standard operating procedures for common challenges. E.g. what to do if stuck, flipped over, loosing radio contact, how to best traverse difficult obstacles such as stairs or rubble, what to avoid etc. just as provided for other off road vehicles.

B. Robot-Mobility and Robustness

Military operation in urban terrain is to a great extent carried out inside of buildings. In case of hostile encounters the troops leave their combat vehicles and move into the buildings to continue their movement. Therefore the ability to traverse stairs and rubble (due to destruction) will be a very frequently needed.

We find the robots ability to traverse obstacles encountered is quite up to demands. Of course the robot sometimes gets stuck but in most of the cases it is not a matter of the robots mechanical abilities but the operators inabilities to grasp the situation and maneuvering in the right way. In many cases the robot could easily be recovered when the operator got to see the situation from close up instead of only observing through the onboard camera.

Going up stairs, and alike, is often easier than going down since the center of mass in the front tends to get the robot sliding when going down. Vegetation such as high grass, sand and snow impose challenges for skid turning the vehicle. In soft snow the Packbot gets stuck when it loses pressure to ground because of snow piling up under its belly. Though worse is, that snow easily piles up on the ramp in front of the camera and blocks the view. In some cases the robot could be recovered from being stuck on snow by driving with the flipper folded down. The snow on the ramp in front of the camera could sometimes be tipped of by tilting the robot vertical, face down, with the flippers. The flippers can also be used to recover the robot from total flip-over. Sometimes deliberately flipping the robot over is a good way to get it freed. Unfortunately flip-overs have proved to wear hard on the antenna attachments. Thin metal wire easily snags up in tracks of the vehicle and when doing so effectively trapping it. Before the field tests both we, and the end-users, were amazed by the supposed ruggedness of the Packbot. After one bad fall and few dents in the chassis we have seasoned our sense to the opinion that the robot is sturdy for being a robot but still has to be handled with care.

Fig. 7 Although the Packbot is fairly sturdy we experienced that it has its limits just above the drop-limit of two meters the manufacturer guarantees. On the top a broken Flipper arm, in the center holders and lid for one of the batteries and in the bottom an antenna that came off its connector and holder due to flip overs.

The Flipper-arms, the antennas and the fastening system of the batteries broke during field tests (Fig. 7). Towards our users we now argue that the robot is approximately as durable as their weapons or their radios. Despite our initial misconception and the crash we find that the Packbot is tough enough to be brought into the field of the users groups we address.

The batteries have proved to hold adequate enough power for the missions we conducted during a day. Of cause it would be convenient if the robot was smaller and lighter but we do find the current is acceptable.

C. Robot Sensors

The Packbot has a fish eye daylight BW/RBG camera, a daylight/IR BW camera, an IR illuminator, a GPS receiver, an electronic compass and an absolute orientation sensor (measuring the roll and inclination of the robot). It also has a battery-power indicator and temperature readers in the electric motors.

As expected the GPS does not give any useful data indoors or close to buildings. Outside, the robot system could not operate far enough from the user (because of the radio link reach) to make GPS position useful (it was so close to the operator anyway). The absolute orientations sensor and the compass did not have a graphical representation in our PDA-interface and were therefore not targeted for evaluation. Despite that we believe that they could provide very useful information to the operator.

The IR-camera is definitely the most used of the two. The fish-eye camera may well be very useful since it gives a broader view, but it demands at least normal indoor light conditions. Unfortunately bad light conditions as good as always accompanied our users operations indoors. Due to the same reason the IR-illuminator proved to be of great aid. Concerning the military user, it should be noted that the IR-illuminator is very visible in night vision goggles as well as the thermal signature of the robot is as strong as for a human in the thermal IR-spectrum, Fig 8. Direct light, such as strong or low angled sunlight, effectively blinds out the cameras in conditions such as if standing in a dark room facing a bright opening. Again the IR-illuminator can be used in some extent to balance this in the close range.

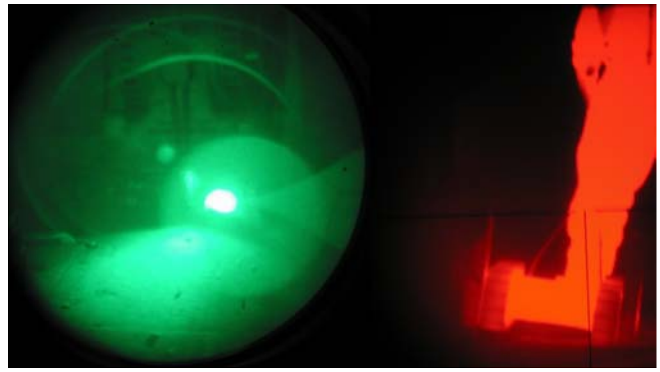

Fig. 8 To the left the Packbot seen through night vision goggles with its IR-illuminator switched on. To the right, seen through thermal IR-sight, the Packbot and the right leg of a person standing behind as a reference.

The low placement of the cameras impacts negatively on the operators' point of view since they easily get blocked by obstacles etc. The low camera positions also make it hard to discover edges like the beginning of a staircase leading down or edges of balconies. This became very clear to us, again in the industrial facilities, where handrails and fencing is designed for adults only and therefore regularly leave the space close to ground unprotected.

The users often expected the picture to display more detail and better situational awareness than it did. Our trials indicate that the operator managed to discover significantly less features and detail through the robot interface than he would have done being in the actual spot. The users performed best in narrow surroundings like in offices or residential buildings. In industrial facilities or outdoors the field of view and the limited resolution gets very restraining. In general, the smallest objects that would be likely to be noted with confidence were vehicle sized in large industrial buildings (like in Fig .4) and man sized in residential or office layouts. In our users point of view it is worth noticing that explosives, mines and trip-wires were not detected even if placed totally visible in the path of the robot. Concerning tripwires a tall antenna on the robot could be a simple feature for triggering trip wired explosives.

The users tended to overestimate the size of objects in the camera view. Movement was beneficial for detection as long as it was not to fast compared to the current frame rate of the camera. As expected the users have problems with long time observation of the video information from the robot. In order to use the system for long time surveillance support, systems such as motion detection are required.

Sound is an important source of information for monitoring of firing and approaching troop or combat vehicles. Audio feedback should therefore be considered to be implemented in robot systems. Two-way audio would also be

useful for tele-communication in hostage or rescue situations. Our users are all equipped with headset hearing protection, which electronically filter out loud noise. The headset can receive
line in audio from radios or other electronic systems and thereby enables the use of sound feedback even in noisy or silence-required circumstances.

D. Robot Radio Link

The capacity and reach of the radio link is of great importance for the usefulness of the robot system. The 802.11b link generally enabled the users to explore the buildings a couple of rooms away indoors and up to a couple of hundred meters outdoors. Unfortunately the distance between the members of the squad was often grater than the reach of the radio link to the robot, meaning that the operator or the squad leader could not move around within the range of his group and still have contact with the robot. Outdoors the perspective of a couple of hundred meters is often to small to enable any considerable tactical freedom of action with the information gained through scouting with the robot.

During demonstrations on exhibitions extensive W-LAN use significantly decreased the quality of the radio link due to overload on the 802.11 bandwidth. The degradation of quality, such as latency and decreased frame rate, that occurs in the outer ranges of the radio link, severely interfere with the usability of the system.

E. Operator Control Unit

The IPAQ 5550 PDA, Fig. 2, we used during the tests shows all the limitations one would expect when taking a office device into a harsh field environment. Thus, it did not meet the requirements of ruggedness or daylight capacity concerning the TFT-screen. However, it holds the advantages of being of convenient size, able to run Pocket Linux, having an integrated an 802.11b radio link, a combined 320x240 pixel TFT touch screen and decent battery capacity.

A joystick seems to be the most desired input device by the users. Unfortunately, the design of the Ipaq joystick key has been changed to be less distinct than on previous models and is therefore not suited for driving the robot since forward/backward/left/right keep being pressed at the same time unintentionally. After having discovered that the joystick of the Ipaq did not work sufficiently we implemented the directional controls on the other hardware buttons of the PDA. Although their placement did not fit very well with the directions they represented, the operators got used to using them reasonably fast.

As mentioned it is also possible to enter drive commands by pressing the symbols overlaid on the video screen. The four green triangles indicate forward, backward, left right and the centered red square indicate stop. We found that the driving with the touch screen was intuitive to inexperienced users but it brought the disadvantage that view of the screen got blocked by the fingers. The touch screen also lacked the tactile feedback and spatial guidance.

The drive commands were given impulse vise in the sense that one push on the forward button means go slowly forward. Another push means go a little bit faster, another push further increase and so on. The robot could then be brought to halt either by pushing the reverse button as many times as the forward button was pressed or by pushing the stop button. The same yields for the left and right commands. A feature that proved very useful was that a push on the forward button while being in a turn ceased the turning and let the robot continue to run in a straight line (tangent line).

Apart from the drive commands also the flippers were controlled through the symbols overlaid on the video, the blue triangles in the right hand upper and lower corner. Also three other frequently used commands were overlaid with buttons on the touch screen, the video on/off, the brakes on/off and the IR-illuminator on/off. We put the video on/off switch here since showing the video in the screen took up so much of the Ipaqs' processor capacity so the mere opening of a drop down menu got delayed. Hence if aiming to navigate in the menus the video could first be turned off to decrease latency (the drop down menus will block the video screen anyway). The need for this adaptation indicates the dilemma with the limited processor capacity of the PDA and the latency it causes. Even though the operators got a feeling and adapted to the delays with increased experience we believe delays interfere severely with the systems usability, precision and efficiency.

The user interface did not show readings from the GPS, the compass or the absolute orientation sensor in any favorable way. The data were displayed numerically in the GPS-window or Pose-window, which, when activated, blocked the video-view displayed in Fig.2. Due to this we have not evaluated the benefits from these sensors, but we believe they can provide very useful data to an experienced user if displayed appropriate.

During our tests we found that the performance of the Ipaq, together with our software, is limiting concerning robustness, ruggedness, CPU-performance, screen size, resolution and daylight capacity. We also discovered a number of specific points of our user interface design to be considered in future designs (out of the scope of this paper).

F. User Specific Findings

1) Missions and Methodology: All basic military behaviours are thoroughly defined and trained in order to minimize reaction times and optimize efficiency. I.e. it is on squad-level defined in detail what equipment the individuals are carrying, what task they carry out, how they move, who opens and closed doors, who is the first to enter into new rooms, how communication is carried out and so on. The high demand of structure and guidelines is forced by the difficulty to overlook and to monitor the complex environment. Robot usage will require an as detailed methodology in order to be efficient.

The military exercises we have taken part in have all been part of the basic soldier training. The aim for the exercises is of course to get the most training out of the available time.

Therefore the pace is often accelerated and oriented towards complex tasks, such as full-scale battle. Routine tasks such as surveillance or low intensity conflicts tend to get less attention. It seems to us that the high pace missions will be challenging for robot use. Probably the initial areas of implementation can be found in the surveillance or low intensity conflicts tasks. If the robot and the soldiers are to move together, an alternating movement can be used, i.e. the robot is driven forward to scout the next section after which the soldiers follow in their ordinary faster pace.

During the tests the robot systems was tried in applications such as:

- Ability tests to traverse unstructured grounds such as rubble and debris.
- Ability tests to discover objects while teleoperating.
- Exploration outside and inside of assorted buildings.
- Exploration and manual mapping of residential blocks.
- Reconnaissance of advance trail for personal and vehicles through large industrial buildings.
- Surveillance and scouting, during dismounted urban warfare, inside of buildings.

The system proved to be of best use for, non-time critical scouting, in narrow and dark surroundings not too obstructed such as basements, staircases, attics and corridors.

2) Information Distribution and Robot Control: We found the information distribution on squad and platoon level to be a bottleneck in our users activity. First, the circumstances for voice communication were often bad due to noise, physical obstacles and distance. There is also an aggravating factor due to the high stress level on the personnel. Second much of the spatial information. Third, the organization is strictly hierarchical in the sense that all information transfer and most of the decisions are handled through the chain of command. In addition, the leaders have to communicate on two networks, the one for his subordinates and on the network for his superior. In total a lot of demands are put on the leaders.

To address this trials are currently made to equip every single soldier with a radio (for speech) for inter squad communication. The radios have proved to eliminate much of the communication problems related to the deliverance of the messages, but the others remain. When communicating face to face, our users often used sketches to illustrate spatial information and instructions for operations.

While testing the robot system we found the sharing of information from the robot will underlie the same distribution difficulties as other information. We explored the information distribution from the operator to the squad leader by speech and sketches. We found that sketches were of great but time consuming aid for handing over information from the operator the rest of the crew. The operators were able to make fairly accurate observations of the areas explored with the robot, Fig. 9. On the other hand, areas indicated, but not open for exploration, such as rooms behind closed doors, tended to be neglected or forgotten. As expected the operator had limits in the amount of information he could hold in his mind at once.

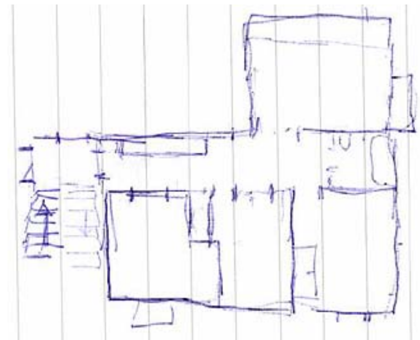

Fig. 9 The operators were able to do fairly accurate sketches of areas they explored with the robot. In this case a three room apartment with staircases to the left, next to the right - the kitchen, to the lower right two bedrooms, at the top right a living room, and in between the bathroom.

We also tested to equip the squad leader with a separate operator control unit so that he could monitor the robots camera in parallel with the operator without them having to cramp up around the same device or even be at the same location. In most cases the leaders did not have the opportunity to continuously follow the robots progress on the PDA. Instead he just wanted to be briefed on particular findings. When so, we found that once the operator discovered something of interest, he could show the video of it to the squad-leader. But he then had to spend a considerable time explaining were the point of interest was located since only he had the notion of the path driven to get there. I.e. there is a need of the interface to build a map and
to have the possibility to save video or images.

3) Organization: Together with our users we concluded that if the MOUT-company was provided with one robot system, it should be treated as a collective company asset that can be requested for use by the squad or platoon leaders. The company commander should handle the prioritizing of usage. The base of the systems and its operators could be co-located with the company's post for medical evacuation, which is aimed to always be strategically centred and accessible to all of the its units.

4) Implementation Integration and Training: While considering implementation it is important to regard integration with other systems. Currently great efforts are being made in adaptations towards Network Centric Warfare. Future robot systems have to implement their needs on the backbone hardware structure in time to be considered. E.g. the future soldier system currently under development in the Swedish Armed Forces does aim to connect every single soldier to the radio network. But it does not consider a radio link that supports the capacity of video transmission.

Besides adaptation to future technology it should be kept in mind that turnover time for equipment in the organizations addressed can be very long which makes compatibility to older systems an important issue. Besides being relevant in the final product development integration might also be necessary in order to achieve relevant testing.

It should be considered that the addressed organization spends more time training than actually performing their tasks (at least in Sweden). The military have both rules and technical systems to evaluate damage and losses during exercises. A robot system participating in an exercise must be implemented in the judging system in order to be correctly evaluated.

5) Differences in Attitude Towards Testing: The users and the researchers seem to have a significantly different view on robot-systems. The researcher, with the robot field as his main working perspective, has the ability to consider isolated functions of the system separately. He is able to judge the benefits and drawbacks, and thereby value and neglect them during tests.

To the user, the occasions when robots can be applied are relatively few. The user also tends to consider the system in total, and he will relate the performance it currently possesses to the established concepts, no matter what state of development the robot-system is. A user may not understand why the system is tested at all if it has any kind of severe flaw.

IV. CONCLUSIONS

The technology in terms of mobility and packaging for compact lightweight robot systems are reaching a level of maturity that suggests deployment in realistic field applications. In the present paper we have discussed the deployment of a Packbot system for use by regular soldiers for urban reconnaissance tasks. The present study has considered the use of laptop and PDA interfaces for the control of the robots. The conclusion is that it is a major challenge to use such devices as part of deployment of robot systems. In principle, the robots platforms have the required performance for live missions, but the interfaces are not yet as mature. There is a need to increase the robustness and functionality of interfaces and at the same time there is also a tactical need to consider the implications of use of robots as part of missions.

A. Robot-System Improvements

It is clear to everyone with teleoperation experience that making use of a vehicle through video feedback it is very demanding. Not only is the actual control demanding but it is also hard to achieve a thorough situational awareness of the targeted area compared to actual presence.

Significant improvements could be achieved with today's technology if considered with an appropriate design. There is a need to display information from several sensors like video, microphones, LADAR, ultrasonic sensors, GPS, compass and inertial sensors simultaneously and in an easily comprehensible way – computer games might suggest new ways to achieve this. The possibility to save information such as positions, video or pictures is required. Also the physical design of rugged portable user-interfaces can be improved. Out-door daylight capabilities is an obstacle to use of LCD screens.

The present platforms are purely teleoperated. The emergence of control methods for semi-autonomous control could provide a significant improve as they would relieve the operator of detailed control during trivial parts of a mission.

Another factor today is the communications technology. Direct point-to-point use of 802.11b wireless network is not adequate for the streaming of video etc over significant distances. There is here a need to design an information grid into which the platforms can be embedded.

B. User-Strategy

The study clearly indicates that highly portable field robots soon will become a standard technology for military deployment. Once available it will become ethically, economically and politically unjustifiable not to make use of the technology during high-risk missions. To deploy the new technology the concerned organizations like the police, the fire brigade, rescue workers and military will need to address a number of issues:

1) Research and Development: Provide researchers and industry with guidelines for development and integration.

2) Develop methodology for use and adapt the organization: Development and adaptation of tactics and behaviours for robots usage.

3) Acquisition, Implementation and Training: Acquisition and implementation of, and training with, the hardware.

V. FUTURE WORK

We aim to improve the operator control unit to further implement the robot-system and develop the methodology for usage. In addition the utility of the systems will be evaluated as part of extended missions, to determine potential long-term effects.

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