ThrowBot: Design Considerations for a Man-Portable Throwable Robot

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ABSTRACT

The pocket-sized ThrowBot is a sub-kilogram-class robot that provides short-range remote eyes and ears for urban combat. This paper provides an overview of lessons learned from experience, testing, and evaluation of the iRobot ThrowBot developed under the Defense Advanced Research Projects Agency (DARPA) Tactical Mobile Robots (TMR) program. Emphasis has been placed on investigating requirements for the next generation of ThrowBots to be developed by iRobot Corporation and SPAWAR Systems Center, San Diego (SSC San Diego) Unmanned Systems Branch. Details on recent evaluation activities performed at the Military Operations in Urban Terrain (MOUT) test site at Fort Benning, GA, are included, along with insights obtained throughout the development of the ThrowBot since its inception in 1999 as part of the TMR program.

Keywords: robotics, ThrowBot, man-portable, urban combat, unmanned ground vehicle.

1.0 BACKGROUND

Although the development of unmanned-systems technologies has significantly advanced over the years, the actual use of robotics in the military has remained elusively just over the horizon; that is until the recent deployment of man-portable systems in theatre for explosive ordnance disposal (EOD) tasks. For the first time in history, the warfighter is able to provide feedback on operation and usefulness of various man-portable systems in combat and assist in directing the future development of robotic platforms as a warfighting tool. Tradeoffs with regard to state-of-the-art technology integration versus size, weight, speed, agility, and mobility have helped minimize the drawbacks and maximize the benefits to the soldier. This spiral development process has identified a need for a throwable sub-kilogram rolling-camera robotic capability, or ThrowBot, that allows for remote reconnaissance of unknown or hostile areas.

Initial prototypes for the ThrowBot were developed under the TMR program, sponsored by DARPA in the late 1990's, and transitioned to SSC San Diego at the end of FY-02. This provided SSC San Diego a varied mix of prototypes to test requirements for future throwable platforms. SSC San Diego, funded by the Office of the Secretary of Defense (OSD), was tasked to take laboratory prototypes developed under the TMR program and determine a path forward to develop a fieldable throwable robotic system.

1.1 Concept of Operations

At base or in a vehicle (HMMWV), the soldier sets up the ThrowBot and its associated controller to charge up the batteries. While prepping for a mission, the ThrowBot and controller are removed from the charging stations and stowed either in a backpack or cargo pockets.

During a combat mission, the system remains stowed until there is a pause in operations, and it is desired to know if hostiles are in a particular

Figure 1. ThrowBot concept.

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nearby vicinity. The ThrowBot is removed from the carrying compartment, activated, and then tossed down a corridor, up a stairwell or into a window as shown in Figure 1. The platform can be thrown by a single person or launched into an upper window or rooftop using an improvised slingshot consisting of surgical tubing held by two soldiers and operated by a third. Landing on a top floor, the remotely operated platform will be able to bypass typical obstacles and travel down stairs. The operator can evaluate the resultant video before determining the next course of action. The ThrowBot can also be used to search for and assess booby traps, enemy personnel, and improvised explosive devices (IEDs).

1.2 Initial Requirements

From previous experience in developing a variety of robotic systems and discussions with prospective users, an initial set of requirements for the ThrowBot-class platforms has emerged. In terms of vision, the camera must be low-light/night capable while not compromising its ability to look into bright sunlit areas without any washout of the picture. It should be possible to point the camera in any direction and elevation angle, zoom the camera on an item of interest and still have a wide field of view for driving in a cluttered environment. The associated video display should also be viewable in direct sunlight.

Effective communications range is also a key factor in order to provide the warfighter sufficient standoff from the enemy while operating the platform in an open area, with a non-line-of-sight capability through building walls. The platform needs to be able to operate in a cluttered environment and should not get hung up in debris such as clothing, rocks or wires.

Deployment in desert scenarios typically encountered in Iraq and Afghanistan imposes a requirement to operate in thermal conditions of 100-140 degrees Fahrenheit.

2.0 TECHNOLOGY ASSESSMENT

2.1 Early Prototypes

In the early TMR ThrowBot efforts, many mobility methods were considered, but not all were brought to the prototype level, and consequently many dynamic methods of overcoming obstacles have not been fully explored. This section provides an assessment of current and past efforts in throwable platforms, including the three prototypes that were selected for further testing by SSC San Diego.

2.1.1 Two-Wheeled Cylinder

One of three prototypes developed by iRobot Corporation for the 1999 subcontract to Draper under the TMR project was the two-wheeled ThrowBot. With dimensions similar to a 12-ounce soda can, it possesses a cylindrical body with a large wheel on each end and a spring-loaded tail. This design potentially allows for large-diameter optics to look sideways through the wheel hubs. However, while the design can self-right, its ability to negotiate terrain or climb over small obstacles is extremely limited, and it has a strong tendency to yaw back and forth while moving, seriously degrading the video. A number of other TMR participants pursued similar two-wheel approaches, but all were eventually abandoned for the reasons cited.

Figure 2. Two-wheeled cylinder.

2.1.2 Six-Wheeled Brick

The solid brick-like six-wheeled platform possesses a rectangular body, with three wheels on each side geared together for full six-wheel drive with skid steering. A paddle, which stows on the top, is used to right the vehicle if it becomes inverted, and to help push the vehicle over obstacles. The vehicle can climb over obstacles as tall as its wheelbase, such as most street curbs.

Figure 3. Six-wheeled Brick.

2.1.3 Four-Wheeled Brick

Similar in body construction to the six-wheeled Brick, the four-wheeled platform was modified by DRAPER laboratory to have larger wheels that make it able to climb bigger obstacles and a slower drive speed to allow greater control by the user. This design and its six-wheeled variant above are the most viable candidates built to date.

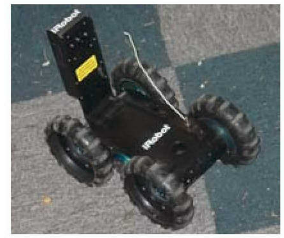

Figure 4. Four-wheeled Brick.

2.1.4 Inflating Weight-Shifting Sphere

A compact package when stowed, this design inflates into a spherical ball after being thrown or emplaced. Limited mobility was achieved by weight shifting the internals, and the inflating skin was susceptible to sharp objects in the environment. The platform also suffered from sensitivity to wind, and therefore was not pursued further.

Figure 5. Inflating sphere.

2.1.5 SpinyBall

Developed by DRAPER, the SpinyBall starts off as a softball sized sphere making it highly portable and easily deployed. When deployed the operator can extend the spiny wheels, exposing the camera and giving the platform a unique solution to driving over difficult terrain. This solution has fairly good mobility but is a complex design with many moving parts, and therefore expensive to build and harder to maintain.

Figure 6. SpinyBall.

2.1.6 Rebound with Flippers

iRobot specifically the Rebound for testing the dual-flipper concept. The Rebound ThrowBot is a quickly constructed prototype designed around a commercial toy car with dual external flippers mounted on the rear. In the laboratory, it has demonstrated superior terrain transverseability and camera placement but suffered from poor reliability and lacked servo control on the flippers.

Figure 7. Rebound.

2.2 Evaluation Platforms

The six-wheel Brick, four-wheel Brick, and Rebound with flippers were the closest to meeting the stated requirements and thus chosen by SSC San Diego for further evaluation. The initial prototypes were intended as mobility demonstration platforms, allowing users to experience the current state of technology, and engineers to investigate where improvements needed to be made to produce fieldable units. Although these prototype concepts were never intended for durability testing, the two Brick options are hardened to withstand casual impacts, and the design allows for further environmental ruggedization.

3.0 USER EVALUATION

In late May 2004 SSC San Diego took the two Brick ThrowBot prototypes and the Rebound ThrowBot shown in Figure 8 to the Fort Benning McKenna MOUT site, where a simulated town rests in the middle of a Georgia forest, complete with furnished buildings, city streets and staffed by army personnel.

Figure 8. Two Brick ThrowBots (foreground center) and one dual-flipper Rebound ThrowBot.

The three ThrowBot platforms were presented to users in teams of four to six per group. After the teams were briefed on the intent of the ThrowBot evaluations, each user was provided the opportunity to drive the platforms through an obstacle course in direct view. Next, each user was given an opportunity to drive the platforms using only video feedback from the operator control unit (OCU). Once each user had mastered the prototypes, the robots were dropped into a realistically cluttered urban environment, and the teams were requested to map the rooms and identify hidden inert weapons, such as grenade launchers, AK-47s, and trip-wire mines (Figure 9).

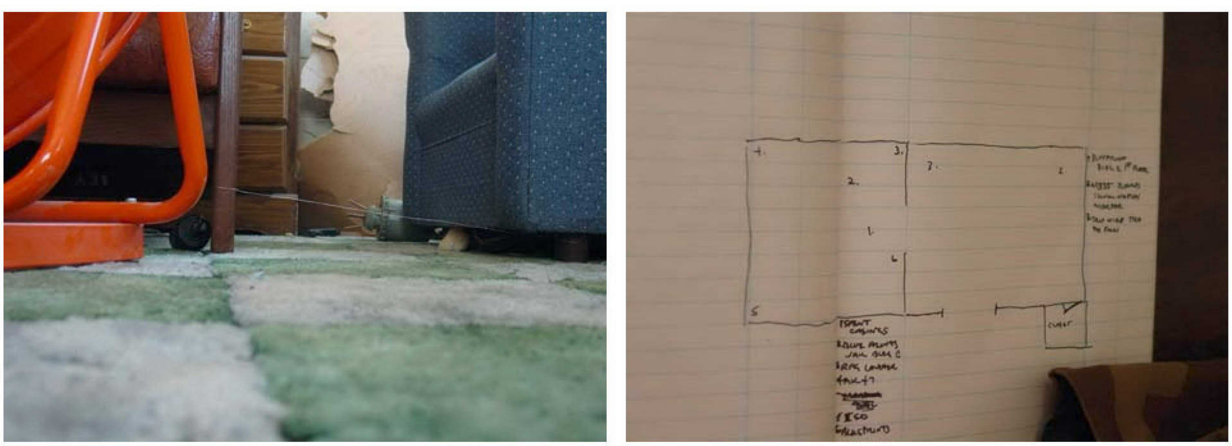

Figure 9. Weapons (inert) hidden at Fort Benning (left) and a map of weapons drawn by users during evaluation (right).

4.0 TECHNICAL ASSESSMENT

Many upgrades for the ThrowBot were identified as a result of interacting with each platform, as well as by direct observation of operating personnel and surveys distributed to users (see Appendix A and Appendix B). These upgrades range from simple user-interface concerns to mission-critical issues, such as communications range and portability.

4.1 Mobility

Users reported that the six-wheeled ThrowBot felt unnatural to remotely drive due to the low height of the camera and its high speed. They reported "jitteriness" causing overcorrection while turning the six-wheeled platform. While the four-wheeled ThrowBot felt more natural to most users due to the higher camera mounting, it was slower than some would have preferred. The speed setting for the individual ThrowBots is a variable parameter based on the gear ratio and settings in the OCU. This issue could be easily addressed in any future design by a readjustment of these parameters to find the ideal ratio of responsiveness and control. Steering overcorrection can be addressed by replacing the open-loop speed control on the prototypes with closed-loop control. Overall the mobility of the platforms was adequate to perform most missions and had the ability to overcome many common obstacles, as seen in Figure 10.

Figure 10: Six-wheel ThrowBot climbing over open grate.

4.2 Portability

Since portability is a major concern for an item intended to be carried by the warfighter in theatre, weight was kept to a minimum during the design of the ThrowBot. However, due to its awkward shape, it was not comfortable to walk around with the platform in a standard cargo pocket, as seen in Figure 11.

Figure 11. Phase I ThrowBot was designed to fit into standard thigh pocket.

To make transporting the ThrowBot easier, several users suggested incorporation of a customized pouch that could be clipped to a standard-issue backpack. Another suggestion was to design detachable wheels that could be taken off easily without tools, making the system more portable. This would allow for future development of specialized wheels for different environments and also facilitate modular maintenance.

4.3 Low-Light Visibility

After entering a few buildings, it quickly became clear that operation indoors and under furniture brought the ThrowBot into conditions of extremely low light. Some areas of the environment could not be fully perceived by the teams due to the lack of visibility under these conditions. Two possibilities are being evaluated for a future design: 1) to equip the unit with a more expensive low-lux camera that can see in almost any lighting condition, 2) to install low-cost lighting on the ThrowBots to illuminate the camera field of view. While lower in cost, the latter option introduces additional battery drain and increases the chance of detection during covert operations.

4.4 Battery Life

The general consensus was that the 2-hour battery life was more than adequate for typical tasks. In the future, built-in rechargeable batteries would simplify logistics support in-theater, but replaceable alkaline batteries allow the unit to return to service immediately.

4.5 Communications Range

Communications range was experimentally found to be approximately 40 meters of open area or through two cinderblock walls of a building, which the majority of users claimed was sufficient for many missions. A more sophisticated communications system would allow the ThrowBot units to be used in an even wider range of applications, with the accompanying trade-offs in cost, size, weight, and power consumption.

4.6 Operator Control Unit (OCU)

The OCU performance was well received by users, aside from issues raised with regard to size and weight. The OCU is currently the size of a small suitcase, as seen in Figure 12. Most users commented that while it could be reduced in size, the existing configuration would not stop them from using it in the field. (It should be noted that the OCU has not been optimized for field deployment but designed for convenient demonstration of the vehicle's mobility.)

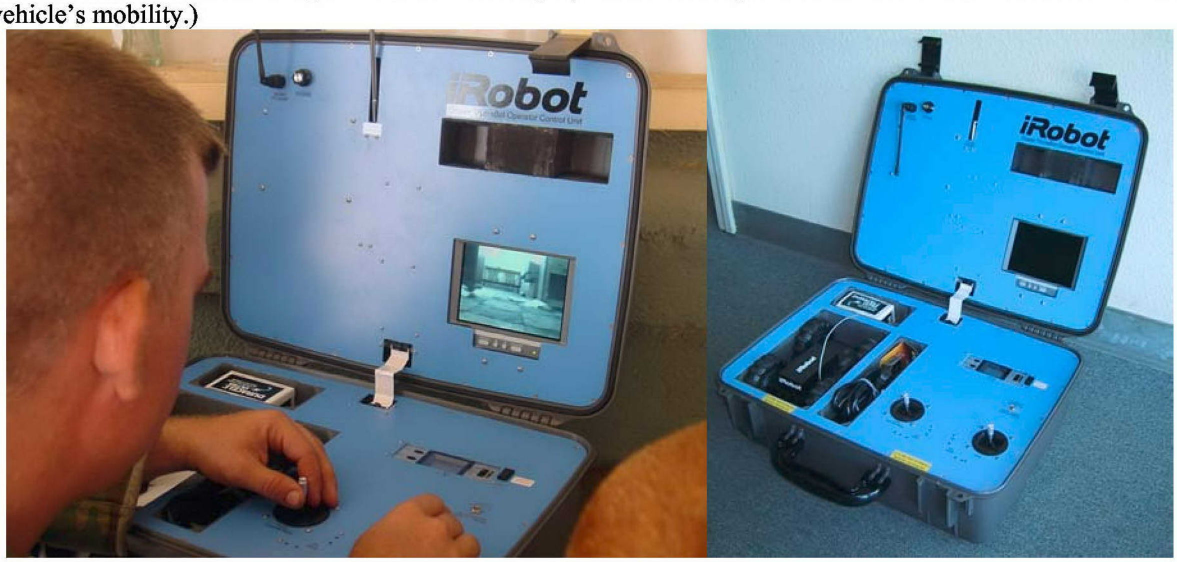

Figure 12. OCU used by Fort Benning personnel during ThrowBot evaluation.

4.7 Camera Location

Users expressed a strong desire for an ability to change the height and elevation angle of the camera and preferred the higher camera location offered by the camera mount on the paddle of the four-wheeled ThrowBot (Figure 13). The camera on the six-wheeled ThrowBot, which is mounted in the front of the platform, was often criticized for being too low and non-adjustable.

Figure 13. Cameras are mounted on the paddle (left) and in the nose (right) of the Four- and Six-Wheeled ThrowBots.

5.0 CONCLUSION

From the feedback of the users at Fort Benning and the reception from warfighters to the notion of being freed from the task of reconnaissance in dangerous urban environments, it is evident that the ThrowBot has shown considerable potential to assist the warfighter in-theatre, reducing the risk to US military and allied forces. There are no significant technical barriers that would prevent the development of a tactically useful ThrowBot on a scale slightly larger than a cell phone. Future ThrowBot designs should retain simplicity and robustness and avoid adding features that add complexity and cost to the system.

Our vision of a next-generation ThrowBot is to evolve the six-wheeled morphology into a tracked platform and to use dual external flippers instead of the central paddle. Existing commercial radio systems can provide sufficient range and security, though hardware-based digital video compression is a must. A single high-resolution camera can be utilized with appropriate processing to provide both wide field-of-view and the ability to zoom in on an item of interest without adding an optical zoom lens. These technologies are all at TRL 6 or above and need to be combined together in a useful tightly integrated system to enable the warfighter to complete the mission with minimal risk.

6.0 ACKNOWLEDGEMENTS

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7.0 REFERENCES

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APPENDIX A

ThrowBot QUESTIONNAIRE

Name___________________________________ Date___________________________

Estimated Run Hours_________________ Platform Type___________________

Recipient is requested to exercise his/her best professional and military judgment to rate each of the following test concerns. Using the scale below, please place the number that best described your answer next to each question, and include remarks for answers rated at 2 or 1. If a question is not applicable to your are of expertise or the item is not available for your review, please write "N/A" in place of a rating number.

RATING PERFORMANCE SCALE

Disagree (1)	Somewhat Disagree (2)	Neither Agree / Disagree (3)	Somewhat Agree (4)	Agree (5)

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1. _____ The battery life on the base platform is adequate.

Comments: ____

2. _____ This platform works best with 4 wheels.

Comments: ____

3. _____ a. The platform's mobility is adequate indoors _____ b. outdoors.

Comments: ____

4. _____ The Operator Control Unit is effective and easy to operate.

Comments: ____

5. _____ The transmission range of the Operator Control Unit/Video is useful.

Comments: ____

6. _____ The camera works best mounted on a flipper.

Comments: ____

7. _____ The camera works best mounted on the front of the platform.

Comments: ____

8. _____ The platform should have zoom camera capability, even if it weighs a pound more.

Comments: ____

9. _____ The platform should have twice the radio range, even if it must weigh twice as much.

Comments: ____

APPENDIX B

Survey Results

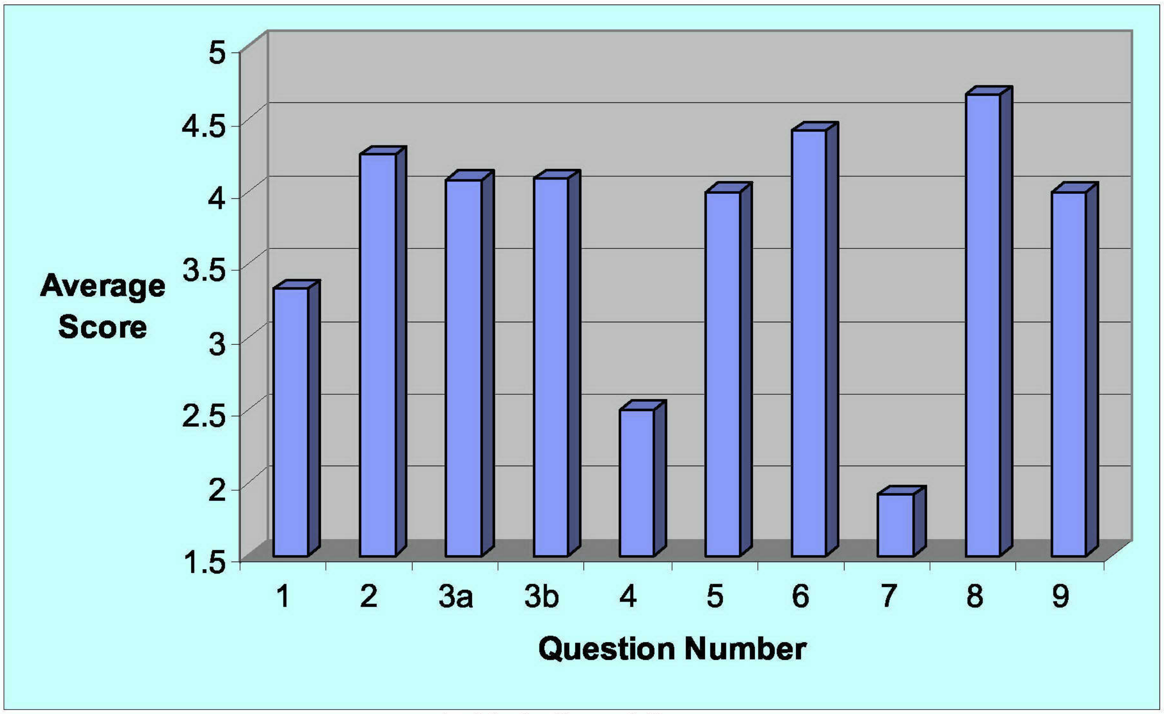

Table 1. Group 1 Scores

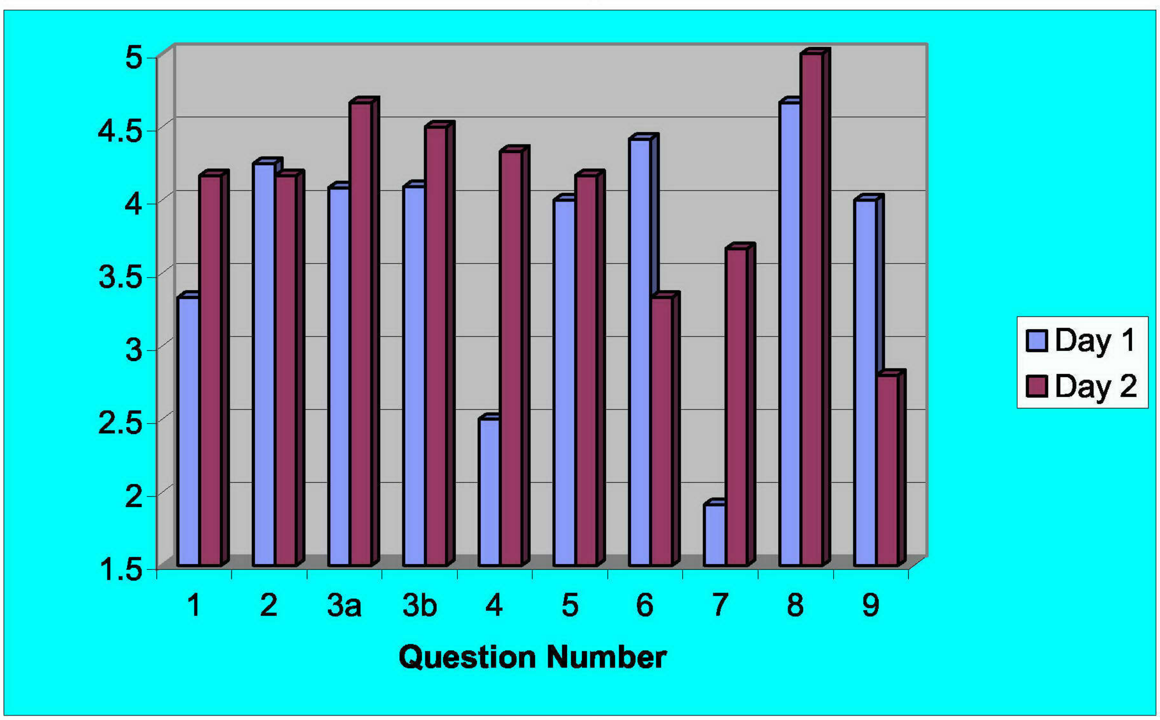

Table 2. Combined Scores