OzBot™ - Haptic Augmentation of a Teleoperated Robotic Platform for Search and Rescue Operations

Michael Fielding  
Intelligent Systems Research Lab  
Deakin University  
Australia  
mrf@deakin.edu.au

James Mullins  
Intelligent Systems Research Lab  
Deakin University  
Australia  
jmullins@deakin.edu.au

Ben Horan  
Intelligent Systems Research Lab  
Deakin University  
Australia  
ben.horan@deakin.edu.au

Saeid Nahavand  
Intelligent Systems Research Lab  
Deakin University  
Australia  
nahavandi@deakin.edu.au

Abstract—A continued increase in computing power, sensor capability, software functionality, immersive interfaces and hardware modularity has given robot designers seemingly endless potential in the area of mobile robotics. While some mobile robotic system designers are focusing on expensive, full-featured platforms, developers are realising the advantages of emerging technology in providing small, low-cost mobile reconnaissance vehicles as expendable teleoperated robotic systems. The OzBot™ mobile reconnaissance platform presents such a system. The design objectives of the OzBot™ platform focus on the development of inexpensive, lightweight carry-case sized robots for search and rescue operations, law enforcement scenario and hazardous environment inspection. The incorporation of Haptic augmentation provides the teleoperator with improved task immersion for an outdoor search and rescue scenario. Achieved in cooperation with law enforcement agencies within Australia, this paper discusses the performance of the first four revisions of the OzBot™ platform.

Keywords: mobile platform, search, rescue, haptic gravitational field, OzBot, expendable, IED, OED

I. INTRODUCTION

With a growing reliance on teleoperated robots for security roles, reconnaissance missions and Improvised Explosive Devices (IED) detection, designers are finding that small low-cost systems capable of visual surveillance are proving increasingly effective. Although there is an existing need for multi-function platforms such as the tEODor™ platform [1] used by many police agencies within Australia and man-portable systems such as iRobot’s PackBot [2], the Foster Miller’s Talon [3] and the Allen Vanguard ROV [4], the focus is shifting to small, simple-to-use man-packable disposable robots. These robots are intended as an expendable first-response device. The development of systems such as Dragon Runner [5], the MPRS [6] and Millibots [7] are all testaments to the growing popularity of a new breed of low-cost robots.

Recently, members of Deakin University’s Intelligent Systems Research (ISR) Lab have been working with local law enforcement agencies to investigate specific requirements of mobile robots within Australia’s current technological and political climate. Platform speed, size, weight, auxiliary capability, maneuverability and range have been evaluated. The outcome of this exploration resulted in a testing methodology and the concurrent development of several OzBot™ platforms. Operational testing of the various platforms has been conducted and the results of these tests are presented herein.

Figure 1. OzBot™ Mk.I robot

The Mk.I robot was the first to be produced in the OzBot™ series. Having predominantly used larger robots as a first-responder system, the ease of deploying the OzBot™ platform was noted as being the systems major advantage by the evaluating officers. Featuring a deployment time of less than ten seconds, operators are able to begin preliminary site investigation moments after arriving.

The Mk.I version of OzBot™ was capable of being controlled in a wireless mode with an operational range of up to 300m, or via a copper tether that carries the live video stream and control data. On-board batteries are capable of maintaining full operational status for 45 minutes. OzBot™ Mk.I drives using a front-mounted differential wheel pair with a non-driven spherical roller located at the rear. If the robot
is flipped during operation, it can still operate and both motion control and the video stream is automatically inverted. Although this robot has proved successful in highly structured environments, it suffered due to its low ground clearance, limited traction and high drag resulting from the rear roller.

Land based urban search and rescue robots are faced with the ever increasing expectations of being able to negotiate any and all variations of terrain. Traditionally, stairs have been one of the most common obstacles faced by such robots and the hardware required to traverse them has placed tight restrictions on platform geometry and increased platform costs significantly. As a result stair-climbing robots are often considered prohibitively expensive and not readily expendable. Platforms being developed such as the Redback [8] take advantage of commercial off the shelf (COTS) technology such as remote control vehicles to supply locomotion. These cost effective platforms are then retrofitted with additional sensors and processing capability. The Redback achieves stair climbing ability for a total expected cost of less than AUD$1K [8]. Such platforms are best suited as a limited-life solution as the plastic construction of the toys suffer when exposed to the inherent wear of navigating harsh environments.

Small platforms with limited stair climbing ability can be transported using a larger mobile platform and deployed when required. Systems such as the Dragon Runner, developed at Carnegie Melon University are built to withstand being thrown into a building or area for investigation [5]. The OzBot™ Mk.II platform employs a similar design philosophy and is shaped to be launched like a grenade from a specially designed compressed air powered launch mechanism. Skids made from a malleable plastic allow the rover to fit snugly into a launcher and then deploy once fired. Once activated and aimed, the rover can be shot onto roofs, through windows or over fences.

Based on the Mk.I design, Mk.II again uses a front mounted differential drive configuration this time employing a dolly wheel at the rear to reduce rolling drag. A necessity identified by the evaluating law enforcement officers was the ability to attach auxiliary devices to platforms. Thermal and night-vision cameras, provision for chemical biological and radiological (CBR) detection systems or additional battery packs can all interface to the auxiliary port. Figure 3 shows one such example, a telescoping camera module. The camera can incrementally tilt to a vertical angle from its horizontal stowed position and can extend the attached camera to a height of up to 1.5m above the ground surface. The camera also incorporates a high sensitivity microphone that is used to relay audio back to the operator. OzBot™ Mk.III overcome issues with traction, increased ground clearance, gave extended range using higher gain antennae and more powerful transmitters, had the ability to shut down limited functionality in a ‘low power’ mode and an improved battery monitoring system.

Figure 3. OzBot™ Mk.III with telescoping camera

Figure 4 shows the Mk.IV rover, a 4x4 skid steer platform with improved battery life, illumination, auxiliary bay functionality and a further increase in communication range. It employs a 900Mhz serial data link and long-range video transmission modules. The chassis is constructed of laser-cut stainless steel and using a material saving design, the chassis weighs less than the previous models while being strong.
enough to stand on while driving. The maximum effective range of the Mk.IV platform is 1500m.

The decision to move to a 4x4 robot resulted from the limitations of control faced by the Mk.I, II & III differential drive style of steering. The dolly wheel and skid configuration was susceptible to becoming snagged on small obstacles and trapping the robot. The 4x4 configuration passed similar obstacles with ease and proved capable of climbing gutters and moving easily through scrub and rough terrain.

Pictured in Figure 5 is a sequence of images taken of the Mk.IV platform firing a solid fuel rocket from its auxiliary detonation module (picture at rear in Figure 4). The detonation module gives provision to deploy 'boot kickers' deployed from behind the platform, detonate all other electrically triggered charges, switch high powered external lighting, trigger active denial systems, etc.

The auxiliary port can be used for additional batteries to allow extended operational duration, up to 1 external video and audio input, secondary communications systems for ultra-long range operation or as payload space for a standalone sensing system or object.

II. CONTROL ARCHITECTURE AND INTERFACES

Controllability is as important as platform capabilities. The effectiveness of an immersive operator interface in providing the operator with the necessary mission-critical information can prove highly advantageous. Considering an outdoor search and rescue scenario, where the operator is required to command the OzBot™ platform to a known goal location, the Haptic Gravitational Field [9] is introduced in the aims of assisting the operator in such a task.

A. THE HAPTIC GRAVITATIONAL FIELD (HGF)

The premise of the presented approach to haptic teleoperation is to increase teleoperator performance through the introduction of application-relevant augmentation. A review of the literature reveals several different approaches providing the teleoperator with important task relevant information via a haptic medium [9,10,11,12]. One particular approach is to provide the operator with haptic information indicating the amount of force exerted by the robot on the remote environment [13], while others have chosen to assist the user in the trajectory task following the use of a haptic approach [12].

The work by Lee et al [14] provides the teleoperator with a haptic indication of surrounding obstacles, thus reducing the occurrence and likelihood of collisions. Figure 6 demonstrates teleoperator immersion for the any particular remote task.

![Figure 6: Operator immersion in teles operate tasks](image)

The OzBot mobile platform implemented in this system provides all-terrain navigation allowing traversal of challenging real-world terrains. Search and rescue is a potential real-world application for teleoperated all-terrain mobile robotics [15]. In these types of operations, a mobile robot can be utilised for several different tasks such as reconnaissance and assisting the injured.

In this work, a haptic augmentation approach is proposed to assist in guiding the teleoperator's navigation of OzBot™ to a particular location in the operating environment. This utilises the haptic nature of the user interface, allowing the teleoperator to focus their visual sense on the immediate challenge of safe navigation while relying on the haptic augmentation to indicate the direction and distance to the goal location.

As a basis for the HGF, the following assumptions are made:

a) The goals absolute location is known, as well as its direction relative to the robot. In this outdoor scenario this may be achieved through signal triangulation to a transmitting beacon, GPS co-ordinates or satellite imagery.

b) The environment is so unstructured that determination and evaluation of obstacles and safe navigational paths is not feasible by an autonomous robot, but better performed by the operator.

The overall objective of the teleoperator is to safely navigate the remote mobile robot from a start location to the goal or target location. It is assumed that in this particular search and rescue scenario the terrain is extremely challenging and unstructured. It is therefore deduced that onboard sensory and computational capabilities are likely to prove inadequate to augment the user with accurate information regarding collision avoidance [14] or
The HGF is intended to provide a haptic indication of the current distance and direction to the goal location. This can prove extremely valuable when the goal location is not clearly identifiable to the teleoperator. The HGF is demonstrated by Figure 8, where $x_r, y_r$ is the current position of the robot and $x_g, y_g$ the position of the goal location, with respects to a world co-ordinate system.

Given the current location of the rover and a known goal location, the Force $\rho$ resulting from the HGF is given by

$$\rho = k_2 + k_3 \left( \sqrt{((y_g - y_r)^2 + (x_g - x_r)^2)} \right)^{-1}$$

(1)

where $k_2$ is the minimum possible haptic force and $k_3$ is a constant of proportionality relating to the distance to the goal location.

In order for the HGF to provide an adequate indication of the distance to the goal location it is imperative that $k_2$ and $k_3$ are chosen appropriately. In addition to providing a haptic indication of the current distance to the goal location, directionality is also considered, as shown in Figure 9.

The direction to the goal location $\phi$ is given by

$$\phi = \arctan ((y_g - y_r)/(x_g - x_r))$$

(2)

Given the current location of the robot $(x_r, y_r)$ and a known goal position $(x_g, y_g)$, the Gravitational Force Vector field results in the haptic force vector,

$$F_{\text{haptic}} = (\rho, \phi)$$

(3)

acting across an implemented haptic control surface (9,14).

The use of the HGF (including directionality) provides the teleoperator with a method to haptically determine the direction and distance to a goal location. This allows the teleoperator to concentrate their visual sense on local navigation of the challenging terrain. This approach also scales the haptic indicative force in proportion ($k_3$) to the relative distance to the desired goal location, providing the capability for an experienced teleoperator to intuitively determine the distance to the goal location.

B. OPERATOR VISION SYSTEMS

In addition to providing haptic augmentation to the user there are many available vision systems designed to also improve operator immersion. Stereo headsets offer a simple lightweight solution, however, remove much of the operator's
situational awareness because of their eyes being covered. Daylight viewable LCDs allow the operator to view video and telemetry data from the robot easily while monitoring their immediate environment through peripheral vision. The latest OzBot controller provides a live video feed through the inbuilt video screen while a secondary headset can be connected to the auxiliary video output.

III. STANDARDISING COMPONENT DESIGN

As the OzBot™ project developed, the value of re-using difficult to make components became obviously apparent. For robots operating in harsh environments such as collapsed buildings, hazardous chemicals spills, extreme temperatures, etc, often a single component failure can result in disabling the entire vehicle. Having the modularity between platform iterations not only speeds up the design phase, it also reduces servicing costs due to the unified nature of spare parts. With this in mind, the design focus moved to standardising robot modules.

Figure 10. Front camera assembly

Figure 10 illustrates the next generation self-contained front module assembly. The front module assembly is enclosed within a chemical resistant polycarbonate tube and incorporates both colour and B&W camera, IR illumination array, 3W Luxeon LED visible light illuminator, dual lasers at offset angles for rudimentary range estimation, tilt servo, status signaling LEDs. Zoom capable and ultra-low light cameras are easily fitted for scenarios where the robot cannot get close due to risk of damage, or where visible illumination is undesirable.

The central controller is currently being produced for all new chassis designs including a retrofit to Mk.IV platforms. Splitting the high power voltage regulation and current monitoring board from the central processor and signal conditioning PCB has resulted in a low electrical noise environment. Using a standard central controller allows transparency to auxiliary items when changing from one platform to the next. Each search and rescue mission will have its own specific challenges; just as it is beneficial to connect the desired auxiliary module to the platform, a first response is even more effective if you can select which base platform is best for the environment. A modular design allows this flexibility giving the optimal robot configuration for a successful mission.

IV. RESULTS

Improving wireless quality and range is of importance to all mobile systems. Maintaining the integrity of the wireless link between operator and robot is vital, especially when operating with sensitive objects such as IEDs or hazardous materials. This applies to both signal quality and signal security. Figure 11 shows wireless range performance including a predicted range for the implementation of an 802.11n standard wireless communications link to be used in future platforms. The new standard supports WPA and WPA2 for encryption and authentication using a 128-bit cipher and 48-bit initialisation vector. Additional security can be added through software if further encryption if deemed necessary.

![Figure 11. Wireless Range](image)

Although range is not expected to increase directly, bandwidth will be considerably improved using the 802.11n standard. This protocol supports repeater nodes allowing extended range by hopping the communications signal. Initial tests have shown an increase in latency less than 10ms per ‘hop’ can be achieved which is acceptable for most applications. Using high gain antennae complimenting the MIMO-based hardware, it is predicted that 4-real time video streams operating at native camera resolution can be achieved along with all telemetry data and any haptic force feedback data, with expected data rates of 100-140MBps.

![Figure 12. Comparison of basic capabilities](image)
TABLE 1. CAPABILITY MATRIX

<table>
<thead>
<tr>
<th>Capability Matrix</th>
<th>MCI</th>
<th>MKII</th>
<th>MKIII</th>
<th>MKIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Material of Manufacture</td>
<td>3mm Al</td>
<td>Lead Acid, Tether</td>
<td>Plastic (PVC)</td>
<td>1.5mm Stainless Steel</td>
</tr>
<tr>
<td>Power (Primary,secondary)</td>
<td>Lead Acid, Tether</td>
<td>Tether, NiMH</td>
<td>NiMH</td>
<td>Lithium Polymer</td>
</tr>
<tr>
<td>Battery Duration (mins)</td>
<td>4.5</td>
<td>20</td>
<td>4.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Radio Range (miles)</td>
<td>300</td>
<td>300</td>
<td>800</td>
<td>1500</td>
</tr>
<tr>
<td>Radio Frequency (MHz)</td>
<td>433 MHz</td>
<td>433 MHz</td>
<td>151.3 MHz</td>
<td>900 MHz</td>
</tr>
<tr>
<td>Video Radio Power (W)</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Video Frequency (MHz)</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Data Radio Power (W)</td>
<td>25 mW</td>
<td>25 mW</td>
<td>3W</td>
<td>3W</td>
</tr>
<tr>
<td>Telemetry</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes, Duplex</td>
</tr>
<tr>
<td>Illumination (IR,Visible)</td>
<td>No, LED</td>
<td>Yes, LED</td>
<td>No, LED</td>
<td>Yes, LED</td>
</tr>
<tr>
<td>Camera</td>
<td>Colour (~2LUX)</td>
<td>Colour (~2LUX)</td>
<td>Colour (~1LUX)</td>
<td>Colour (~1LUX)</td>
</tr>
<tr>
<td>Expansion bay</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Wheel type</td>
<td>Hard Compound Rubber</td>
<td>Soft Compound Rubber</td>
<td>Hard Compound Rubber</td>
<td>Hard Compound Rubber</td>
</tr>
<tr>
<td>Weight</td>
<td>6 kg</td>
<td>2 kg</td>
<td>6 kg</td>
<td>2 kg</td>
</tr>
<tr>
<td>Payload</td>
<td>1.5 kg</td>
<td>None</td>
<td>5 kg</td>
<td>30 kg (80 kg max)</td>
</tr>
<tr>
<td>Controller</td>
<td>Type 1</td>
<td>Type 1</td>
<td>Type 1</td>
<td>Type 1</td>
</tr>
</tbody>
</table>

The robot capability matrix presented in Table 1 shows basic specifications comparing the major attributes of each OzBot™ platform revision. In every case the most successful components have been carried forward into the new design. A significant advancement in operational duration is clearly evident, especially in context of payload. More efficient motor controllers and powertrain has allowed for stronger torque while weight reducing materials and improved design has meant the more featured platforms weigh similar amounts to the previous design.

Figure 12 shows a comparison of payload capability and achievable operational duration. Battery chemistry and chassis layout has allowed increased number of cells to be incorporated into the design, and lithium polymer charge cycle times are also improved when compared to lead acid or NiMH cells.

V. CONCLUSION

Working closely with the experienced operators of larger teleoperated search, rescue and IED disposal vehicles has given the team at the ISR Lab valuable insight into the challenges faced and expected functionality of the specialised systems. The experience working with local experts in the field of IED neutralisation by remote means has assisted in advancing the capability and usability of the OzBot™ mobile vehicle. A need for low-cost mobile platforms with a range of 500m, visual inspection capability and ability to attach various auxiliary modules has been identified. The OzBot™ series of platforms have evolved significantly and ongoing development will continue to advance the platform and operator control capabilities of our law enforcement officers. Work continues on the OzBot™ family with the addition of a tracked stair capable variant and an expanded sensor suite.

ACKNOWLEDGEMENT

The authors would like to thank the law enforcement personal that have contributed their time and expertise toward the successful development of the OzBot™ platform. The authors would also like to note the support from the Intelligent Systems Research Lab at Deakin University in providing financial assistance throughout the project.

REFERENCES