



Using Mobile Devices for Robotic Controllers: Examples and Some Initial Concepts for Experimentation

by Rosemarie E. Yagoda and Susan G. Hill

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Rosemarie E. Yagoda and Susan G. Hill
Human Research and Engineering Directorate, ARL

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14. ABSTRACT Many studies have been conducted on displays and controls for use by humans in controlling unmanned systems. During the summer of 2010, a project was undertaken to learn more about the potential for using mobile devices for robotic controllers and current implementations. This project consisted of two parts: (1) searching videos on the internet to identify some examples of using mobile hand-held devices as robotic controllers and (2) viewing existing prototype of a robotic controller on a smart phone and making user-interface design recommendations to improve the existing display interface. This report documents the results of this two-part project.					
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Contents

List of Figures	v
1. Introduction	1
2. Method	1
3. Some Examples of Mobile Device Interfaces	2
3.1 Wii Remote Examples.....	4
3.1.1 Wii Remote and LabVIEW	4
3.1.2 NXT BlueWii Using Mindsensors Servo Controller and Wii Remote	4
3.1.3 Wii Remote Driving a Mobile Robot	5
3.1.4 Wii Remote Controlling a Robot.....	6
3.2 iPhone Examples	6
3.2.1 iPhone Controlled Inspection Robot With Video Feedback (WIFIBOT M)	6
3.2.2 iPhone Packbot Operator Control Unit (OCU)	6
3.2.3 Using an iPod to Control Drones	7
3.2.4 New Use for Your iPod or iPhone: Controlling Drones	7
3.2.5 iPhone Mars Rover	8
4. Design Concepts for an Existing Prototype Interface	9
4.1 Google Android Robot Controller: Overview of the Current Configuration.....	9
4.2 Design Concepts for the Google Android Robot Controller for Robot Movement Control.....	10
4.3 Design Concepts for the Google Android Robot Controller for Robot Camera Capability Control	12
4.4 Design Concepts for the Google Android Robot Controller for Robot Guarded Teleoperation Capability Control.....	17
4.5 Summary of Suggested Design Concepts	18
5. Conclusion	19
6. References	20

Appendix. Matrix of Some On-line Videos of Mobile Device Robotic Controllers	21
List of Symbols, Abbreviations, and Acronyms	27
Distribution List	28

List of Figures

Figure 1. Wii Nunchuk and Wii Remote Controllers. The Wii Remote (right) is $5.83 \times 1.43 \times 1.21$ in. The Nunchuk (left) measures $4.45 \times 1.5 \times 1.48$ in.....	3
Figure 2. Apple iPhone is $4.5 \times 2.31 \times 0.37$ in.....	3
Figure 3. The Sony PlayStation Portable hand-held control device is about $6.7 \times 2.9 \times 0.9$ in.....	4
Figure 4. Current configuration of the Google Android Robot Controller developed by ARL CISD.	10
Figure 5. Concept for using directional arrows instead of virtual joystick for a future experimental comparison: (a) directional arrows on left and flipper controls on right; (b) directional arrows on right and flipper controls on left, consistent with the current configuration.	11
Figure 6. Experimental concept of adding a Menu button to present another level of options to the user. The dotted box represents that the Menu button has been clicked.....	13
Figure 7. After the Menu button is clicked, a Menu screen presents additional options to the user. The darkened Menu button shows that it is highlighted, to show this is the Menu page. In this case, the Camera Mode button is being clicked to get to Camera controls (identified by the dotted box).....	14
Figure 8. When the camera mode is chosen, camera controls are displayed. These camera controls include both video and still photographs. Video recording status (i.e., currently recording) is shown in the upper left corner on the status bar. The number of still images taken (or some other information) can be identified in a small area on the screen as well.	15
Figure 9. Design options for indicating that video recording has been turned on and is currently recording. Indication of REC can be featured nearer to the video on/off rather than in the status bar.	16
Figure 10. Concept for adding the ability to turn the guarded teleoperation function on and off. (a) Tele-operation guard is OFF (i.e., pure teleoperation without obstacle avoidance). (b) Tele-operation guard is ON (i.e., obstacle avoidance is being used).	18

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1. Introduction

The U.S. Army has a great interest in unmanned robotic systems. Robotic systems are seen as potential force multipliers because some robotic systems can do tasks that would otherwise require one or more Soldiers. Robotic systems are also seen in terms of potential force protection because some technology can be used in environments where Soldiers might be at risk, thereby reducing Soldiers' exposure to potential harm.

A related area of research pertains to human interaction with unmanned systems (UMS). Many studies have been conducted on appropriate displays and controls for use by humans in controlling UMS. For example, within the U.S. Army Research Laboratory (ARL), there has been a series of experiments examining various size displays and various types of controls for use with small unmanned robots (e.g., Cosenzo and Stafford, 2007; Pettitt et al., 2008; Redden et al., 2008, 2009, 2010a, 2010b; Redden and Elliott, 2010).

During the summer of 2010, a project was undertaken to investigate the current applications using mobile devices for robotic controllers. This project was divided into two parts: (1) searching internet videos to identify examples of mobile handheld devices used as robotic controllers and (2) making user-interface design recommendations to improve an existing prototype of a smart phone robotic controller developed by ARL. This report documents the results of this project.

2. Method

An internet search was conducted for examples of mobile handheld devices that were used for robotic controllers. The online videos obtained were categorized in terms of the hardware device used. The four hardware devices used in the videos were the Nintendo* Wii Remote, the Apple iPhone,[†] the Sony PlayStation[‡] Portable (PSP) console, and a Sony personal digital assistant (PDA). For each example, there is a brief description of the video detailing the application and the function of the handheld device. Observations of controller features and issues were recorded for each video. Therefore, the video had to be of sufficient quality and length to see the interface in order to describe it. Some unanswered questions are also listed when the video did not provide answers to questions that arose from the viewing. A matrix of

*Nintendo is a registered trademark of Nintendo of America Inc., Redmond, WA.

[†]iPhone is a registered trademark of Apple Inc., Cupertino, CA.

[‡]PlayStation is a registered trademark of Sony Computer Entertainment Corporation, Foster City, CA.

the examples was developed to describe the device in various categories. This matrix is presented in the appendix. An extensive literature review was not conducted. However, a literature review should be conducted in the future.

Second, a prototype user interface robot control application, utilizing a Google* Android[†] phone to control an iRobot PackBot[‡] small robot, was reviewed. This prototype user interface was developed by ARL (Fung, 2010). The review consisted of observation of an experienced user interacting with the controller to control the small robot (iRobot Packbot) in an inside area (i.e., laboratory and hallway areas) and a step-by-step review of possible commands. After using the initial smart phone control application, concepts for enhancing the user interface were developed. The intention was to provide some ideas for human-in-the-loop experimentation that could provide information for future interface design iterations. The current robot control application and concepts for interface enhancement are presented in section 4 of this report.

3. Some Examples of Mobile Device Interfaces

Ten videos were identified as examples of robotic controllers using mobile devices. Six of the 10 used a Wii Remote, sometimes called the “Wiimote.” One used a Wii Nunchuk in addition to the Wii Remote (see figure 1). Both the Wii Remote and the Nunchuk are controllers used for the Wii console made by Nintendo. Two of the examples of mobile device controllers used an Apple iPhone (see figure 2). One of the examples used a PSP handheld console manufactured and marketed by Sony Corporation (see figure 3), and another used a PDA made by Sony.

These video examples are briefly described in the following paragraphs and are grouped by hardware device. Each example contains a reference to a uniform resource locator (URL) where the video can be viewed. All URLs were current as of 25 January 2011.

*Google is a registered trademark of Google Inc., Mountain View, CA.

[†]Android is a registered trademark of Google Inc., Mountain View, CA.

[‡]PackBot is a registered trademark of iRobot Corporation, Bedford, MA.



Figure 1. Wii Nunchuk and Wii Remote Controllers. The Wii Remote (right) is $5.83 \times 1.43 \times 1.21$ in. The Nunchuk (left) measures $4.45 \times 1.5 \times 1.48$ in.



Figure 2. Apple iPhone is $4.5 \times 2.31 \times 0.37$ in.



Figure 3. The Sony PlayStation Portable hand-held control device is about $6.7 \times 2.9 \times 0.9$ in.

3.1 Wii Remote Examples

3.1.1 Wii Remote and LabVIEW

Video URL: <http://www.youtube.com/watch?v=EeBAYeoX7-8&feature=related> 1:36 (min:s)

Description: The video demonstrates the Wii Remote accelerometer capabilities using LabVIEW. The Wii Remote controller is connected via bluetooth to the laptop, the laptop is then connected (also via bluetooth) to the uC (MPC555). Additional functions can be activated using the 'A' button (shown in figure 1, directly below the arrow buttons near the top). For instance, the button could be used to activate the flippers or manipulate the camera attached to the UMS. The Wii Remote is used to test software and hardware of the robot.

Observations: This program visually displays the accelerometer movement output in a three-dimensional (3-D) visualization and also in graphical form. The Wii Remote is not shown controlling an actual robot. The 3-D and graphical visualization provides a clear sense of the accelerator and control output. It might be helpful to an operator to be able to see that output at the same time as seeing robot control to begin to build connections and relationships between Wii Remote movement and robot control.

Unanswered questions: How sensitive is the accelerometer? Can you change the sensitivity based on operator preference? Can you implement safeguards in order to avoid over correction situations – would this cause more harm than good? Would it be beneficial to incorporate the LabVIEW in the operator control unit (OCU)? Will incorporating LabVIEW into the OCU result in a trade-off between good performance and workload?

3.1.2 NXT BlueWii Using Mindsensors Servo Controller and Wii Remote

Video URL: <http://www.youtube.com/watch?v=3fZuOrDa3ec> (5:08)

Description: The video demonstrates the accelerometer capabilities using both the Wii Remote and Nunchuk. BlueWii is a Lego mobile robot with a servo driven arm (using a Mindsensors Servo Controller). BlueWii uses an NXTCam to track the location of a blue ball and sends feedback of the location of the blue ball via the light-emitting diodes (LEDs) on the Wii Remote. The arrow buttons on the Wii Remote control the robotic arm, whereas the accelerometer is used to drive the robot. When the 'B' button (a large trigger-like button on the reverse side of the Wii Remote) is pressed, additional functions are activated and controlled using the accelerometer. BlueWii incorporates object detection (blue ball) and robot provides feedback to the Wii Remote (blue lights strobe on the bottom of the Wii Remote).

Observations: The Wii Remote can facilitate capability (i.e., driving, moving a robotic arm, and changing the camera point of view) switching using both the accelerometer and the arrow buttons. Both hands are used, one each for the Wii Remote and the Nunchuk. The capabilities of driving (forward, backward, and continuous range of directions), controlling the robotic grippers (open, closed, lifted up or down on floor), and changing the camera point of view are controlled by combinations of movements of the Wii Remote and Nunchuk, such as both up (backward), both down (forward), or one up and one down (continuous turning).

Unanswered questions: What is the maximum number of capabilities that an operator can control using the Wii Remote? Will there be additional workload associated with switching between capabilities and the optimal way to control each robot capability? Will two-handed operations inhibit other activities by the operator?

3.1.3 Wii Remote Driving a Mobile Robot

Video URL: <http://www.youtube.com/watch?v=buZzj8F-Ab0&feature=related> (1:31)

Description: The video demonstrates the Wii Remote accelerometer operating a robot in simulation. One can tilt or roll the Wii Remote (i.e., use the accelerometer) to change the view angle in the line of sight simulation. The directional buttons are used to drive the robot.

Observations: When using the directional buttons to control the robot, you have to be careful not to move the Wii Remote; considering when you tilt the Wii Remote your point of view changes. This is an important consideration when allocating modes of operation. It is important to make sure one mode of operation does not disrupt another.

Unanswered questions: It is unclear if there is a speed control for driving. It also appears that the view of the robot being controlled is a "bird's-eye-view," and it is not clear how that kind of external view of a real robot would be achieved. While the person is able to control the simulated robot using this control, it is not clear how it would actually be implemented or if the control would be equally usable if the camera was attached to the actual robot.

3.1.4 Wii Remote Controlling a Robot

Video URL: <http://www.youtube.com/watch?v=qA4Ew5WgWd4> (1:21)

Description: The video demonstrates the Wii Remote accelerometer operating a robot within line of sight. This was programmed in C# and was able to control the robot in just under 50 lines of code.

Observations: It is important to note you have to hold the Wii Remote the proper way (i.e., arrow buttons on either the right or left side of the Wii Remote) in order for the robot to move in the correct direction using the accelerometer – this is the mistake the programmer made in the video. In order to avoid mistakes such as this, one possible solution is to place stickers stating Left, Right, Top, Bottom, or make it so the operator can only hold the Wii Remote one way.

Unanswered questions: Most of the video shows the robot moving rather than the programmer manipulating the Wii Remote; therefore, it is unclear how much the Wii Remote had to move to affect changes in the robot direction or speed.

3.2 iPhone Examples

3.2.1 iPhone Controlled Inspection Robot With Video Feedback (WIFIBOT M)

Video URL: http://www.youtube.com/watch?v=bIGUPMY20ZE&feature=player_embedded (3:06)

Description: The video demonstrates an inspection robot being controlled within line of sight using an iPhone. There is a video data feed from the robot to the iPhone. This video feed fills the entire screen of the iPhone. To maneuver the robot the operator must drag their finger across the display; there are no real controls (i.e., arrows or navigational cues). At the end of the video, it also shows another possible interface using the PlayStation 2 remote (this basically looks like driving a remote control car).

Observations: The person must be line of sight to the robot; otherwise, the video feed and control movement (sliding finger left, right, up [forward], or down) are not necessarily compatible. For example, in one video, sliding the finger upwards (towards the top of the iPhone) resulted in the finger position being in the sky above the building in the video.

Unanswered questions: What type of information needs to be provided to the operator? Are navigational cues necessary or can you just as effectively maneuver the robot using the video feed, as in the video? Considering there was a video feed lag throughout, what are the implications of the video feed lag with a video feed only control?

3.2.2 iPhone Packbot Operator Control Unit (OCU)

Video URL: <http://www.youtube.com/watch?v=mkM92ateTwo> (1:55)

Description: An Apple iPhone native application (app) is used to control an iRobot PackBot. This iPhone app provides a video feed, flapper arrows (up and down), and directional arrows to operate the robot. The iPhone is connected directly to the PackBot's WiFi network, and no proxy machine is needed. This app does not require line-of-sight operation, considering the video demonstrates both line of sight and beyond line-of-sight operation.

Observations: This interface seems pretty effective in operating the PackBot. There does not seem to be too much of a video lag when operating the robot. Also, the video shows the robot operated out of the line of sight; this could be due to the fact that the controls and the video feed are separate, which is similar to the standard OCU for a PackBot. At times, it was observed that two fingers were needed to engage the two directional arrows simultaneously while adjusting directions.

Unanswered questions: It is not clear how the speed is controlled. The use of two fingers on such a small display seems like it may be difficult to maintain, but perhaps it doesn't need to be maintained for long periods of time.

All of these examples are included in the matrix presented in the appendix. Two other examples not captured in the chart in the appendix are listed in the following subsections.

3.2.3 Using an iPod to Control Drones

Video URL: http://www.youtube.com/watch?v=YlbEbQ6TJMc&feature=player_embedded (1:05)

Description: An iPod touch controls a quadrotor. The accelerometer is used to move the drone forward or sidewise to corner or change direction. Command buttons also indicate some additional actions.

Observations: The accelerator moves the drone; feedback on the accelerator control is given by showing a moving dot within a circle. The dot shows direction and perceived velocity.

Unanswered questions: It is not clear what the additional actions are on the iPod. It also appears that zero velocity will land the quadrotor, but exactly how height is controlled is not apparent.

3.2.4 New Use for Your iPod or iPhone: Controlling Drones

Video URLs:

<http://www.youtube.com/watch?v=TSv2ca-IECc&NR=1> (2:40)

<http://www.youtube.com/watch?v=V3KrFV0-WFw&NR=1> (1:56)

<http://www.youtube.com/watch?v=GA2Av74pjTY&feature=related> (1:21)

<http://www.youtube.com/watch?v=1X3VXa7897Y&feature=fvw> (0:54)

<http://www.youtube.com/watch?v=fFpX4hWUqJ0&feature=related> (1:41)

<http://www.youtube.com/watch?v=gP26CE8VEiE&feature=related> (0:20)

Description: The Parrot AR Drone runs off a built-in WiFi network where you connect to an iPhone or iPod touch. The accelerometer is used to move the drone forward or sideways to corner or change direction. Command buttons also indicate some actions such as rise, down, rotate, move back, move forward, etc.

Observations: Augmented reality is used on the display to add additional information to the screen. This control seems pretty sophisticated compared with other display interface videos. The best view of the controller is the first video (2:40).

Unanswered questions: Using the accelerometer to operate a UMS presents many new issues, challenges, and potential areas of research. For instance, the sensitivity and durability of the interface, type of feedback provided to the operator (i.e., tactile, visual, auditory), over- and/or under-correction due to environmental changes, team configuration, operator location, rate of change versus frame rate information, and what are the advantages versus disadvantages to using a small touch screen device to operate a UMS?

3.2.5 iPhone Mars Rover

Video URL: <http://iphonemarsrover.com/> (1:48)

Description: This iPhone-based app controls an unmanned ground vehicle (UGV) using the accelerometer. The interface is a grid-based display with corresponding directional arrows. This display contains a dot that is manipulated via the accelerometer; this is how the UGV moves. Auditory feedback is provided to the operator; this could be used when a goal is obtained. Visual feedback is also provided to the operator based on the tilting of the interface (i.e., tilt left and the bar on right increases while the bar on the right decreases). In the video, there is also a bird's-eye view of the robot's operating environment.

Observations: This application provides a grid-based display to where tilting the device maneuvers the UMS. It would be interesting to compare the following: grid-based display with accelerometer, video-feed display with accelerometer, and a standard touch screen interface with directional arrows. In addition, the minimum display size needed for all of the aforementioned conditions is not known.

Unanswered questions: The audio feedback heard in the video was not explained and it is unclear what it is used for.

4. Design Concepts for an Existing Prototype Interface

A prototype user interface robot control application, using an Android phone, was built by researchers in the ARL Computational and Information Sciences Directorate (CISD), Asset Control and Behavior Branch (Fung, 2010). This prototype was reviewed and then used to control a Packbot small robot in a laboratory setting. After using the smartphone robot control application, concepts for enhancing the user interface were developed.

The current interface is simple, with minimal functionality. The design concepts developed and presented here serve two purposes. The first purpose is to provide some suggestions for design concepts that can be implemented and used for human-in-the-loop experiments. Such future experimental research results could form the basis of design guidance for future mobile handheld user interfaces. The second purpose is to suggest additional capabilities for the smartphone application beyond the mobility control currently implemented. The current robot control application and concepts for interface enhancement are presented in the following section.

4.1 Google Android Robot Controller: Overview of the Current Configuration

This small mobile device is currently used to remotely control the iRobot PackBot. A detailed description of the current functionality of the controller is provided below and shown in figure 4.

Across the top of the screen is the standard Android status bar. Information includes (from left to right) the WiFi signal strength, phone reception signal, battery power, and time.

Directly below the status bar is the area for viewing real-time, streaming video data from the payload camera on board the robot. The live-video stream is used for teleoperation of the robot.

Below the video area is an area of unused real estate on controller display. In the figure, it is just black.

The flipper controllers are on the left side of the lower half of the interface. There is one soft button to move the flippers forward and one to move them backwards. Each button is used to control both flippers simultaneously in one direction.

On the right side of the lower half of the interface is the soft button labeled *Take Control*. This is used to take initial control and operate the robot. This button allows the user to take away control from another controller.

The *Exit* soft button on the lower right of the interface is used to exit the program.



Figure 4. Current configuration of the Google Android Robot Controller developed by ARL CISD.

The robot movement is controlled via a virtual joystick; the joystick is shown as the round circle in the center of the lower area. This virtual joystick operates like a trackball for operating the robot and, potentially, other robotic capabilities. The trackball can be moved and the robot will respond to the input. The speed of robot is controlled via the trackball, with the faster the input (i.e., finger movement) the faster the robot moves. It should be noted that there is not just one speed, but a range of speeds.

4.2 Design Concepts for the Google Android Robot Controller for Robot Movement Control

Several different design concepts were developed using the initial design as a starting point. The alternative designs were developed to provide user interface concepts that would add additional functionality to the current design. Providing alternative concepts was thought also to provide a starting point for new interface designs that could be experimentally tested with humans in the loop.

The two design alternatives shown in figure 5 use directional arrows to replace the two buttons (up, down) for the flipper movement and four arrows (forward, backward, right, left) to control robot movement. Other examples of controllers have used arrows as directional controls (see section 3.2.2). The potential research question is whether a joystick and buttons (original configuration) provide for better human performance than the alternative arrow design concepts.

Figure 5a shows the directional arrow design consistent with some previous work, for example, <http://www.youtube.com/watch?v=mkM92ateTwo> (see section 3.2.2).

Figure 5b presents directional arrows for robot mobility in a manner that is the same configuration as the current interface design, with the flipper controls on the left and the movement controls using arrows, on the right side.

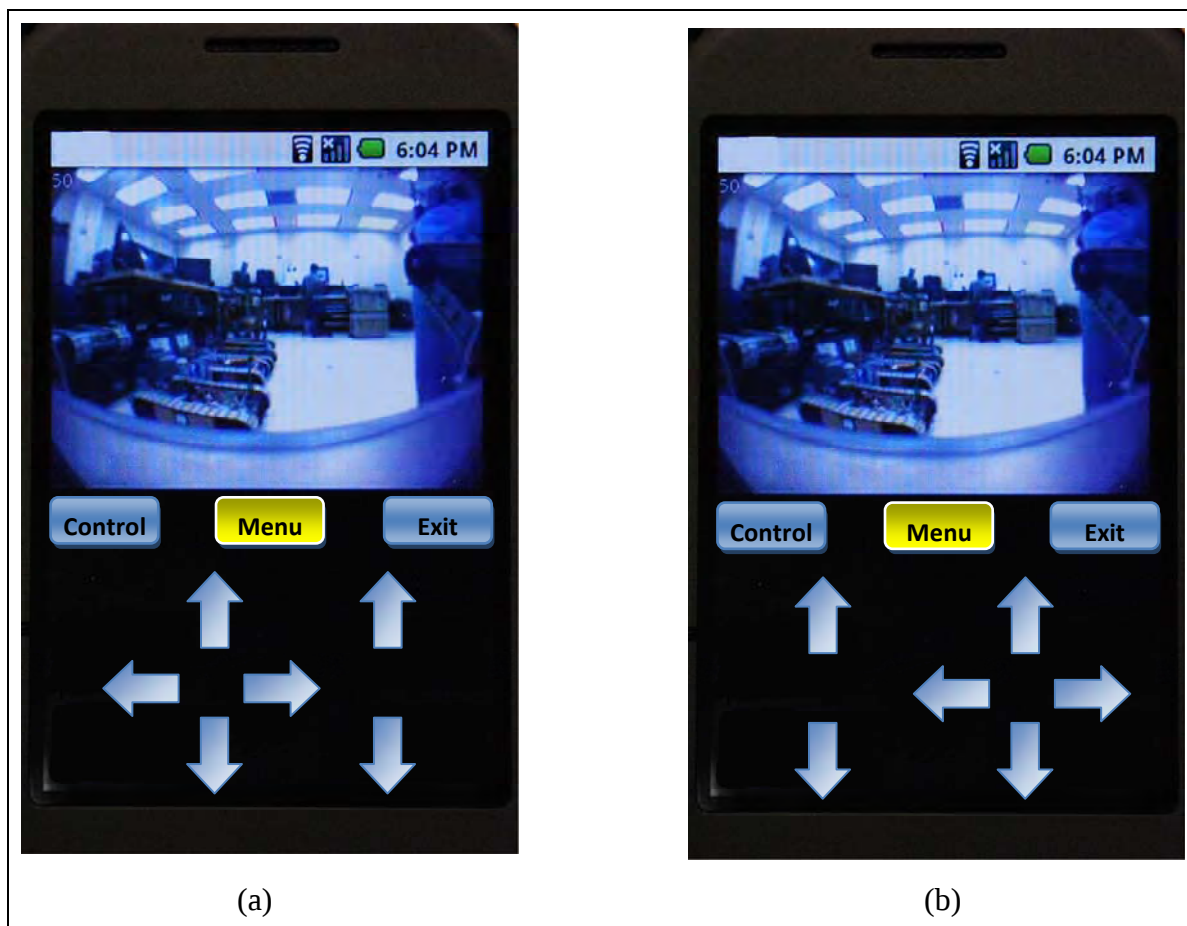


Figure 5. Concept for using directional arrows instead of virtual joystick for a future experimental comparison: (a) directional arrows on left and flipper controls on right; (b) directional arrows on right and flipper controls on left, consistent with the current configuration.

The Menu button  is a new feature to the interface that would allow for additional controls to be added. The Menu button is just one possibility for adding functionality. However, for the experimental evaluation of directional arrows for robot movement, the Menu button should be removed for the experiment in order to keep the configuration consistent with the original interface. However, if additional capabilities would like to be added to this design, a potential location for the menu button is provided.

One of the assumptions for this interface is that there is only one speed (on/off) – there is no speed control on this interface. If possible, a speed control could be implemented via the force of input (hard, soft, fast, slow) that can manipulate the speed of the robot.

4.3 Design Concepts for the Google Android Robot Controller for Robot Camera Capability Control

Another area to explore is the design concepts for capabilities in addition to mobility control. One such capability is camera control. There is a camera on-board the small robot that is used for teleoperation. That same camera could also be used for reconnaissance or surveillance. The ability to control the location of the camera and direction in which it is pointed would be beneficial. One possibility for how camera controls could be implemented on the mobile device robot controller is presented in figures 6–8. In this design concept, robot mobility is controlled via the virtual joystick shown in the current configuration.

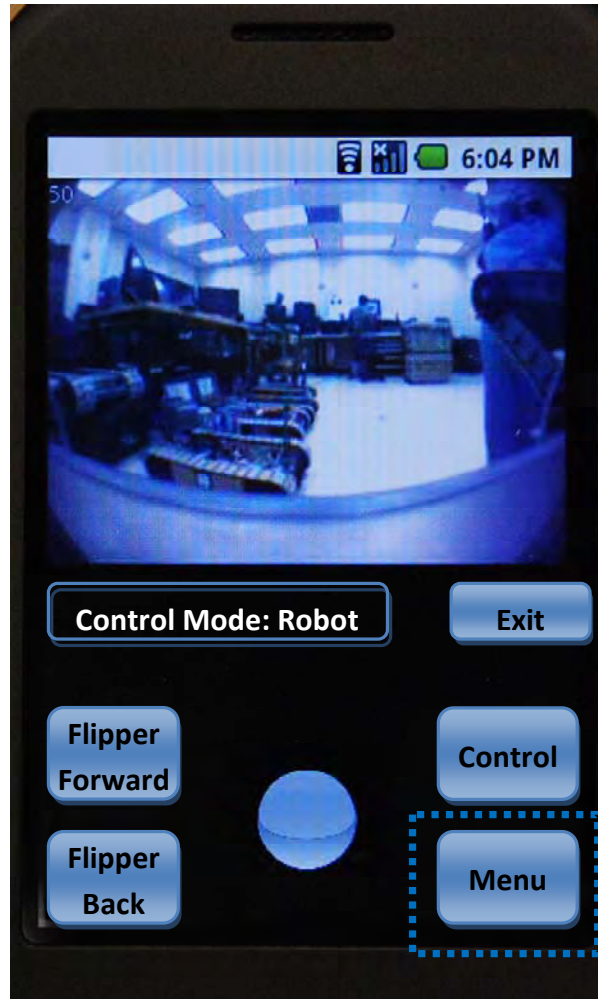


Figure 6. Experimental concept of adding a Menu button to present another level of options to the user. The dotted box represents that the Menu button has been clicked.

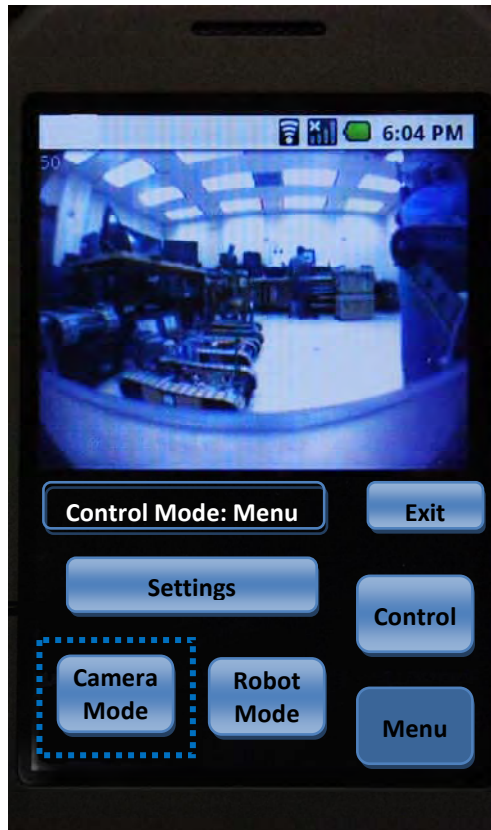


Figure 7. After the Menu button is clicked, a Menu screen presents additional options to the user. The darkened Menu button shows that it is highlighted, to show this is the Menu page. In this case, the Camera Mode button is being clicked to get to Camera controls (identified by the dotted box).



Figure 8. When the camera mode is chosen, camera controls are displayed. These camera controls include both video and still photographs. Video recording status (i.e., currently recording) is shown in the upper left corner on the status bar. The number of still images taken (or some other information) can be identified in a small area on the screen as well.

The design concept shown in figures 6–8 includes the use of a Menu button.



The menu button allows the operator to access additional capabilities of the robot without using additional space when controlling the robot (i.e., in the Robot Control Mode). When choosing the Menu button, the feedback provided to the user could be a notice of which control mode is currently active, such as Control Mode: Menu.



Another aspect of this design concept is to have feedback available to the user that will show what is currently being controlled. Feedback to the user on this display is shown as the Control Mode. For these possible design concepts, three possible control modes are shown: menu, robot, and camera.

When the menu button is clicked, the menu screen displays the three possible areas that can be controlled. Within the Menu, the operator is able to switch between controlling either the robot or the camera by clicking the corresponding button, either Robot Mode or Camera Mode. After clicking, the desired mode will automatically populate. Feedback is provided as to which control mode has been chosen. When Robot Control is chosen, control mode is shown as “robot.” Similarly, control mode “camera” is shown when camera mode is chosen.

It should be noted that the control button should probably be moved off the main Robot Control Mode interface since it is not used often (except when initially taking control of the robot from another operator). This would allow for additional capabilities to be added to the Robot Control Mode (e.g., guarded teleoperation).

Currently, the Settings button shown in figure 7 is a placeholder; it does not have any suggested functionality associated with the button for these design concepts. However, it would allow for additional capabilities to be added in the future (e.g., robotic capability settings and adjustments).

Figure 9 illustrates design options to indicate recording mode. A control could be available to turn video recording ON and OFF on a Video button.



Figure 9. Design options for indicating that video recording has been turned on and is currently recording. Indication of **REC** can be featured nearer to the video on/off rather than in the status bar.



When video data is being recorded, a red **REC** appears at the top of the interface next to the red dot ●, which indicates camera mode. This provides additional visual feedback as to when the camera is recording video.

If the information in the status bar cannot be manipulated, then **REC** can be added to the Video ON/OFF button or a red box could be added around the button to indicate that video recording is enabled and being used.



The Capture button provides the means to take still photos using the camera payload on robot. Several alternatives exist for displaying the number of still photos captured; the number can be displayed in small circle displays, such as or , or the number could be displayed in **bold and white** and placed close to the Capture button.

It is also important the video data and still photos collected be managed appropriately. For example, each image/video should have some metadata associated with it, such as the time/date stamped for that image/video. The operator may also potentially want the capability to playback the videos, so such playback capabilities will need to be added. Also, it may be important to allow the operator to “star” certain videos for prioritizing the importance of the videos.



Another possible camera capability is to have a camera zoom function. Two buttons are proposed, one to zoom in (i.e., magnify) and one to zoom out (i.e., broaden). No additional feedback is provided to the operator during the zoom operation; it does not seem as though a zoom indicator would be necessary, due primarily to the amount of screen real estate available and a possible clutter effect resulting.



With the camera control, a camera pan/tilt manipulation is conceptualized. Assuming the camera onboard the robot has pan/tilt, a virtual joystick centered in the bottom half of the display would be used to control this function. The joystick can also be used to control the robot instead. If the operator would like to use the virtual joystick for robot control, then click “Menu” and select “Robot Mode” to change the virtual joystick from camera pan tilt control to robot mobility control.

4.4 Design Concepts for the Google Android Robot Controller for Robot Guarded Teleoperation Capability Control

This design is moving from standard teleoperation to semi-autonomous robot control by incorporating object avoidance capabilities (i.e., guarded teleoperation).

The control button was replaced with the Guard ON/OFF button in the Robot Control Mode (compare with figure 6). The control button can be accessed through the Menu. The Menu screen remains the same (see figure 7). As shown in figure 10, feedback is given as to the on/off status of the teleoperation guard in the area where the control mode is presented, with Guard: OFF and Guard: ON specifically presented. The guard mode status (on/off) will be displayed in the robot control mode only; that is the control mode to which it is most germane. Experimental studies could show that the teleoperation guard status information may be needed in other modes.



Figure 10. Concept for adding the ability to turn the guarded teleoperation function on and off. (a) Tele-operation guard is OFF (i.e., pure teleoperation without obstacle avoidance). (b) Tele-operation guard is ON (i.e., obstacle avoidance is being used).

A decision will need to be made as to the default position for the guard mode, either a default of guard on or guard off. That decision will need to be made as more is known about the teleoperation guard mode functionality and reliability and the expected tasks and missions to be performed.

4.5 Summary of Suggested Design Concepts

Within this section, the current configuration was presented and future design concepts were suggested. The current configuration using simple, minimal controls, including a virtual joystick, is explained in section 4.1 and shown in figure 4.

The first type of design concept was to suggest an alternative to using a virtual joystick by using directional arrows. Experiments comparing the current virtual joystick to one or more configurations of directional arrows would provide information on the best approach to use for control robotic movement.

The second type of design concept includes ideas of possibilities for including additional capabilities to the current configuration. Two specific capabilities considered are camera control and guarded teleoperation control. The concepts are based on the addition of a menu structure and feedback displays. Experiments could be performed to examine alternatives for button placement and other specific elements pertaining to the interface, such as to how best to provide information about video recording status or still imagery descriptive data.

Human factors design guidance is needed for mobile device interfaces for the future. This is particularly true for mobile device interfaces used for robotic control.

5. Conclusion

There are a number of examples of mobile handheld devices that have been used as robotic controllers; some examples were identified in videos publicly available via the Internet. The primary devices are the Wii Remote and smart phones, both of which utilize accelerometers as sensor input devices. Smart phones, unlike Wii Remotes, have input and control display interfaces. Although small, the display interface can show video or still imagery as well as other kinds of visual information, such as icons. These interface-design characteristics were explored in various ways in examples given throughout this report. The examples provided are a starting point for the information about what controls are needed and how to implement each. Additional information on what currently exists in terms of mobile handheld robotic controllers is needed. An extensive literature review is needed to provide in-depth account of the current small, mobile handheld robotic controllers for future research.

The concepts for a proposed user interface on a smart phone are presented in this report (in section 4) and could be easily implemented in the future. It would be useful to examine how robot operators implement the proposed concepts, as well as other concepts, in an effort to develop more knowledge on the design of mobile handheld device user interfaces.

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**Appendix. Matrix of Some On-line Videos of Mobile Device Robotic
Controllers**

Table A-1. Examples and characteristics of robotic controllers using Wii remote control.

Functions	Function Definitions	Wii Ex1	Wii Ex2	Wii Ex3	Wii Ex4	Wii Ex5	Wii Ex6
OCU	Operator control unit - the OCU within this context refers to the capabilities that are incorporated in the device to operate the UMS.	Wii remote, simulation display	Wii remote and nunchuck, no display	Wii remote, no display	Wii remote, no display	Wii remote, no display (normal OCU is through voice recognition)	Web browser based and Wii remote - can change button configuration based on user preference
Navigation	The input modality for UMS direction and/or orientation.	Accelerometer	Accelerometer using both Wii remote and nunchuck simultaneously	Accelerometer (tilt and roll to change view angle)	Accelerometer	Script based programming with Wii remote buttons	Web browser using the robot navigation pad or Wii remote
Location	Presentation of the physical location of the UMS.	None	None	None	None	None	None
Speed	Presentation of the speed of the UMS.	No speed control, constant (no display)	No speed control, constant (no display)	No speed control, constant (no display)	No speed control, constant (no display)	None	None
Feedback	The type of feedback provided to the operator through the OCU.	Visual - Accelerometer 3D visualization	Visual - LED lights on Wii remote	None	None	None	None
Mode of operation	Team configuration during UMS operation.	None	None	None	None	None	None
Robot motion control	The input modality for UMS motion control.	Accelerometer	Accelerometer	Directional arrows	Accelerometer	Wii remote buttons and voice control	Wii remote buttons or web browser (the directional arrows align with what is presented online)
Robot capability control	The input modality for UMS capability control.	Accelerometer after 'A' or 'B' button is pressed (function switch)	Directional arrows and accelerometer, 'B' button is used for additional functions	Accelerometer to change camera angle within the simulation	none	Over 168 functions - script based dance moves using Wii remote and voice control	Headlight, camera - controlled through web browser and Wii remote buttons. 'autonomous docking'

Table A-1. Examples and characteristics of robotic controllers using Wii remote controller (continued).

Functions	Function Definitions	Wii Ex1	Wii Ex2	Wii Ex3	Wii Ex4	Wii Ex5	Wii Ex6
Display mode	The type of display used to provide visual information to the operator through the OCU.	LabVIEW simulation - 3D visualization	None	None	None	Can also be controlled using PC to 'click' script commands	Web browser, if Wii remote is not used (no display, line of sight)
Network	The type of network used to connect the OCU and the UMS.	Bluetooth - laptop - uC	Bluetooth - laptop - Wii remote	None	Bluetooth - laptop - Wii remote	Bluetooth - laptop - Wii remote - USB UIRT	Bluetooth - laptop - Wii remote
Implementation environment	The UMS operating environment.	Simulation	Line of sight	Simulation	Line of sight	Direct control, programmable toy	Line of sight, surveillance toy
Application	The operational context of the UMS (i.e., MOUT, SAR, 'toy', simulation).	Simulation	Toy	Simulation	Laboratory	Toy	"Home and office surveillance robot"
Platform	The type of UMS used within the scenario.	None	BlueWii, Lego mobile robot	None	X80 Robot	"Robosapien Dance Machine" WowWee V2	WowWee Rovio

Notes: Wii Ex1: <http://www.youtube.com/watch?v=EeBAYeoX7-8&feature=related> 1:36 (min:sec) (accessed 25 January 2011)

Wii Ex2: <http://www.youtube.com/watch?v=3fZuOrDa3ec> 5:08 (accessed 25 January 2011)

Wii Ex3: <http://www.youtube.com/watch?v=buZzj8F-Ab0&feature=related> 1:30 (accessed 25 January 2011)

Wii Ex4: <http://www.youtube.com/watch?v=qA4Ew5WgWd4> 1:21 (accessed 25 January 2011)

Wii Ex5: <http://www.youtube.com/watch?v=6wsFwCnzRqE> 12:33 (accessed 25 January 2011)

Wii Ex6: <http://www.youtube.com/watch?v=KMRO7LtAFRk&feature=fvw> 4:33 (accessed 25 January 2011)

Table A-2. Examples and characteristics of robotic controllers using other mobile devices.

Functions	Function Definitions	iPhone Ex1	iPhone Ex2	PSP Ex1	PDA Ex1
OCU	Operator Control Unit - The OCU within this context refers to the capabilities that are incorporated in the device to operate the UMS.	Touch screen video interface	Touch screen video interface with directional arrows and flapper controls (up/down arrows)	Robot video feed display, directional arrows	Touch screen video interface
Navigation	The input modality for UMS direction and/or orientation.	Touch screen video interface, controlled by dragging a finger across the screen to move the robot	Touch screen video interface with directional arrows and flapper controls (up/down arrows)	Directional arrows	Touch screen video interface, controlled by dragging a finger across the screen to move the robot
Location	Presentation of the physical location of the UMS.	None	None	None	None
Speed	Presentation of the speed of the UMS.	None	None	None	None
Feedback	The type of feedback provided to the operator through the OCU.	Visual - payload camera, real time	Visual - payload camera, real time	Visual - payload camera, real time	Visual - payload camera, real time
Mode of operation	Team configuration during UMS operation.	none	Operator does not have to be line of sight	None	None
Robot motion control	The input modality for UMS motion control.	Touch screen - finger scroll	Touch screen - directional arrows	Directional arrows	Touch screen - finger scroll
Robot capability control	The input modality for UMS capability control.	None	Touch screen - directional arrows for flapper control	None	None
Display mode	The type of display used to provide visual information to the operator through the OCU.	Real time video data - there is a time delay though	Real time video data	—	—

Table A-2. Examples and characteristics of robotic controllers using other mobile devices (continued).

Functions	Function Definitions	iPhone Ex1	iPhone Ex2	PSP Ex1	PDA Ex1
Display mode	The type of display used to provide visual information to the operator through the OCU.	Real time video data - there is a time delay though	Real time video data	—	—
Network	The type of network used to connect the OCU and the UMS.	Wireless	Wireless – PackBot’s WiFi network	—	—
Implementation environment	The UMS operating environment.	Line of sight with video feedback	Line of sight not required. Same capabilities as current PackBot OCU	—	—
Application	The operational context of the UMS (i.e., MOUT, SAR, ‘toy’, simulation).	Small modular robot - surveillance	SAR - lab video	—	—
Platform	The type of UMS used within the scenario.	WiFiBot M	iRobot PackBot	—	—

Notes: iPhone Ex1: http://www.youtube.com/watch?v=bIGUPMY20ZE&feature=player_embedded 3:06 (accessed 25 January 2011)

iPhone Ex2: <http://www.youtube.com/watch?v=mkM92ateTwo> 1:55 (accessed 25 January 2011)

PSP Ex1: <http://www.youtube.com/watch?v=H4FIgPHW-q4&feature=related> 1:33 (accessed 25 January 2011)

PDA Ex1: <http://www.youtube.com/watch?v=S28Bsx5nsgE> 0:47 (accessed 25 January 2011)

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List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
LED	light-emitting diode
OCU	operator control unit
PDA	personal digital assistant
PSP	PlayStation Portable
UGV	unmanned ground vehicle
UMS	unmanned system
URL	uniform resource locator

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