PDA–Based Human–Robotic Interface*

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Abstract - *There is a desire to provide small, lightweight mobile interaction devices. This paper describes a PDA-based teleoperation interface for a mobile robot. This interface differs from previous PDA teleoperation interfaces in that it uses only touch based interactions rather than stylus interaction. Three screens were developed: an Image-Only screen, a Sonar and Laser Range Finder Based screen, and Image with Sensory Overlay screen. This paper presents the interface motivation and design and discusses issues that arise when employing a PDA as a touch screen. This paper also describes the planned human factors evaluation.*

Keywords: Personal Digital Assistant (PDA), teleoperation, Human-Robotic Interaction

1 Introduction

Teleoperation of a mobile robot is a basic operation that requires human–robot interaction. This paper presents a Personal Digital Assistant (PDA) based teleoperation interface for a mobile robot. Three touch-based PDA screens were developed: an Image-Only screen, a Sonar and Laser Range-Finder based screen, and an Image with Sensory Overlay screen. This interface uses the PDA as a touch screen for teleoperation and does not require a stylus to generate commands. Stylus-based interaction is not practical for all potential users as it is difficult to use while walking or running.

This paper presents the interface motivation and design and discusses issues that arise when employing a PDA as a touch screen. Section 2 presents the related work while Section 3 describes the design considerations and screen designs. Section 4 discusses future work and the conclusions.

2 Related Work

Many current teleoperation methods require hand held controllers, such as joysticks. Examples of such systems are: Laird et al.'s [6] Man Portable Robotic System (MPRS) and its associated Operator Control Unit (OCU) for tunnel and sewer reconnaissance; and Hainsworth's [5] user interfaces for remote mine rescue systems. Barnes and Counsel [2] study teleoperation and telerobotics with and without haptic feedback to the operator. Suzuki et al. [10] used joysticks with a multi-robot teleoperation system designed to consider human-robotic cooperation during inspection tasks. Rybski et al. [9] designed an interface based on a low-cost commercial game console joystick to provide versatile autonomous and teleoperated control of multiple miniature robots.

Figure 1: Foster-Miller's Operator Control Units [12]

Currently the Matilda [14], Packbot [13], Talon [12], and Solem [12] robots provide an interface via a large, heavy OCU similar in size to a toolbox (i.e. Figure 1's Standard OCU). Some companies; such as Foster-Miller [12] and Cybernet Systems Corporation [11]; have developed wearable OCUs (i.e. Figure 1's Wearable OCU).

The ability to provide small, lightweight mobile interaction devices includes PDA-based interfaces. The PDA-based teleoperation interface developed in this work differs from previous PDA teleoperation interfaces [4, 8] and user interfaces [3] in that the PDA is used as a touch screen. Therefore, the interface does not require a stylus. This interface also does not employ gesture or speech interaction capabilities and is intended to be a very simple, easy to use interface.

Stylus-based interaction is not practical for many users as it is difficult to use a stylus while walking or running. Additionally, a stylus is small and can easily be lost or misplaced. Gesture-based interaction is not practical for all situations as gesture recognition relies on cameras that are sensitive to lighting conditions and field of view limitations. Speech-based interaction is not always practical, as it requires a verbal communication link between participants; relies on voice recognition technology; and may not be feasible in all situations. Providing voice commands in loud, noisy environments as well as situations when noise is not permitted hampers the use of speech-based interfaces.

Fong [4] designed and implemented the collaborative control architecture that allows the operator and robot to communicate. The associated *PdaDriver* interface permits both collaborative control and vehicle teleoperation. His work is different from this work in that his interfaces are based on the collaborative control architecture. In our system, the human acts as a teleoperator with complete control of the system. While it is true collaborative control is intended to assist the operator, the required screens, as designed by Fong, require stylus-based interactions that are not easily transformed to accept touch-based interactions due to the limited PDA screen real estate issue.

Perzanowski et al. [8] developed a multimodal interface for mobile robots. The robots understand speech, gestures, and PDA-based input. Operators can provide a limited set of commands to command a robot or a team of robots to navigate to a location. The difference between their work and this work is related to the interaction capabilities. Their interface has been designed to permit multimodal interactions such as gestures and speech interactions in addition to the PDA based interactions. Their research reports indoor laboratory environments that are amenable to such interactions. The focus of this work is interfaces for military or search and rescue personnel during field operations. These field environments may hinder the use of speech and gesture based interactions. Therefore, the goal is to provide an interface that is available in all potential environments.

Eisenstein et al. [3] developed user interfaces for different computing platforms, ranging from workstations to cellular phones. They point out that each computing platform has its own constraints. Some devices are mobile while others are not. Some systems support extensive graphical capabilities while others provide limited interaction capabilities. Some systems are equipped with enhanced input and output devices while others are constrained by limited input. They indicate that mobile computing increases the probability of environmental change while the user is carrying out a task. This work was inspired by the work of Eisenstein et al. The PDA was chosen as a portable, convenient computing device for mobile robot teleoperation.

3 Design

The PDA-based interface is designed provide interaction in a manner similar to a wristwatch. Thus, the interface design is rotated 90 degrees clockwise so that the PDA can be attached to the arm, as presented in Figure 2. The final design will eliminate the need to hold the PDA.

Figure 2: PDA alignment.

Many issues arise when designing a PDA-based interface. The screen size is limited; therefore important information cannot be simultaneously displayed. Interfaces designed for desktop or laptop computers are able to simultaneously display a large amount of information. The interaction types with standard computers include mouse and keyboard interactions, and potentially speech, tablets, and gestures. A PDA-based interface provides only limited display real estate and interaction capabilities. Therefore, it is suggested that a touch-based PDA interface composed of different screens for differing conditions will facilitate the screen real estate and interaction constraints.

This interface includes three different screens. The first screen, an Image-only screen, may be preferred when the operator cannot directly view the robot and its environment. The second screen, the Sonar and Laser based screen, may be preferred when the operator is teleoperating the robot in a small area that contains many obstacles. The third screen, the Image with Sensory Overlay screen, may be preferred when the operator needs to simultaneously view all forward facing sensory data.

If computer-based interfaces are compared with PDA based interfaces, some additional issues arise. The PDA interface is a small, portable device that is available everywhere, but computer-based interfaces are not as convenient. Laptop computers are cumbersome to carry and are not always appropriate for all environments. On the other hand, PDAs have limited software and computing resources, therefore programming a PDA can be more difficult than programming computer-based counterparts.

Issues arise when designing a touch-based interface for a PDA. Touch-based interfaces require buttons and interaction capabilities that are large enough to accommodate human fingers. In certain environments, the operator may also be wearing bulky gloves. Therefore, the buttons occupy much of the PDA screen area. Techniques that provide button transparency and maximize information presentation must be employed.

While PDA-based interfaces are more portable than their computer counterparts, it should be noted that they might not provide a complete interaction solution. First, certain PDA LCD-screens are not visible in bright sunlight or through polarized sunglasses. Second, the processing capabilities of such devices are rather limited. Therefore, the ability to provide real-time updates and interactions may be compromised. Finally, wearable interaction devices, as in Figure 1, may be preferred.

3.1 PDA and Robot Hardware

A Toshiba E740 Personal Digital Assistant has been employed for the interface development and testing. It runs Microsoft Pocket PC 2002 and is equipped with 64 MB of RAM, a 400 MHz XScale processor, built in wireless communication, and a 240X320 TFT LCD screen.

This work employs an ATRV-Jr robot. The sensing capabilities include a camera, a laser range finder, and seventeen sonar sensors. The camera and laser range finder provide forward facing data while the sonar are located around the robot. Five sonar face forward, ten face away from the robot's sides (five on each side), and the last two are mounted on the rear of the robot.

3.2 Interface Interaction

Standard interactions are provided across the three screens. All interaction buttons are transparent since the buttons must be large enough to accommodate human fingers but also maximize the screen usage. Standard buttons hide the area behind them.

The standard interface provides five large, transparent buttons, four for driving and one emergency stop button. The four drive buttons are laid out to represent the robot's corresponding driving direction if the operator was standing behind the robot or next to the robot while facing the same direction as the robot. The drive button functionality remains constant, even if the operator is facing the robot. It is possible that this fixed functionality may confuse an operator. Since the focus is military or search and rescue operators, it is anticipated that they would receive extensive training and be able to adapt to this limitation.

As can be seen from Figure 4, the four drive buttons are aligned along the outer edges of the screen. This ensures that the central screen real estate is fully visible. A benefit of the button positioning is that tactile feedback can be employed with minimal or no visual requirements. The emergency stop button position was chosen to provide maximal tactile feedback while ensuring the button's selection could not be recorded as another command. The corner positioning provides easy access without requiring visual interaction. This particular position also minimizes the required reach distance. A complication appeared when this button was placed in the other three screen corners. The operator could accidentally activate system functions rather than issue the emergency stop command.

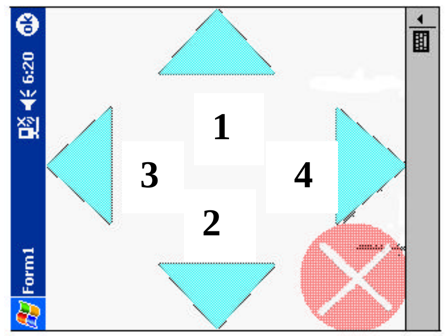

Figure 4: The drive buttons and the emergency stop button

The robot can be commanded to drive forward, backwards, turn left, turn right, or a combination of forward or backwards and left or right. The operator selects button 1, in Figure 4, to command the robot to move forward. Button 2 provides the reverse command. Buttons 3 and 4 provide turn left or right commands, respectively.

If the operator commands the robot to move forward (button 1) but over shoots the desired location, simply selecting reverse (button 2) commands the robot to stop moving forward and start moving backwards. A similar behavior exists if the robot is commanded to turn left (button 3) and then the operator selects turn right (button 4). The operator could select the emergency stop button before commanding the above mentioned changes but this action would require two selections to command the same action. First the emergency stop button selection followed by the next directional selection. The implementation is intended to reduce the number of required interactions.

If the operator commands the robot forward (button 1) but then needs to turn while still moving forward, he or she can select the appropriate direction (either button 3 or 4) and the robot completes the turn while moving forward. During this activity, the operator may reverse the drive direction (button 2) or change the turn direction (buttons 3 or 4) without halting the robot's progress. Again, the operator could issue an emergency stop command and then select the drive and turn directions. The result would be a total of three-interface button selections rather than one.

3.3 Screen Transitions

The ability to easily and quickly transition between the screens is important. Since the interface is intended to be strictly touch-based, menus or existing button functionality are not used for transitions, as this would require fine-grained stylus interactions. One motivation was to require only gross interaction capabilities. Therefore, the PDA's program buttons have been reprogrammed to provide the screen transition capability.

Figure 5: Program buttons as screen transition buttons.

The first button, labeled 1 in the Figure 5, provides the Image-Only screen when selected. The second button, labeled 2 in the figure, displays the Sonar and Laser based screen while the third button, labeled 3 in the figure, displays the Image with Sensory Overlay screen. The fourth button provides help information.

3.4 Interface Screens

The interface designs are based upon providing rapid but meaningful information. The screens employ visual, sonar, and laser range-finder data. An important criterion was the presentation of information rather than raw data. It is common to see raw sonar data presented as protruding from a graphical robot. Such displays have been shown to be difficult to understand by non-engineering operators [1]. Therefore, the focus was to design displays that provide insight into the robot's environmental view while minimizing the associated data processing requirements.

The display designs are not without disadvantages. Each screen provides limited sensing capability. Only the Sonar and Laser screen provides the operator with sensory information that surrounds the robot. The remaining two screens provide sensory information only from the front of the robot. This limitation leaves the robot susceptible to undetected attacks and hinders the operator's ability to back the robot up long distances. Such a capability is required when the robot is in a confined space and cannot turn around.

3.4.1 Image-Only Screen

The Image-Only screen provides the operator with the view from the robot's forward facing camera, as shown in Figure 6. Many individuals are comfortable working with real-time image based systems because of the similarities to the human visual system. As well, images typically provide a large amount of information that is not easily obtained with other sensory modalities.

It is intended that an operator should be able to command the robot even when the robot is not within the human's sensory field. In this case, the operator must rely upon the robot's sensing capabilities in order to understand the remote environment. An image display of the remote environment is a logical choice.

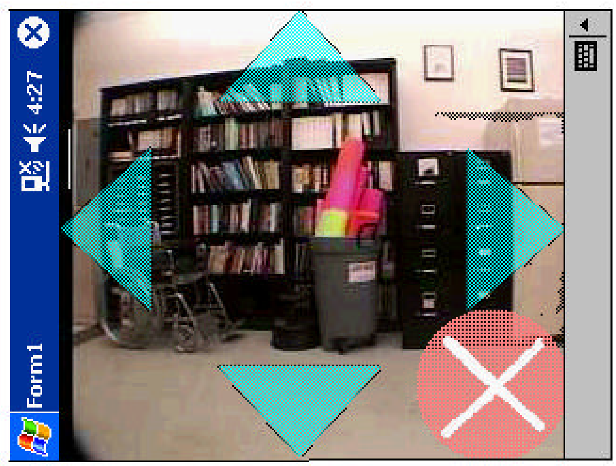

Figure 6: The Image-Only Screen

The Image-Only screen does have associated disadvantages. First, it only provides the forward facing camera image; therefore, the operator is unable to obtain environmental information pertinent to the robot's sides or rear. An additional disadvantage is related to the camera field of view. The camera position and the camera parameters limit the field of view such that an unviewable area exists between the provided image and the robot. Therefore, it is possible that obstacles located in this area may be undetected.

As can be seen in Figure 6, the Image-Only screen provides an image that encompasses the entire screen. The transparent buttons permit viewing of the underlying image. It is relatively easy to hide the buttons and redisplay them when necessary.

Processing is required to resize the image from the 640x480 camera image size to the required 240x320 PDA display size. This processing occurs on the robot's processor and the resized image is sent via wireless communications to the PDA. This is done because the robot has faster processor capabilities than the PDA, thus allowing the display of more frames per second.

3.4.2 Sonar and Laser Based Screen

The Sonar and Laser screen is intended to provide the associated sensor data surrounding the entire robot, as shown in Figure 7. This screen should permit the operator to command the robot even when the robot is located in a small area that contains many objects and obstacles.

An advantage of the Sonar and Laser screen is that it provides sensory information on all sides of the robot. Therefore, the operator should be able to obtain pertinent environmental information. This is the only screen that provides such environmental information. The other screens provide feedback only from the front of the robot.

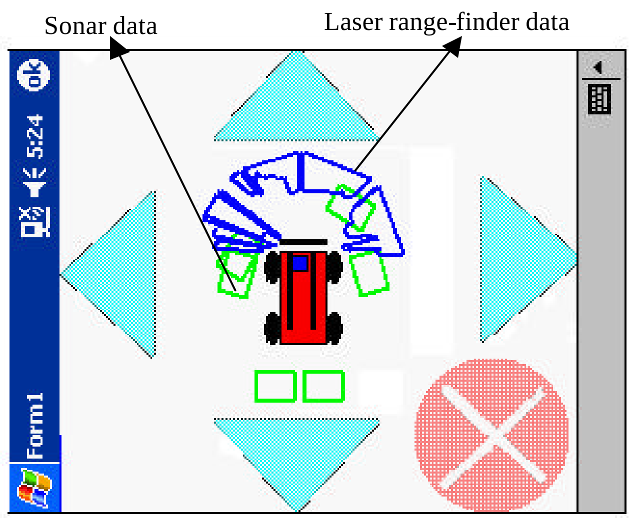

Figure 7: Sonar and Laser (Sensor) Based Screen

The disadvantage of this screen is that the operator may not understand the presented information. Sonar and laser range finder information is not necessarily intuitive to non-engineering operators and may hinder their ability to command the robot. An attempt has been made to provide a meaningful display that provides some perspective to the detected information. As can be seen in Figure 7, the sonar data is represented as rectangles. The laser information is displayed as outlines thus providing an indication of the information detected by the laser.

The raw sonar data is processed to determine which sonar provides valid readings and rectangles are drawn to represent the detected objects. The raw data from the laser-range finder is processed to connect all 180-laser data points to each other. If the laser reading is not the maximum distance, the readings are connected as a line.

3.4.3 Image with Sensory Overlay Screen

The Image with Sensory Overlay screen is intended to provide the sonar and laser range finder data overlaid on the camera image, as shown in Figure 8. The intention is to provide an image that is enhanced by the representation of what the robot detects in the environment via the sonar and laser range finder. Therefore, the sensory data and camera image information is presented in concert to provide simultaneous viewing of all forward facing sensory data.

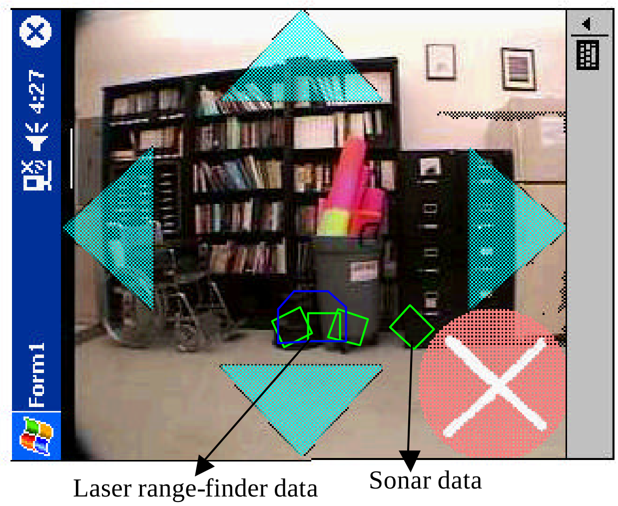

Figure 8: Example Image with Sensory Overlay Screen

The advantage of this screen is that it provides all forward facing sensory and image information. This should allow the user to quickly determine what the robot's processes detect. Future system versions may include automatic obstacle avoidance and this screen should facilitate the operator's ability to determine if the robot detects an obstacle and will avoid it.

There are three primary disadvantages associated with this screen. First, this screen may be confusing since the sensory data is overlaid on top of the image. Operators are comfortable with interpreting images, but the addition of the sensory information may not be clear. The second disadvantage is that this screen does not provide environmental information surrounding the entire robot. As previously mentioned, this can expose the robot to attack and make it difficult to back the robot up for long distances. Finally, there is a possibility that the sonar and laser range finder can detect obstacles that are not within the camera's field of view. In particular, the sensors may detect obstacles in front of the robot that exist between the robot and the camera image. The presentation of such information is hampered by this view. If this information is simply ignored, then the operator may encounter problems.

This screen is still under development. As with the Image-only screen, processing is required to resize the image to the PDA display size. The raw sonar and laser range finder data are represented similarly to the sensor-based screen as rectangles for the sonar data and connected lines for the laser range finder data. This information is overlaid on the camera image. The real world object coordinates will be mapped to the image plane using the camera parameters [7]. The sonar and laser range finder positions relative to the camera will be included.

4 Future Work and Conclusions

A user evaluation will be conducted to determine which screen is the most understandable and facilitates the operator's decision-making process. Thirty novice users will participate in the evaluation during which they will teleoperate a mobile robot using the PDA-based interface. This study will include individuals with no mobile robot experience but who have PDA experience. The defined hypotheses for this evaluation are:

- The Image with Sensory Overlay and Sensor Based interfaces induce higher workload levels for the defined user group than the Vision Based interface.
- The Vision Based interface is easier to use for the defined user group than the Image with Sensory Overlay and Sensor Based interfaces.
- The Vision Based interface is the preferred teleoperation interface by the defined user group.
- The Image with Sensory Overlay interface is preferred for teleoperation over the Sensor Based interface by the defined user group.

This paper presented a PDA based teleoperation interface for a mobile robot composed of three touch-based screens: the Image-Only, the Sonar and Laser Range-Finder, and the Image with Sensory Overlay. The motivation and design of the interface was discussed. A discussion was provided related to the design issues.

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