Evaluation of Control Interfaces for a Hexapod Robot in a Remote Operating Environment

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Abstract— **The field of legged robotics is quickly evolving to changes in technology and the requirements of their operating environment. With an increasing emphasis on robotic exploration and operation in search and rescue and military environments comes the need for designing efficient control interfaces for human operators. While significant work has been done on this topic in the control of aerial and wheeled systems, comparatively little research has been focused on the unique control needs of legged systems in remote operating environments. This work aims to be a preliminary study to help prepare for future research into this realm. Two different control interfaces for a hexapod robot are presented along with a general framework for measuring the situational awareness of the operator when controlling the system in a remote operating environment. Results show that there are many considerations regarding training time, data collection, and proper analysis to be considered for any future work.**

I. INTRODUCTION

Legged robots are a rapidly evolving segment within the field of robotics and maintain high potential for use in activities such as exploration and search and rescue. Their ability to adapt to large variations in terrain composition and height makes them suitable candidates for these types of tasks where wheeled and tracked systems can often fail. This increased adaptability, however, comes at the cost of the relative simplicity in design and control that is afforded to wheeled and tracked systems. As such, the major focus in recent years has been on the development of more robust and efficient control strategies for locomotion of legged robots over complex, unmodeled terrain. With tasks such as search and rescue in mind, many of these systems offer some form of human-robot interface used to control the system in a remote environment. This interface should be designed in such a way that the cognitive burden on the operator is minimized, allowing for increased situational awareness and/or multitasking abilities. Research into methods for reducing this burden have been made in the field of military Unmanned Ariel Vehicles, but little such analysis has been performed on the operation of legged robots.

This work presents a preliminary study on the effectiveness of two different human interface strategies used to control a hexapod robot. The effectiveness of each controller will be measured based on user performance when presented with a set of distractive elements meant to divide their attention between the remote operating task and awareness of their immediate surroundings.

II. BACKGROUND

When human observation or intervention in a location or situation is desirable but impossible due to high risk, Remotely Operated Systems (ROS), are often sent in their place. These systems are a staple in the military and search and rescue communities where they are used to remove their human operators from otherwise potentially harmful scenarios. While there exist many different types of ROS, they fit into three basic categories [1] based on their operating medium: Land, sea, and air. Traditionally, sea-based systems have been referred to as Remotely Operated Vehicles (ROV) [1]; this work avoids conflicting with this definition by referring to the more general class of remotely operated systems discussed here as ROS. This more generalized definition better extends to robotic systems that are not typically considered a vehicle, but which are the main focus of this work.

There has been a significant amount of research [2]–[5] on the control of ROS to support enhanced situational awareness (SA) within the operating environment and decrease the cognitive burden on human operators. The situational awareness of such systems is described by [6] as ”the perception of the robots’ location, surroundings, and status; the comprehension of their meaning; and the projection of how the robot will behave in the near future”. From this definition, it is implied that performance of the ROS is directly related to the remote operator’s ability to successfully obtain and maintain situational awareness within the vehicle’s environment. This is supported by the authors’ previous work [7] where they noted that the primary cause for incidents in remote operation of robots in a complex environment were due to a lack of awareness by the operator of the robot’s location and surroundings. Situational awareness in this context can be called *remote SA*. Situational awareness may also apply to the operator’s perception of their immediate surroundings as well, in what can be called *local SA*. As an example, it would be desirable for a lone operator deployed in a combat context to be fully aware of their own immediate surroundings and situation while also being able to effectively maintain awareness of the remotely operated vehicle’s progress. Losing one’s bearing on either front could lead to a degradation in performance of the vehicle or exposure to harm for the operator.

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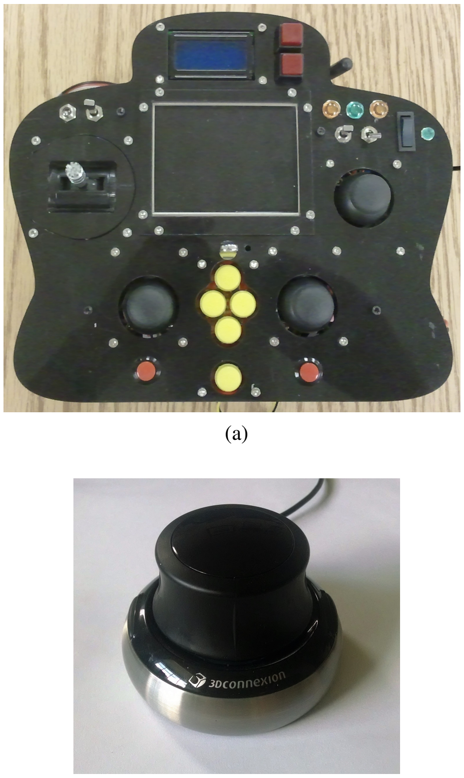

(a)

(b)

Fig. 1: Two different controllers to be tested. (1a) is a traditional set of joystick controls and (1b) is a 3D mouse designed for use with CAD software. The 3D mouse will be used in tandem with the screen on the joystick controller

The effort required to maintain awareness on both fronts can be attributed to more than a single source of influence. Three such components are

1) Suitable controls
2) Sufficient sensory feedback from the ROS
3) An understanding of operator duties based on the level of ROS autonomy

For the operator to make efficient use of the provided controls, it is important that the available sensory feedback from the ROS enables them to make informed navigation decisions and corrections. A live video stream is the most common form of feedback from the system, and arguably one of the most important since a majority of human navigation decisions are made based on visual information [citation needed]. Additional sensors to provide information about the system and it's environment such as body orientation, body acceleration rates, and scene mapping (e.g. LIDAR) can also be included as supplementary information for the operator. The user interface must present this information in a logical, easy to interpret manner to effectively convey the state of the system to avoid confusion [6].

The level of autonomy the ROS is capable of also plays a considerable role in operator SA [8], [9]. Fully teleoperated systems can often require a considerable amount of control input from the operator. With an autonomous system, various functions such as obstacle avoidance and navigation can be controlled by the system, theoretically lessening the control burden on the operator. While increasing autonomy of the system should lead to an increase in local SA, [6] showed that relying too much on these capabilities can lead to a decrease in remote SA. By allowing the robot to autonomously navigate, the operator failed to internalize their own set of landmarks during the process, making it difficult to understand the robot's position relative to the starting point.

In evaluating the level of SA, it is possible to look towards studies regarding distracted driving. In these works, researchers evaluate a driver's level of distraction based on the timing and accuracy of their responses to distracting activities such as talking on the phone [10], turning off a random LED array [10], drinking water [11], and even completing math problems [11]. In each of these evaluations, the goal is to divide the driver's attention between the primary task of operating the vehicle and a secondary diversion task in order to record and understand the effects that they have upon proper operation. Understanding these effects would allow implementation of warning and correctional systems in future vehicles. Evaluating the effects of a robot control interface for operator awareness could be done much the same way. By presenting the operator with a secondary task and recording the accuracy and timing of their responses, a comparison between interfaces could be made with the understanding that a more effective layout would come with a lower cognitive burden. The writer has hypothesized that there are certain control interface elements which require fewer mental resources, thereby freeing the operator to allocate these resources towards other tasks requiring their attention. By comparing user performance between interfaces, the more effective interface would have the higher score.

The goal of this work is not to find an optimal user interface that maximizes operator SA, but to extend the principles utilized in other ROS to a teleoperated hexapod robot [12] for preliminary investigation. Two control interfaces are presented which task the user with fundamentally different interaction requirements. The participants were given an operating task and metrics on their performance were collected along with an evaluation of the controllers. The results of this study will help to inform future development of control interfaces and human control studies for legged robots.

III. HARDWARE

Two control interfaces (figure 1) and a camera unit (figure 3) were developed with remote operation of a legged system in mind. For this study, these interfaces control only a subset of the robot's DoF, illustrated in figure 2. The body height of the robot is fixed at its highest walking height for these trials, thus any control of the vertical direction is not needed. Rotation about the robot's longitudinal axis (roll) is also ignored since this orientation is not a typical mode of control. The joystick interface (1a) was chosen to emulate the common layout of modern video game controllers. This interface is familiar to a large population and represents

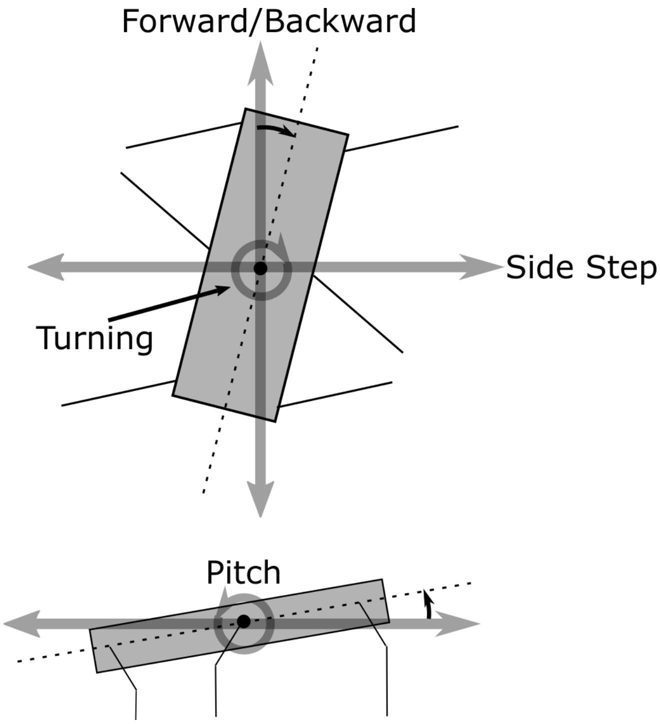

Fig. 2: The controllable body degrees of freedom of the hexapod test robot

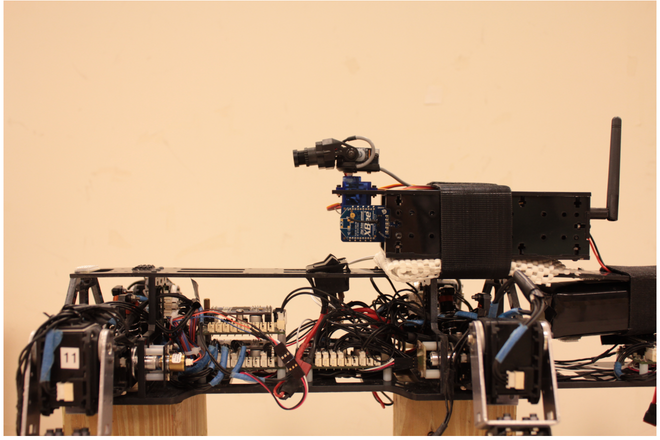

Fig. 3: The camera unit mounted to the robot

a good starting point for control of legged system. To target a different population of potential users, a six DoF 3DConnexion SpaceNavigator (1b) was also interfaced with the robot. If the control knob is viewed as the body of the robot, this controller offers a 1:1 ratio between movements of the knob and the robot. As an example, pushing the entire knob forward makes the robot walk forward while pulling it backward makes the robot walk backward. The same goes for the rotational DoF as well; rotating the knob about the vertical axis makes the robot turn in place while rotating about the transverse axis makes the body of the robot pitch up or down.

Implementation of each control scheme differed drastically because of the required inputs and hardware interfacing requirements. The joystick controller is a collection of both digital and analog buttons, switches, and joysticks that are interfaced with an Arduino Mega2560 microcontroller. The microcontroller continually reads the sate of all interfaces and forwards the information to the camera unit for further processing. When using this interface, the upper left and bottom two joysticks control the robot; the upper left joystick has the same functionality as the lower left joystick. This joystick was used as the throttle control on a traditional RC plane controller and was included for its ability to maintain its position in the vertical directions without requiring constant user input. The USB interface of the SpaceNavigator required an additional Raspberry Pi for reading and parsing of the serial data from the device. The SpaceNavigator sends packets of data containing the translational and rotational positions of the control knob whenever it is in a non-zero state. This data is transformed into a form that the robot can understand and then sent to the joystick remote. A switch on the remote determines which of the two interaces, joystick or SpaceNavigator, is active and sends the appropriate information along to the camera unit through an Xbee wireless radio. When the SpaceNavigator mode is active, the information that was received from the Raspberry Pi is sent.

The camera unit consists of an Arduino Nano microctronoller, Xbee radio, 5.8GHz video transmitter, and Fatshark video camera attached to two pan-tilt microservos. Data from the remote interfaces is received and robot control data is forwarded to the robot while data regarding the action of the camera is used to control the pan-tilt servos. The camera orientation is limited to $\pm 90°$ from center vertically and $\pm 30°$ from center horizontally. The camera controls depend upon the the interface mode being utilized. In joystick mode, the upper right joystick is used to control the camera orientation and the yellow analog buttons are all used to recenter the camera. In SpaceNavigator mode, the upper right and bottom joysticks may all be used for controlling the camera orientation while the buttons on the SpaceNavigator are used to recenter the camera.

IV. EXPERIMENT

Volunteer participants were tasked with navigating an obstacle course (figure 4) using only a video feed viewed on the joystick remote. Each participant was given time to familiarize themselves with the robot and the two control interfaces by guiding the system through the obstacle course with full visual access to the robot. After the participant felt comfortable with the system, the obstacle course was reset and the robot placed at the starting point. Each trial consisted of two required tasks: controlling the robot and responding to a change in their surroundings. The control task required that the participant turned their back to the obstacle course and navigate the robot through it using only the video feed from the robot mounted camera. The participants were also instructed to monitor the status of an orange LED in the upper right hand corner of the remote. This LED was programmed to turn on after a random amount of time since it was last turned off. Pressing either of the two

TABLE I: Response times

	1		2		3		4		5	
# of responses	0	16	2	0	1	8	10	5	0	5
Mean Response Time	0	2.94	106.59	0	27.00	28.20	1.5	12.85	0	50.23
Response Time Standard Deviation	0	1.70	15.274	0	0	65.98	1.01	23.92	0	22.57

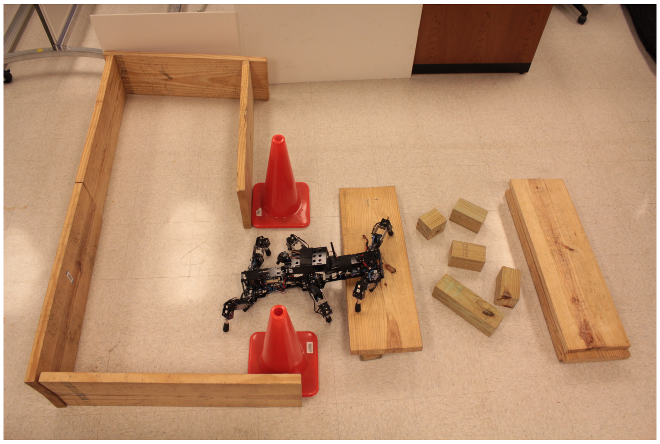

Fig. 4: The obstacle course used in the experiments

red buttons on the remote would turn the LED off, measure the time elapsed since the LED came on, and set up a new timer to turn the LED back on in a random amount of time $(5 - 20\ ms)$. Throughout the course of each trial, the time required to react to this LED by turning it off was recorded as the participant's response time. Each participant completed two trials, one for each control interface. At the conclusion of these trials, feedback on their thoughts of the two interfaces was recorded.

V. RESULTS

Table I shows basic statistics of the collected response times for 5 male participants. Each column contains two sub-columns of data relating to the two completed trials for each participant; the first sub-column is for the joystick interface and the second sub-column is for the SpaceNavigator interface. Participants 1 and 5 never responded to the LED when using the joystick interface so no data was recorded. No data was recorded for participant 2 when using the SpaceNavigator interface for the same reason. Subject 3 only responded to a single LED event, so the standard deviation could not be calculated. Unfortunately, the course completion time was not collected for any participants due to an error in collection procedures.

Participant 4 reported spending a significant amount of time playing video games and did well with the joystick interface with and average response time of 1.5 s and standard deviation of 1.01 s. This same participant had a considerably higher average response time and standard deviation, 12.85 s and 23.92 s respectively, when using the SpaceNavigator interface. In opposite fashion, participant 1, who reported only occasionally playing video games, had an average response time of 2.94 s and standard deviation of 1.70 s with the SpaceNavigator interface. This participant never responded to the LED at all when using the joystick interface, so no data was recorded. These results could be indicative of a trend in which individuals with significant experience playing joystick-based video games perform better with a joystick interface, while others perform better with a non-traditional interface such as with the SpaceNavigator. Because there are several trials without any response data to use in any such correlation, it is not possible to definitely say whether this is true. Three out of the five participants indicated they were more comfortable using the joystick interface due to prior experience with similar video game interfaces. This anecdotal evidence supports the idea that previous experiences can have an impact on the user's perception of the interface, though there hasn't been enough research to understand the effects on their performance.

Making any assumptions based on such a small amount of data would be inappropriate. Without evidence from a larger number of participants, it is impossible to say whether there is a meaningful relationship present. Furthermore, a more powerful tool such as a t-test or ANOVA should be used, but would require a complete set of data without the holes this preliminary collection contains.

VI. DISCUSSION

The small amount of data collected during the course of this study severely limited the level and quality of analysis possible. At this time it is unclear what the motivating factor behind reluctance to participate in the study was, though interaction with possible candidates indicated that it was fear of breaking some part of the system. In addition to the small population size tested, the recorded data on those who did participate was seen in table I to contain several trials where no user response to changes in the LED were recorded. It is interesting to note that only one out of five participants lacked LED responses when using the SpaceNavigator while the joystick interface had two instances of no user response and one trial where only a single response was recorded. While this could be the result of an increased level of cognitive burden when using the joystick interface, it could also be the unfortunate side effect of the training and testing procedures. With the small amount of available space and short time frame, training was limited to the participant controlling the robot within the obstacle course for a few short minutes. It is highly likely that this was insufficient time needed to understand the various idiosyncrasies of the robot and the way it controls. Pairing this lack of experience with the fact that the joystick trial was always executed first offers compelling evidence for why the users may have forgotten about responding to the LED. After the joystick trial, the participants would have developed a familiarity with the course that aided in reducing the their cognitive load for the second trial involving the SpaceNavigator. In a more formal study without the same space and time constraints, increased training time paired with multi-trial runs of randomized obstacle courses would increase the chance of seeing more reliable results. The inclusion of data on the time required to complete the course or even the number of collisions with the environment could have been used as a secondary form of performance metric, helping to mitigate the loss of response data.

In speaking with participants, information useful for guiding developemnt of the next generation of interfaces and experimental procedures was gathered. One of the most prevailing opinions was that the lack of travel in the control knob of the SpaceNavigator severely limited the ability to peceive one's influence on the device, thus making it generally more unpopular than the joystick option. A device with a more exaggerated sense of movement would alleviate this concern and could lead to a higher rate of satisfaction among users. However, it is unclear whether such a change would have had any effect on the population tested here since a majority (three of five) participants expressed a high level of preference for the joystick itnerface based on their experiences with video game controllers. The effect of user perception on the the effectiveness of a control interface was not included in this study, but could be a very proftable area of research within the scope of this problem.

VII. Future Work

Though the preliminary data collected does not give any solid indication of interface performance or even preference, it has provided valuable insight into improvements that can be made in experiment and interface design along with future research paths which could be followed. More immediate work should include the addition of camera stabalization, shrinking of the camera unit, a custom 3D control interface to address participant complaints regarding the SpaceNavigator, and development of a detailed questionnaire to help make correlations between user experiences and effective control elements. Beyond these, the addition of visual, acoustic, and haptic feedback mechanisms, more advanced methods for quantifying the cognitive burden of individual control elements, and the effect of user perception of an interface on user performance would help direct future designs.

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