User Study Results on Attitude Perception of a Mobile Robot

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ABSTRACT

Teleoperating a mobile robot over rough terrain is difficult with current interaction implementations. These implementations compromise the human operators' situation awareness acquisition of the mobile robot's attitude, which is crucial to maintain a safe teleoperation. So, we developed a novel haptic device, to relay a mobile robot's attitude (roll and pitch) to the human operator. A user experiment was performed to evaluate the efficacy of this device in two configurations. A natural attitude configuration between the robot and haptic device, and an ergonomic attitude configuration, which shifts the representation of pitch to the yaw axis. Our results indicate participants were able to successfully perceive the attitude state in both configurations, the natural 58.79% and the ergonomic 63.18% of the times, both are significantly above the 1/3 probability chance. Interestingly, the perception of attitude state was significantly higher in the roll axis over the pitch axis, for the critical and unstable states.

CCS CONCEPTS

• **Human-centered computing** → **Haptic devices**; **User studies**; • **Computer systems organization** → *External interfaces for robotics*;

KEYWORDS

Attitude Perception, Haptic Device, Human-Robot Interaction, Teleoperation, Mobile Robots

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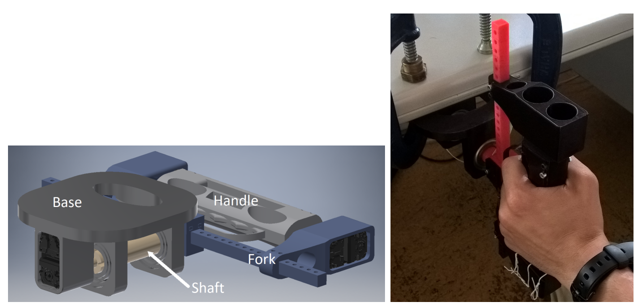
1 INTRODUCTION

Attitude (roll and pitch) awareness is crucial for a human operator to safely and efficiently teleoperate a mobile robot through rough terrain. Current teleoperation system implementations do not provide adequate attitude feedback to the human operator, most of the feedback from these systems is visual (e.g. [2], [4]). This reliance on visual cues from a mobile robot's onboard cameras can create an illusion of flatness in rough terrains [3]. Which leads the operator to unknowingly lose awareness of the robot's attitude, and subsequently teleoperate it into dangerous situations (e.g. rollovers) [1, 5]. As such, we developed a new attitude haptic feedback device (AHFD) (Fig. 1 (a)), that takes advantage of human body proprioception to relay the mobile robot's attitude. The AHFD acts on the hand-wrist system, by rotating the operators hand to the same attitude angles (roll and pitch orientations) of the robot. This device has a range of motion of 180 degrees for each axis, and can be used by both left and right-handed operators. However, a natural mapping of the attitude onto the AHFD could be uncomfortable at higher angles, due to hand-wrist-arm anatomical limitations. We conducted a user study to investigate if using our device for determining the attitude of a mobile robot is viable, and if an ergonomic configuration of the AHFD is as good as the natural configuration.

2 METHOD

To determine if participants could perceive the attitude of a mobile robot with our attitude haptic feedback device (AHFD), we used a classification task. Where the only information about the robot's attitude was given to participants by the AHFD, which they could not see or hear, since it was hidden below a cardboard cover and participants wore headphones playing white noise. This was to ensure no other sensory cues (visual or auditory) were influencing the participants judgement. The AHFD was put in random *roll* and



(a) 3D model in natural configuration

(b) Participant grabbing device in ergonomic configuration

Figure 1: Attitude Haptic Feedback Device.

pitch angles, within a range of [-90 to 90] degrees in both axis, with 0° in both axes corresponding to the mobile robot being levelled. For each random attitude presented to the participants, they had to classify it according to which attitude state they perceived the robot was in. These attitude states were classified for each axis (*roll* and *pitch*). And the states were *stable* (range of [-35, 35]), *unstable* (range between [-65, -35[and]35, 65]) and *critical* (range between [-90, -65[and]65, 90]), corresponding to the robot's likelihood of rolling or tipping over, in the *roll* and *pitch* axes. Also, the AHFD was put into two configurations *natural* and *ergonomic*, for participants to judge the attitude of the robot. The *natural* configuration maps the AHFD *roll* and *pitch* axes to the mobile robot's corresponding *roll* and *pitch* axes. The *ergonomic* configuration represents the robot's pitch axis as the yaw axis in the AHFD (Fig. 1 (b)), while maintaining the same mapping for the roll axis. This configuration more closely corresponds to participants anatomical hand-wrist range of motion without having to change the position of the upper-arm through all the attitude ranges.

The study was performed with 22 participants (15 males, 7 females), aged between 21 to 33 years old, and just one participant was left handed. All participants went through the *natural* and *ergonomic* configurations in a random order, and within each configuration had to classify the attitude state of the robot 15 times. Participants had a 15-minute training session with the AHFD in each configuration prior to the corresponding test. We evaluated whether participants can distinguish between the attitude states, as well as, if there is any difference in attitude perception when in the *ergonomic* configuration compared to the *natural* configuration.

3 RESULTS

Our first step, was to analyse the *number of correct answers* given by participants when classifying the attitude states using a binomial test to check if they were greater than 1/3, for 99% confidence level. The percentage of correct answers on natural configuration was 58.79% ($B(388, 660, 0.5) = 0.58, p < 0.0001$), and for ergonomic configuration was 63.18% ($B(417, 660, 0.5) = 0.63, p < 0.0001$). We also computed the percentage of correct answers by attitude axis and configuration, the results are shown in table 1. In a second step, we analysed the possible interaction between *configurations*, *attitude axes* and *attitude states*, for the dependent variable *correct number of answers*. A three-way repeated measures ANOVA, at 99% confidence level was used for this analysis. There was a statistically significant interaction between *attitude axes* and *attitude states* ($F(2, 42) = 6.669, p = 0.003$) (Fig. 2). As well as, for *attitude axes* ($F(1, 21) = 16.711, p = 0.001$) and *attitude states* ($F(2, 42) = 11.206, p < 0.001$). Post-hoc pairwise tests using Bonferroni correction for these cases revealed the following. For Attitude

Table 1: Percentage of correct answers of perceived attitude state by attitude axis and configuration

		Attitude Axis	
		Pitch	Roll
Configuration	Natural	51.52%	66.06%
	Ergonomic	58.18%	68.18%

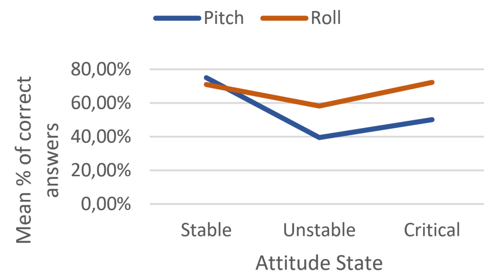


Figure 2: Three-way repeated measures ANOVA interaction between Attitude Axis and Attitude State

Axis, participants perceived correctly more attitude states in the roll axis on average 0.614 ± 0.150 ($p = 0.001$) times than in the pitch axis. For attitude state the stable ($1.205 \pm 0.275, p = 0.001$) and critical states ($0.614 \pm 0.222, p = 0.35$) had significantly more correctly perceived answers than in the unstable state. There was no statistical significant differences between *configurations*.

4 DISCUSSION

Our evaluation shows participants can correctly classify the *attitude states* with the AHFD in both *natural* (58.79%)and *ergonomic* (63.18%) configurations, significantly better than chance (which is 1/3). Yet, no statistical difference or interaction was found between these *configurations*. Which may mean that both configurations are equally suitable for conveying a mobile robot's attitude. The most interesting finding was the interaction between *attitude states* and *attitude axes*, where participants were equally good at classifying the *stable* state for both *attitude axes* (roll and pitch). This can be explained by the continuous 70 degree range that is associated to the *stable* state, which does not occur in the other *attitude states* (unstable and critical). And participants were more accurate in identifying the *unstable* and *critical* states in the *roll* axis than in the *pitch* axis. This we believe is due to the roll axis being more intuitive to perceive than the pitch axis in the current version of the AHFD.

In future work, we aim to refine and improve upon the AHFD to better convey the mobilt robot attitude to the human operator. We then intend to test the AHFD within a teleoperation task with a real mobile robot, to investigate whether it helps human operators acquire situation awareness of the terrain and the mobile robot's attitude.

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