Attitude Perception of an Unmanned Ground Vehicle Using an Attitude Haptic Feedback Device

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Abstract— **In order to safely teleoperate an unmanned ground vehicle (UGV) through rough terrain, a human operator needs to be aware of its attitude. This awareness ensures (s)he can avoid rolling or tipping over the UGV, due to steep slopes or terrain depressions. Yet, it has been challenging to develop teleoperation systems that can provide attitude awareness, to human operators. So far, all research has been focused in implementing solutions through visual modality.**

We take a different approach, using haptic feedback to transmit an UGV's attitude to an human operator. Our novel attitude haptic feedback device (AHFD) provides information about the UGV's roll and pitch, and their direction of rotation, thorugh the use of upper limb proprioception. We also discuss a preliminary user study to understand the influence two different AHFD configurations (natural and ergonomic) have on attitude perception.

Our results indicate there is no difference between the two AHFD configuration in judging attitude states and direction of rotations. Yet, natural configuration is perceived as causing higher physical strain and demand, while the ergonomic a higher overall mental effort. We also found participants had more difficulty in judging pitch attitude at higher angles.

I. INTRODUCTION

For successful teleoperation of an unmanned ground vehicle (UGV) in rough terrain, a human operator needs to be aware of the UGV's attitude. This awareness, allows the human operator to avoid slopes or depressions that exceed the UGV's attitude limits. Thus, ensuring the UGV will not roll over its side, nor tip over its front or back. When a human operator is in the same physical space as the mobile robot, or watching the robot from an outside perspective, it is easy to understand these attitude limits, and steer the UGV away from dangerous terrain slopes.

In a remote teleoperation task the attitude awareness of an UGV is very difficult. This is due to the human operator just seeing what is happening to the robot through its onboard cameras [1]. This creates a detachment between the physical dynamics acting on the UGV, and what the human operator senses through the interface [2]. Lewis and Wang [3] hypothesized the egocentric view of the onboard camera creates an illusion of flatness in environments with ambiguous cues. Leading the human operator to have a false perception of what is happening, thus losing situation awareness. In a teleoperation experiment done by McGovern et al. [4], they establish vehicle roll and pitch control to be a major problem. Since all the accidents they registered were due to rollovers. Most rollovers were because the human operator sent the vehicle of a ramp or trying to traverse a slope that was too steep. They also noted that in the debriefing the human operators had no indication of the dangerous attitude the vehicle was approaching.

Casper and Murphy [5] also reported that sensor impoverishment led to the rollover of the Solem robot, while searching for victims inside the world trade centre. The view from the Solem camera was disorienting when the robot was right side up, when it rolled over the camera images did not provide any information of what had happened. This can be attributed to the fixed on-board cameras in the mobile robot. Which has the unwanted effect of the camera image appearing flat when the mobile robot is perpendicular to a slope. The illusion of flatness also happens when the mobile robot is facing up or down a slope. And if the mobile robot is in an inclined position a horizontal area appears sloped [3].

Aviation has solved this loss of attitude awareness by using an artificial horizon, in the instrument panel or through the heads-up display. This allows the pilot to know the attitude of the aircraft and control it during an instrumented flight (e.g. [6], [7]). This artificial horizon has been also applied in UGV teleoperation. Bruemmer et al. [8] describes a visual interface that among other things has an artificial horizon and numeric indication of the UGV's roll and pitch. Yet, as pointed out by Lewis and Wang [3] these artificial horizons do not work in UGV teleoperation, due to the presence of outside visual references.

Drury et al. [9] developed a GUI for the VGTV-Extreme robot, that showed the shape and pitch inclination of the robot. Use of this pose display resulted in fewer robot tips into an unstable position. With 5 out of 19 participants tipping the robot when pose display was present, against the 11 who tipped over the robot when pose display was absent.

Lewis and Wang [3] compared a fixed camera with linear attitude display against the use of a gravity-referenced camera, in an UGV teleoperation simulation. The gravity-referenced camera always maintains a normal to gravity. As such, terrain that is not horizontal with gravity, in the roll axis, will show a camera image with the UGV's body tilted to one of the sides. Their results showed neither condition group

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had confidence in estimating the UGV's roll and pitch. That in the linear attitude display condition participants primary source to understand the UGV's attitude, was the landscape. The gravity-referenced camera condition had the same roll over high rates as in the linear attitude display condition. Lewis and Wang [3] also point out that the gravity-referenced camera does not provide pitch information. And that high-frequency terrain features such as sudden dips or rubble could remain hidden from operators' awareness.

The current attitude feedback solutions do not provide adequate situation awareness of the teleoperated UGV's attitude. These solutions reliance on the visual channel, mean they are often ignored by human operators. Since, a human operator's focus is on the environment shown through the on-board cameras [3]. They also clutter the visual user interface, this means there is less real estate to show the image from on-board cameras, and may create visual perception overload. The gravity-referenced camera [3] is a more elegant solution, that does not overload the visual perception. But it does not prevent roll overs, nor is it able to provide pitch information. The major problem with the current crop of attitude feedback displays, is they rely on visual feedback to transmit information that is kinematic.

Although there has been extensive research in controlling mobile robots with haptic devices [16], [14], [15], there has not been to our knowledge any research on using haptic devices to provide attitude feedback of a mobile robot.

As such, this paper proposes a novel attitude haptic feedback device (AHFD), that uses upper limb proprioception to inform a human operator of a teleoperated UGV's attitude. The AHFD motion acts on the pronation and supination of the forearm, to represent roll, and on the palmarflexion and dorsiflexion of the wirst, to represent pitch. The AHFD can provide information in the roll and pitch axes, with differing slopes and at high velocity depending on how the attitude of the UGV changes over time. We believe using haptic feedback to convey an UGV's attitude, ensures complete perception and comprehension of how attitude can directly impact UGV control. Which is frequently missed, by human operators, from the on-board cameras, or needs to be inferred from the GUI, when present. We believe the AHFD will help human operators to successfully understand an UGV's attitude, and thus safely navigate an UGV through rough terrain. The paper also reports on a preliminary user study, to investigate how the developed AHFD ergonomics may influence a human operators's perception of an UGV's attitude.

The paper is structured as follows. Section 2 discusses the design of the attitude haptic feedback device. Section 3 presents the experimental set-up and procedure of our preliminary user study with the AHFD. Results of the user study are presented in Section 4. Sections 5 and 6 are discussion of the results and conclusion, respectively.

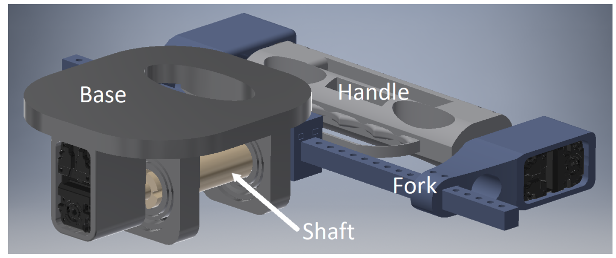


Fig. 1. Model of AHFD device, with Roll and Pitch axes motors, shown in black

II. Attitude Haptic Feedback Device (AHFD) Design

This section describes the attitude haptic feedback device (AHFD) design, and its components. The intent is to provide a human operator with the information of an unmanned ground vehicle's (UGV) attitude, which changes due to terrain conditions. The AHFD (Fig. 1) gives information of roll and pitch angles, and attitude rotations of the UGV. The main axis is roll, with the secondary axis being pitch. The device uses two Herkulex DRS-101[1] motors to make rotations in each axis, and are located at the end of each axis shaft (Fig. 1).

The choice of these motors was due to their specifications: 0.325 degrees of resolution, a stall torque of 1.2 N.m, and maximum rotation speed 0.166sec/60°. Has we wanted the device to move instantaneously, with the smallest lag possible, to the current UGV's attitude. For example, if the robot suddenly fell into a ditch, the device would produce almost instantly, that brisk change in attitude. This hopefully will help inform the human operator that something unexpected happened to the UGV. The other aspect of choosing these motors was they enable to change the overload protection settings. This allows us to test different movement resistance values from the human operator, before overloading the motor. These motors also have a range of motion of 320 degrees. But we limited them to work on 180 degrees, due to the human wrist-arm anatomy, has a fail-safe for preventing any lesion.

The device was modelled so it could be as portable as possible. Due to constraints in search and rescue operations. As an example of these constraints, Casper and Murphy [5] mention the human-robot ratio. Ideally the ratio should be one person to one robot, in transporting the robot and control equipment to the disaster site, as well as, in operating the robot. Because there is a limitation on the number of people allowed in a disaster hot zone, where logistical issues arise with increasing in the number of people. The AHFD dimensions are as follows:

- Base (see Fig. 1 grey part): length 138.928mm; width 122mm; height 72.028mm
- Rotation Shaft (see Fig. 1 off-white part): length 128.098mm; radius 9.5mm

[1] http://www.dongburobot.com/jsp/cms/view.jsp?code=100788

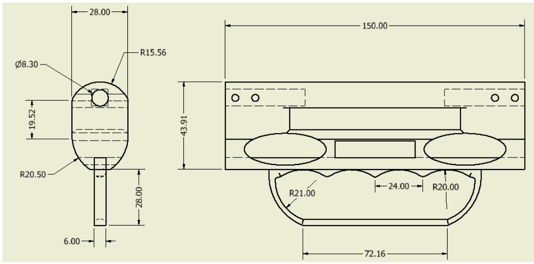
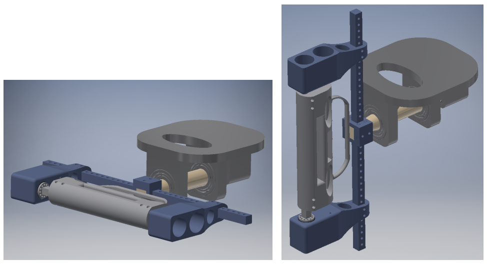


Fig. 2. Handle Schematics



(a) initial Roll orientation is leveled with horizon (*Natural configuration*)

(b) initial Roll orientation is at a 90°angle to the horizon (*Ergonomic configuration*)

Fig. 3. Example of different initial roll orientations.

- Fork: (see Fig. 1 blue part): width 310mm; length 104.379mm; height 30.006mm

The AHFD can be fixated to any hard surface with clamps or other means. The handle, where participants grab the device, was designed to be within the ergonomic patterns established in [10]. We decided on designing the handle for a power grip, since our intention was to stimulate the forearm and wrist proprioceptors to transmit the attitude information, and provide a comfortable rest position for the hand while using the device. Following Patkin's [10] recommendations the handle is of an oval shape with 28mm of thickness, 44mm of depth to fit into the palm, and a length of 150mm to fit the palm width. The handle has knuckle shapes for grip orientation, with a 20mm radius and a 24mm spacing for each finger, see Fig. 2. The handle is ambidextrous.

Due to its modularity, the AHFD initial orientation can be configured for right-hand and left-hand users, without the need of software adjustments. In addition the roll and pitch zero angle can be changed to any of the quadrants as well, see Fig. 3. This configuration modularity is possible because the shaft joint for each axis is square shaped, allowing the shaft to be easily disassembled, and reassembled in another orientation. With this hardware functionality, no software algorithm is needed to shift the starting zero angle or the motors' direction of rotation.

III. Experimental Method

Has a preliminary user study we wanted to understand if AHFD ergonomics could influence the attitude perception of human operators. Since, the AHFD *natural* configuration (Fig. 4a), where the initial roll orientation is levelled with the horizon, can put stress (at higher angles) on the upper limb of the user. And, the alternative AHFD *ergonomic* configuration (Fig. 4b), where the initial roll orientation is realigned 90°with the horizon, thud aligning pitch with the yaw axis. Possibly meaning a human operators need to adjust their attitude mental model of the unmanned ground vehicle (UGV). So our concern is whether any of these two configurations (*natural*, *ergonomic*) have any negative impact in the human operators attitude perception of an UGV. And also to find out which of these configurations provides better attitude understanding to human operators.

To answer these questions we performed a preliminary user study, focused only on the attitude feedback without any control over the UGV. Participants had to successfully distinguish between different attitude states (*stable*, *unstable*, *critical*) of an UGV, and the direction of rotation in both *roll* and *pitch* axes, for each AHFD configuration (*natural*, *ergonomic*). We made this choice of judging attitude states, instead of absolute attitude angles, as it represents the operators mental model of how a steeper attitude can endanger the UGV's operation. The attitude states were defined has:

- *Stable*: The UGV's attitude does not compromise any movement. Its range [-35, 35] degrees.
- *Unstable*: Refers to an UGV's attitude that compromises one or more axes of movement (the mobile robot can begin to slip or loose traction), and an increased probability of tipping or rolling over. Its range [-65, -35[and]35, 65] degrees.
- *Critical*: Corresponds to an UGV's centre of gravity being on or over, the tipping or rolling point. Its range [-90, -65[and]65, 90] degrees.

The range of angles within each state was chosen based on a simplification of the robotic platform RAPOSA-NG dynamic characteristics, through empirical testing [11], and the slops definition from Lewis and Wang [3]. The experiment has the AHFD rotating to random angles, within the range of [-90, 90] degrees, for each axis (*roll* and *pitch*). This range was chosen as it would give a notion at the limits of UGV rolling or tipping, and due to anatomic wrist-arm movement constraints.

We evaluated if participants could perceive the different attitude states through the AHFD, in two configurations (*Natural* and *Ergonomic*). We also evaluated if participants could perceive the *direction of rotation* in relation to a previous attitude. Subjective evaluation of participants *physical and mental load* was also performed.

- Hypothesis 1: Participants can judge correctly the attitude states, in both *Natural* and *Ergonomic* configurations, significantly above the likelihood of it being by chance.
- Hypothesis 2: Participants can judge correctly the *direction of rotation* in relation to a previous attitude, in both *Natural* and *Ergonomic* configurations, significantly above the likelihood of it being by chance.
- Hypothesis 3: Participants overall physical effort is higher in the *Natural* configuration.

- Hypothesis 4: Participants overall mental effort is higher in the *Ergonomic* configuration.

Full details of the experimental set-up are described in the following sections.

A. Participants

Twenty-two people (15 males, 7 females) voluntarily participated in the experiment. Participants were aged between 21 to 33 years old, and were students or researchers from other fields. Twenty-one participants were right-handed, and one was left-handed, their dominant hand was used to grasp the AHFD. None of the participants had a vestibular or proprioceptive disorder, and no musculoskeletal disorder of the upper body (hand, wrist, forearm, elbow, upper arm, shoulder). No participant had contact with the AHFD, nor the experimental software, prior to the experiment.

B. Design

The experiment involved three independent variables *Roll State*, *Pitch State* and *Configuration*. Both *Roll and Pitch States* have three levels (*Stable*, *Unstable*, *Critical*). *Configuration* has two levels (*Natural*, *Ergonomic*. These were arranged into 2 blocks of trials covering all *configurations*, and were presented using a fully repeated measures design - every participant completed both blocks. Within each block, all *Roll and Pitch States* were presented 5 times, in a random order. Also, within each attitude state, the angle was picked randomly from the range and was a multiple of 5.

To mitigate practice effects, the experimental design followed complete counterbalancing and block randomization, has used in past work [12]. There was a 15-minute training session for each block and a 5-minute break between blocks. So, half of the participants experienced *Natural* configuration (15-minutes training, then experiment), then *Ergonomic* configuration (15-minute training, then experiment), while the other half experienced the inverse arrangement. This led to a total of two order conditions.

C. Apparatus

1) Attitude Haptic Feedback Device (AHFD): The device was configured for each block the participant was in (*Natural* or *Ergonomic*). And when in the *Ergonomic*, configured to be used by a right-handed or left-handed participant.

2) Training Software: To assist the participants in understanding, and creating a mental model of the feedback given by the AHFD, we created a custom training software. It allows rotation in the *roll* and *pitch* axes. Showing through colours the attitude states for each axis (green = *Stable*, yellow = *Unstable*, red = *Critical*), see Fig. 4.

3) Experiment Software: To ensure randomly generated *roll and pitch states* for each configuration and participant, as well as, record the participants answers and completion times of each trial, we created a custom experiment software. The random generation of *target attitude states* was done by first generating a list for each defined range of angles, through an arithmetic progression which incremented in steps of 5. A total of 5 lists were created, corresponding to the following ranges: *stable* [-35, 35], *negative unstable* [-65, -35[, *positive unstable*]35, 65], *negative critical* [-90, -65[and *positive critical*]65, 90]. Then a random attitude list with 15 random elements, containing 5 elements of each state, for each axis (*roll* and *pitch*) is generated by calling the following function:

1 Randomly choose which range list to access, for each state, between *negative unstable* and *positive unstable*, as well as, between *negative critical* and *positive critical*. No choice as to be made for the *stable* state, since there is only one list;
2 From each selected list choose a random value, and add it to the random list;
3 Repeat the process 5 times;
4 Shuffle the random list.

This function is called at the beginning of each configuration.

To record the time taken by the participant in each trial, the software started counting the elapsed time after the 5 seconds wait, because we configured the AHFD to reach the random orientation in 5 seconds. And stopped counting when the participant pressed the submit button.

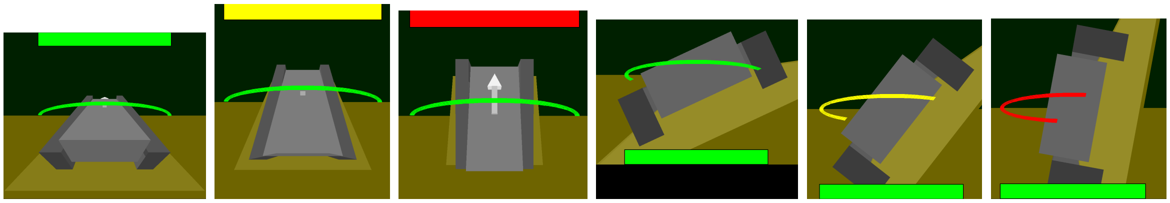
4) Physical Environment and Props: The experiment took place in an empty class room, this space was selected to minimise outside distractions. An Asus Zenbook UX303UB laptop was used to run the training and experiment software, and to play the background white noise through stereo headphones. So the participant would not hear the motors moving giving audio information of the AHFD movement. The AHFD was attached to a table, and a cardboard box put on top of it, so participants could not see the movement of the device, this was to ensure participants did not have any visual clue of the orientation of the AHFD. An office chair was also used to adjust the seat height to each participant, ensuring (s)he had the arm in a natural relaxed position, and the legs did not hit the AHFD when it was rotating.

D. Procedure

Participants met the experimenter outside the classroom, and where escorted inside, where they received the experimental instructions, to review. They had to also fill demographics information (gender, age, dominant hand, academic level, vestibular condition, proprioceptive condition, musculoskeletal condition). The experimental procedures were also discussed orally, and participants encouraged to ask questions. Participants were asked to sit in the office chair and grab the AHFD handle. The chair's height was then adjusted so participants arm would be in a neutral position.

The experimenter runned the training software and explained how the AHFD worked. Mentioning specifically that the 3D model being presented was merely an aid for understanding what was happening with the device. And also, mentioning the attitude states and their relation to how it would affect an UGV. After this explanation, the participant had 15 minutes to train with the AHFD, by changing the 3D model attitude with the arrow keys (Fig. 5a).

After the training session ended, the participant was asked to put on the headphones, and the experiment software was initiated. A rundown of what was going to happen during



(a) Pitch stable (b) Pitch unstable (c) Pitch critical (d) Roll stable (e) Roll unstable (f) Roll critical

Fig. 4. Training software

(a) Training session (b) Experiment session

Fig. 5. User Study

the experiment session was given by the experimenter. After this the experimenter would start playback of the white noise and get out of the room, with the participant then starting the experiment.

The experiment consisted in the participant pressing the begin button, then waiting for 5 seconds, this was to ensure the AHFD finished its movement. Afterwards the participant would answer the questions presented on the screen, and press the submit button, no time limit was given to answer the questions (Fig. 5b). This process was repeated 15 times.

At the end, a questionnaire about the physical and mental effort was shown for the participant to answer. When the questionnaire was finished the participant would be prompted to call the experimenter and start a 5-minute break. After the break, the experimenter would start the training software again for the second configuration, and the all process was repeated. In total, the experiment took on average 60 minutes to complete.

E. Measures

The primary measures used in this study were, *correct answers* given for *perceived roll and pitch states* (*stable, unstable, critical*), *perceived roll direction of rotation* (*left, right, no movement*), and *perceived pitch direction of rotation* (*up, down, no movement*). With the secondary measure being *post configuration questionnaire*, subdivided in *physical effort* and *mental effort*. A third measure was *time to answer* the set of questions.

F. Analysis

The analysis of *perceived roll and pitch states* data and *perceived roll and pitch direction of rotation* data was done for each AHFD configuration using a binomial test, with a 99% confidence level. These analyses were done to see if participants' number of correct answers were significantly greater than 7. The cut point of 7 was chosen because the sum of probabilities for the number of correct answers higher than 7 is 0.088, following binomial distribution $B\left(15, \frac{1}{3}\right)$.

We then performed a Wilcoxon signed-ranked test for related samples, to check for differences between configurations on both *perceived roll and pitch states*, as well as *perceived roll and pitch direction of rotation*. The Wilcoxon signed-ranked test for related samples was also used to check for differences in each *attitude state* (*stable, unstable, critical*) between axes. A Friedman's test was performed to check for differences between *attitude states* within each axis.

The *post configuration questionnaire* was analysed using Wilcoxon signed-ranked test for related samples, to check for differences between *natural* and *ergonomic* configurations. Finally, a repeated measures ANOVA analysis was performed on the *time to answer* measure, to check for differences in response time between the *natural* and *ergonomic* configurations. All Wilcoxon signed-ranked tests, Friedman's tests and the ANOVA statistical test were done with 95% confidence.

IV. RESULTS

Binomial tests for each AHFD configuration on number of correct answers for *perceived roll and pitch states* (Table I and Fig. 6) were all statistically significant.

Binomial tests for each AHFD configuration on number if cirrect answers for *perceived direction of rotation* for *roll* and *pitch* (Table II and Fig. 7) were all statistically significant.

No statistical significant differences were found between the *Natural* and *Ergonomic* configurations for both *perceived roll and pitch states*, as well as *perceived roll and pitch direction of rotation*. Though the number of correct answers

TABLE I
PERCEIVED ROLL AND PITCH STATES

AHFD Configuration	**Mean**	**Median**	**Binomial Test**	**One-tailed $p - value$**
Natural+Roll	9.909 (±2.557)	10	0.864	< 0.001
Natural+Pitch	7.727 (±2.178)	8	0.545	< 0.001
Ergonomic+Roll	10.227 (±2.214)	10	0.909	< 0.001
Ergonomic+Pitch	8.727 (±2.831)	9	0.682	< 0.001

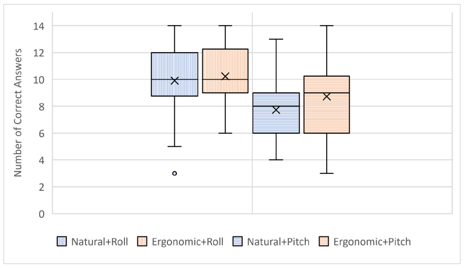


Fig. 6. Number of correctly perceived roll and pitch states by AHFD configuration

TABLE II

PERCEIVED DIRECTION OF ROTATION

AHFD Configuration	Mean	Median	Binomial Test	One-tailed $p - value$
Natural+Roll	9.455 ($\pm$2.039)	10	0.864	< 0.001
Natural+Pitch	9.182 ($\pm$2.367)	9	0.864	< 0.001
Ergonomic+Roll	10.227 ($\pm$2.214)	10.5	0.864	< 0.001
Ergonomic+Pitch	8.727 ($\pm$2.831)	9.5	0.773	< 0.001

for *perceived pitch states* in the *Ergonomic* configuration $(median = 9)$ shows a tendency to be higher than on the *Natural* configuration $(median = 8)$, $(Z = -1.604, p = 0.058, one - tailed)$.

There was a statistically significant difference between *Roll* and *Pitch* axes in the number of correct answers for *Unstable* and *Critical* states (Fig. 8):

- In *Unstable* $(Z = -3.782, p < 0.001, one-tailed)$ *Roll* $(median = 3)$ was higher than *Pitch* $(median = 2)$.
- In *Critical* $(Z = -3.664, p < 0.001, one - tailed)$ *Roll* $(median = 4)$ was higher than *Pitch* $(median = 2)$.

A statistically significant difference was found between *attitude states* within the *Roll* axis $(\chi^2(2) = 10.092, p = 0.006)$ and within the *Pitch* axis $(\chi^2(2) = 25.268, p < 0.001)$. Post-hoc analyses with Wilcoxon signed-rank tests were conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.017$. Within the *Roll* axis, the median number of correct answers for each state were $Stable = 4$, $Unstable = 3$ and $Critical = 4$. There was a statistically significant increase in number of correct answers:

- *Stable* vs *Unstable* $(Z = -2.614, p = 0.004, one - tailed)$,
- *Critical* vs *Unstable* $(Z = -2.182, p = 0.014, one - tailed)$.

Within the *Pitch* axis, the median number of correct answers for each state were $Stable = 4$, $Unstable = 2$ and $Critical = 2$. There was a statistically significant increase in number of correct answers:

- *Stable* vs *Unstable* $(Z = -4.377, p < 0.001, one - tailed)$,

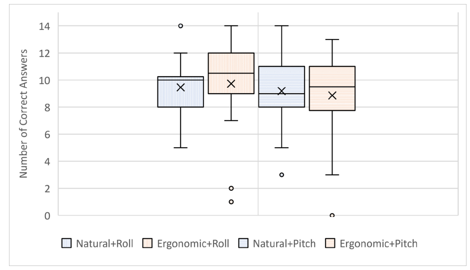


Fig. 7. Number of correct answers for direction of rotation in roll and pitch by AHFD configuration

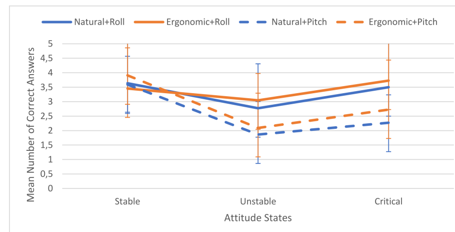


Fig. 8. Mean number of correct answers by axes and attitude states

- *Stable* vs *Critical* $(Z = -3.645, p < 0.001, one - tailed)$,
- *Critical* vs *Unstable* $(Z = -2.193, p = 0.014, one - tailed)$.

The *physical effort* questionnaire analysis revealed a statistical significance in the amount of straining $(Z = -2.308, p = 0.016, one - tailed)$, and physical demand $(Z = -1.781, p = 0.049, one - tailed)$ between the two configurations. Where 8 participants felt the *Natural* configuration strained their wrists and forearms more than the *Ergonomic* configuration. The *Natural* configuration was perceived, by 10 participants, to be on average 1.4 times more physically demanding.

The *mental effort* post questionnaire analysis revealed statistical significance for the following scales:

- Mental work $(Z = -3.216, p < 0.001, one - tailed)$, was perceived as higher in the *Ergonomic* configuration by 14 participants, on average by 1 point.
- Mental demand $(Z = -3.666, p < 0.001, one-tailed)$, was perceived as higher in the *Ergonomic* configuration by 16 participants, on average by 1 point.
- Mental model of attitude $(Z = -2.221, p = 0.016, one - tailed)$, was perceived as harder in the *Ergonomic* configuration by 10 participants, on average by 2 points.
- Task success $(Z = -2.230, p = 0.016, one - tailed)$, was perceived as higher in the *Natural* configuration by 12 participants, on average by 1 point.
- Satisfaction in distinguishing the attitude states $(Z = -2.066, p = 0.029, one - tailed)$, was perceived as higher in the *Natural* configuration by 10 participants, on average by 1 point.
- Overall attitude perception $(Z = -2.425, p = 0.008, one - tailed)$, was perceived as harder in the

Ergonomic configuration by 13 participants, on average by 2 points.

- Pitch orientation perception ($Z = -1.822, p = 0.041, one - tailed$), was perceived as easier in the *Natural* configuration by 11 participants, on average by 1 point.
- Mental and perceptual activity for thinking ($Z = -3.216, p < 0.001, one - tailed$), deciding ($Z = -2.398, p = 0.012, one - tailed$), calculating ($Z = -2.818, p = 0.002, one - tailed$) and remembering ($Z = -3.252, p < 0.001, one - tailed$), had 14, 12, 11, 14 participants, respectively requiring more effort on the *Ergonomic* configuration, on average by 2, 1, 2, 2, respectively.

Finally, *time to answer* the set of questions was statistically significant ($F(1, 329) = 11.497, \boldsymbol{p < 0.001}$). Mauchly's Test of Sphericity indicated that the assumption of sphericity was not violated. Post-hoc pairwise test using Bonferroni correction revealed participants were on average $3.895 \pm 1.149s(\boldsymbol{p = 0.001})$ faster on the *Natural* than on the *Ergonomic* configuration to respond the set of questions.

V. Discussion

This preliminary user study sought to investigate if the AHFD ergonomics has any influence in human operators' perception of an UGV's attitude. So, we tested two AHFD configurations, *natural* and *ergonomic*, in a task to judge the perceived *attitude states* of *pitch* and *roll*, as well as, their *direction of rotation*. The choice of judging attitude states, was to see if participants mental model of steeper attitude angles was associated with increase in danger when controlling an UGV. With this study we also wanted to find which AHFD configuration provides better attitude understanding.

Participants number of correct answers for judging *attitude states* and *direction of rotation* were statistically higher than chance for both AHFD configurations. Thus, our first and second hypothesis are confirmed. This is a strong indication the AHFD can be used, by operators, to acquire information on possible dangerous slopes when controlling an UGV. Overall there was a tendency for *ergonomics* to have higher number of correct answers in *attitude states* and *direction of rotation*, though no statistically significant difference was found between the two configuration.

Interestingly, *roll* showed a statistically higher success rate for judging the *unstable* and *critical* states. We believe this is due to, participants inexperience in deriving *pitch* angles from palmarflexion or dorsiflexion of the wrist. Also, in this preliminary study, the *unstable* state was harder to identify in both *roll* and *pitch* axes. This we believe, is because the *unstable* state is bounded by the other two states, and thus participants misjudge when the angles are near the boundaries.

These primary results gives us evidence the AHFD helps augment attitude awareness of an UGV, in either configuration. Though, some limitations still need to be addressed, mainly in improving *pitch* attitude perception, at higher angles.

Although no statistical difference was found between the *natural* and *ergonomic* configurations for the primary measures, the secondary and third measures showed a statistically significant difference between the two.

As expected the *natural* configuration was perceived to be more physically demanding on average 1.4 times, causing more strain on the wrist and forearm, than the *ergonomic* configuration. As was previously mentioned, this can happen because the *natural* configuration can stress the wrist's palmarflexion or dorsiflexion when the forearm is doing a pronation at higher *pitch* and *roll* angles. Although this is not enough to prove our third hypothesis, there was an overall tendency for the *natural* configuration to be perceived as having a higher overall physical effort.

In contrast, we can prove our forth hypothesis, that *mental effort* is statistically higher in the *ergonomic* configuration. With participants perceiving that *ergonomic* requires more mental work and perceptual demand to understand the *pitch* orientation and the overall attitude. This is also true for the mental visualisation of the UGV's attitude, where *ergonomic* required more thinking, remembering, calculating and deciding. A consequence of this, was participants felt they were more successful in performing the task, and distinguishing attitude states in the *natural* configuration. Likewise, this explains the participants being on average 3.895 seconds faster answering the questions in the *natural* configuration.

These results confirm our concern about the impact *ergonomic* configuration has on overall mental effort. That it requires a high spatial perception ability from participants, to mentally adjust their frame of reference, due to the realignment of the initial roll orientation by 90°with the horizon, meaning pitch aligns with the yaw axis. This higher mental effort in *ergonomic*, may also explain the tendency for better results in the primary measures. We believe the higher overall mental effort improved participants' focus to perceive the shown attitudes and rotations.

This preliminary user study allowed us to understand perception of *attitude states* and *direction of rotations* are not statistically different between both configurations, and the success rates were not due to chance. It also, helped us be aware the *natural* configuration is perceived to cause higher physical strain and demand. And the *ergonomic* configuration is perceived as requiring higher overall mental effort. We also found participants had more difficulty in perceiving *pitch* attitude for higher angles (*unstable* and *critical*).

VI. Conclusion

Within this paper, we presented the design of our attitude haptic feedback device (AHFD). Which uses upper limb proprioception, to inform a human operator of an UGV's attitude. Conveying to the person's upper limb a similar physical sensation as if (s)he were inside a vehicle feeling the attitude change. Thus, having the advantage of using a naturalistic feedback, that is recognizable and perceived at the moment it happens with the UGV. Which the visual channel may miss, due to competing information. We believe it can allow the visual channel to be only used for the camera image. Help the human operator in teleoperation tasks of UGVs (e.g. finding victims, searching for targets, robot navigation).

This paper also describes a preliminary user study to understand how the AHFD ergonomics could influence the attitude perception of a human operator. Our results revealed participants were successfully able to perceive the attitude states and direction of rotations. That the natural configuration was perceived to cause more physical strain and demand. And, the ergonomic configuration requires more mental effort. The results also show participants had more difficulty in judging pitch attitudes for higher angles.

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