Feeling the Slope? Teleoperation of a mobile robot using a 7DOF haptic device with attitude feedback

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Abstract—A well-known challenge in rover teleoperation is the lack of situational awareness (SA) of the operator. This often leads to an erroneous perception of the status of the rover and its surrounding environment and, consequently, to faulty decision-making. We present a novel teleoperation interface to control a rover in the context of planetary exploration. The proposed interface employs a 7-DOF force feedback device (sigma.7) to command locomotion while providing haptic feedback to ensure appropriate situational awareness. In particular, the device provides proprioceptive cues to convey the rover’s attitude. This can be particularly useful where visibility is poor, or the horizon is not visible. In systematic experimental trials controlling a robot in an outdoor environment, we evaluated the validity of using sigma.7 as an alternative to the standard joystick. We tested the use of attitude as an aid to situational awareness. We found no significant detriment in manoeuvrability compared to a conventional joystick, thus validating the sigma.7 as an effective control device. Regarding SA, results showed no statistical difference between the visual and haptic cues for attitude feedback, thus validating the haptic method as an effective alternative feedback method to offload the visual information into the haptic channel. Finally, qualitative observations of the participant’s behaviour during the experiments showed that operators with haptic feedback were comprehensively aware of the rover’s status.

I. INTRODUCTION

Locomotion in unstructured environments with limited visibility (e.g., Moon surface) involves complex tasks and decision-making processes that current state-of-the-art autonomy does not fully address. Such cases often require human intervention through direct teleoperation, enabled by low-latency telerobotics. For ground rovers in the context of planetary exploration, it is essential to convey appropriate Situational Awareness (SA) to the operator regarding the robot’s status and any possible mobility faults. The latter are often unexpected events that onboard state-of-the-art autonomy still fail to solve and require human cognitive and dexterous skills through direct teleoperation [1]. Validation of low latency operations, developed by ESA and NASA, provides an opportunity for novel and more effective interaction methods between humans and robotic platforms in future planetary operations that acquire valuable scientific data [2]. For example, Fong [3] reported that scouting missions were more successful when operators could manually control a rover compared to offloading the visual information into the haptic channel. Finally, qualitative observations of the participant’s behaviour during the experiments showed that operators with haptic feedback were comprehensively aware of the rover’s status.

* This work involved human subjects in its research. All ethical and experimen-tal procedures and protocols were performed following the guidelines of the Ethics Committee of Instituto Superior Técnico (CE-IST).
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Conventional teleoperation interfaces often convey a vast amount of visual information to the operator. Such an approach can lead to an increase in the operator workload and difficulty acquiring the relevant information. One way to reduce the cognitive load on the human visual channel is by resorting to haptic feedback during teleoperation. Providing haptic cues during robot teleoperation can significantly improve the detection of faults [8], reduce task difficulty and create a greater sense of operator immersion [9]. Finally, unstructured environments with poor lighting conditions (e.g. Moon surface) can lead to navigation shortcomings such as hazardous orientations that can be effectively conveyed through haptic feedback [10].

Corujeira [10] presented a handheld passive haptic device to provide proprioceptive cues regarding the attitude of a remotely operated rover. Results of the systematic user study revealed that participants successfully perceived the attitude states (stable, unstable and critical) and direction of rotations. However, this device only conveys feedback and did not allow to the control of the robot. In this paper, we propose a novel teleoperation system that uses a 7DOF force feedback haptic device that allows the operator to control the locomotion of a mobile rover while receiving haptic attitude feedback.

The novelty of the presented work is three-fold. First, the teleoperation system integrates proprioceptive cues to convey the rover's attitude using a bilateral force feedback haptic device, commonly used for manipulation tasks [11]. The current literature in robot locomotion mainly employs force feedback devices to convey information regarding collision avoidance [12], wireless signal strength [13], or goal following indications [13]. Yet, to the best of our knowledge, there is no approach in the literature exploring a force feedback device for locomotion and proprioceptive cues to convey the attitude of the Interact rover. Fig. 4 shows the implemented system architecture. Here, the communication between the rover and the operator control unit was achieved using the Data Distribution Service (DDS™) standard and RTI Connext® software as an implementation of this standard. Finally, the functional blocks for action rendering, haptic rendering, and the interface to the sigma.7 were implemented using MATLAB Simulink®.

**II. TELEOPERATION SYSTEM: DESIGN AND IMPLEMENTATION**

We propose a teleoperation system to control a rover with a multimodal feedback system (visual and haptic). This one includes a force feedback device (sigma.7) for the locomotion and proprioceptive cues to convey the attitude of the Interact rover. Fig. 4 shows the implemented system architecture. Here, the communication between the rover and the operator control unit was achieved using the Data Distribution Service (DDS™) standard and RTI Connext® software as an implementation of this standard. Finally, the functional blocks for action rendering, haptic rendering, and the interface to the sigma.7 were implemented using MATLAB Simulink®.

**A. Haptic Control**

1) **Virtual Joystick Design:** The implemented teleoperation system emulates the behaviour of a conventional joystick by simulating the dynamics of a spring-mass-damper system with the sigma.7 device. With this implementation, the operator can push the sigma.7 forwards and backwards, sideways, and turn the wrist to achieve all the navigation motions available for the Interact rover (Ackerman steering and spot-turn motions), similarly to a conventional joystick.

The integration of the sigma.7 device into the teleoperation control was performed with a Simulink block that wraps functionalities of the Force Dimension SDK1. With this block (see Fig. 5), we can send a force command \( F(t) \) to the sigma that specifies the force and torque to be applied to each of the 7 axes (6 axes in the Cartesian space, plus the gripper axis):

\[
F(t) = [F_x \ F_y \ F_z \ F_\alpha \ F_\beta \ F_\gamma \ F_\lambda]^\top
\]  

(1)

and receive state information \( p(t) \) and \( v(t) \) about the current pose and velocity:

\[
p(t) = [p_x \ p_y \ p_z \ p_\alpha \ p_\beta \ p_\gamma \ p_\lambda]^\top
\]  

(2)

\[
v(t) = [v_x \ v_y \ v_z \ v_\alpha \ v_\beta \ v_\gamma \ v_\lambda]^\top
\]  

(3)

where \( p_\alpha, p_\beta, \) and \( p_\gamma \) are the controller’s roll, pitch, and yaw, and \( p_\lambda \) is the gripper opening. By extension, \( v(t) \) refers to the velocity in those same axes.

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1https://www.forcedimension.com/software/sdk [accessed on March 2023]
With these inputs (force) and outputs (pose and velocity), we implemented a position control algorithm based on a spring-mass-damper model (PD controller). The final control loop is shown in Fig. 5 and described by Eq. (4):

$$F(t) = r(p) K_S [p_d - p(t)] + r(p) K_D v(t)$$  \(4\)

Here, \(p_d\) is the desired controller pose, \(K_S\) and \(K_D\) are diagonal matrices with the spring (proportional component) and damping (derivative component) coefficients for each of the axes, and \(r(p)\) is a pose-dependent resistance factor.

By implementing the spring behavior \((K_S)\) on the sigma.7, the operator can feel the center position for the actuation area (see Fig. 6), while the rover commands are estimated based on the displacement from this center position (Section II-A2). Yet, to hold the sigma.7 at the central orientation of the Cartesian space, the operator would feel some wrist strain because it required a wrist twist compared to the natural resting position of the wrist. For that reason, the central pose of the sigma.7 included a wrist offset \((\gamma_0)\) around the z-axis to ensure a comfortable resting position of the wrist and enable maximum range of wrist rotation. This leads to a goal position (for the control loop) described by

$$p_d = [0 \ 0 \ 0 \ 0 \ 0 \ \gamma_0 \ 0]^T$$ \(5\)

Given the characteristics of a spring model, the system will become unstable to disturbances for high stiffness coefficients. Therefore, it was critical to include a damping coefficient, \(K_D\), to ensure the stability of the implemented spring system. Both the spring and damping coefficients were experimentally tuned to achieve the following goals:

1) Avoid fatigue during operation while clearly indicating the actuation center of the sigma.7. For this, the axes used for the input of the rover’s movement (Section II-A2) had a lower stiffness coefficient to avoid fatigue but high enough to feel the center clearly. The remaining axes had a significantly higher stiffness to indicate that movement in that axis will not generate rover movement.

2) The system supports the weight of the operators’ hand (avoid operation fatigue) and emulates the feeling of actuation in a 2D plane (Fig. 6). To achieve this goal, the system had a high stiffness coefficient on the z-axis \((K_Z)\), such that the operator could comfortably rest their hand while holding the sigma.7.

3) The system is stable and critically damped (smoothly tends to the goal position without oscillations). To achieve this goal, the natural frequencies of each of the axes using the spring model was experimentally determined via excitation. These natural frequencies were then used to estimate the respective critical damping coefficient matrix \((K_D)\) which was iteratively tuned.

Moreover, to implement the required behavior, it was necessary to dynamically change the resistance of each axis, while maintaining the system stable and critically damped. Thus, we used the resistance factor \(r(p)\) which allows modification of both the stiffness and damping coefficients proportionally. In the presented work, the different resistance factors are used to indicate, to the operator, the actuation area within the available workspace of the sigma.7 (green area in Fig. 6). Here, we define the actuation area as the subset of the available workspace where the sigma.7 can move with low resistance to cause a motion of the rover (Section II-A2). Outside of this area, the movement of the sigma.7 does not cause a change in the rover speed (due to saturation at the maximum rover speed) and the operator feels a significantly higher resistance to convey the fact that the controller has reached the maximum speed possible (blue area in Fig. 6). Lastly, the definition of the actuation area also prevents the sigma.7 from reaching the physical limits of the workspace where the operator may feel contact forces unrelated to teleoperation.

The final force profile within the workspace can be visualized in Fig. 7 (example for the x-axis). With this profile, the operator feels an increase in the applied force as the sigma.7 moves from the center until the border of the actuation area. Once the sigma.7 reaches the end of the actuation area (W1), the operator feels a significant increase in resistance. To ensure the continuity of the applied forces at the edge of the regions with different resistances, \(r(p)\) is defined as a piecewise continuous function. For example, in the x-axis:

$$r(p_x) = \begin{cases} K_1^x x, & -x_{\text{max}} \leq x \leq x_{\text{max}} \\ K_2^x x - (K_3^x - K_1^x) x_{\text{max}}, & x_{\text{max}} < x \\ K_2^x x + (K_3^x - K_1^x) x_{\text{max}}, & x < -x_{\text{max}} \end{cases}$$ \(6\)

where \(x_{\text{max}}\) defines the boundary between the areas W1 and W2, and \(K_1\) and \(K_2\) are the respective resistance coefficients.
Fig. 7: Force profile of sigma.7

To modulate resistance depending on region.

Fig. 8: Mapping between sigma.7 controller position to velocity of rover.

2) Actuation Rendering: To control the rover, the actuation rendering modules outputs a locomotion command \( \dot{q} \) that contains the desired linear \((v_x, v_y)\) and angular velocity \((w_\theta)\) components:

\[
\dot{q} = \begin{bmatrix} v_x & v_y & w_\theta \end{bmatrix}
\]

Given the implemented behavior of the sigma controller (Section II-B1) and the defined actuation area, the input to the rover \( \dot{q} \) is computed proportionally to the displacement of the sigma.7 controller from the central position \((p_d)\). The \(x\)-axis maps into linear speed, while the \(y\) and \(\gamma\) map into rotational component of the \(\dot{q}\) command:

\[
v_x = \frac{p_x}{p_{x_{max}}} \cdot v_{x_{max}}
\]
\[
w_\theta = \frac{p_\theta}{p_{\theta_{max}}} \cdot \frac{p_\gamma}{p_{\gamma_{max}}} \cdot w_{\theta_{max}}
\]

Here, for the angular component of the \(\dot{q}\) we combined the values coming from the \(y\) and \(\gamma\) axes of the sigma.7. This allows the operator to decide if (s)he prefers to twist their wrist \((\gamma)\) or move their hand sideways \((y)\) to rotate the rover. Finally, the \(\dot{q}\) outputted by the actuation rendering module filters the values (see Fig. 8) to achieve two goals. First, saturation of the velocity values depending on the rover’s maximum velocities \((v_{x_{max}}, w_{\theta_{max}})\). Second, creation of a dead-band region where the \(\dot{q}\) command is zero. The definition of this region was experimentally determined such that only significant motions of the operator’s hand maps into rover motion.

B. Haptic Rendering: Attitude Feedback

To provide situational awareness regarding the attitude of the rover, the sigma.7 tilts in such a way that it reproduces the current attitude of the rover (roll and pitch). This type of feedback explores the proprioceptive abilities of the operator to recognize, in an intuitive way, the current attitude of the rover. Such haptic cues are closer to the way the attitude would be naturally perceived if the operator was inside the rover, compared to conventional visual attitude displays. Thus, we present the “haptic rendering” module, were the haptic cues are modulated by changing the desired pose \((p_d)\) of the sigma.7 in the control loop (Eq. (4)) to integrate the rover’s attitude:

\[
p_d(t) = \begin{bmatrix} 0 & 0 & \text{roll}(t) & \text{pitch}(t) & \gamma_0 & 0 \end{bmatrix}^T
\]
feedback study. These trajectories were varied during a series of pilot tests to ensure the experimental trials had a series of characteristics.

For the control study, the trajectory ensured different manoeuvres, i.e., straight lines, spot-turns, and curves with various radii. Due to weather conditions the trajectory varied slightly from day-to-day. Nevertheless, all control trajectories had the same manoeuvring characteristics. This practical limitation was taken into account during the processing and analysis of the experimental metrics. Finally, the length and complexity of the trajectory were iterated upon to ensure that all participants drove the rover for a minimum of 5 minutes. For the attitude study, the marked trajectory ensured various changes in pitch and roll. For this, the trajectory included the rover climbing up and down a curb, moving over an inclined ramp, going over a speed bump, and traversing a section with the two left wheels on the curb.

C. Procedure

Before executing the experimental trials of the user study, all participants read the description and instructions of the user study. After reading these, participants signed a consent form which allowed the recording and publishing of the experimental data, including imagery and sound. For participants that did not consent to having their image recorded, the position of the video camera was altered to record only the devices, the visual interface, and audio of their verbal reporting.

A training session preceded all experimental conditions. During the training sessions, the participants learned how to control the rover with the different control devices (sigma.7 or joystick) and interpret the information on the visual interface (including the artificial horizon). The trials would only start once the experimenter confirmed that the participant was able to perform all necessary maneuvers with the robot and report the necessary information (attitude). For both studies, participants were instructed to follow the marked trajectory.

D. Experimental Task

1) Control Study: The control user study focused on the operator’s ability to execute specific manoeuvres. Thus, we designed an experimental task that focused on executing a pre-defined trajectory with various manoeuvres achievable by the locomotion capabilities of the rover (Ackerman and spot-turn steering). Moreover, the trajectory was designed to be executed starting at either end. Thus, The direction of the trajectory was also included in the condition permutations.

2) Attitude Study: For the attitude user study, we designed a task that ensured changes in pitch and roll that would be replicable for all participants. Thus, we marked trajectory in a terrain with elevation changes to ensure that all participants experienced the same changes in attitude. For the created trajectory, there were a total of eighteen (18) interest points of relevant attitude changes the participants needed to verbally report. Before the experimental tasks, participants were given words they could use to describe the attitude ("up", “down”, “left”, “right”, and “horizontal”) to facilitate the reporting and decrease the mental workload associated with the double task (driving the rover and reporting attitude). However, they were additionally instructed to use whatever words or descriptions they felt were adequate and better matched their mental model of the current status of the rover.

E. Experimental Metrics

1) Control Validation: A search through the current state of the art did not reveal experimental metrics that could quantify manoeuvrability to answer RQ1. Thus, we devised a series of indirect measures to infer manoeuvrability. Higher capability for manoeuvrability meant that the participants could execute the manoeuvres required by the pre-defined trajectory. Therefore, we measured how closely participants followed the marked trajectory, resulting in three experimental metrics. First, Mean Square Error (MSE) along the complete trajectory, which quantified the average error (Euclidean distance) of the rover’s position along the trajectory, compared to the expected trajectory. Second, Maximum Squared Error (ME) along the trajectory, which quantified the maximum error of the rover position during the task. Third, Normalized Warp Path Distance (WPD) [14], which quantified the similarity between the executed and expected trajectory.

Here we assume that lower values of all metrics imply greater manoeuvrability. Moreover, the experimental metrics were calculated by comparing the trajectory recorded during the task execution by the participants with a pre-recorded trajectory (expected trajectory). The rover’s position was measured using a GPS (Global Position System) capable of (RTK Real-Time Kinematics) with an average 1-8 centimetres accuracy. Finally, all recorded trajectories were re-sampled to equally spaced points, and the points on the executed and expected trajectories were matched using DTW algorithm [14].

2) Attitude Feedback Validation: The perception (RQ2) and characterization (RQ3) of attitude changes were measured based on the utterances of perceived attitude change by the participants during verbal reporting. Here we consider that more accurate reporting implies a more effective feedback modality (visual and haptic). Thus, to answer RQ2 and RQ3, respectively, we defined two experimental metrics. First, attitude perception (AP) that was obtained by verifying if the attitude change at each interest point had a corresponding utterance from the participant. Here, the reports were classified
TABLE I: Descriptive statistics ($M, SD$) and statistical analysis (paired-samples t-test) of the metrics for the control study.

<table>
<thead>
<tr>
<th></th>
<th>SC</th>
<th>JC</th>
<th>Paired-samples t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSE</td>
<td>$M = 0.130$ m, $SD = 0.068$</td>
<td>$M = 0.136$ m, $SD = 0.058$</td>
<td>$t(16) = 0.396, p = 0.698$</td>
</tr>
<tr>
<td>ME</td>
<td>$M = 1.115$ m, $SD = 0.271$</td>
<td>$M = 1.258$ m, $SD = 0.289$</td>
<td>$t(16) = 1.926, p = 0.072$</td>
</tr>
<tr>
<td>WPD</td>
<td>$M = 0.277$, $SD = 0.074$</td>
<td>$M = 0.281$, $SD = 0.071$</td>
<td>$t(16) = 0.174, p = 0.864$</td>
</tr>
</tbody>
</table>

Fig. 10: Mean Square Error (MSE) ($p = 0.698$).

Fig. 11: Maximum Squared Error (ME) ($p = 0.072$).

Fig. 12: Attitude (pitch and roll) characterization (AC), $X^2(1) = 0.122, p = 0.727$ ($N = 971$ classified points).

TABLE II: Descriptive statistics ($MR$: mean rank) and statistical analysis (Kruskal-Wallis H test) of the attitude study.

<table>
<thead>
<tr>
<th></th>
<th>HF</th>
<th>VF</th>
<th>Kruskal-Wallis H test</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>$MR = 479.38$</td>
<td>$MR = 494.6$</td>
<td>$X^2(1) = 1.362, p = 0.24$</td>
</tr>
<tr>
<td>AC</td>
<td>$MR = 482.62$</td>
<td>$MR = 488.38$</td>
<td>$X^2(1) = 0.122, p = 0.727$</td>
</tr>
</tbody>
</table>

As aware and lack of report as unaware. Second, attitude characterization (AC), obtained by verifying each reported attitude matched the actual attitude of the rover. Reports were classified as correct, or incorrect, and lack of report as unaware.

IV. RESULTS AND DISCUSSION

A. Control Validation Study (SC vs JC)

We performed the Shapiro-Wilk test on the metrics MSE, ME, and WPD, and all confirmed normality (p-value $> 0.05$). The population for this study had a total of twenty-two (22) participants aged between 21 and 30 (average age 25). Eight were female, and fourteen were male. We excluded the data from five participants from the analysis due to incomplete or inaccurate recorded data, mainly due to substandard localization data, and recording issues. As such, the analysis was performed on the data of 17 participants. Accordingly, Table I and Figs. 10 and 11 show the results of the statistical analysis (paired-samples t-test). These results reveal no statistical difference between using the joystick (JC) and the sigma.7 (SC). However, for the ME metric, there was a statistical tendency ($p = 0.072$) for higher ME in JC condition, compared to SC. From the presented results we can conclude that there was no significant detriment to the operators’ ability to manoeuvre the rover when using sigma.7 compared to the joystick (RQ1). Thus, validating the novel interaction method (sigma.7) as an effective control strategy for the locomotion of remotely operated rovers. Finally, since the proposed system (section II-A) was an initial prototype, beyond quantifying rover maneuverability, we sought to find the system’s shortcomings and common interaction behaviours. Next iterations of the control method will integrate the lessons learned during the control study:

- Participants were fast to understand the control method with sigma.7. Most participants could understand how to use the device to control the rover, even before receiving instructions from the experimenter.
- Having two interaction methods to rotate the rover (side motion and wrist rotation) often generated confusion or unwanted motion. Participants often pulled the device left (closer to their body and visual interface, see Fig.9) without noticing they were outside the defined dead-band. This led to a rotation component in the robot’s trajectory that needed compensation (small wrist rotations) to maintain the intended motion.
- Twisting the wrist was reported as a very intuitive method to rotate the rover. However, it appeared to be an issue for some participants, as they would try to twist the sigma.7 beyond the actuation area to increase the robot’s rotation speed. Thus, they often twisted their wrist to uncomfortable positions where the resistance was very high, leading to discomfort.

B. Attitude Feedback Validation Study

Since the AP and AC data is non-parametric, we performed a Kruskal-Wallis H test for these metrics. The results of this analysis are summarized these results in Table II and Fig. 12. Due to the different design of user study, a group of fifty-two (52) participants aged between 21 and 35 (average age 27), participated in the attitude trials. Regarding gender, 19 participants were female, and 33 were male. We excluded from the analysis the data from six participants. One participant was female, and 33 were male. We excluded from the analysis the data from six participants. One participant went the wrong way, another reported commands given to the robot instead of attitude changes, and four participants did not have recorded data of the reports. As such, the analysis was performed on the data of 46 participants (23 participants per condition). The results of the statistical analysis show no significant difference for both metrics when comparing HF and VF conditions and support the answers to our second and third research questions: the ability of the operator to perceive (RQ2) and characterize (RQ3) changes in attitude is not impacted by the feedback modality (VF, HF). These results show that haptic feedback can be an effective way of reducing the cognitive load on the human visual channel...
by resorting to haptic feedback during teleoperation. Here, participants with the haptic feedback were able to correctly perceive and characterize attitude similarly to participants that we reading the values the visual indicator (artificial horizon). However, participants from the haptic group had the advantage of focusing their visual focus on the image stream, unlike the visual group. For example, one participant in the visual feedback group reported that he/she mainly focused on the visual indicator of attitude and was driving the rover with his/her peripheral vision (unwanted behaviour).

Moreover, when using visual feedback, several participants often reported the wrong attitude and had to correct themselves, indicating a higher mental workload during the experimental task. When using haptic feedback, participants often reported which of the four wheels was on the curb, indicating comprehensive knowledge of the rover’s attitude (high SA). This type of attitude description indicates sensory immersion that the visual group did not demonstrate. The different type of reporting between the two groups provides a systematic indication that the haptic modality has the potential to convey the robot’s status in a more intuitive manner. This sense of immersion will likely lead to enhanced SA and, consequently, more effective decision-making during teleoperation during more complex tasks that require different goals integration in the robot operation.

Additionally, the SA probing technique (verbal report of attitude) potentially impacted the experimental metrics, as it required the participants to pay attention to a single element of the system. We expect that in more complex tasks with a different probing technique (e.g., SAGAT), the feedback modality significantly impacts the operator’s SA, as the visual focus of the operator needs to be distributed through various elements of the GUI. Finally, attitude changes within the designed trajectory were mainly in the pitch axis (realistic environment). Thus, the conclusions from the reported results should be contextualized within these limitations of the study.

V. Conclusions

In this paper, we presented the design and systematically evaluated a new interaction for haptic driving of a remotely operated rover using a 7DOF force feedback device. Moreover, the proposed teleoperation system conveyed haptic cues to the operator regarding the rover’s attitude. Two systematic user studies validated the system. Results from the first study showed no detriment in manoeuvrability compared to a joystick, thus validating 'sigma.7’ as an effective control method. The second study showed no statistically significant difference in perceived and characterized attitude reporting, thus validating the proprioceptive attitude cues as an effective alternative to the visual indicator. Moreover, this alternative can offload the visual channel by conveying attitude information through the haptic channel.

Although the presented work was integrated into a context of low-latency telerobotics for planetary exploration, the proposed system and the findings of the systematic evaluations can be extended to other teleoperated mobile robots in unstructured environments (e.g., search and rescue scenarios) or with low visibility conditions (e.g., underwater vehicle). Lastly, the proposed haptic driving could be adapted to teleoperate robots with different DOFs of mobility (e.g., aerial vehicles). However, in such scenarios, relevant feedback information would be studied better to fit the needs of the operators in those contexts.

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