Teleoperation with Force Feedback:  
Easing Unmanned Vehicles Operation in Unknown Scenarios

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Abstract

This work presents a solution for teleoperation of unmanned vehicles in unknown scenarios with increased transparency and safety. The proposed solution includes the implementation of a novel vibration feedback, resulting in an increased awareness of the vehicle surroundings and operators comfort. Furthermore, two newly developed anti-collision methods that take into account both vehicle and environment constraints are applied. The proposed solution was tested and validated by 28 subjects teleoperating an omnidirectional ground vehicle through an unseen maze and afterwards by 46 subjects using a virtual quadcopter in a 3D environment. Experimental results show a decrease in task workload and completion time when using the proposed scheme. Furthermore, the vibration feedback was compared with other haptic feedbacks in an experiment where users had to identify the direction of a single obstacle. The existing feedback solutions were outperformed both in preciseness and celerity.

Keywords: Teleoperation, Haptic Control, Force Feedback, Obstacle Avoidance, Unmanned Vehicle

1. Introduction

Nowadays, mobile robots have an increasingly importance in high risk tasks where the presence of humans can be hazardous or impractical due to distance, scale or other environmental barriers. Such applications include inspection of high voltage power cables [1], search and rescue missions [2], journalism [3] and investigation [4].

In the last years, a significant progress has been made in the control systems of mobile robots. However, the complexity and uncertainty of many tasks require the sophisticated cognitive capabilities of a human operator. Ideally, in teleoperation, the operator safely controls the vehicle at a distance while perceiving the task environment and making real time decisions. Therefore, having a complete awareness of the vehicle surroundings is vital to guarantee the success of the task.

Before 2009, most of the works regarding the use of haptic methods for teleoperation of single UAVs has been made by Lam et al. [5, 6, 7] and Brandt and Colton [8]. These first works focus mainly in the use of haptic feedback to assist the user and provide a collision free teleoperation.

More recent works include a series of studies by Mersha et al. [9, 10]. In these studies, an approach based on network theory and port-Hamiltonian systems is used to formulate the proposed teleoperation scheme and evaluate its passivity. In [11], Stramigioli et al. introduce the concept of virtual slave which is later extended by Mersha et al. [12] to a multidimensional and underactuated case. Other relevant works include the application of an admittance framework for teleoperation of UAVs by Mahony and Hou [13].

All aforementioned works share a similar conclusion: the teleoperation of unmanned vehicles can be improved through the use of a haptic feedback transmitting information regarding the state of the vehicle and its surroundings to the remote operator.

The key contribution of this paper is the implementation of a collision-free haptic teleoperation scheme for unmanned vehicles. This scheme includes a new anti-collision methods and a novel haptic feedback based on vibration. The referred methods were implemented and then evaluated by 28 subjects in two different experiments, and by 46 subjects in a third experiment.

The rest of the paper is organized as follows. In Section 2, the teleoperation architecture is introduced. The obstacle identification, the anti-collision systems and the haptic interfaces are explained. Different haptic feedbacks are implemented and experimentally evaluated in Section 3. Section 4 presents the results of an experiment using an UGV and Section 5 shows an experiment using.
a virtual quadcopter. Finally, concluding remarks are provided in Section 6.

2. Bilateral Teleoperation Scheme
This section introduces the structure of the proposed teleoperation system. Posteriorly, the main methods used for the anti-collision systems and haptic feedback are briefly explained.

2.1. Architecture of the Teleoperation Loop
The scheme of the bilateral haptic teleoperation considered is represented in Fig. 1. The operator interacts with the system through the master device, a haptic device capable of transmitting to the user a force related to the slave device’s state and perception of the environment. The master controller is in charge of mapping the user command to a reference signal for the slave device, an unmanned vehicle being teleoperated. The master controller is also responsible for converting the slave output into an appropriate force feedback for the user.

The slave controller, composed of the onboard microcontroller and sensors, adapts the master reference signal received according to the state and surroundings of the slave device. By controlling the vehicle locally, the slave controller guarantees the stability of the vehicle and ensures a collision-free navigation, even in the absence of commands from the master.

2.2. Workspace Mapping
In order to overcome the difference in the workspaces of the master and the slave devices, a car driving metaphor (rate control) is usually used [5, 6, 9]. In opposition to pose control, where the pose of the master is mapped to the pose of the slave, in rate control, the pose of the master is mapped to the velocity reference of the slave. This method allows the human operator to manipulate an unbounded robot through a bounded device.

The mapping of the master device position is described as

\[
v_s = \lambda v q_m \tag{1}\]

for rate control, where \(\lambda_v\) is a scaling matrix, \(q_m\) the position of the master device end effector and \(v_s\), represents the desired velocity reference for the slave.

2.3. Obstacle Perception
Before applying an anti-collision system or generating a haptic feedback, the slave surroundings has to be examined to obtain a proper signal that can be used later.

This thesis presents two newly developed obstacle perception methods. The first method consists of obtaining a principal obstacle vector that represents the major direction and proximity of obstacles surrounding the vehicle. The second method, developed by Ruivo [14], uses the information regarding the slave environment to define the allowed velocity space.

For the first method, consider spherical coordinates in the body fixed frame of the slave represented by azimuth \(\theta\) and elevation \(\phi\). Let \(d(\theta, \phi, t)\) denote the radial distance from the origin of the body fixed frame of the slave to the first obstacle along direction \((\theta, \phi)\) at time \(t\). For each point inside an observation zone, defined by the observation radius \(R_o\), consider a unitary vector pointing from the obstacle to the vehicle frame origin. The principal direction of obstacles, \(\theta_{\text{obs}}\), is computed by taking a weighted average of all unitary vectors, \(u(\theta, \phi, t)\), within the observation zone as follows:

\[
\theta_{\text{obs}}(t) = \begin{cases} \theta_d(t) \|\theta_d(t)\|, & \text{if } \|\theta_d(t)\| \neq 0. \\ 0, & \text{otherwise.} \end{cases} \tag{2}\]

\[
\theta_d(t) = \sum_{\theta, \phi} u(\theta, \phi, t) f(R_o - d(\theta, \phi, t)) \tag{3}\]

where \(f\) is a monotonic crescent function, with \(f(0) = 0\). Obstacles closer to the vehicle have higher weight value. The final vector obtained, \(\theta_{\text{obs}}\), points away from the main direction of obstacles and the risk magnitude is obtained as the current minimum distance to obstacle:

\[
d_{\text{obs}}(t) = \min (d(\theta, \phi, t)) \tag{4}\]

As in the previous method, the second method starts by selecting all points inside the observa-
tion zone, defined by the observation radius, $R_o$. Afterwards, obstacles are identified by clustering consecutive points and subsequently these clusters are simplified through a line simplification method. This results in each obstacle being defined by a set of line segments. The final step is to calculate the closest point to the vehicle frame for each line segment. Unlike the first method that resulted in a single vector, this method results in a group of feature vectors, each defined by a distance and a direction. The number of resulting feature vectors depends on the slave surroundings.

2.4. Obstacle Avoidance

Two methods were applied for collision avoidance. The first method (main direction method) uses the main direction and distance to obstacles, the second method (clipping method), developed by Ruivo [14], uses the obstacles feature vectors. For both methods, two systems were implemented, an avoidance system and a deconfliction system.

The approach used for anti-collision is represented in figure 2 for the one dimension case. According to the distance to obstacle, the speed reference towards the obstacle is limited. For an obstacle in the safe zone, the speed towards the obstacle is only restricted by the maximum physically allowed speed of the vehicle, $V_{\text{max}}$. Below the warning radius, $R_w$, the speed is reduced until it becomes zero at distance $R_d$, the danger radius. If the obstacle enters the danger zone, the maximum allowed speed becomes negative, i.e. the vehicle is forced to move away from the obstacle. Inside the critical zone the vehicle moves away from the obstacle at maximum speed.

![Figure 2: Relation between velocity and distance to obstacle.](image)

Figure 3 shows the difference between the two used systems (avoidance and deconfliction) for the wall example. With the avoidance system, if there is any obstacle along the direction of the velocity reference, then the vehicle velocity is reduced accordingly to the relations previously shown (Fig. 2). This results in the vehicle being slowed down until it stops at a radial distance $R_d$ from the obstacle. On the other hand, if the deconfliction system is used, then only the component of the velocity towards the obstacle is limited and any tangential component is kept unchanged. For the wall example, the deconfliction system results in an intuitive smooth displacement along the wall.

![Figure 3: Vehicle approaching wall with constant velocity reference. Difference between avoidance system and deconfliction system.](image)

The first anti-collision method (main direction method) uses the vectorial properties between the main direction of obstacle vector, $\theta_{\text{obs}}$, and the vehicle reference velocity vector, $v_v$, to obtain a corrected reference velocity, $v_c$, accordingly to the distance to obstacle relation previously shown (Fig. 2). For the avoidance system, the main direction method is described by (5). First, if the user is not moving the vehicle towards an obstacle, then the anti-collision system is not activated. This condition is verified through the signal of the inner product $\theta_{\text{obs}}(t) \cdot v_v(t)$. Otherwise, if this condition is not verified, and the obstacle is inside the warning zone, then the speed reference is proportionally reduced as the distance to $R_d$ reduces. Inside the danger zone, the user command is ignored and the vehicle is pushed away from the obstacle with the same direction as $\theta_{\text{obs}}$, with magnitude proportional the distance to $R_d$. Inside the critical zone, the vehicle is always pushed away from the obstacle at maximum speed.

$$v_c = \begin{cases} v_v, & \text{if } R_d \leq d_{\text{obs}} < R_w \\ \frac{d_{\text{obs}} - R_d}{R_w - R_d} v_v, & \text{if } R_w \leq d_{\text{obs}} < R_c \\ \frac{d_{\text{obs}} - R_c}{R_d - R_c} V_{\text{max}} \theta_{\text{obs}}, & \text{if } R_d \leq d_{\text{obs}} < R_c \\ \frac{d_{\text{obs}}}{R_c} V_{\text{max}} \theta_{\text{obs}}, & \text{if } d_{\text{obs}} < R_c. \end{cases}$$

(5)
For the avoidance system, the main direction method is described by (6). The approach used is similar, however for the deconfliction method only the component of the velocity towards the obstacle is affected. The component of the velocity towards the obstacle is calculated using the inner product between the velocity reference vector and the main obstacle vector, $\mathbf{v}_{obs}(t)$. Inside the warning zone, this component of the velocity is proportionally reduced as the distance to the obstacle approaches $R_d$. Inside the danger zone the direction of this component of the velocity is shifted, forcing the vehicle to move away from the obstacle, while maintaining any desired movement transverse to the obstacle main direction.

The second method (clipping method) starts by drawing the allowed space velocity of the slave. Afterwards, the feature vectors obtained during the obstacle detection process are used to clip the allowed velocity space. After doing the clipping for all obstacle feature vectors, the reference velocity is adapted accordingly to the new allowed space velocity and to the sub-mode being used.

Although providing similar results, in the presence of multiple obstacles the clipping method provides a more robust solution for both avoidance and deconfliction systems. However, the signal used for the main direction method can simultaneously be used as a haptic feedback reference. Furthermore, the main direction method requires less processing time. The method used should be chosen according to the available processing time. If, for example due to sensors low sampling rates or low communication rates, the anti-collision system is not the limiting factor, then the clipping method should be used. Otherwise, if the anti-collision system is limiting the cycle rate, then the main direction method should be used.

2.5. Haptic Feedback

In the preceding sections we saw some methods used to analyze the vehicle surroundings and provide an obstacle related single final vector of risk. Besides being used for anti-collision systems, this vector can also be used to haptically transmit relevant information to the user. In this section we present some solutions regarding how this trade of information can be made. Furthermore, a novel haptic feedback based on vibration is also presented.

The master device is considered to have a local spring-damper system that pushes the end effector to its center of operation. Regarding the force feedback, driven from obstacles surroundings the vehicle, three methods were studied and compared: a standard force feedback, a stiffness feedback and a novel vibration feedback.

In the force feedback case [5], a force is applied to the end effector pointing away from the obstacle. The intensity of this force is proportional to the distance to the obstacle. This force may be interpreted as a force offset (Fig. 4), shifting the neutral position of the master device. When moving in the direction of an obstacle, the force exerted by operator in the end effector has to increase to maintain it in the same position. If the operator releases the end effector, the slave vehicle will move away from the obstacle until it reaches a safety distance, since the end effector is pushed to a non-neutral position. In the presence of an obstacle, this method requires the operator to counter the force feedback to maintain a neutral position, increasing the workload.

$$
\mathbf{v}_s = \begin{cases} 
\mathbf{v}_s - \theta_{obs} (\theta_{obs} \cdot \mathbf{v}_s) \frac{R_w - d_{obs}}{R_w - R_d}, \\
\mathbf{v}_s - \theta_{obs} (\theta_{obs} \cdot \mathbf{v}_s) + \theta_{obs} V_{max} \frac{R_d - d_{obs}}{R_d - R_c}, \\
\mathbf{v}_s - \theta_{obs} (\theta_{obs} \cdot \mathbf{v}_s) + \theta_{obs} V_{max}, \\
\mathbf{v}_s, 
\end{cases} 
$$

if $R_d \leq d_{obs} < R_w$ and $(\theta_{obs} \cdot \mathbf{v}_s) < 0$.

if $R_c \leq d_{obs} < R_d$ and $(\theta_{obs} \cdot \mathbf{v}_s) < 0$.

if $d_{obs} < R_c$ and $(\theta_{obs} \cdot \mathbf{v}_s) < 0$.

otherwise.

For the avoidance system, the main direction method is described by (6). The approach used is similar, however for the deconfliction method only the component of the velocity towards the obstacle is affected. The component of the velocity towards the obstacle is calculated using the inner product between the velocity reference vector and the main obstacle vector, $\theta_{obs}(t)$. Inside the warning zone, this component of the velocity is proportionally reduced as the distance to the obstacle approaches $R_d$. Inside the danger zone the direction of this component of the velocity is shifted, forcing the vehicle to move away from the obstacle, while maintaining any desired movement transverse to the obstacle main direction.

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Figure 4: Representation of local force, force feedback and stiffness feedback along stick displacement. Adapted from [5].

The stiffness feedback [5] is interpreted as an extra spring to the spring-damper system which stiffness increases with the proximity to an obstacle. As in the preceding case, the operator needs to in-
crease the applied force to the end effector in order to maintain the reference velocity when heading to an obstacle. In this case, no force feedback is given to the operator when the end effector is in a neutral position (Fig. 4) or when the slave vehicle is moving away from an obstacle. If released, the end effector moves to the neutral position.

Finally the vibration feedback is designed as a pulsed stiffness feedback which frequency increases with the proximity to obstacles. Both methods mentioned before, require the user to counteract the feedback forces, possibly increasing the workload of the task. By taking advantage of the vibrotactile sensing, it is possible to intuitively transmit information of the slave surroundings without demanding high physical efforts from the operator. Moreover, small vibrations seem easier to perceive than small increases in force, therefore improving the human perception of obstacles through the master device.

Figure 5 provides an example of vibration feedback and respective pulse parameters to be adjusted: width, period, amplitude and direction. For the duration of the pulse (width), a value around 0.02 s is recommended. In case a smaller value is used, the user might be unable to perceive the vibration feedback. On the other side, higher width values will make the user feel small kicks instead of a simple vibration, causing discomfort.

To further increase the available bandwidth for feedback, the amplitude and period of the signal should vary as represented in Fig. 6. First, the period is reduced with proximity to the obstacle, while the amplitude of the force is kept constant. After reaching minimum desired period, the amplitude starts increasing. In the safe zone, there is no haptic feedback so the amplitude of vibration is set to zero. If the obstacle is closer than the danger radius, then the frequency and amplitude variables are kept at maximum value.

3. Haptic Experiment

With the objective of comparing the effectiveness of the developed vibration haptic feedback with feedbacks normally used in teleoperation, an experiment was conducted. In this experiment, subjects had to identify the direction of a virtual obstacle through a haptic feedback transmitted by the master device.

3.1. Setup

The first experiment consists of a series of rounds where the subject has to guess the direction of an obstacle by interacting with the master device. Figure 7 presents the visual interface of this experiment. In each round, the direction of the obstacle is randomly selected between eight possible directions. A round ends when the user makes a guess, clicking on the respective button. Holding the master device, the subject feels the haptic feedback and tries to identify where the obstacle is located. The three haptic feedbacks previously described were used: force feedback, stiffness feedback and vibration feedback. As time passes during a round, the distance to the obstacle reduces at a steady rate, increasing the force feedback, and making the identification of the obstacle location easier.
task and about the presence of different haptic feedbacks. However, the subjects were not aware of how many different feedbacks were used, or how they worked. The master device used was the 3 DoF fully-actuated haptic joystick Novint Falcon, Fig. 8.

Each subject executed eighteen rounds corresponding to six rounds for each kind of haptic feedback. The haptic feedback used as well as the obstacle direction were randomly selected in each round. The performance evaluation of each haptic feedback was based on the number of correct guesses and on the time taken to make a decision.

3.2. Results

The main results of the haptic experiment are shown in Fig. 9. A full factorial ANOVA test was applied. In average, subjects correctly answered 67.2% of the times using vibration feedback, against 37.5% and 45.8% for force and stiffness feedbacks respectively (Fig. 9(a)). The respective average response times for vibration, force and stiffness feedbacks are 13.48 s, 16.98 s and 18.33 s (Fig. 9(b)).

![Figure 8: User interface.](image1)

![Figure 10: Top view of the maze used for experiments.](image2)

![Figure 9: Main results of haptic experiment for each type of feedback: force, stiffness and vibration feedback.](image3)

![Figure 11: visual interface. LIDAR scanner top view.](image4)

4. 2D Experiment

With the purpose of comparing different haptic feedbacks and two collision avoidance systems in a real case scenario, we conducted an experiment which consists of solving an unseen maze. During this experiment, subjects had to teleoperate a custom made omnidirectional ground vehicle through an unseen and unknown obstacle-laden course.

4.1. Setup

In the assisted teleoperation experiment, the subject has to teleoperate the vehicle inside a small unknown maze and find the exit (Fig. 10). During this experience the operator is unable to see the vehicle or the maze. The only information available is the haptic feedback from the master device and a top view of the obstacles detected by the onboard sensor (Fig. 11).
and controls the motors via a MD25 motor controller board.

Figure 12: Slave vehicle, OMNI-ANT.

Each subject executes two sets of trials, each with four rounds, one for each feedback (no feedback, basic force feedback, stiffness feedback and vibration feedback). Regarding the collision avoidance methods, the two versions of the clipping method were used (avoidance and deconfliction). The different feedbacks appear in a randomly generated order for each subject. After each round, the subject was asked to rate his/her workload using the NASA TLX rating scale \[15\]. In the end, each subject completed a small questionnaire. The performance of the teleoperation system was based on the task duration, task workload and questionnaire results.

4.2. Results

A first analysis compares the overall results using the avoidance system and the deconfliction system. A significant decrease in the duration of the task, when the deconfliction system is used, is confirmed in the results of Fig. 13(a), with a reduction in the average completion time from 46.94 s to 34.30 s. The NASA TLX scores (Fig. 13(b)) indicate that the deconfliction system resulted in less workload, as expected.

The comparison of the results between each type of haptic feedback shows a slight increase in workload for the force feedback. However, the difference in workload and completion time between vibration feedback, stiffness feedback and no feedback was statistically insignificant.

In the end of the experiment, subjects were asked to try to identify the different kinds of haptic feedback and differentiate their favorite (Fig. 14). Although having a lower score, the stiffness feedback was placed in second most of the times, whereas the vibration and force feedback switched between first and third favorite choices. Some subjects either liked all solutions with feedback or were unable to identify the different feedback solutions. It is important to notice that there were no collisions during these experiments.

5. 3D Experiment

In order to evaluate the proposed teleoperation scheme and the efficiency of the haptic feedback in a 3D scenario, a third experiment was conducted. In this third experiment, subjects had to control a simulated quadcopter through three unknown virtual mazes.

5.1. Setup

As in previous experiments, the master device used is the Novint from Falcon, which is connected to a computer running the simulation in Matlab (Fig. 8). The simulated vehicle corresponds to a model of a quadcopter with stabilized attitude dynamics, position dynamics and translational velocity controller. Figure 15 shows one of the three mazes used during this experiment. The blue dot represents the initial position and the exit is represented by the red arrow. Some mazes had a no light zone, represented by the black area, where lights were turned off while the vehicle was inside of it.
Figure 15: Simulation maze.

During operation, subjects had a first person view of the vehicle on the screen as if a camera was attached to the vehicle body fixed frame of reference, see Fig. 16.

Figure 16: Examples of user visual interface.

Three different cases were implemented for this experiment:

- A0F0 Without anti-collision system and without haptic feedback.
- A0F1 Without anti-collision system and with haptic feedback.
- A1F1 With anti-collision system and with haptic feedback.

When the anti-collision is used, the quadcopter is unable to collide. The quadcopter model is assumed to have incorporated sensors that provide the distance from the vehicle to obstacle in all directions. For the cases without collision avoidance system, in case of collision, a red light flashes on the screen and the user is unable to move the vehicle for three seconds. For this experiment only the vibration feedback was implemented.

Each subject had to complete nine trial, the three different cases for each maze. The order of these nine trial was randomly generated for each subject.

After each trial, subjects completed a small questionnaire. The evaluation of each case was based on the following variables: task completion time, number of collisions and the results of the questionnaires.

5.2. Results

A first analysis compares the task completion time and number of collisions between the three use cases. Figure 17(a) shows a reduction in task completion time when the haptic feedback is used, with a reduction in the average completion time from 62.8 s to 58.7 s and a further reduction to 57.7 s if the anti-collision system is used. Results present in Fig. 17(b) show that the use of haptic feedback had a major impact in reducing the number of collisions, achieving a mean reduction of almost 50 % from 2.16 to 1.23 collisions for each trial. When the anti-collision system was used, there were no collisions, so this case is not graphically represented.

The results of the questionnaire are presented in Fig. 18 accordingly to the use case. Figure 18(a) shows that, as expected, when using a haptic feedback, subjects obstacle awareness increased significantly, with mean response values increasing from 7.70 to 8.56 and 8.67, respectively for the A0F1 and A1F1 cases. Regarding the operation comfort, Fig. 18(b) shows similar results, with mean response values increasing from 8.13 to 8.75 and 8.83, respectively for the A0F0, A0F1 and A1F1 cases.

Figure 18(c) shows an almost linear increase in task easiness for the three cases, with mean response values varying between 7.42, 8.25 and 8.58, respectively for the A0F0, A0F1 and A1F1 cases.

Finally, figures 18(d) and 18(e) show the results of the questions concerning the haptic feedback. For the A0F0 case, there was no haptic feedback applied, consequently subjects did not feel it and therefore this case is not represented. Regarding the intensity of the haptic feedback, results indicate that subjects felt the haptic feedback with slightly more intensity when the anti-collision system was used. This increase in intensity is justified, since
without colliding, subjects could stay more time close to obstacles, therefore increasing the haptic feedback activity. In some cases, around 8% of the trials, users were able to maintain a safe operation without getting close to obstacles. Consequently, although the haptic feedback was active, subjects did not feel the haptic feedback. For these cases, the response to the last question loses meaning and therefore was not included in results analyses. Responses regarding the helpfulness of haptic feedback indicate that the haptic feedback was considered helpful independently of using an anti-collision system or not, with a mean response value of 8.41 and 8.40, respectively for the A0F1 and A1F1 cases. In overall, the effectiveness of the haptic feedback was not statistically affected by the use of an anti-collision system.

A novel haptic feedback based on vibration was introduced and evaluated in an experiment where subjects had to point the direction of a single obstacle. Results show that the vibration feedback outperformed other haptic feedbacks in both time required to perceive the obstacle and direction precision. Nonetheless, results regarding the use of different haptic feedbacks in a real scenario support that there is no optimal type of haptic feedback. Instead of finding a unique type of haptic feedback, results indicate that the haptic feedback should be individually adapted for each operator.

Afterwards, the effectiveness of the vibration feedback was evaluated by 46 subjects using a virtual quadcopter. Results show that the use of a haptic feedback had a major impact in increasing obstacle awareness, and significantly reduced the number of collisions. The impact of the haptic feedback helpfulness was even greater in these 3D scenarios than it was in the previous 2D experiment. During this experiment, it was also verified that the helpfulness of the haptic feedback is independent of whether an anti-collision system is used or not.

As final remark, it can be concluded that the proposed haptic teleoperation scheme provides an improved solution for the teleoperation of unmanned vehicles with increased vehicle surroundings awareness and reduction in task workload.

6. Conclusions

This work presents a generic haptic teleoperation scheme that provides a more intuitive control of the vehicle with increased user comfort and lower task workload. Furthermore, the use of a haptic feedback allowed to significantly improve user obstacle awareness, increasing teleoperation safety and efficiency.

An anti-collision system that uses the obstacle main distance was also designed. As the obstacle perception method, this anti-collision system requires a reduced processing time in comparison with other methods. For the anti-collision method, two sub-modes were implemented, avoidance and deconfliction. Comparison of these two sub-modes in an experiment where 28 users had to teleoperate an UGV through an unseen maze, reveals that, as expected, the deconfliction sub-mode guarantees a significant reduction in task completion time as well as in task workload.

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