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Measuring the effects of visual feedback on mobile robot teleoperation

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Abstract— **This paper presents a study about the influence of visual feedback conditions on robot teleoperation. Several factors are analyzed to understand the sensory-motor strategies developed by users in order to succeed in an Unmanned Ground Vehicle driving task. It is mainly focused on the influence of the remote camera viewpoint. By analyzing measurable metrics, it is attempted to infer how the operator integrates the mobile robot model within teleoperated navigation-based task. We defined metrics to assess performance and experimental conditions to determine direct effects and cross-relations. Namely, we measure maneuver anticipation, visual direct effects and image features relevance, while conditions are a variable robot camera viewpoint, the presence/absence of a head tracking system and the type of task. The dependency between navigation performance and viewpoint is found to be linear, while anticipative effects highly depend on the use of a tracking system.**

Keywords-component; Teleoperation, perception, UGV.

I. INTRODUCTION

Teleoperating a mobile robot requires the user to be present within the remote world. The interaction between the distant scenario and the operator has a big impact on performance. Several techniques have been employed according to the literature [1-4] to improve user's comfort and efficiency through the visual feedback. In previous work [5] we presented preliminary results in studying qualitative and quantitative metrics to evaluate operators' performance while teleoperating an Unmanned Ground Vehicle (UGV) through visual feedback. In this paper, we present new methods and results about how the visual feedback affects the performance in teleoperation in path following based tasks. Also we compared such metrics to a more qualitative evaluation and show how difficult may be to infer the operators' performance from a mere qualitative study.

In this paper, we present new methods and results about how the visual feedback affects the performance in teleoperation in path following based tasks. In this paper we present new results and we try to give answers to some remaining questions: 1) what are the visual cues a user is referring to when moving the robot-camera system? 2) what is the link between the actual performance and the performance derived by only considering the direction the camera is looking at? 3) How the mismatch between both of them reflects in decisions taken by the operator (for example anticipating turns while following a path)? 4) Whether or not the use of a Head Tracking System (HTS) to drive the camera is beneficial as it intuitively should be? Answering to these questions can give us hints in determininghow much the robot model and its motor capabilities can be integrated by a teleoperator, in particularly difficult perceptual conditions, i.e. when no training is provided and no proprioceptive information (about the robot shape) is available.

II. EXPERIMENTAL SETUP

In the experiments, users have to follow a path teleoperating a UGV. Users do not have any previous knowledge about the robot nor the path. The UGV runs at constant speed (0.15 m/s) and only the steering can be controlled through a joystick. Users receive the UGV images through a Head Mounted Display (HMD) with a Head Tracking System (HTS). The UGV webcam has a horizontal FOV of 36 degrees and a vertical FOV of 28 degrees. The frame acquisition is made at 15 frames per second. The total teleoperation delay is 180 ms, thus acceptable according to the thresholds known in the literature.

The scene can be observed from three different Points of View (POV), as shown in figure 1. Those positions have the Bottom of the Field Of View (BFOV) as a common constraint, while the Top of the Field of View (TFOV) spans less or more space depending on the fixed tilt (when HTS is off). We also depict the Centre of the Robot (COR) which is used for performance evaluation. Three different paths are used in the experiments because we intend to compare the results in different conditions and across different styles and path complexities. The experiment was carried out by 7 people, doing 9 trials each (3 paths and 3 POVs). The use of the HTS is alternated between trials. To avoid the influence between experiments, the user never makes two trials in a row.

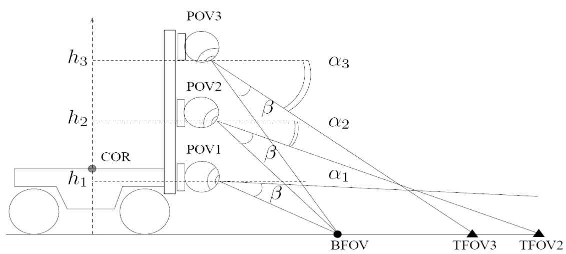


Figure 1. Our UGV, with the three Point of Views

III. RESULTS

A. *Anticipation*

The anticipation is calculated as the distance between the position of the UGV when the first maneuver is done,

TABLE I. ANTICIPATION

	POV 1 (m)	POV 2 (m)	POV 3 (m)
Without HTS	0.505 (0.232)	0.425 (0.084)	0.460 (0.107)
With HTS	0.383 (0.076)	0.807 (0.241)	0.785 (0.121)

B. Zones of interest in the real (paths) plane

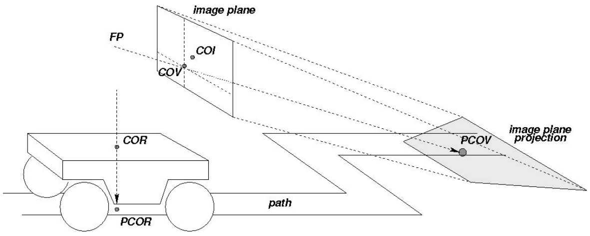


Figure 2. Projection of image plane on the ground plane and location of salient points for performance evaluation

and the position of the first corner of the path. We identify the coordinates of the first maneuver when the user turns the joystick over a threshold. In Table I is represented the mean of the anticipation and the standard deviation between brackets for the three points of view, with and without HTS. As we can see, the anticipation is almost constant when the HTS is not used. On the contrary when the HTS is used, the behavior is reverted.

In Figure 2 we can see, in gray, the projection of the camera frustum on the ground plane. Making an accumulation of these parallelograms we obtain an energy distribution. Figure 3 shows the energy accumulation in the path 2 for all the experiments. We can see how the exterior of the corners have more energy, meaning that these are the zones where the camera frustum is most frequently projected. The same effect appears in all the three paths.

C. Zones of interest in the image (camera) plane

Using the data coming from the tracking system it is possible to make a replaying of the experiments based on virtual reality, because for each time instant the position and orientation of the robot and camera are known. We make an accumulation of the paths in the camera space to extract the areas in which the paths are more present.

In Figures 4(a) and 4(b) we can see the accumulation view from a test carried out with the POV1 and POV3 respectively. The centroid of this energy distribution is called Center of View (COV) and its projection on the path plane is called Projected Center of View (PCOV), as depicted in Figure 2.

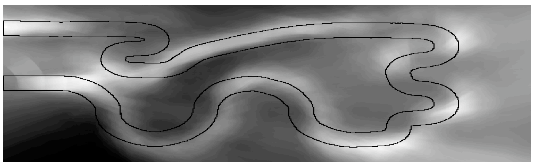
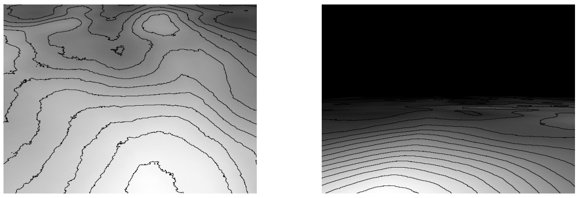


Figure 3. Energy accumulation in the Path 2

Analyzing the data of all the experiments we obtained that the COV distribution presents more dispersion in the pan axis (std. dev. 4.56 degrees) than tilt (std. dev. of 1.60 degrees).



(a) POV1 (b) POV3

Figure 4. Accumulation of the track in the subjective view

The mean is placed in the bottom of the image, at 11.30 degrees, independently on the use of the HTS. On the contrary, when the HTS is used the pan distribution is almost zero-mean (average of 0.8 degrees), while when the HTS is not used, the distribution is displaced to the left with an average of 4.73 degrees, meaning that users tend to well-center the path in their field of view (which, by the way, does not imply to keep the robot on track).

D. Robocentric performance Vs. visuocentric performance

An attempt of estimating the robot model integration at the cognitive level is done by calculating and comparing the robot performance and the visual performance, which is equivalent to compare a metric applied to the Projected Center of Robot (PCOR) and the PCOV. Performances are calculated by summing a weighted distance of the respective points from the center of the path. A one-way ANOVA suggests that the POV has an influence on both the robo-centric performance ($p < 0.000012$) and visuo-centric performance in the same sense, but with less intensity ($p < 0.0022$). Higher POV implies less performance in both cases. The performance surprisingly decreases when the HTS is used, but with a lower slope: the influence of HTS is confirmed by the ANOVA ($p < 0.0024$).

IV. CONCLUSIONS

In this paper we proposed metrics to assess how a different viewpoint can affect performance of a path following task using a mobile robot. We conclude that using more degrees of freedom for users is not necessary a benefit, because of attention issues. We also proposed VR-based metrics to assess the attention zones and purely perceptual-based metrics.

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