Free Look UGV Teleoperation Control Tested in Game Environment: Enhanced Performance and Reduced Workload

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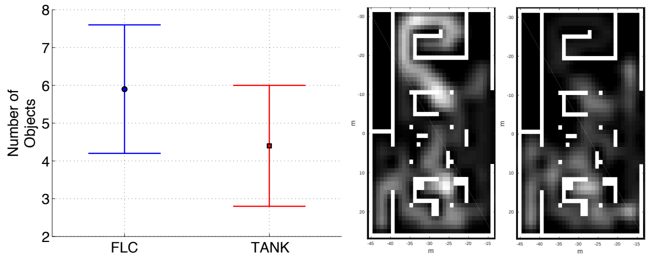
***Abstract*—Concurrent telecontrol of the chassis and camera of an Unmanned Ground Vehicle (UGV) is a demanding task for Urban Search and Rescue (USAR) teams. The standard way of controlling UGVs is called *Tank Control* (TC), but there is reason to believe that *Free Look Control* (FLC), a control mode used in games, could reduce this load substantially by decoupling, and providing separate controls for, camera translation and rotation. The general hypothesis is that FLC (1) reduces robot operators' workload and (2) enhances their performance for dynamic and time-critical USAR scenarios. A game-based environment was set-up to systematically compare FLC with TC in two typical search and rescue tasks: navigation and exploration. The results show that FLC improves mission performance in both exploration (search) and path following (navigation) scenarios. In the former, more objects were found, and in the later shorter navigation times were achieved. FLC also caused lower workload and stress levels in both scenarios, without inducing a significant difference in the number of collisions. Finally, FLC was preferred by 75% of the subjects for exploration, and 56% for path following.**

***Index Terms*—Teleoperation, UGV, Search and Rescue, First Response, Disaster Response, FPS, Computer Game**

I. INTRODUCTION

Today, teleoperated UGVs play an increasingly important role in reducing human risk exposure in a number of applications, such as bomb demolition, reconnaissance, and search and rescue. A common factor in such missions is that they are time critical, i.e. the time needed to find a victim, or dismantle a bomb, can have a large impact on the success of the mission. Furthermore, it is clear from the literature that the workload of robot operators is high and that the quality of their situational awareness (SA) has a significant impact on mission time. The current *Tank Control* (TC) way of separating the chassis and camera control might involve a relatively high cognitive load and hinder SA acquistion and maintenance. A First Person Shooter (FPS) control method, called *Free Look Control* (FLC), might reduce this load substantially and advance (continuous) situational awareness. The contribution of this paper is that we work out the expected operational effects of this control method (i.e., the claims), and perform a user study to test the "claimed" improvements on situational awareness, mission time and success in a UGV search and rescue applications (some of the results are shown in Figure 1).



(a) (b) (c)

Fig. 1. FLC increased the number of symbols found (a,left) and gave a more uniform coverage (b), than Tank Control (a, right) and (c). See also Figure 8.

In many UGV teleoperation missions, the *time* needed to complete a mission is critical. Victims in burning houses can be saved, a bomb on a timer can be dismantled, and in military operations, staying too long in the same place is a risk in itself [1],[2]. A number of studies have been performed to investigate how the mission time is divided between different activities [1], [3], [4], [5], [6], and a well established conclusion is that a significant amount of the time is spent creating and maintaining the *situational awareness* of the operator. In fact, the fraction of mission time spent on improving situational awareness was estimated to as much as 49% in [5] and to roughly 30% in [6]. Furthermore, [7] concluded that most of the critical incidents in the investigated Urban Search And Rescue (USAR) competition was due to lacking situation awareness. The things that make situational awareness difficult for the operator is the high cognitive workload, in combination with poor lightning conditions and narrow fields of view, which makes it hard to for the operator to estimate scales using a video stream, [4].

In this work we use inspiration from the computer game industry in the design of the UGV control interface, as advocated in [8], [9], [10]. In particular, we turn our attention to the FPS genre, including titles such as Quake, Doom, Halo, Half-Life, and Call of Duty [11], [12]. There are interesting correspondences between the task requirements of teleoperated FPS-agents and USAR-UGVs. In both situations, a human operator is to control an entity, using a video screen and an input device such as a game pad, that is to complete a task by moving around in a 3D environment, often switching between searching and navigating.

There are several reasons to think that the FPS control mode, also known as *Free Look Control* (FLC)[1] is good for teleoperation.

First, in FLC *Translation* and *Rotation* are decoupled. That is, translation is controlled with one device (joystick 1 or the keyboard) while rotation is controlled with another device (joystick 2 or the mouse). This makes it easy to point the camera in the desired direction reducing the amount of attention needed to control the UGV, thus leaving more cognitive capacity for the surroundings of the UGV. On the other hand, in *Tank Control*, that is used in most UGV systems today, the input devices (sticks) are assigned to different parts of the UGV hardware. One stick controls the UGV tracks, moving forwards/backwards, or rotating right/left, while the other stick controls the pan/tilt-unit, panning right/left or up/down. This creates a redundancy in rotation, both pan/tilt and tracks can produce rotation, while translation sideways has to be achieved by a rotate-translate-rotate sequence. A video illustrating the difference between Tank Control and FLC can be found here[2].

Second, the developments in the computer game community gives a clear indication that human operators prefer FLC to Tank Control. The first successful FPS games are considered to be Wolfenstein 3D and Doom [11], which appeared in 1993. Both these used Tank Control, which was standard in the genre until 1996 when the game Quake was released. In Quake, there was an option to use another control mode, FLC, and in 1997, with Quake 2, the FLC option was made the default choice [12]. Since then, FLC has totally dominated the genre, with a few notable exceptions, that actually provide additional arguments for using FLC. *Resident Evil* is one of the few games still using Tank Control, and when asked to explain the reasons why, the producer, Jun Takeuchi, answered as follows: ”I think that by imposing certain restrictions on the player you actually help to heighten the fear and the tension, and, ultimately, you create a better horror game.” [13]. Thus, in the gaming community, Tank Control is known to heighten the fear and the tension of the user, which makes it highly inappropriate for UGV teleoperation, given the situational awareness problems described above.

Third, even if the two control modes were equally efficient, it would still make sense to control UGVs in the same way as the majority of the computer games, in order to take advantage of the number of pre-trained operators available. In fact, as noted by Gkikas et al. ”There is a large existing expert player community that has developed sensorimotor skills comparable to these of a musical instrument player or an expert typewriter. Actually, one important aspect of game satisfaction for these people is the challenge of achieving mastery in these skills” [11].

The main contribution of this paper is that we complement the theoretical work presented in [14], and the hardware proof of concept implementation presented in [15], with a user study explicating the envisioned operational benefits and assessing the actual usefulness of the approach. The results of this study show that FLC indeed leads to improved performance and reduced workload, and that it is preferred by a majority of the participants in the evaluation (as predicted by at the arguments above). Note that even though FLC is the standard interface for computer games, it is hardly studied at all in the context of UGV teleoperation, apart from the work in [10], [14], [15].

The outline of this paper is as follows. First, related work is presented in Section II. Then, in Section III we describe Tank Control and FLC in more detail. The main results of the paper are presented in Section IV, in terms of a user study comparing the two control modes in a search and rescue scenario. Finally, discussions are found in Section V and conclusions are drawn in Section VI.

II. RELATED WORK

To address the UGV teleoperation and situational awareness problem described above, a lot of work has been devoted to the design of Operator Control Units (OCUs).

In a study of OCUs based on experiences from the AAAI Robot Rescue Competions in 2002-2004 [16], the authors noticed an evolution over time, towards a large single interface, with a large percentage of the screen dedicated to video. The idea of creating a virtual 3D rendering of the UGV and its surroundings was explored in [17] and the use of multi-touch OCUs including fusion of sensor information to lower the operator’s cognitive load was investigated in [18].

The OCU designed in the search and rescue project NIFTi was described in [19]. There, the authors identify seven fundamental problems in OCU design, propose a solution focussing on sensor data presentation, and discuss experiences from end-user evaluations.

The issue of whether or not to use a pan tilt mounted camera on teleoperated UGVs was discussed in [9]. There, it was noted that so-called Travel-gaze decoupling makes a certain amount of ecological sense, since humans can easily look to the side while we move forward. However, it was concluded that: “This is probably too difficult to implement and the added degrees of freedom probably add to the complexity of the user’s control problem”. However, as we shall see Travel-gaze decoupling is not a problem when using FLC.

The idea of teleoperating a UGV using a First Person Shooter (FPS) interface was first suggested in [10]. There, the authors note that: “Urban Search and Rescue possesses most of the same characteristics as a successful computer game, ... and ... the FPS interface is most appropriate. It gives the user the most intuitive feel for the robot’s situation, optimizing the decision-making ability of the operator. Per unit of robot time, this is, arguably, the most effective method of solving the task.” The proposed solution is very related to the design presented here. It is argued that the User Interface (UI) should be composed of a large central video feed, with status updates in the form of icons in the periphery of the screen. The changes in status can then be examined in detail when the need arises, whereas large changes can be identified while still keeping eyes on the video feed. However, lacking

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[1] *Free Look Control* is also sometimes called *Mouse Look Control*.

[2] http://youtu.be/45iqvjB-2hA

the ideas presented in [15] the authors are not able to fully implement the FPS interface, as can be seen in the following quote: “Unfortunately, *mouselook*, where moving the mouse rotates the player’s head in the game world, was not something that could be implemented with the robot’s existing PTZ camera implementation.” Thus, the design in [10] was only able to implement a coarse approximation of the FPS interface, whereas our is exact, as was shown in [15].

The idea of exploring video games for new HRI interfaces was also discussed in [8]. There, it is argued that Video Game Based Frameworks (VGBF) are very useful for both evaluating existing OCUs and inspiring the design of new OCUs. The authors then go on to make a detailed categorization of input and output devises as well as methods used in different games and discuss different combinations of real video streams and rendered images of the vehicle surroundings.

In this paper, we go beyond the work described in [10], by investigating a version of FLC that is mathematically exact and verified in a prototype implementation. This is done using the concepts presented in [14], building upon a feedback linearization scheme proposed by Lawton *et al.* [20]. This approach was later refined in [15] where the quality of the translation/orientation decoupling was experimentally verified.

In sum, there has been technical developments to transfer the FPS control method to teleoperated robots. However, a clear identification of the operational benefits with empirically founded results is lacking. This paper presents a user study investigating the practical implications of the proposed design. We will show evidence that supports and reifies the predictions made in [10] regarding the benefits of FLC (described above). Our findings indicate that FLC is indeed preferred by a majority of users and improves mission performance as well as mental workload in realistic search and rescue scenarios.

III. The Two Control Modes

In this section we will describe FLC and Tank Control in more detail. For a technical details on how to apply FLC to a tracked UGV using feedback linearization we refer to [15], which also includes an experimental[3] verification of the approach. A video illustrating the two control modes, and the experiments of this paper, can be found here[4].

FPS games are characterized by a large video feed showing a first person view corresponding to the controlled character, see Figure 2 and [11]. The objective of the game is then to move this character in some 3D environment and interact with that environment, e.g. by participating in a simulated combat situation. The character is controlled using either a keyboard and a mouse, or a gamepad, such as the one depicted in Figure 3. In this paper, we use a gamepad.

Fig. 2. Screenshot from a typical FPS game.

Fig. 3. A gamepad with two joysticks. Control devises of this type are used for both computer games and UGV teleoperation.

If the game uses FLC, as most games do, the control mode works as follows. The gamepad has two sticks, left and right. The left stick is used for *translation*. Moving the stick forwards/backwards makes the character move forwards/backwards (towards or away from what is in the middle of the screen, see Figure 2), and moving the stick right/left makes the character move to the right/left (side-step), without changing the gaze direction. The right stick is used for *rotation*. Stick forward/backward makes the character look up/down, stick right/left makes the character turn right/left on the spot, without changing its location. If both sticks are moved at the same time, a combination of translation and rotation occurs.

If the game uses Tank Control, the control mode works as follows. The left stick is used for controlling *the legs* (or tracks if we consider a UGV). Moving the stick forwards/backwards makes the character move forwards/back-wards relative to the body orientation, and moving the stick right/left makes the character turn right/left on the spot, without changing its location. The right stick is often not used at all, but sometimes it controls *head rotation* (or camera pan/tilt unit if we consider a UGV). Moving the stick forward/backward makes the head look up/down, while moving the stick right/left makes the head turn right/left. If both sticks are moved at the same time, a combination of leg and head movement (tracks and camera pan/tilt unit) occurs.

Remark 1: Note that it can be difficult to simultaneously control leg and head movement using Tank Control. This so-called Travel-gaze decoupling was discussed in [9], as described in Section II above.

To conclude, endowing the UGV with a FLC interface was experimentally verified with acceptable deviations from the ideal performance.

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[3] Hardware verification of FLC: http://youtu.be/lV-YTqrBbX0

[4] Evaluation of FLC vs Tank Control: http://youtu.be/45iqvjB-2hA

IV. USER EVALUATION

In this section, we will present the user evaluation[5]. As described in Section I, UGV missions are often time critical, and situation awareness has a large impact on performance. Furthermore, on the short term, high operator workload (focus) can correlate with high performance, but in order to achieve consistent high performance over long periods of time, the operator workload cannot be too high [21].

Fig. 4. Screen shot from the Path following scenario. The operator should reach the end of the dashed path as fast as possible, without colliding with moving or static obstacles, or deviating too much from the path.

In a typical search and rescue task, the UGV operator switches between navigating (following a known path to get to a given location) and exploration (searching an area for objects or victims). We wanted to test the two control modes in both these scenarios. Therefore, we created a virtual environment with two instances of a path following scenario, shown in Figure 4 and two instances of an exploration scenario, shown in Figure 5. A typical execution of the exploration scenario can be found in Figure 6.

We chose to perform the user evaluation in a simulated environment for a number of reasons. First, the simulation environment enables systematic manipulation and replication of experimental conditions, as well as the possibility of collecting a large number of accurate and fine-grained data (such as the number of symbols found during exploration, the number of obstacle collisions, the amount of path deviations, the completion times and so on). Second, it has been shown in [22] that virtual environments can be used for cost-effective user evaluations of teleoperation tasks (particularly, for the first systematic investigation of new human-robot interaction and collaboration methods). Third, the prototype platform[6] used in [15] has severe limitations in terms of wireless range (both control and video feed) and battery life, which would provide substantial constraints to the test of our research question.

We applied the Situated Cognitive Engineering (sCE) method [23] to explicate the FLC design rationale and test method, in terms of use cases, functional requirements (or core functions), and the corresponding claims and metrics for evaluation.

Fig. 5. Screen shot from the Exploration scenario. The operator should search the smoke filled environment, looking for symbols, such as the one on the wall to the left.

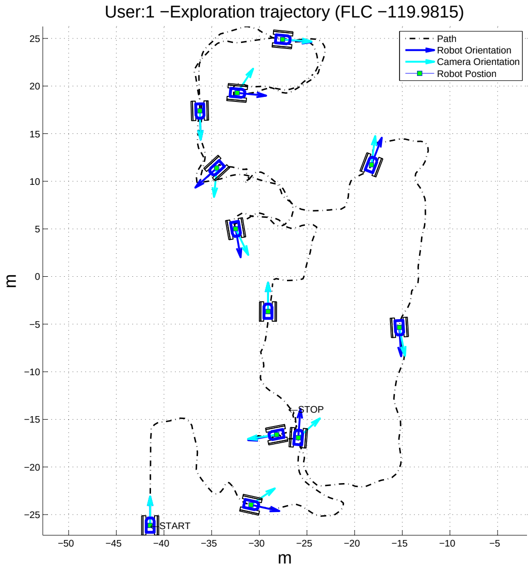

Fig. 6. Example execution of the Exploration scenario. The environment is an industrial building of roughly 30 by 50 meters.

The sCE method starts with identifying *core functions*, based on operational demands, human factors knowledge and envisioned technology. The claims are hypotheses connected to the situated core functions (i.e., functions that apply to the use cases). Each claim describes the (expected or proven) effects in terms of (expected) *upsides* (advantages) and *downsides* (potential disadvantages that should be reduced as much as possible). These upsides and downsides define what will be measured in the evaluation.

We derived the following core functions:

1) *FLC supports the operator by decoupling the control of rotation and translation.*
2) *Tank Control allows the operator to control the UGV chassis and the pan tilt camera independently.*

Associated with these functions we specify the following

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[5] Evaluation of FLC vs Tank Control: http://youtu.be/45iqvjB-2hA

[6] Prototype for verification of FLC: http://youtu.be/lV-YTqrBbX0

claims, with corresponding upsides/downsides (U/D) and metrics in parenthesis.

- Claim 1: FLC supports the user in pointing the camera in the desired direction.
  - U11: More items will be found in the environment (number of items found)
  - U12: Less mental effort is required (mental effort[7])
  - U13: Easier to avoid moving obstacles during path following (completion time, number of collisions, avoiding moving obstacles in path following)
  - D11: More collisions during search (number of collisions)
- Claim 2: Tank Control enables more precise movements by providing direct control of the platform.
  - U21: Less collisions during search (number of collisions)
  - U22: More exact navigation through environment (deviation from path)
- Claim 3: FLC is more intuitive to use.
  - U31: Better usability and preferred mode of control (usability, preferred mode, mental effort).
- Claim 4: Tank Control heightens tension and focus of the user. (inspired by [13], see Section I above)
  - U41: Better focus on task in Path following (preferred mode)
  - U42: Less collisions (number of collisions).
  - D41: Less accurate situation awareness (Situational awareness in exploration), higher mental effort (mental effort),
- Claim 5: FLC is more appreciated by operators with more extensive gaming experience.
  - U51: Users with game experience will prefer FLC compared to TC (gaming experience, preferred mode)
  - D51: Users without game experience will prefer TC compared to FLC (gaming experience, preferred mode)

To conclude, we decided to measure the following:

Measurement	How?	Claim
General		
Reported overall usability	Q	U31
Reported gaming experience	Q	U51, D51
Number of collisions	Data log	U13, D11, U21, U42
Exploration		
Symbols Found	Data log	U11
Situation Awareness	Q	D41
Preferred mode	Q	U31
Stressing mode	Q	U12, U31,D41
Mental effort	Q	U12, U31, D41
Path following		
Completion time	Data log	U13
Path deviation	Data log	U22
Avoiding moving obst.	Q	U13
Preferred mode	Q	U31, U41
Stressing mode	Q	U31, D41
Mental effort	Q	U12, U31, D41

Above, the *How* column corresponds to the measurements being collected by either data logging in the simulation environment (Data log), or through a questionnaire (Q). The *Claim* column shows what claims (upsides/downsides) are associated with this measurement.

A. Experimental method

Participants Sixteen participants took part in the experiment as paid volunteers. The average age of the participants was 24 and they were all college students. None of the participants had any previous experience with search and rescue tasks. All participants had sufficient computer experience to be able to perform the task in a virtual environment.

Experimental design The experiment was within subjects. There was one independent variable, control mode, with two levels: FLC and Tank Control. To exclude any learning effect we used a Latin square design where we balanced control mode with four comparable virtual environments, two versions of *path following*, see Figure 4, and two versions of *exploration* see Figures 5, 8 and 9. Thus each participant completed path following with both FLC and Tank Control as well as exploration with both FLC and Tank Control, in varying order.

Materials The evaluation was carried out using a simulation environment based on Unity3D[8] and an Xbox gamepad connected to a PC.

Tasks As described above, the participants had to perform two tasks: exploration and path following. In the exploration task, participants had to explore an indoor industrial environment with a UGV. Every time the participant found a symbol, see Figure 5, they had to mark it by pointing the camera in the direction of the symbol and pressing a button on the gamepad. The task was to find as many symbols as possible in a given time (2 min). In the path following task, the participant had to control the UGV along a path in an industrial environment, see Figure 4, as fast as possible without colliding with moving or static obstacles or deviating too much from the path.

Procedure At the beginning participants were given a general, written instruction about the experiment. Then participants had to fill in a general questionnaire containing questions about computer and game experience. Then they were given instructions for the tasks and carried out training sessions. Then, the participants completed both tasks twice, once with each control mode.

B. Results

A summary of the results can be found in Table I, and most of them are illustrated in Figures 7-13.

Below we describe the results in more detail, first in general, then for the two different scenarios, and finally in relation to the claims above.

1) General results: To measure usability, we used a questionnaire that resulted in a value from 0-100, where 0 is difficult and 100 is easy. A dependent samples t-test was conducted to compare the usability of Tank Control and FLC. There was a significant difference in the reported usability

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[7] Rating Scale of Mental Effort (RSME) [24]

[8] unity3d.com

TABLE I
SUMMARY OF THE USER EVALUATION RESULTS.

Measurement	**Predicted**	**Best in Eval.**	FLC M	FLC SD	TC M	TC SD	t(15)	p
Reported usability	FLC	FLC	38.9	6.9	30.3	9.7	3.61	<0.01
Number of collisions	Tank Control	No sign. res.	-	-	-	-	-	-
Symbols Found	FLC	FLC	5.9	1.7	4.4	1.6	5.17	<0.01
Expl. Situation Awareness	FLC	FLC	3.69	1.3	2.69	1.3	-2.74	≤ 0.05
Preferred mode in Expl.	FLC	FLC	12/16	-	4/16	-	-	-
Less Stressing mode in Expl.	FLC	FLC	12/16	-	4/16	-	-	-
Mental effort Expl.	FLC	FLC	49.8	23.0	66.6	24.2	3.41	<0.01
Completion time	?	FLC	128.7	16.1	139.0	20.9	-2.2	<0.05
Path deviation	Tank Control	No sign. res.	-	-	-	-	-	-
Avoiding moving obstacles	FLC	FLC	3.4	0.9	2.6	0.96	-2.27	<0.05
Preferred mode in Path	?	No sign. res.	9/16	-	7/16	-	-	-
Less Stressing mode in Path	FLC	FLC	12/16	-	4/16	-	-	-
Mental effort Path	FLC	FLC	58.4	26.2	70.0	20.3	-2.8	<0.05

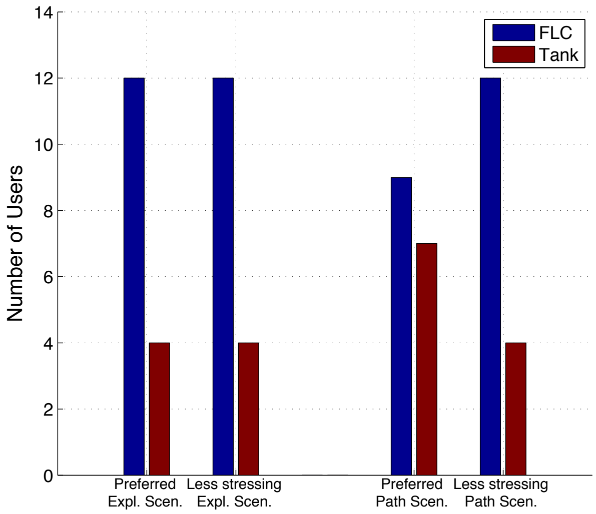
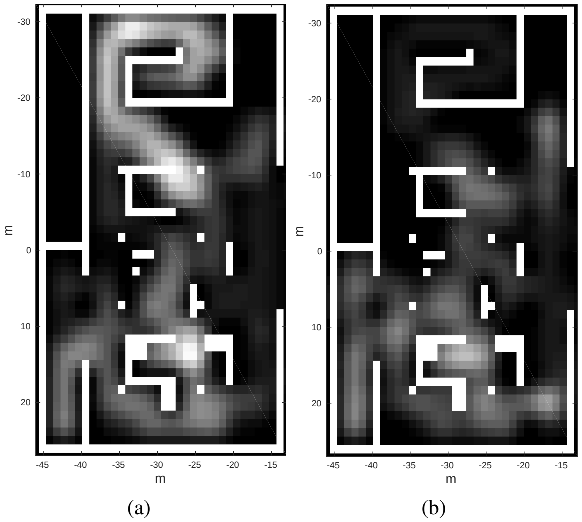


Fig. 7. Preferred Control mode, as well as Least Stressing Control Mode, for the two scenarios, Exploration and Path Following.



(a) (b)

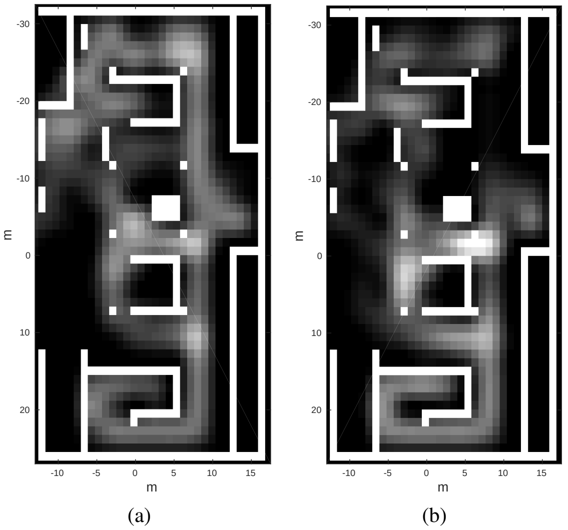
Fig. 8. The most visited parts of the Exploration scenario (version 1) using FLC (a), and Tank Control (b).

with FLC (M=38.9, SD=6.9) and with Tank Control (M=30.3, SD=9.7) conditions (t(15)=3.61, $p<0.01$). This shows that the participants found FLC easier to use than Tank Control.

To measure preference, the general questionnaire after the whole experiment included a question where twelve out of sixteen participants stated that they preferred FLC to Tank Control in the exploration scenario. In the path scenario, nine out of sixteen preferred FLC to Tank Control, see Figure 7. The participants preferring different control modes for the two scenarios stated that the reason for changing their preference was that control of the camera in the path scenario was less relevant.

Regarding prior experience, the data shows a clear positive correlation between gaming experience and preference of the FLC control mode. The sample correlation was 0.33 for exploration and 0.38 for path following.

2) Results for the Exploration scenario: To measure what areas were explored we discretized the search area in 1 by 1 meter squares and accumulated the number of visits to each square. The results can be found in Figures 8 and 9. It is



(a) (b)

Fig. 9. The most visited parts of the Exploration scenario (version 2) using FLC (a), and Tank Control (b).

clear from the figures that the visited area is much more uniform using FLC, and in both cases a significant part of the environment in the upper part of the figure, furthest away from the starting position, was not reached by a majority of the Tank Control operators. Note that there are two versions of each scenario in order to let each participant perform the task with both FLC and Tank Control.

There was a significant difference in the traveled distance during exploration. In FLC (M=207.7, SD=60.5) and Tank Control (M=161.6, SD=46.6) conditions (t(15)=3.84, p<0.01). Participants were able to explore more of the environment using FLC, than when using Tank Control, see Figure 10.

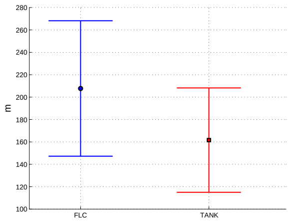
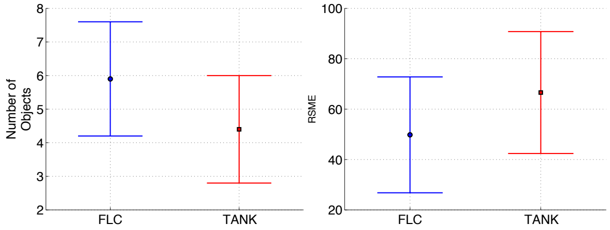


Fig. 10. In the Exploration scenario, the UGVs controlled using FLC travelled a larger distance.

To measure the number of objects found, we logged data during the simulation. Dependent samples t-test was conducted to compare the number of objects found with Tank Control and FLC in the explore task. There was a significant difference in the number of objects found using FLC (M=5.9 , SD=1.7) and Tank Control (M=4.4, SD=1.6) conditions (t(15)=5.17, p<0.01). More objects were found with FLC than with Tank Control in the explore task, See Figure 11 (a).



(a) (b)

Fig. 11. In the Exploration scenario using FLC, more object were found (a), and a lower mental workload was reported (b).

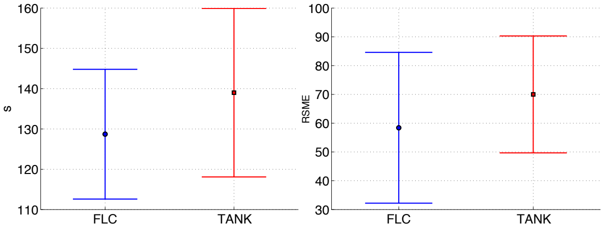
There was no significant difference in the number of collisions.

To measure mental effort we used a questionnaire. There was a significant difference in the reported mental effort in FLC (M=49.8, SD=23.0) and Tank Control (M= 66.6, SD= 24.2) conditions (t(15)= 3.41, p<0.01). Participants reported a lower mental effort using FLC compared using Tank Control in the explore task see Figure 11(b).

To measure situational awareness in the explore task the questionnaire was used. There was a significant difference in how confident participants felt they had explored the entire area in FLC (M=3.69, SD=1.3) and Tank Control (M=2.69, SD=1.3) conditions (t(15)=-2.74, p<0.05). With FLC participants were more confident they had explored the entire area.

3) Results for the Path following scenario: To measure time to completion we logged the data of the simulations. Dependent samples t-test was conducted to compare time to complete the task, reported mental effort and angle excursion with the Tank Control and FLC conditions in the path task. There was a significant difference in the time to complete the path task for FLC (M= 128.7, SD= 16.1) and Tank Control (M= 139.0, SD= 20.9) conditions (t(15)= -2.2, p<0.05). Participants completed the path task faster with FLC than with Tank Control, see Figure 12(a).

To measure mental effort we used a questionnaire. There was a significant difference in the reported mental effort in FLC (M=58.4, SD=26.2) and Tank Control (M= 70.0, SD= 20.3) conditions (t(15)= -2.8, p<0.05). Participants reported a lower mental effort using FLC compared to using Tank Control in the explore task. See Figure 12(b).



(a) (b)

Fig. 12. In the Path following scenario using FLC, shorter mission times were measured (a), and less workload was reported (b).

There was a significant difference in the amount sideward viewing that was taking place during path following. The average angle between chassis and camera orientation was measured. In FLC the angle was (M=0.40, SD=0.14) corresponding to 23°, and in Tank Control it was (M=0.15, SD=0.17) corresponding to 8.6°, conditions (t(15)=4.8, p<0.01). Participants were able to look around more in the environment when using FLC than when using Tank Control, see Figure 13.

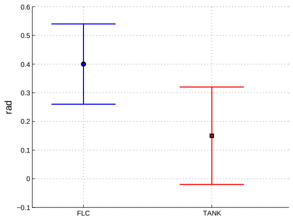


Fig. 13. In the Path following scenario, FLC operators tended to use larger average deviations between UGV and camera orientation.

There was no significant differences in the measured deviation from the path, and no significant differences in the number of collisions.

To measure perceived difficulties with moving obstacles, we used a questionnaire. There was a significant difference in how easy people found it to avoid moving obstacles using FLC (M=3.4, SD=0.9) and Tank Control (M=2.6, SD=0.96) conditions (t(15)=-2.27, $p<0.05$). People found it more difficult to avoid barrels using Tank Control than when they used FLC.

V. DISCUSSION

We begin the discussion with comparing the results above with the four claims of Section IV. We see that regarding Claim 1, *'FLC supports the user in pointing the camera in the desired direction'*, the upsides U11,U12 and U13 were confirmed, but not the downside D11. In Claim 2, *'Tank Control enables more precise movements by providing direct control of the platform'*, none of the two upsides U21 and U22 were confirmed. In Claim 3, *'FLC is more intuitive to use'*, the single upside U31 was confirmed. Regarding Claim 4, *'TC heightens tension and focus of the user'*, none of the two upsides U41 and U42 were confirmed, only the downside D41. Finally, Claim 5 *'FLC is more appreciated by operators with more extensive gaming experience'* was confirmed in terms of both upsides and downsides, there was a clear correlation between prior gaming experience and preference of the FLC control mode.

Thus, for FLC, all upsides and only one downside (relative disadvantage of operators without gaming experience) were confirmed, and for Tank Control, all the downsides and none of the upsides were confirmed.

VI. CONCLUSIONS

To conclude, the FLC interface was recently shown to be applicable to tracked UGVs. In this paper, FLC's expected operational effects were explicated, and subsequently compared to Tank Control in both exploration and path following tasks. Our data indicate that, in an Exploration scenario, FLC reduces workload, leads to more objects found and is preferred by a significant majority of users. Similarly, the data show that in a Path following scenario, FLC reduces workload, shortens mission time, but is not preferred by a significant majority of users.

Since exploration and navigation along a known path are two core tasks in any search and rescue mission, these results indicate that the FLC control mode can be an important component of a future human-robot disaster response team.

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REFERENCES

[1] C. Lundberg, "Assessment and evaluation of Man-portable robots for High-risk professions in urban settings," Ph.D. dissertation, Royal Institute of Technology (KTH), Stockholm, Sweden, 2007.

[2] P. A. Buxbaum, "Robot Wars," *Defense Technology International*, March/April 2006.

[3] R. Murphy, "Human–Robot Interaction in Rescue Robotics," *IEEE Transactions on systems, Man, and Cybernetics, Part C: Application and Reviews*, vol. 34, no. 2, 2004.

[4] D. Woods, J. Tittle, M. Feil, and A. Roesler, "Envisioning Human–Robot Coordination in Future Operations," *IEEE Transactions on systems, Man, and Cybernetics, Part C: Application and Reviews*, vol. 34, no. 2, 2004.

[5] J. Burke, R. Murphy, M. Coovert, and D. Riddle, "Moonlight in Miami: An ethnographic study of human-robot interaction in USAR," *Human-Computer Interaction, special issue on Human-Robot Interaction*, vol. 19, pp. 1–2, 2004.

[6] H. Yanco and J. Drury, "Where Am I? Acquiring Situation Awareness Using a Remote Robot Platform," *IEEE Conference on Systems, Man and Cybernetics*, 2004.

[7] J. L. Drury, J. Scholtz, and H. A. Yanco, "Awareness in human-robot interactions," in *Systems, Man and Cybernetics, 2003. IEEE International Conference on*, vol. 1. IEEE, 2003, pp. 912–918.

[8] J. Richer and J. L. Drury, "A video game-based framework for analyzing human-robot interaction, characterizing interface design in real-time interactive multimedia applications," in *Proceedings of the 1st ACM SIGCHI/SIGART conference on human-robot interaction*. ACM, 2006, pp. 266–273.

[9] S. Hughes, J. Manojlovich, M. Lewis, and J. Gennari, "Camera control and decoupled motion for teleoperation," in *Systems, Man and Cybernetics, 2003. IEEE International Conference on*, Jan. 2003.

[10] B. A. Maxwell, N. Ward, and F. Heckel, "Game-based design of human-robot interfaces for urban search and rescue," in *In Computer-Human Interface Fringe*. Citeseer, 2004.

[11] K. Gkikas, "The evolution of FPS games controllers: how use progressively shaped their present design," in *Panhellenic Conference on Informatics (PCI)*, 2007.

[12] A. Cummings, "The Evolution of Game Controllers and Control Schemes and their Effect on their games," in *The 17th Annual University of Southhampton Multimedia Systems Conference*, 2007.

[13] M. Grimm, "No change coming to resident evil controls," in *The Escapist Magazine, March*, March 2009.

[14] P. Ögren and P. Svenmarck, "A new control mode for teleoperated differential drive UGVs," in *46th IEEE Conference on Decision and Control*, 2007, pp. 5794–5799.

[15] P. Ögren, P. Svenmarck, P. Lif, M. Norberg, and N. E. Söderbäck, "Design and implementation of a new teleoperation control mode for differential drive ugvs," *Autonomous Robots*, vol. 37, no. 1, pp. 71–79, 2014. [Online]. Available: http://dx.doi.org/10.1007/s10514-013-9376-6

[16] H. A. Yanco and J. L. Drury, "Rescuing interfaces: A multi-year study of human-robot interaction at the aaai robot rescue competition," *Autonomous Robots*, vol. 22, no. 4, pp. 333–352, 2007.

[17] C. W. Nielsen, M. A. Goodrich, and R. W. Ricks, "Ecological interfaces for improving mobile robot teleoperation," *Robotics, IEEE Transactions on*, vol. 23, no. 5, pp. 927–941, 2007.

[18] M. Micire, J. L. Drury, B. Keyes, and H. A. Yanco, "Multi-touch interaction for robot control," in *Proceedings of the 14th international conference on Intelligent user interfaces*. ACM, 2009, pp. 425–428.

[19] B. Larochelle and G. Kruijff, "Multi-view operator control unit to improve situation awareness in usar missions," in *RO-MAN, 2012 IEEE*. IEEE, 2012, pp. 1103–1108.

[20] J. Lawton, R. Beard, and B. Young, "A decentralized approach to formation maneuvers," *Robotics and Automation, IEEE Transactions on*, vol. 19, no. 6, pp. 933–941, 2003.

[21] B. Larochelle, G.-J. Kruijff, N. Smets, T. Mioch, and P. Groenewegen, "Establishing human situation awareness using a multi-modal operator control unit in an urban search & rescue human-robot team," *RO-MAN, 2011 IEEE*, pp. 229–234, 2011.

[22] C. H. Horsch, N. J. Smets, M. A. Neerincx, and R. H. Cuijpers, "Comparing performance and situation awareness in usar unit tasks in a virtual and real environment," in *Proceedings of the 10th International ISCRAM Conference, Baden-Baden, Germany*, 2013, pp. 556–560.

[23] M. A. Neerincx, "Situated cognitive engineering for crew support in space," *Personal and Ubiquitous Computing*, vol. 15, no. 5, pp. 445–456, 2011.

[24] F. Zijlstra and L. van Doorn, "The construction of a scale to measure subjective effort," Delft University of Technology, Tech. Rep., 1985.