Augmented reality to improve teleoperation of mobile robots

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***Abstract*—In this article we want to discuss the skills required for human tele-operators of mobile robots. We show the classical problems related with teleoperation but focus our discussion in not specialized operators. We want to show how a proposal based on augmented reality interfaces can improve the performance of operators controlling the robot. We present the validation of our solution in two experiments: one in a controlled circuit and another one in a real environment. To carry out our experiments we use a low cost robotic surveillance platform.**

***Index Terms*—Teleoperation, Augmented Reality, Human-Robot Interface.**

I. Introduction

In last years surveillance, tele-assistance, telepresence, etc. systems have been growing up exponentially, so it is really difficult to find environments where robots have not been tested. People have realized that a mobile robot can reach spots very difficult to cover using static cameras, which is very useful in security applications. Their routes can be planned in advance, but also on demand, which is very useful in surveillance tasks, or tele-assistance. They can also be used in combination with facial recognition algorithms, incorporating person following abilities, and serve as mobile hotspots providing more realistic telepresence [17]. Lately many companies and universities have been investing in telepresence robots and for this reason we can find many of them in the market as we can see in figure 1. Consequently the amount of people who operate robots will also have to grow.

Fig. 1. Actual telepresence Robots

Until now, operators supervising camera systems are only trained to manage cameras whose location cannot be changed, so they do not have to worry about driving them. They have been trained mainly in issues related to privacy legislation and its application to different spaces as homes, companies buildings, or public buildings. There are not formal programs on how to train robot tele-operators in Spanish legislation as we can see in [18] but we think that special courses [22] could be taken for operators specialist. The special role of this new robots in dangerous environments and how the operator will work in diverse stressful environments are analyzed in [21]. We can find in [24] a low level study about human performance issues in teleoperated robots and different possibilities to fix it.

On the other hand, robots have been used mainly by technical people in large companies, universities, and mainly in research environments. We have made teleoperation interfaces that let us drive the robots and made tests in our research laboratories. Generally, these interfaces are based on recycled software we made for research experiments, mainly for debugging purposes. They allow us to teleoperate our robots, showing all kind of messages and warnings but, do they serve for not technical users?

In a R&D environment, we have usually developed teleoperation interfaces that allow us to monitor and command all components of our robot, that is, move servos, show status tasks, configure camera parameters, etc.

We think that the time when no technical people will have to control mobile robots has come. Will they be able to use the teleoperation interfaces we have made? How can we improve their experience? This is the general goal of this work.

We think that most options described before are not useful for newbies and temporal tele-operators in productions environments.

Regarding ”advanced features”, that will be probably incorporated in commercially available robots, we will also have carefully incorporate them in our interfaces. For instance, we can equip robots with precise localization algorithms and great navigation systems that will be able to keep them located in different environment, and at any kind of circumstances like busy corridors, new furnitures, etc. But what will happen when this autonomy fails? Probably the human operator will have to drive the robot. Will a simple map and our traditional interface let non-technical users reach the desired destination? How can we improve interfaces to facilitate teleoperation in simple navigation tasks? This is the concrete problem faced in this paper.

Our hypothesis is that the use augmented reality on a simple teleoperation interfaces could help non-experience tele-operators to drive robots. In order to validate this claim, we have built a simple teleoperation interface for a commercially available low-cost wheeled robotic platform. We have enriched this environment with augmented reality, that is, the interface will show virtual images overlapped on the real video received from the robot in some situations.

To test the validity of our proposal we make a set of experiments using non-technical users, and people with basic robotic skills. These experiments would let us see if augmented reality can be useful for rookies or occasional operators . The evaluation will be both objective, measuring time and accuracy in achieving a particular task, an subjective, by asking the operators.

The rest of the paper is organized as follows. In next section, we present a summary of typical teleoperation robot interfaces and typical profile of users. Then we will describe the different components of our teleoperation system, and the experiments that we have carried on. Finally, we evaluate the date and discuss the results.

II. Teleoperation

The teleoperation definition [20] will be simplified to "wireless control of a device via camera or monitor system over a distance".

There are three classes of teleoperation systems:

1) Closed loop control (Direct teleoperation): It is only possible in real-time conditions of operation, all orders from operator are implemented.
2) Coordinated teleoperation: Similar to direct teleoperation but with some internal control system, for instance in low light conditions switch on lights in the device.
3) Supervisory control, the robot received high level orders to works

According to the definition in [1], teleoperation is made by distinct blocks (figure 2).

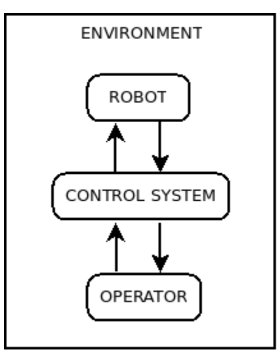

Fig. 2. Simplified teleoperation structure.

If we use this architecture to describe a general teleoperation system we have:

- Operator: Human.
- Control system: Application to control the robot.
- Communication: The communication layer will be transparent to our evaluation and we will not describe into details (the arrows in the figure).
- Robot: Agent.
- Environment: The circuits which we will use to develop ours experiments.

As mentioned in the previous section, currently there are many interfaces to teleoperate robots and we typically find several ones for the same robot. This neither means that these interfaces are adequate for every environment, nor it means that all the interfaces made the same work, nor that all interfaces are usable by any user.

As engineers, we used to think that computer based interfaces for mobile robots have to provide total control over the platform. That is, interfaces where we can see the state of any sensor, and where we can control any actuator in all their ranges. However, according to usability studies by Jakob Nielsen [12], this is not true.

According to these usability rules, if we want a common user interacting seamlessly with our robot, we should design a minimal interface only with the essentials controls. That should be enough to perform the task and will prevent many errors.

Thus, interfaces have to be divided at least into two categories. The first type are appropriated to researchers. They need and want the total robot control. This means that all interfaces adapted used in this group will be able to perform robot behavior showing/providing in each case as much information as possible.

The second group will be oriented to people without experience on robotics, teleoperation or robot-human interaction. In these cases, interfaces should offer a suitable environment since an excess of options increases the risk of erroneous actions.

In this article we are only going to analyze the second group. We have decided simplifying an existing research interface to offer the operators only the minimal controllers necessary to accomplish a simple navigation task. We have used the Rovio robot (described in section III). The main task has been driving this type of robot from one fixed place to another, following a planned track, and only using the control interface, that is, operators have only subjective vision provided by the on-board camera of the robot.

Next section describes in more detail the interface that we have built, and how augmented reality has been added to improve teleoperation experience. We will also describe the groups of volunteers that have tried both interfaces.

III. Environment description

We described in more detail each relevant element involved in our experiments. Followint the general architecture described in last section we have:

- Operator: In our case will be a group of non-experts volunteering people.
- Control system: We will describe two different interfaces, a basic one, and an improved version where augmented reality has been added.
- Robot: The WowWee Rovio robot will be used in all ours test.
- Environment: the tracks in different scenarios which we use to develop ours experiments.

A. Operators

For our experiments we have chosen people willing to use robots, as we do not want to get into other typical analysis (uncanny valley, children interaction, etc). In particular, we have used people with no previous experience tele-operating robots.

The group of operators that has tested our system is made up by 8 people. They agree to make the test without any reward. The group is wide in characteristics. Their ages were between 25-50 years old and they have different scholar grades. They work in different jobs without any relationship with robotics (nurse, civil servants, or software developers). Therefore, the final group seems to comply with the principal premise of non technical robotics operators.

Our population test the interface on the tracks that we have prepared a priori. They do not know anything about the robots, neither about the environments.

All teleoperation test are carried out using the images captured by the robot. The users have not more information than the one given by robot interface and a map of the track.

After the tests, users filled up a questionnaire in which they can explain their experience and this will give us some feedback about the interaction with the robot. We also measure the time needed for each different users and their personal data (ages, sex, previous experience for future data analysis).

B. Interface and Augmented reality

The interface we use is made up by two main blocks. The interface itself, and the augmented reality system that displays signals on it. The second module can be activated or deactivated without any visible change for the user.

The teleoperation interface has been developed in C++ using Qt. In figure 3 we can see the initial appearance of the interface. As we mentioned above, it is simplified to the maximum not allowing any configuration on the robot to avoid distracting the operator or creating some kind of error.

Augmented reality (AR) is basically a mechanism by which virtual information can be overlaid in a real image. This mechanism is currently being used in many environments such as mobile phones, video games and has also been used in robotics [14], [13] or [15].

Our hypothesis is that placing synthetic elements over the images sent by the camera of a mobile robot would improve teleoperation experience.

In our interface, the augmented reality information overlaid are arrows indicating the turn direction that operator should has to command. These arrows are placed in the image over real labels placed in the environment. When activated, the AR system analyzes images received from the robot and when a label is detected, it superimposes a virtual arrow. These arrows (as we can see in figure 7) facilitate user decision-making in the navigation tests. Arrows scale with the distance and also keep the perspective when are laterally seen.

We want to make clear that in this preliminary version the arrows are associated to each label, that is, the AR system always shows the same arrow at each spot (different among spots, but the same every time the same spot is seen). We are planning to associated the arrows not only to the spot, but also related to the task, that is, to help in different trajectories.

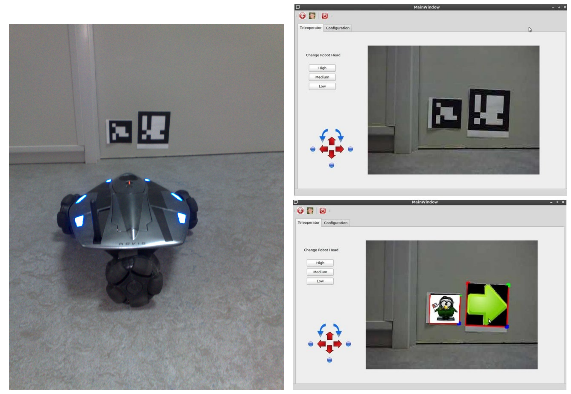

Fig. 3. Teleoperation interface capture

To implement our augmented interface we have used the ARUCO library. This library is based on OpenCV and it has been developed by the research group Vision Applications (AVA) at the University of Córdoba (Spain) [19].

C. Robot

There are many commercial available mobile platforms. We have decided to use a very cheap one, named Rovio ™manufactured by WowWee ™and shown in figure 4.

The reasons for choosing this device are:

- We need omnidirectional movement.
- The robot is very cheap (< 300€)
- It has been designed to be tele-operated (very reduced computer power onboard).
- It uses its camera as the main method of data acquisition for navigation.

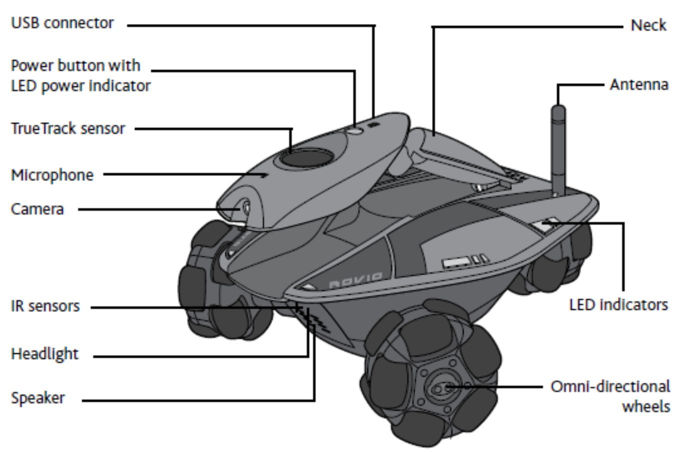

Fig. 4. Robot Rovio ™WowWee ™

D. Experimental Environment

We have designed two different experiments, in both the operator has to drive the robot to a specific destination following a pre-established route.

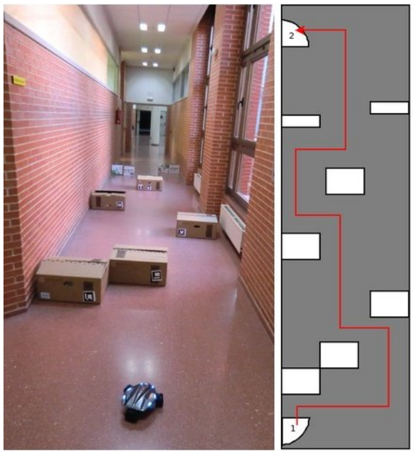

Fig. 5. Corridor Map and AR track way

The first scenario was a small and challenging environment specifically designed for this experiment. It has made up by several obstacles located very close to each other, so an accurate control is required. This environment was made placing some boxes in a corridor of our building, as shown in figure 5. In this environment there are no other moving agent allowed except for the mobile platform. The marks used to AR, describe the path in figure 5.

The second environment is a more realistic one. We also use the corridors of the building of the School of Engineering of the Universidad de León (figure 6). It was less challenging in terms of the trajectory control, but in this case there are higher levels of uncertainty, because we made no control of the ”agents” in the environment, that is, people could appear in the trajectory of the robot, and could change the operator knowledge of environment. For instance somebody could cover necessary information to get a good localization (office number or corridor position).

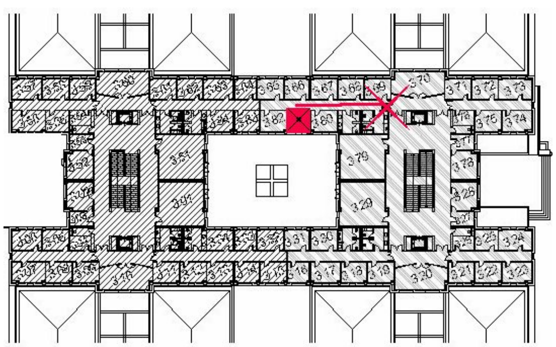

Fig. 6. Trajectory of the second experiment over the floor plant of the School of Engineering Univ. de León.

IV. Experiments

There are several parameters that could be taken into account when evaluating users in our experiments:

- Time to do the exercise
- Precision driving the robots
- Distance traveled to destination

The first one can be define as the time necessary to reach the destination. The second one will be measured as the number of collisions (the less, the better). The third one can be calculated as the number of wheeled complete turns, which is a not very precise measurement, but we don’t have external ground truth.

In this approach we only want to analyze the time that operator uses to finish the path. The reason is that at the end of the experiments we present a poll of questions about the experience to obtain our conclusions.

Fig. 7. In the top left image we show the real image sent by the robot, the right top the ”virtual” arrow that is seen when the AR module is active. Bottom Left shows the same arrow when the robot is closer. Bottom-right pictures show a different arrow.

Initially, all users test the robot for about 2-5 minutes where they can interact with it and visually check the sensitivity of the control system.

A. *Scenario 1*

The first test in this environment is traveling throught the proposed circuit. The objective, go from point 1 (beginning of corridor) to point 2 (end of corridor) assisted only by the map given in figure 5.

The second test is to drive the robot for the same circuit assisted by augmented arrows.

	Mean	Standard deviation
With Augmented Reality	4,31625	1,6008
Without Augmented Reality	3,79625	0,8429

TABLE I
TIME SUMMARY IN MINUTES

The time after the tests can be seen in table I (in minutes). We can appreciate a time difference between navigation using augmented reality and without use the RA for this circuit. We represent the result in figure 8 where column 1 represents the interaction without RA and column 2 with it being the Y axis the time spent on testing and where the filling point represents the mean.

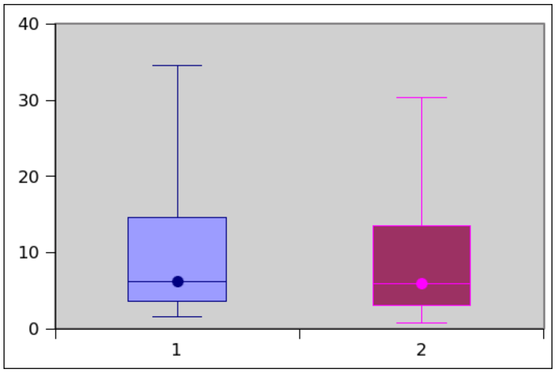

Fig. 8. Experiments results on enviroment 1

B. Scenario 2

The test in this environment was made in the same way as the experiments in first environment: minimalist interface (with and without AR) and a map. The most important changes between environments are given by:

1) The corridor is not restricted or modified (is the natural state of this corridor), but the AR codes were added to different doors and walls.
2) The environment is not bounded, so people can appear in any moment.

This test begins at the stairs in the floor and the goal is to arrive at the specified office in the middle of the corridor. In the figure 9 we can see a picture from a real test.

We found a problem in this environment: the office number was in a position that could not be reached by robot camera. For this reason, in a first approach we wrote the numbers in a sticker, but due to low quality camera resolution, the user needed to move the robot too close to the sticker to read the number without problems. Without this information, people was not able to do the test, because it was so difficult to get the real localization in the map. This does not allow us to obtain valid results to compare with the AR way as in the first circuit. For this reason we do not use this values to evaluate the environment, instead of this we will focus our conclusions in subjective operator evaluation.

Again in this environment the augmented arrows were used. Also we use pictures to represent the owner of the office, and in this way make the test easier to operator as we can see in figure 3.

	Mean	Standard deviation
With Augmented Reality	+5	-
Without Augmented Reality	2,4625	0,6267

TABLE II
TIME SUMMARY SCENARIO 2

The results of this tests in minutes can be seen in table II. In this scenario we only show AR results because as we present before, it was too difficult for the operators to find the correct office without a proper preparation of environment.

Fig. 9. Corridor on environment 2.

C. Firsts conclusions

There are several conclusions we can draw from these experiments. The main one is that, according to the data, augmented reality helps non-expert operators to control the robot.

This affirmation has to be kept as ”preliminary” because the population used in the experiment can be increased in size (larger population would be necessary) and also because of its composition (a control group should be established, background, sex, age, etc. factors) should be analyzed. Anyway, we think this is a basis for further research

Analyzing the data in more detail, it seems that in specially hard environments (experiments in scenario 1) augmented reality its a particularly helpful tool.

Also in the case of difficult environment, like highly symmetric environments, as the one evaluated in circuit 2, users find it more useful than in circuit 1. The reason is that in circuit 1, the goal is to arrive at one precise point without any handicap. But if the environment presents several similar goals the AR is a helpful tool to fulfill the task, as we conclude from data in table II.

V. Conclusion and further work

In summary, we think that we have preliminary data showing that augmented reality is a useful tool to help non-technical operators to drive mobile robots. We also think that more experiments, involving a large number of operators has to be made.

On the other hand, we think that more research has to be done. In particular, we are planning to extend the experiments on more sophisticated robots, both in the controllable degrees of freedom (i.e. including pan-tilt cameras), and in adding more sensory information, particularly non-human sensors data (laser, ultra-sonic, or 3D raw data from new cheap sensors as the MS-Kinnect).

Regarding other issues, the surveys has shown that this basic system needs to be improved. Most users comply about the lack of precision in the turn movements. That was in part "intended" to make the robot less predictable, but we are planning to repeat the test providing a more precise control, probably using a joystick.

Users also asked for more types of signals (in addition to arrows). We are planning to include them and also including other type of information, for instance alert sounds in some situations (beeps when people is detected, or a ring when obstacles are too close). Also, as mention in section III-B, we are planning to associated the arrows not only to spots, but also related to the task.

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