

Tangible Interfaces for Robot Teleoperation

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ABSTRACT

In this paper we present some results obtained through an experimental evaluation of tangible user interfaces (TUIs), comparing their novel interaction paradigms with more conventional interfaces, such as a joystick and a keyboard. Our main goal is to make a formal assessment of TUIs in robotics through a rigorous and extensive experimental evaluation. Firstly, we identified the main benefits of TUIs for robot teleoperation in a urban search and rescue task. Secondly, we provide an evaluation framework to allow for an effective comparison of tangible interfaces with other input devices.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces—evaluation, methodology

General Terms

Experimentation, Human Factors, Performance

Keywords

Tangible user interfaces, robot teleoperation, experimental evaluation

1. INTRODUCTION

Tangible interfaces emerged in the field of human-computer interaction (HCI) as a novel type of interface that exhibits interesting characteristics. These devices allow for novel interaction paradigms, such as motion sensing, gesture recognition, and tactile feedback. Even more, most of them are designed as hand-held controllers, hence they are portable. In robotics, the interest around TUIs is growing fast, despite a well-defined deployment of these devices has not been defined yet, mostly due to the lack of rigorous evaluation studies and theoretical foundations, as reported by Marshall et al. [1]. To achieve a comprehensive assessment of the role of tangible interfaces in robotics, we identified some open questions: in which tasks do TUIs exhibit an effective performance? Under which conditions TUIs provide a more natural and effective human-robot interaction with respect to other input devices? What are the main human cognitive processes involved in their usage? This paper represents our first step in a long-term evaluation process to formally assess the role of tangible interfaces in robotics. We summarize some results gathered from an extensive experimental evaluation of TUIs for a robot low-level continuous teleoperation task in a urban search and rescue (USAR) context, such as after a bacteriological attack in a subway. Our study aims at identifying the main conditions and factors where the novel interaction paradigms of TUIs may provide an advantage with respect to traditional controllers. We analyze three different aspects: (i) the performance achieved by a tangible interface as a mere controller (first experiment), (ii) the advantage of including tactile feedback (first experiment), and (iii) the benefits of using it within the environment (second experiment). We also introduce here an evaluation framework, modeled as a four dimensional space, whose variables are: mission-related performance, environment conditions, robot control degree, and operator interaction comfort.

2. INTERFACES

In our investigation, we consider three representative implementations of well known control paradigms for robot teleoperation. First, we adopted a Wiimote remote controller endowed with three built-in accelerometers that allow for motion sensing control and a rumble for obstacle detection. Second, a joystick handled with one hand, with a direction control cross-pad and two extra buttons for linear and angular speed. Finally, a conventional four-arrows keypad. When attending remote runs, operators monitored the robot status through a graphic remote interface, RIHA (Robot Interface for HRI Awareness) [2], which provides powerful graphical functionalities (e.g. 3D view, 2D egocentric view, camera).

3. EXPERIMENTS

Experiments have been divided into two parts: a remote robot teleoperation in a virtual scenario, and a real robot teleoperation under different operator mobility conditions. We tested 21 (3 females and 18 males) participants, taken from a class of students of Computer Science and AI, most of them with no experience of robot navigation. Ages range from 21 to 39 (mean = 25.38, std = 3.73), and 14 of them did not have any previous experience with Wiimote devices.

3.1 Remote Robot Teleoperation

As for the first experiment, our preliminary hypothesis was that TUIs with motion sensing and tactile feedback might guarantee lower navigation times and number of collisions with respect to traditional interfaces, because they are...
more comfortable and enhance situation awareness. Moreover, we expected TUIs to be more robust to harder robot mobility conditions. The environment was divided into three sections: easy, medium and hard, to simulate different fatigue conditions during robot control. Participants were required to guide the robot through the path, and had to perform one run per each interface type. We measured two dependent continuous quantitative variables: navigation time (measured in seconds) and number of collisions. As for the independent variables (IV), we considered interface type and mobility hardness. The analysis has been conducted through a generalized linear mixed model (GLMM). According to Type III test of fixed effects and their relative estimated marginal means, we inferred the following observations (see Figure 1):

- the Wiimote is significantly better than both the joystick ($t(N) = 5.92, p < 0.001$) and the keyboard ($t(N) = 4.11, p < 0.001$), while the keyboard is better than the joystick ($p = 0.004$);
- navigation times within an easy environment are significantly lower than those with medium mobility hardness ($t(N) = 2.28, p = 0.025$), which in turn are lower than times with hard mobility ($t(N) = 3.34, p = 0.001$).

![Figure 1: Mean navigation time interaction graph](image)

Figure 1: Mean navigation time interaction graph for the first experiment.

As for the number of collisions, applying the same statistical method we noticed how the Interface and Mobility Hardness factors are statistically significant, whether Interface x Mobility Hardness seems not to be. Moreover, the experimental results show that the Wiimote and the keyboard are significantly better, in terms of collisions, than the joystick ($p = 0.001$ and $p = 0.002$), while the Wiimote with tactile feedback is not statistically significant with respect to the keyboard ($p = 0.087$). Furthermore, the number of collisions is significantly lower within easy environments, with respect to medium and hard ones ($p = 0.001$).

### 3.2 Operator Mobility

The second experiment focused on the operator mobility factor. We addressed the following issue: evaluating the benefits of operator mobility and tactile feedback for real robot teleoperation, as well as estimating how much they can counterbalance the lack of a powerful graphical interface. The second experiment was again a path-following task, but this time it involved the teleoperation of a real Erratic wheeled robot equipped with a URG Hokuyo laser range finder. The scenario, arranged within our department, consisted of two different parts, which were equivalent in terms of size. In the first section, subjects had a full access both to the environment and the robot. The second part was a remote teleoperation with no visibility nor access to the environment. In this latter part participants were supported by RIHA graphical interface. Subjects were required to perform the first section with a Wiimote, while the remote part with the keyboard. In this experiment we measured the navigation time (in seconds), and we considered the operator visibility as independent variable. We performed a 1x2 repeated-measures data analysis over the acquired data, evaluating the statistical difference of navigation times with respect to the two considered visibility treatments. The analysis shows that navigation times performed with the Wiimote in the full visibility condition are significantly lower than those obtained in the remote run with the keyboard ($p = 0.006$, point probability $= 0.0, z = -2.678$).

### 4. DISCUSSION AND CONCLUSION

We summarize our results, according to our proposed evaluation framework, as follows:

1. **Mission-related performance.** Tangible interfaces are a valuable input for USAR robot teleoperation, in terms of navigation times and number of collisions. However, tactile feedback does not seem to significantly enhance the robot control in single-robot control.

2. **Environment conditions.** Best effectiveness is achieved in open spaces or semi-cluttered areas, but the device is too sensitive for narrow spaces. The operator mobility and presence within the environment enhances the performance only under full visibility conditions, but is not robust with respect to the distance between the robot and the operator, nor to any occlusion.

3. **Robot control degree.** High reactivity, which allows for a fast execution of complex movements (e.g., accelerating while rotating) with natural commands.

4. **Operator cognitive load and interaction comfort.** The learning effort is low, even for unskilled users.

This experimental evaluation pointed out one problem: TUIs are too sensitive for tight and cluttered areas. This problem could be solved through shared control paradigms. Our future work will be the evaluation of high-level paradigms enhanced by TUIs: gesture recognition and pointing targets. It would also be interesting to develop and evaluate a tangible multi-human / multi-robot interface (MHMR) for USAR robots.

### 5. REFERENCES
