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Tangible tabletops and dual reality for crisis management: case study with mobile robots and dynamic tangible objects

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Abstract

In this paper, we present an experimental study between tangible interaction and tactile interaction on tabletops in a dual reality environment. We recruited 32 participants to take part in a user study, which consists of remotely displacing robots and exploring a simulated disaster area using a tabletop and robot toys on its surface. We present our results and we focus on the differences between the two interaction techniques for remote control of robots. Our findings indicate that the tangible interaction outperforms the tactile interaction in usability and in terms of committed errors, classified by different criteria. Meanwhile they indicate also that for the user workload there is no significant difference between tangible and tactile interactions.

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Keywords: Tangible interaction; tactile interaction; tabletop; dual reality; crisis management; robots.

1. Introduction

The main motivation for the research exposed in this paper is to explore new possibilities for Human-Computer Interaction (HCI), particularly tangible interaction technique [8] [26], and Human-Robot Interaction (HRI) in a dual reality environment, using tabletops. We believe that with such concept of combining tangible interaction on tabletops with dual reality [14] in order to remotely control and manipulate robots, we will be able to build engaging serious games and playful training applications, which will facilitate the learning and working experience in addition to provide instant and intuitive feedback to the user. Based on the definition of Ishii [8], Tangible User Interfaces (TUIs) bridge the physical world and the digital world to enable users to intuitively manipulate information. Plus, Ullmer and

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Ishii in [26] also mentioned that "tangible interfaces give physical form to digital information, employing physical artifacts both as representations and controls for computational media".

This paper is organized as follows: in Section 2 we present a brief state of the art about dual reality, tangible interaction and some related works connecting HRI and tabletops. In Section 3 we expose our study design and its context. In Section 4 we discuss our findings and their analysis, we also highlight the advantages of each interaction technique. Finally, we conclude in Section 5 by exposing our roadmap and what is next to do in this work.

2. State of the art

In this Section, we introduce the state of the art and some definitions of Dual Reality, Tangible interaction on tabletops and Human-Robot collaboration. It is structured in three subsections as follows.

2.1. Dual reality

The term "dual reality" has been first introduced in the Ph.D. thesis of J. Lifton [14] where he defines the dual reality as "an environment resulting from the interplay between the real world and the virtual world, as mediated by networks of sensors and actuators. While both worlds are complete unto themselves, they are also enriched by their ability to mutually reflect, influence, and merge into one another".

Raber et al. [20] replicated a realistic task from retail domain, namely that of shelf planning, where retailers have to plan and organize their shelf layouts to optimize their profit. They have designed the same real and a virtual environments where real and virtual products could be placed at arbitrary positions on the respective shelves in a shelf unit. Both environments can influence each other and are always synchronized in the Dual-Reality condition.

In [18] authors show several examples of dual reality paradigm applications, realizing abstract models implying to cross the valley separating the abstract conceptualization and its actual completion in the physical world. The examples depict how the concept of dual reality can be used in different domains, including applications on tabletops such as [12], [10] and [1]. To our knowledge, there has been no work for controlling mobile robots remotely in a dual reality setup.

2.2. Tangible interaction on tabletops

In addition to the definitions given in [8] and [26], the physical artifacts (also known as tangible objects) employed as representations and controls can be static, such as in [24], or dynamic (mobile, equipped with a motor(s) and sensor(s), a screen, etc.) such as in [22]. Although both tangible and tactile interfaces offer one and two handed interactions, it is reported in some studies that in some cases participants do not use bimanualism with neither tangible nor tactile interaction [25]), while others report positive results for bimanualism in both tangible [24] and multi-touch [3] interaction on tabletops. There could be many factors effecting this difference, notably the design of the system and the nature of the task. Notwithstanding, some studies report that TUIs performed better than tactile user interfaces in sorting [24], grouping [19], manipulation and acquisition [25], and layout manipulation [15] tasks.

Tabletops or tabletop computers are, in majority, horizontal interactive displays resembling a traditional table, allowing users to directly interact with the system and collaborate. Their –usually and often– large workspace surface and display provides an interaction environment that emphasizes collaboration, planning, organizing, and other spatially-situated activities [16] [21] [23], characteristics well-suited to the task of orchestrating a team of robots.

2.3. Human-Robot collaboration on tabletop

There are currently few studies concerning the human-robot collaboration on tabletops. In [4] and in [5] Guo et al. discussed a robots manipulation method using a TUI. In this system, they used physical toys representing robots on a tabletop and they created a mapping from the toys to the robot space using two multicamera systems to track the robot space (see Figure 1). As such, users can manipulate toys on the tabletop to move the corresponding remote robot to a desired position. A shortcoming of this system is that it lacks the feedback from the robot(s) and the user has no real time feedback on the robot's situation.

(a) (b)

Fig. 1: (a) The tabletop workspace with the TUIs on top and the Vicon ceiling setup [5]. (b) The robot workspace with Vicon cameras and robots [5].

Another related work is that of Kato et al. who developed a multitouch interface for controlling multiple robots [9]. This system relies on ceiling-mounted cameras to track the mobile robots on the ground. By manipulating the corresponding image of a robot on the multitouch tabletop, it enables users to control the robots on the ground.

3. Study design

This study aims at understanding the benefits of tangibility in interacting with the virtual side of a dual reality to affect the real side. The study is focused mainly on assessing the usability of a TUI system and participants' workload. Therefore, we have developed the first version of a simplified crisis management application on the TangiSense tabletop [11], which is available in two versions: tangible version and tactile version. Both of them operate in a dual reality setup, meaning that the tabletop and objects (tangible or graphical) on its surface represent the virtual side on one hand and, on the other hand, there are the real robots on the ground that represent the real side of the dual reality. The tangible version uses physical dynamic objects (equipped with RFID tags) on the tabletop surface to command the real robots on the ground and to interact with the system. Meanwhile, the tactile version uses graphical elements to command the real robots on the ground and to interact with the system. Both versions offer the same functionalities and both user interfaces are implemented on the same physical support (tabletop).

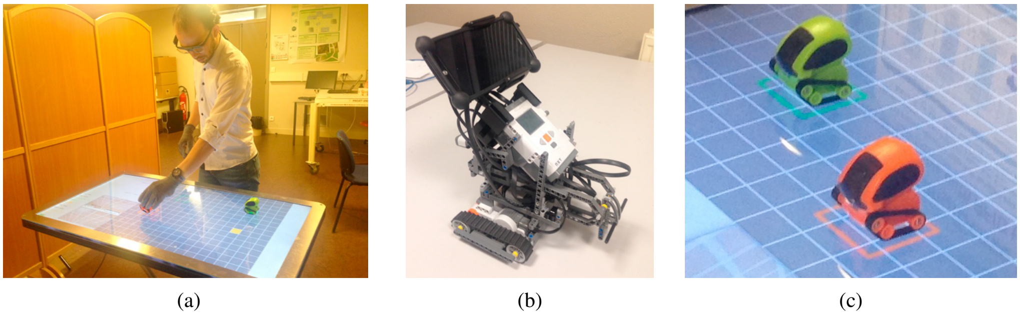
In this context, the real area of the supposed disaster is also represented on a small scale on the tabletop. Also we suppose that we previously know the intervention field map so we can represent it on the tabletop (see Figure 2). The real mobile robots we use are Lego Mindstorms NXT (Figure 2). They are a low cost and useful small robots enabling fast prototyping of HRIs. The Lego Mindstorms NXT robots can be programmed in several languages; here we used *RobotC*. The robots are programmed in order to navigate to a waypoint autonomously following a Model Predictive Control (MPC) framework. For more details about the MPC algorithm, the reader is referred to [13] and to [17]. It is a useful model for the limited capacity of this type of robots. XBee communication is used to send the desired position (goal) from the tabletop to where the robot should go, and a smartphone camera installed on each robot is used to visualize the robots surroundings.

The application context is similar to the work of [6]. Moreover, it could be generalized to different fields in which it is useful to do information gathering using robots. For instance, military fields (in battlefield, do information gathering before, during or after a military intervention), nuclear (dangerous contaminated or polluted areas) and space exploration (on the moon or other planets) are all possible application domains. Furthermore, they also all fit with the generic tasks and dual reality model described in [18]. The hypothesis behind this study were the followings:

H1. Users experience better usability in a TUI than in a tactile interface.

H2. Users workload using the TUI is lower than when using the tactile interface.

H3. Users make less errors during their trials using the TUI than using the tactile interface.



(a) (b) (c)

Fig. 2: (a) A participant taking the experiment with two tangible robots. (b) Lego Mindstorms NXT robot equipped with a camera. (c) Mini-robots toys on the tabletop, equipped with RFID tags.

3.1. Participants

We recruited 32 participants (9 female, 23 male) mostly Ph.D. students and undergraduates with different scientific majors, aged from 22 to 39 years old and with an average age of $M = 27.97$ and $SD = 4.28$, all right-handed, all with normal or corrected to normal vision and all having normal arm mobility. Participants were told to use their dominant hands during the whole experiment trials preferably, but this was not mandatory as some participants may be more comfortable using their non-dominant hands. However, they were required to use the same hand while performing on TUI and on tactile interface. The study was designed as a repeated measure, therefore every participant experimented both versions of the application.

3.2. Tasks

A first task consists of controlling one robot remotely, taking it from its current location to a predefined location. A second task consists of controlling remotely two robots simultaneously, taking them from their current locations to their predefined destinations. As a secondary task, while the robot(s) is (are) moving, participants need to explore the disaster area via a live video feedback and take photos of supposed victims on the ground. In the case of tactile interface, participants use their fingers on the tabletop surface to select the robot they want to interact with and point out the destination or take a photo (of a victim) using its camera. Whilst in the case of TUI, participants grab physically the mini-robot (Figure 2) with their hands and place it on the predefined destination on the tabletop. For taking photos of victim(s) in TUI, participants use a camera tangible object and place it on the corresponding video frame of a robot to capture a photo at that instant of the video. To make these tasks stressful for participants, they have to use the second robot (and consequently explore and take photos of victims) in the same time when exploring the field and taking photos using the first robot.

3.3. Scenario

Participants are asked to complete two tasks on each one of the tangible and tactile interface systems: a task using one robot and a task using two robots. Everyone performs four tasks in total, whose running order is counter-balanced between the two systems and the two tasks. For a given participant, the tasks' order is the same in the two conditions.

A presentation of both systems, their functioning, user interfaces as well as the functioning of each tangible object is given to the participants. This is followed by a familiarization phase with the application during which participants are encouraged to try both versions and to ask questions freely. To make sure that the participants have understood the systems, their functionalities and what they have to do, participants go through a quick test.

Before each task, the participant has that current task explained and the user interface demonstrated (including the tangible objects and the potential of using two-handed interactions on the tabletop). After performing each task, participants must answer a NASA-TLX questionnaire [7] to evaluate their workloads, by evaluating separately the mental demand, physical demand and temporal demand of the task, their performance, effort and their frustration. When finishing the two tasks in a given system, participants evaluate its usability by filling in a SUS questionnaire, containing the 10 standard questions [2]. We calculated the global score for each participant in each system, then based on these scores we calculated the means and the errors' ranges. The global score of a given participant is obtained as follows: (1) for each of the odd numbered questions, 1 is subtracted from the scores. (2) For each of the even numbered questions, their scores are subtracted from 5. (3) The new values (scores) are summed together and multiplied by 2.5. The template questions we used can be found in [2].

4. Results

In this Section we present and discuss the workload and usability results, as well as the errors made by participants during their performances.

4.1. Workload

We used the NASA-TLX questionnaire to assess the participants' workload after each trial. Each sub-scale of the NASA-TLX was evaluated separately. Figure 3 shows the means of sub-scales for each of the four tasks. We notice that there are slight differences between the tasks with one robot and the tasks with two robots, in both conditions in all sub-scales. The differences in each sub-scale when using two robots are more important in favor of the tangible interaction than when using one robot, except for the performance sub-scale where they are basically equal. Although, when we did a paired (dependant) t-test for each of the NASA-TLX sub-scales (alternate hypothesis: participants workload using the TUI is lower than when using the tactile interface) comparing one robot results in each condition and then two robots results in each condition, all the *p-values* were largely greater than .05 (a confidence interval of 95%). Therefore, we cannot conclude on anything related to comparing the workloads of participants with tangible and tactile interfaces in this context, unlike other results that we will present in the following subsections.

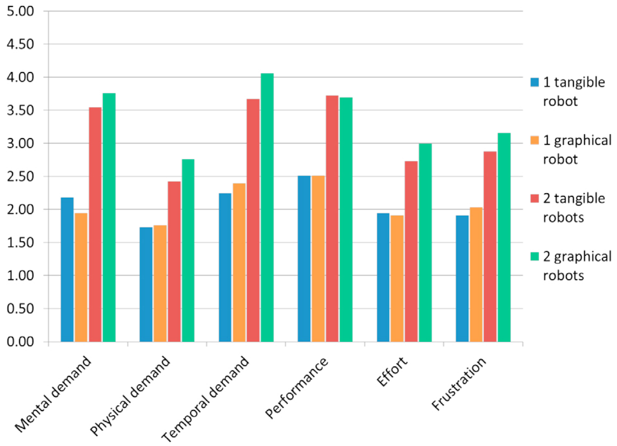


Fig. 3: NASA-TLX sub-scales means for one and two robots and in tangible and tactile interaction technique.

4.2. Usability

Meanwhile, participants have experienced better usability in tangible than in tactile interface: Figure 4 shows the means of the SUS global scores, for both systems, with error bars using a confidence interval of 95%. Although the error bars overlap, the *paired t-test* shows that on average the tangible interaction technique had significantly greater score ($M = 86.02, SE = 2$) than tactile interaction technique ($M = 81.17, SE = 2.39$), $t(31) = 1.99$, $p < .05$, $r = .34$.

Since the Pearson's correlation coefficient (r) is between 0.3 and 0.5, we can say that the effect size is from medium to large. Note that the conducted *paired t-test* is one-sided because we were expecting that the scores are quite different.

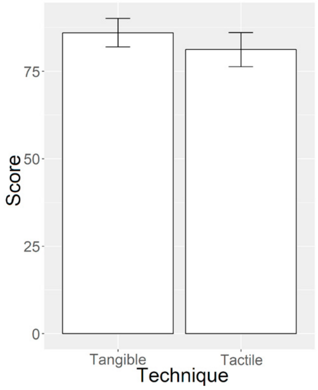


Fig. 4: SUS global scores means with error bars, for tangible and tactile interaction technique.

4.3. Errors

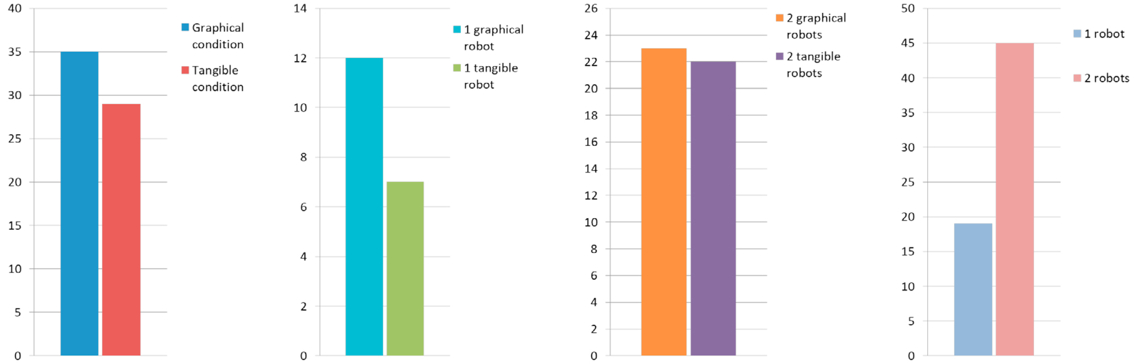
During the trials, we were noticing the participants' behaviors and we noted the committed errors into several categories. Because of lack of space, we cannot expose and discuss them in details. Categories and their descriptions are shown in Table 1.

Table 1: Errors' categories and their descriptions.

Error	Description
Incorrectly placed	An object is not placed by the participant on the right position on the tabletop.
Not detected	A tangible object is put on the tabletop surface but not detected and not known as present on it.
Wrong object used	Participant did not use the right object for a given task.
Wrong robot selected	Participant did not select or grab the right robot to manipulate.
Missed signal	When participant does not see the flashing signal to start moving a robot.
Missed photo	When participant does not take a photo of a victim on the ground that has appeared on the video feedback.

Figure 5 shows the totals of errors classified by different criteria. We notice that participants made less errors using tangible interaction than using tactile interaction, whether with one or two robots. Although the results of all NASA-TLX sub-scales (in tangible and in tactile interaction separately) are less than double between two robots and one robot trials, we notice that the number of errors made with two robots (45 errors) is more than double of the number of errors made with one robot (19 errors).

Furthermore, two questions among others in the post-experiment questionnaire were the followings: "I had a full control on the *robot tangible object* while using it" and "I had a full control on the *robot graphical object* while using it". The answers were measured in a Likert scale from 1 (strongly disagree) to 5 (strongly agree). Participants said that on average they have had full control on the *tangible robot object* ($M = 4.25$) more than on the *graphical robot object* ($M = 4.03$).



(a) (b) (c) (d)

Fig. 5: (a) Sums of errors in Tangible interaction and in Tactile interaction techniques. (b) Sums of errors when using one robot in tangible interaction and in tactile interaction techniques. (c) Sums of errors when using two robots in tangible interaction and in tactile interaction techniques. (d) Sums of total errors when using one robot and when using two robots, regardless of the interaction technique.

4.4. *Tasks completion rates*

Using the errors committed by participants, we could come out with completion rates of tasks. We proceeded as follows for each task: if the participant does successfully complete a task then we assign 1, if s/he does not then we assign 0. At the end and for each task we sum up the scores assigned for each task and divide the sum by the number of participants (32). Figure 6 shows the completion rates of tasks by number of robots and interaction technique. Our results show that for only one robot tasks have the same completion rate of 84.38% in tangible or tactile interaction technique. Whilst for two robots, the completion rate in tangible interaction (78.13%) is higher than the completion rate in tactile interaction (68.75%).

We also notice that using two robots has a lower completion rate than using one robot, regardless of the interaction technique. This result is coherent with the significant differences of workloads (between one and two robots) and also coherent with the differences in committed errors (between one and two robots), for each of the interaction techniques.

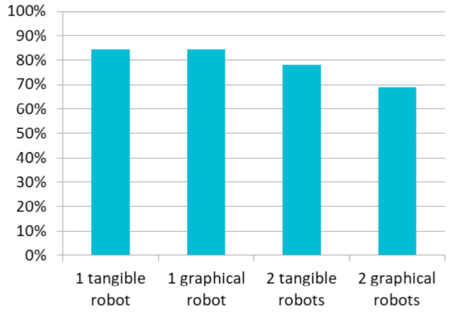


Fig. 6: Tasks completion rates by number of robots and by interaction technique.

5. Conclusion

In this paper we have presented an experimental study about tangible interaction and tactile interaction on tabletops in a dual reality environment. The results show that under heavier workload, the benefit of tangible interaction is not significant. Meanwhile, we have seen the differences between the tangible interaction and the tactile interaction techniques in usability and in terms of committed errors in favor of tangible interaction technique. Although the studied scenario is simple, the empirical results of this study suggest a tendency towards improving the user performances and user experience when using tangible interaction. Such benefits could be useful in situations where users work under pressure and are stressful, such as crisis management application [6]. In the near future, we aim at analyzing further data of the experiment such as the reaction times, further investigate the interplay between workload and tangible interaction and do more experiments on different levels of complexity of tasks in dual reality. We also plan to explore the advantages of TUI systems on human-human cooperation with more demanding and more stressful scenarios for stakeholders of crisis management and in other domains such as design and education.

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