Evaluation of Hands-free Human-Robot Interaction Using a Head Gesture Based Interface

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ABSTRACT

Within this work, we present a usability study on head motion and head gesture based human-robot interaction. The hands-free interface has been developed to support disabled people who cannot use their upper limbs. The presented pilot study was carried out with 24 able-bodied subjects at the age from 19 to 67 years. The subjects controlled an assistive robot with head motions and head gestures to perform several pick and place tasks. The evaluation has been carried out objectively as well as subjectively. The interaction design has been proven successful and assessed overall positive by the subjects.

Keywords

Head Gesture; Hands-Free; HRI; Usability Study; Inertial Measurement Unit

1. INTRODUCTION

For people with a partial or total loss of motor function of the hands, e.g. people suffering from tetraplegia[1], an interaction with their environment is very tedious or even impossible. Hands-free assistive devices can support people with disabilities to compensate their physical limitations. Assistive human-robot interaction can increase the autonomy of tetraplegics in activities of daily living [1] as well as in working life [2].

The interaction design, presented in [3] and evaluated within this work, allows the control of a robot with head motion and head gestures. The end-user's head motion is captured with an inertial measurement unit (IMU). To transfer head motion to robot motion, the mapping proposed in [4] is used. Robot and gripper motion are organized in four control groups, the end-user can switch between these four groups with head gestures.

[1]Tetraplegia is the partial or total paralysis of all limbs and torso.

HRI '17 Companion March 06-09, 2017, Vienna, Austria

ACM ISBN 978-1-4503-4885-0/17/03.
DOI: http://dx.doi.org/10.1145/3029798.3038298

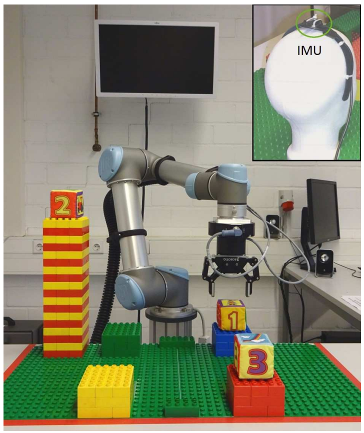

Figure 1: Experimental Setup.

2. STUDY

The head motion and head gesture based interaction design was investigated with a usability study with N=24 subjects. The ethical committee of the university gave its approval to carry out the usability study.

The subjects were recruited with announcements on the university website and in the local newspapers. The subjects were grouped in a junior and a senior group. The junior group was formed by 12 subjects at the age of 19 to 30 years. The 12 members of the senior group were between 43 and 67 years old. The subjects had no known neck movement limitations. Within each age group, one half of the subjects, with an equal number of males and females, already had experience of about one hour with head motion based human-robot interaction.

The inertial measurement unit was attached to a headset-like carrier to capture the end-user's head motion, as illustrated in Figure 1. For robot control, head motion is mapped to the motion of the robot UR5 and the gripper. Visual feedback is given to the end-user with a 27-inch screen placed in the back. The control tasks are build of LEGO® DUPLO® and soft toy cubes. They are performed on a table in front of the subject.

The subjects were introduced to the interaction design with an introduction video. Afterwards, human-robot interaction was tested for about ten minutes in a free explorative phase. In the following predefined task, every action the subjects had to perform was announced. The subjects were told, which head gesture they had to perform and how they have to move and position the cubes. Finally, the subjects had to stack three cubes on top of each other in the correct position and orientation. The level of difficulty increased from cube 1 to cube 3.

For subjective evaluation, the subjects rated several statements regarding the graphical user interface, the head gestures and robot control in the different control groups.

The Mann-Whitney U test with a significance interval of $p = 0.05$ is used to determine significant differences among the factors age, sex and previous experience.

3. RESULTS AND DISCUSSION

The time the subjects needed to complete the different control tasks was measured and analyzed depending on the factors age, sex and previous experience.
An experienced user required 6 min to perform the predefined task and 6.5 min to complete the complex task. These times can be seen as minimum reference times.

The subjects are divided into two age groups. The time 11.94 ± 2.85 min required by senior group members to perform the predefined task is significantly higher than the time of 9.61 ± 1.40 min, which subjects from the junior group needed to complete this task. The younger subjects were also significantly faster in moving and positioning the first cube of the complex control task (1.51 ± 0.5 min for junior group and 2.57 ± 1.78 min for senior group). Regarding the entire complex task, there is no significant difference in time of junior group (14.02 ± 4.88 min) and time of senior group (15.99 ± 5.02 min).
Members of the junior group tend to be faster in solving the control tasks, if subtasks are announced or if the control strategy is obvious. However, for performing more complex tasks, the younger subjects planned inefficiently or rather did not adequately plan, how to move the robot to solve the task. Most of them just started moving the robot with a strategy of trial and error which took a lot of time. This could explain why the difference of the mean value in time compared to the older subjects decreases with increasing difficulty. The differences according to the factor age may stem from a lower experience with computers and the barrier which is given by the digitalization.
Separating the subjects by sex shows that male subjects tend to complete the control tasks faster than female subjects. Males completed the predefined task in 10.3 ± 2.27 min and the complex task in 13.92 ± 6.39 min. Females required 11.25 ± 2.72 min and 16.08 ± 5.59 min. Nevertheless, the time difference between female and male subjects for handling the cubes of the complex task is getting smaller from cube 1 to cube 3.
Subjects with about one hour of previous experience completed all tasks significantly faster than subjects who used the system for the first time. First time users needed 11.91 ± 2.82 min for the predefined task and 18.64 ± 6.19 min for the complex task, while subjects with previous experience needed 9.63 ± 1.51 min to complete the defined task and 11.36 ± 2.73 min to stack the three cubes of the complex task. Even after about one hour of previous experience an enormous learning effect can be seen.

The number of trials, the subjects needed for correct head gesture performance and therefore switching between the different control groups was counted. In total, the subjects performed $x = 1707$ switching processes during the control tasks. The subjects needed in average 1.46 trials for correct gesture performance with a standard deviation of $\sigma = 0.92$. There are no significant differences depending on the different gestures, age, sex or previous experience. In 70.34% of switching processes, the gestures were performed and recognized at the first try. In 18.15%, the subjects needed two trials for correct gesture performance. Three or more trials were needed to perform the gesture correctly in 11.51%.

Subjective evaluation was carried out with a questionnaire. Several statements are rated on a Likert scale from 1 "I do not agree at all" to 5 "I totally agree". The subjects agreed, that the graphical user interface is visually appealing and clearly arranged with a value of 4.04 ± 0.91 and that all relevant information for the human-robot interaction is shown by the visual feedback on the screen (4.21 ± 0.83). According to the subject's assessment, the correct performance of all gestures was easy (4.22 ± 0.91). The subjects agreed, that switching between the different control groups by performing the head gestures is fast (4.21 ± 0.88) and easy (4.08 ± 0.93).

The subjects evaluated that correct performance of the head gestures was easy in the questionnaire. Nevertheless, the objective evaluation shows that the error rate is relatively high.

4. CONCLUSION

Within this work, 24 able-bodied subjects took part in the experiments. An additional usability study with tetraplegics will be carried out, as they are very well suited end-users of the system. Head motion based control of an assistive robot provides an opportunity to increase the autonomy of disabled people considerably.

Overall, the interaction technology and interaction design have been proven successful. The head gesture recognition algorithm will be improved to increase adaptability and robustness.

5. ACKNOWLEDGMENTS

The authors would like to thank all the subjects who took part in the study. This work was funded by the Federal Ministry of Education and Research of Germany.

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