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That confirms what users reported in the interview after the test: Most of them liked the touch control and would prefer it over the screen button based interaction. Nevertheless, as described above, some strange situations occurred, when the users did not respect the assumption of perpendicular forces (pushing only). Once informed on the rules, also these users managed to navigate the robot safely with the touch interface.

Table 1. Durations of navigation task for the test users in the experiment using GUI buttons compared to touch control

	duration of tests for individual users in minutes									
GUI	1:45	2:00	1:48	2:34	1:50	1:22	1:19	1:29	1:15	1:50
touch	0:51	0:52	0:54	1:01	1:10	1:00	0:52	1:06	1:00	1:18

The benefits of the touch-based control result from the analoguous speed control and that it is reachable from nearly any position. In many situations with the GUI based control, the user had to walk around the moving robot when turning it around, which is avoided by the touch based navigation.

Recently, additional usability studies have been conducted with elderly users, that besides the haptic control also comprise a remote control mode using a tablet pc and the autonomous navigation behaviours of the robot. Analysis of this study is still ongoing work.

8 Conclusion and Outlook

It could be shown that an intuitive input modality for local manual robot control can be implemented with very simple capacitive touch sensors placed within the enclosure of a mobile robot. The existing obstacle avoidance capabilities of the robot can easily be combined with the manual control due to a modular navigation concept, which is based on a dynamic window approach.

User studies showed that people favor the touch motion control over a GUI-button-based local motion control.

Some drawbacks could be observed due to the coarse spatial resolution of the only 12 sensor areas. There are parts of the robot's cover that are oriented in different directions but are in the sensing range of the same electrode. In these cases, the direction of the virtual force does not necessarily correspond to the surface normal of the enclosure, which causes a wrong rotation direction in some cases. Also the assumption that the force applied by the user is always perpendicular to the surface is inappropriate. Depending on the relative position of the user to the desired direction of movement, the robot may be pulled sometimes instead of being pushed only. In these cases, the resulting force is tangential to the surface, which is not modeled yet.

Thus, one aspect for optimization is the number of sensor electrodes, which needs to be increased in order to reflect the different parts of the robot's surface better. The second option to overcome the drawbacks of the undirected observations of contact is to spend more effort in the mapping from touch sensor readings to the desired motion command. We plan to apply machine-learning approaches in order to learn the mapping from example data. People's interaction behaviour is to be observed while being instructed to move the robot in certain directions. A function approximation can be trained with the values of the touch sensors, the relative position of the user, and the current velocity of the robot as input and the motion vector to the desired position as a target.

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