M. Koch, A. Butz & J. Schlichter (Hrsg.): Mensch und Computer 2014 Workshopband,
München: Oldenbourg Wissenschaftsverlag, 2014, S. 157-166.

Modelling Touchless Interaction for People with Special Needs

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Abstract

Touchless interaction has recently been gaining more and more attention through affordable input devices like Microsoft Kinect or Leap Motion. Touchless interaction is also attractive to people with impairments, however, few applications using touchless interaction have been made available to this target group so far. Usually, people with special needs receive individually configured software by their consultants which can be challenging because in many cases the performance regarding interaction with the system varies drastically, even from day to day. It is thus a valid objective to introduce a user modelling approach that can ultimately replace part of consultants' time-consuming configuration tasks. This has partly been successfully implemented in the past regarding conventional and touch-based interaction. This paper presents a prototypic application for modelling touchless interaction capabilities of people with special needs and reports the results of an initial study.

1 Introduction

Natural user interfaces where users can use their natural abilities are gaining widespread acceptance. While touch-based interaction is nowadays widely used with smartphones and tablets, touchless interaction has recently also been getting more attention through affordable input devices like Microsoft Kinect and Leap Motion. The capabilities of these devices are getting better and better, so can for instance, the Leap Motion controller, track smallest finger movements, and every joint of both hands. This is of great interest also for people with special needs (who have, e.g., impairments like spastic tetraplegia). However, when these groups of people want to be able to use the new touchless input devices for their daily work, they face challenges, mostly because the interaction design does not really fit their needs. Interaction via touchless input devices at the moment often presumes skills (e.g., regarding interaction speed or precision) that cannot be accomplished by these groups of users.

It is therefore mandatory that the interaction design considers the given restrictions of the individual user, which leads to a personalized interaction approach. (Biswas & Robinson 2009) have shown in their work that the cognitive and physical capabilities of the group of users with disabilities vary dramatically in terms of age, gender, and the presence and severity of impairments. For the interaction design itself, specific guidelines can help, e.g. accessibility guides, but are not sufficient when it comes to meeting the individual requirements of users with disabilities. Thus, in the daily business of consulting people with special needs, the configuration of software according to users' needs is of crucial importance. Even if the consultant is well aware of a user's capabilities, configuration of software (based on experience and heuristic knowledge) can be time-consuming. In many cases users' capabilities vary from day to day (e.g., after a weekend where the user was not able to use the respective application). This is where an automatically maintained user model in combination with adaptive system behaviour can help both involved parties. While conventional interaction (e.g., using mouse and keyboard) and partly also touch-based interaction has been successfully analyzed and modeled in the past, this is not entirely true for touchless interaction.

This paper presents a prototypic application for modeling touchless interaction capabilities of people with special needs and reports the results of an initial study. It is structured as follows: Section 2 provides a short overview on related work, Section 3 describes our modeling prototype, Section 4 describes our initial study and presents its results, and Section 5 provides a summary of our findings.

2 Related Work

Regarding personalization of systems for people with disabilities, (Gajos et al. 2008) discuss systems that automatically generate ability-based interfaces (i.e., interfaces adapted to users' individual abilities). They e.g., found out that although people with motor impairments were not significantly faster regarding their interaction with the system, they made fewer errors. The evaluation of Gajos et al. is similar to ours regarding the task-based approach.

In our evaluation (see Section 4.3), we use the performance of users without known impairment as a reference for the interpretation of the results of people with disabilities. A similar process is described by (Biswas & Robinson 2008) who compare the performance of motor-impaired and able-bodied users regarding pointing abilities.

Regarding touchless interaction, our work is dependent on the precision of the Leap Motion controller, as we calculate several fine-grained metrics based on the controller's recordings (e.g., average distance between a user's and a given line) in order to derive a user's touchless interaction abilities. Thus, the findings of (Weichert et al. 2013) who analyze the robustness and accuracy of the Leap Motion controller are of high relevance for us. They use a setting with an industrial robot for the evaluation of the Leap Motion controller's accuracy and found that a deviation between a desired 3D position and the measured positions of less than 0.2 mm has been obtained. They summarize that although it was not possible to achieve the theoretical accuracy of 0.01 mm under real conditions, a high precision with regard to gesture-based user interfaces was achieved.

Another important indicator for the applicability of the Leap Motion controller for our purposes is provided by (Potter et al. 2013) who have shown that the controller can be used to accurately track hands and fingers, so that the Australian Sign Language (Auslan) can be reliably recognized. Although their work was done using the Beta version of the Leap Motion controller, it certainly shows its ability to be used for people with impairments.

The Microsoft Kinect controller was used by (Altanis et al. 2013) for children with motor impairments. Their empirical study is based on Kinems, which is a method for professionals to help children with dyspraxia, autism, and ADHD improve their skills through game play. They have used several highly configurable games, which can be modified by a teacher, and played by the children. These games were designed for children to build and develop basic gross motor planning and coordination skills. An example game trains hand movements along a given area, while the teacher can define specific settings in the game: i) type of path, i.e. horizontal, vertical, or diagonal paths, ii) time limit, iii) width of the path, iv) length of the path, 20-40-60 cm. The game records all the hand movements in order to visualize it for the teacher, when the training session is over.

While the user’s input in our approach is currently not semantically useful, (Vikram et al. 2013) showed in an example application handwriting recognition using Leap Motion. By treating the input as a time series of 3D positions, and using a fast algorithm using dynamic time warping, they were able to recognize characters in online fashion. Although their work hasn’t considered people with impairment, it shows what could be addressed in further work.

3 Prototype

Our prototypic modelling application for touchless interaction with the Leap Motion controller at the moment consists of three test cases (also see (Kurschl et al. 2014)) for a detailed description). A similar test-case-based approach has successfully been used earlier to model users’ touch-based interaction capabilities (see (Kurschl et al. 2013)). Regarding the touchless interaction application, the test cases are embedded in a launcher that, besides the test cases, also involves a very simple user administration unit and a high score list that combines the results of the three test cases. Further, the prototype records in a very fine-grained way users’ interaction within the test cases (by tracking the user’s finger tip position at every time frame of the Leap). These raw recordings can be used later to compute metrics for user’s ability to interact via touchless input (see Section 4.3.1).

The first test case, the *draw line test*, presents to the user a line with a start and finish flag. The user then has to follow this line with the hand (or finger; only the front most position is recorded). It is the aim to follow the line as precisely as possible. The test contains 10 levels (L0-L9) that differ regarding their level of difficulty (L9 is the most difficult level). While the first levels require a user to only follow a straight line from start to finish, the more difficult levels contain check points between start and finish that have to be reached (the line is usually not straight then but can be a complex curve, e.g., representing a heart).

The second test case, the *seesaw test*, presents to the user a seesaw balancing a ball. The user then has to use both hands to balance the ball and react in case the ball is rolling towards the left or right end of the seesaw. It is the aim to keep the ball from dropping for 20 seconds per level which requires the user to be able to coordinate both hands for the duration of the level. This test includes three levels (again, the last level is the most difficult one). The levels differ from each other regarding the size and inertia of the ball and the response of the seesaw.

In the third test, the *wipe away test*, the user has to wipe free a picture that is covered with (digital) dirt. The test contains three levels that are equally difficult but contain different pictures. It is the aim of this test to find out whether the user can reach all areas of the screen.

The user can decide himself how many tests and levels he wants to take and receives points for every finished level that are added to the user's high score. Regarding the draw line test, the points reached for every level might differ, because the users receive points for every check point that is reached (i.e., if a check point is missed, the score is lower).

So far, we have introduced the following user model features that correspond to touchless interaction capabilities (also see (Kurschl et al. 2014)): Precision, Reaction Time, Endurance, Hand Coordination, and Reachable Areas. *Precision* is linked to the draw line test and measures how accurately the user can follow a given line. *Reaction Time*, *Endurance*, and *Hand Coordination* are linked to the seesaw test. *Reaction Time* measures the time span between the movement of the ball in a certain direction and the user's reaction. *Endurance* measures how long a user can perform at his best regarding touchless interaction. *Hand Coordination* measures how well a user can coordinate both hands. *Reachable Areas*, linked to the wipe away test, determines what areas of the screen can be reached by the user.

For the study described in this paper, only *Precision* is relevant. We use two concrete metrics to determine the precision with which a user is able to follow the lines: the *distance* between the user's position (again, only the front most position of the hand is recorded) and the optimum position (i.e., the position on the line), averaged over all time frames, and the *area* between the user's line and the given one (both measured in millimetres). The *distance* and *area* metrics seem to be strongly correlated which might suggest using only one of them. However, in some cases (depending on e.g., the nature of a user's tremor) they strongly differ. We observed during our initial tests cases where the *distance* metric provided the more reliable results and other cases where this was true for the *area* metric. We thus decided to keep both and use them in conjunction.

4 Initial Study and Results

This section describes an initial study conducted in March 2014 and presents its results.

4.1 Participants and Aims

The study involved two groups of participants and two different kinds of tests. First, we aimed at testing the first part of the modelling prototype (i.e., the draw line test) with the actual target group (*group 1*). In cooperation with the EDP workshop[1] in Hagenberg, Upper Austria, we conducted user tests with 5 probands (4 male, 1 female). The probands have different kinds of impairments, reaching from learning disabilities over visual impairment to spastic tetraplegia. They generally have good computer skills but are dependent on individually adapted input devices. It was the aim to evaluate the metrics introduced to model a user's touchless interaction abilities related to predefined gestures and movements.

Second, in order to identify general challenges regarding touchless interaction with the Leap Motion controller, and to solve potential general usability issues before offering the full set of test cases to *group 1*, we conducted an exhaustive user study with 103 participants, most of them (university or high school) students (without any known impairment) (*group 2*). We further aimed at evaluating the general acceptance of the touchless interaction paradigm. Participants were recruited during an open house at the University of Applied Sciences Upper Austria, Faculty of Informatics, School of Informatics/Communications/Media and participated voluntarily. The system (a standard PC, Leap Motion, 21 inch display) was set up in one of the computer labs of the university.

4.2 Method

Regarding the first part of the study *(part A)*, the participants of *group 1* were given concrete tasks. A task in the draw line test is a specific line the user has to follow with the hand. The solving processes of the tasks were recorded in a fine-grained log table so that the metrics introduced before (e.g., area between the given line and the line drawn by the participant) could be computed from the log data later. It was our aim not only to record the task solving processes to compute the metrics but also to again evaluate the metrics themselves in order to find out whether the results match with the observations made by experts (i.e., consultants).

The second part of the study *(part B)* involved all three test cases (i.e., also the tasks of *part A*) described in Section 3 and took place after *part A*. Two methods were used for this part of the evaluation: observation and semi-structured interview. The observation covered all test cases individually and included some general aspects that were observed for all test cases: whether participants understood the games (i.e., the instructions and objectives) without further explanation, whether they found the input area of the Leap without instruction, whether they noticed the next level starting, whether they gave up (because they believed the test case was too difficult), and how many levels they finished.

The observation related to the draw line test further aimed at finding out whether users could identify their starting position without help, whether they started at the correct flag, reached all check points, followed the line precisely directly from the beginning, and whether they moved from start to finish directly, i.e., ignoring the checkpoints.

Regarding the seesaw test, the observation further aimed at finding out whether the participants put both hands in position in the input area of the Leap right from the beginning,

[1] At the EDP workshop Hagenberg, people with motor or cognitive impairment do computer-based tasks like digitalizing slides or photographs for a couple of hours a day. They are supported by a team of consultants.

whether they were able to control the seesaw with both hands, whether they noticed when their hand(s) were outside the input area, whether they understood that the ball dropped from the seesaw implied the end of the level, and whether they recognized the simulated physical characteristics of the seesaw and ball.

Regarding the wipe away test, the observation aimed at finding out whether the participants could reach all areas of the “screen”, and whether they used both or only one hand(s).

The interviews aimed at revealing whether participants had fun testing the games, whether they found the touchless interaction more exhausting than conventional interaction with mouse and keyboard, what kinds of input devices they had already used before, whether the instructions provided by the intro screens of the test cases were sufficient, and whether they had the impression that the games were tendentially easy or difficult to interact with.

In addition to the observation and interviews regarding common usability and acceptance aspects, we monitored in detail user interaction for the draw line test also for *group 2* to gain additional reference values for the metrics we introduced to model *precision* for future user studies. The reference values should help us to assess the performance of people with disabilities in the draw line test.

4.3 Results

This section summarizes the results of the initial study for *group 1* and *group 2* (see Section 4.1 and Section 4.2.) split up into *part A* and *part B*.

4.3.1 Part A

The data we got from the live recording can again be split up into *group 1* (5 people with disabilities, mainly, spastic tetraplegia) and *group 2* (103 persons without any known impairment). Additionally, two consultants (1 male, 1 female) also participated in *part A* of the study that took place at the EDP workshop Hagenberg in order to gain immediate reference values independent of the tests with *group 2* (which took place later).

For the draw line test, we computed from the recorded positions i) the average distance between the drawn line to the given one and ii) the average area between the drawn and the given line. Table 1 lists the average distances for of *group 1* (P1-P5) and the two consultants (R1, R2). Some values are missing (marked as N/A) due to a problem during recording.

Table 2 lists the mean, median and maximum of the average values of the participants of *group 2*. The results show that in many cases, the average distances of *group 2* are only a fraction of those of *group 1* which can be additionally explained by our data; we also recorded the tremor of participants with and without impairment (spastic tetraplegia; see Figure 1 for an example comparison, based on (Kurschl & Augstein 2014)).

Table 3 lists the values for the metric “areas between the given and the drawn line” for all participants of *group 1* (P1-P5) and the two consultants (R1 and R2). Table 4 lists the mean, median and maximum values of the same metric for the participants of *group 2*. Again, some values are missing (marked as N/A) due to a problem during recording.

	L0	**L 1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L 7**	**L8**	**L9**
P1	0.038	**0.367**	0.169	**0.314**	**0.247**	**0.183**	**0.293**	0.176	**0.183**	0.412
P2	0.091	0.127	**0.260**	0.164	N/A	0.134	0.209	0.278	0.150	0.330
P3	0.057	0.036	0.030	0.026	0.126	N/A	0.028	0.036	0.132	0.270
P4	**0.116**	0.108	0.116	0.038	0.098	0.124	0.282	0.119	0.062	0.366
P5	0.050	0.161	0.097	0.029	N/A	0.154	0.156	**0.360**	0.123	**0.460**
R1	*0.022*	*0.018*	*0.021*	*0.019*	*N/A*	*0.112*	*0.028*	*0.084*	*0.027*	*0.269*
R2	*0.019*	*0.014*	*0.011*	*0.009*	*N/A*	*0.125*	*0.024*	*0.030*	*0.025*	*0.348*

Table 1. Computed average distance from the given line for 5 persons with spastic tetraplegia (P1 to P5) and 2 consultants (R1 and R2) who participated in order to gain reference values.

	L0	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
Avg	0.035	0.026	0.037	0.026	N/A	0.103	0.035	0.036	0.035	0.198
Md	0.019	0.017	0.019	0.018	N/A	0.093	0.022	0.026	0.028	0.252
Mx	0.233	0.181	0.356	0.225	N/A	0.325	0.270	0.212	0.124	0.526

Table 2. Mean, median and maximum of the average distance for 103 people without know impairments.

	L0	**L 1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L 7**	**L8**	**L9**
P1	0.011	**3.135**	**2.734**	**12.593**	**1.985**	**5.036**	13.033	**8.473**	**5.084**	7.731
P2	0.072	0.095	1.656	0.549	N/A	2.079	4.602	2.980	1.793	0.435
P3	0.045	0.027	0.012	0.016	0.112	N/A	0.043	0.071	2.357	3.182
P4	**0.412**	2.358	1.120	N/A	0.238	8.737	**18.936**	1.391	N/A	1.641
P5	0.003	0.406	0.316	0.046	N/A	0.728	2.384	6.211	1.542	**8.118**
R1	*0.012*	*0.016*	*0.007*	*0.173*	*N/A*	*0.023*	*0.009*	*0.398*	*0.059*	*0.230*
R2	*0.006*	*0.019*	*N/A*	*N/A*	*N/A*	*0.002*	*0.031*	*0.005*	*0.060*	*1.430*

Table 3. Computed area between the given and the drawn line for 5 persons with spastic tetraplegia (P1 to P5) and 2 consultants (R1 and R2) who participated in order to gain reference values.

From the current data can we see that in some cases, the results for participants with disabilities differ only slightly from those of the reference group, whereas in others there are notable differences. The findings correlate with the opinions of the two consultants regarding the participant's ability to use touchless interaction via Leap motion in general. We conclude that for people whose values for the average line distance and the area between the lines are around the median values of the reference group (*group 2* and R1 and R2), touchless interaction with the Leap motion controller can be recommended.

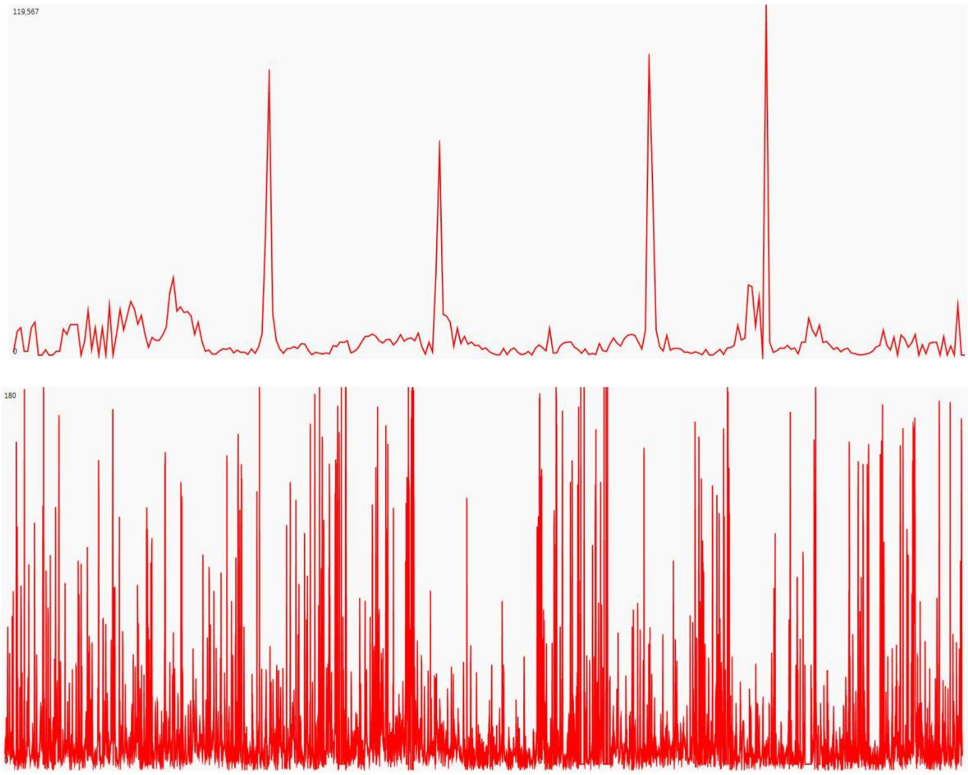

Figure 1.The monitored tremor of participants without (top) and with a significant tremor (bottom).

	L0	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**
Avg	0.085	0.412	0.073	0.051	N/A	0.154	0.245	0.168	0.114	0.451
Md	0.009	0.008	0.011	0.008	N/A	0.022	0.028	0.044	0.047	0.377
Mx	2.686	1.578	3.979	1.707	N/A	3.094	7.35	6.055	1.427	2.468

Table 4. Mean, median and maximum of the areas between the given and drawn lines for 103 people without know impairments.

4.3.2 Part B

In total, 103 users participated. The draw line test was taken by 93 participants, 74 persons did the seesaw, and 71 the wipe away test. The results of the observation revealed (for all test cases) that users were able to understand the instructions for the game and the game's objectives without further explanations (85 of 93 participants at the draw line test, 69 of 74 at the seesaw test, 56 of 71 at the wipe away test). Further, the majority of the participants could find the input area of the Leap without help (87 of 93, 65 of 74, and 53 of 71). Most users noticed the next level starting after a completed one (88 of 93, 65 of 74, and 62 of 71) and no user gave up because the level was too difficult (this might be biased by the fact that the levels were designed for the needs of people with motor and/or cognitive impairment).

In addition to the general findings, we identified some usability issues for the individual test cases. 25 participants did not start at the right flag at the draw line test (however, all checkpoints were ultimately reached by all users and only 5 users ignored the checkpoints). Based on these findings, we changed the appearance of the start flag. At the seesaw test, 72 of 73 users could control the seesaw using both hands. All users interpreted the simulated physical characteristics of seesaw and ball correctly and all users except for 3 recognized immediately that the dropped ball signified the end of the level. 16 of 74 users did not immediately notice when their hands were out of the input area. Based on this observation, we added a coloured frame around the screen that signifies whether the user's hand(s) are inside input area or not (using red/green colour code). At the wipe away test, most users (68 of 71) could reach all areas of the screen and all except for 5 used only one hand for wiping.

The interviews we additionally conducted revealed the following results. 91 of 103 participants stated they found the games entertaining. Many of them had already been using touchless input devices before (35 had prior experience with the Leap motion controller, 48 with Microsoft Kinect, and 69 were at least familiar with Nintendo Wii). For 72 of the participants, touchless interaction using Leap Motion was more exhausting than conventional therapy. This is of high relevance for us since the actual target group should be able to interact with the controller for a longer period of time. We derived that it would most probably be necessary to let users support their arms during interaction.

5 Summary

We presented a prototypic user modelling application for touchless interaction and reported the results of an initial study. The study aimed at assessing the expressiveness of two metrics introduced for measuring the ability to use touchless interaction with Leap Motion (*part A*) and at evaluating our application regarding usability (*part B*). For *part A*, we did user tests with 5 persons with different impairments and a control group consisting of two consultants and 103 students. For these user tests we used only the draw line test because the remaining two test cases had not yet been sufficiently tested regarding usability before. For part B, we have described the results of an observation and interview with 103 participants without known impairment. Here, we used the full set of available test cases. The initial results have shown that with the help of the two metrics described in Section 3, we could pretty well reproduce expert's opinions. We have also shown that the metrics can be used to derive whether touchless interaction should be recommended to a person at all or not. For part B, we found that the participants could generally handle the application well and understood its instructions. We derived from the opinions of the participants improvements of user interface and interaction design. As already said our interaction modelling application is still in a prototypic state and needs to be significantly extended to provide a comprehensive user modelling tool. The two metrics we used in part A of the study are limited to assessing user's ability to perform predefined touchless gestures which makes up only part of the touchless interaction possibilities. The movement time, as a third metric to measure the interaction performance will be added. Further, the remaining test two cases have to be evaluated with the actual target group (regarding usability, and significance of the metrics used there).

Acknowledgements

We would like to thank T. Burger, K. Kaser, C.Pointner, J. Lengauer, P. Geschwentner, C. Gould, B. Gruber, D. Kern, K. Liedl, B. Oberndorfer, D. L. Pham, V. Pitako, T. Puchner, G. Schnegelberger, K. Zölzer for their valuable input.

References

Altanis, G., Boloudakis, M., Retalis, S., Nikou, N. (2013), *Children with Motor Impairments Play a Kinect Learning Game: First Findings from a Pilot Case in an Authentic Classroom Environment*. Interaction Design and Architecture(s) Journal - IxD&A, N. 19, 91-104

Biswas P. & Robinson P. (2008). *Automatic Evaluation of Assistive Interfaces*. In Proceedings of the 13th International Conference on Intelligent User Interfaces (IUI08), New York, USA.

Biswas P. & Robinson P. (2009). *Effects of Physical Capabilities on Interaction*. In Proceedings of the EuroTV 2009 Conference - Dening the Architecture for Next Generation Inclusive Television Workshop, Leuven, Belgium.

Gajos, K.Z., Wobbrock, J.O. & Weld, D.S. (2008). *Improving the Performance of Motor-Impaired Users with Automatically-Generated, Ability-Based Interfaces*. In Proceedings of the 26th Annual SIGCHI Conference on Human Factors in Computing Systems (CHI08), Florence, Italy.

Kurschl, W., Augstein, M., Burger, T. & Pointner, C. (2014). User Modelling for People with Special Needs. *Submitted to Journal of Mobile Multimedia, In Review*.

Kurschl, W., Augstein, M., Stitz H., Heumader, P. & Pointner, C. (2013). *A User Modelling Wizard for People with Disabilities*. In Proceedings of the 11th International Conference on Advances in Mobile Computing & Multimedia, Vienna, Austria.

Potter, L.E., Araullo, J. & Carter, L. (2013). *The Leap Motion controller*. In Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration.

Vikram, S., Li, L., Russell, S. (2013). *Handwriting and Gestures in the Air, Recognizing on the Fly*. In Proceedings of the CHI '13 Extended Abstracts on Human Factors in Computing Systems, Paris, France, 1179–1184.

Weichert, F., Bachmann, D., Rudak, Bartholomäus & Fisseler, D. (2013). Analysis of the Accuracy and Robustness of the Leap Motion Controller. *Sensors (Basel), 13*(5), 6380–6393.