Waggle – Orientation-based Tablet Interaction

Johannes Schwank
Computer Graphics & HCI
University of Kaiserslautern
Kaiserslautern, Germany
schwank@cs.uni-kl.de

Franca-Alexandra Rupprecht
Computer Graphics & HCI
University of Kaiserslautern
Kaiserslautern, Germany
rupprecht@cs.uni-kl.de

Achim Ebert
Computer Graphics & HCI
University of Kaiserslautern
Kaiserslautern, Germany
ebert@cs.uni-kl.de

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Abstract
Nowadays, mobile devices, like smartphones and tablets, are essential items in our daily life. Further, more and more people use tablets in their everyday work for remote control, observing diagrams, performing web analytics, etc. However, the full potential of the tablet usage is not tapped yet; built-in sensors like accelerometer or gyroscope offer a wide range of interaction capabilities, which are not fully used. In this paper, we introduce Waggle – a novel concept for orientation-based two-handed touch-less interaction on mobile devices through smart tilting and turning. Future design decisions can be founded on two parameters (movement angles and discretization), which are examined in two pilot studies. The first pilot study evaluates the maximum angle for basic rotation axis. The second pilot study tackles the discretization of tilt and turn angles. Both pilot studies are conducted and used to gain the optimal configuration for the two-handed Waggle interaction.

Author Keywords
Interaction; Mobile devices; Tilt and turn; Evaluation.

ACM Classification Keywords
H.5.2 [User Interfaces]: Input devices and strategies, Interaction styles, Evaluation/methodology; I.3.6 [Methodology and techniques]: Interaction techniques

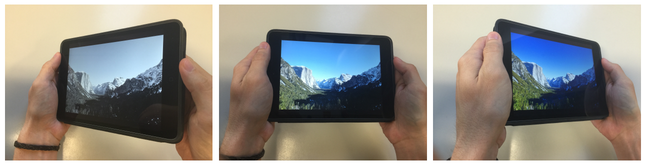


Figure 1: The waggle interaction allows users of mobile devices to select values or to change viewports on the visualized data.

Introduction

Established interaction approaches on smart devices feature touch gestures in combination with elements such as buttons or sliders. Although the resolution of mobile devices is high, it does not provide more precise interaction and the available display space compared to common desktop monitors is still very limited. Adding additional UI-elements leads to an even more shrinked viewport and hidden information. Furthermore, while performing touch gestures, the fingers may also hide important information. A touchless interaction overcomes these issues, but it is to examine if such an interaction is applicable on mobile smart devices.

The principle of a multiscopic image (visualization of two or more images, each visible due to the user's head position) can be adapted to mobile devices using the built-in sensors such as accelerometer and gyroscope. This enables tilting as a touchless orientation-based interaction for displaying different views or adjusting parameters.

In this paper, we present the so-called Waggle metaphor – a novel orientation-based method to interact with mobile smart devices by enabling multiple views on the underlying data by changing the inclination of the device. Our contribution are two pilot studies that provide data of the maximum tilt angle and step intervals size to gain the optimal configuration for the two-handed Waggle interaction.

Related Work

Considering mobile devices and the angle of the viewpoint to the display, lenticular lenses are one of the first thoughts. In general, they are used to generate glasses-free, automultiscopic 3D images. Special lenses are set in a way that two stripes (one of each images) are covered. Depending on the viewing angle, only one image can be seen [8]. One of the disadvantages is that the two images have to be already calculated in advance. In our approach, with each change of the viewing angle, the displayed image is adjusted.

Wagner et al. [7] introduced and evaluated a toolkit that supports bimanual tablet interaction via support-hand interaction zones. This includes bimanual taps, gestures and chords. Based on the built-in sensors such as accelerometer and gyroscope, tilting and turning provide additional interaction capabilities. However, the interaction zones can be included to activate / deactivate waggle interaction.

Tilting and turning as interaction metaphor of mobile devices finds relevance in the work of [1, 2, 3, 5, 6]. Baglioni et al. [1] analyzed device tilting interaction using accelerometer. They found out that the tilt gestures are additional input channels that do not interfere with other input gestures like touch. While they give an overview over accelerator based input techniques like shaking the device (e.g. skip the next song on Apple's iPod), many examples where tilting is used as additional input metaphor are collected by Scoditti et al. in [6]. Rekimoto investigates tilting interaction to select items from linear and circular menus [4]. In his approach, tilt angles are associated to menu items. In [2], Partridge et al. describe TiltType, a technique that supports text input. They correlate tilt angles to letters that are organized in circular menus. Roudaut et al.[5] proposed to use tilting to switch between applications. Tapping the device's

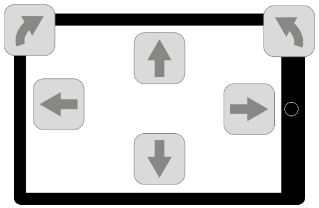


Figure 2: 6 simple filters based on 3 DOF.

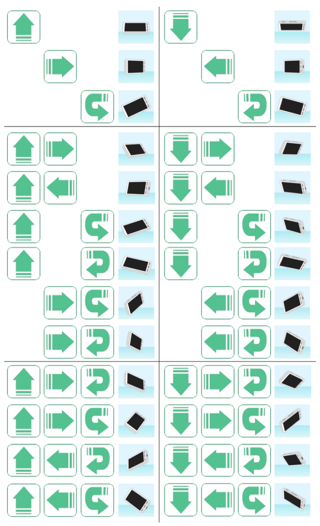


Figure 3: Waggle directions of a mobile device. This provides 6 simple filters (rows 1-3). Combinations of them enable additional 20 possibilities. Example: tilt the device to the left and turn it clockwise.

back side activates the switching mode while tapping on the front side the desired application is selected.

Rahman et al. [3] defined the range-of-motion i.e. the rotation of the wrist along each axis. They motivated also the need to specify a discretization of the tilt angles, which can directly influence the tilt interaction. In their evaluation, linear discretization is compared to sigmoid and quadratic discretization. They found out that "users can control comfortably at least 16 levels on the pronation/supination axis and that using a quadratic mapping function for discretization of tilt space significantly improves user performance across all tilt axes.". Most of the work such as [1, 3, 5] targets one-handed interaction. But since tablets becoming more popular nowadays and are mostly held with two hands, the two-handed interaction is getting widespread and has not been investigated in detail. Therefore, we extend the above mentioned work and examine the tilting and turning technique further.

Concept

Our approach provides an orientation-based interaction metaphor available for all modern mobile devices with built-in accelerometer and gyroscope. The viewing angle is solely changed by using the data generated by the built-in accelerometer and the gyroscope of the used device. Omitting additional UI-elements, Waggle avoids occlusion and does not require any UI-elements. In contrast to other research, we focus on a two-handed interaction that is common when working on larger mobile devices like tablets.

The initial viewpoint shows the data-set without any filters and layers. Tilting the device along one of the axes (longitudinal, lateral, or perpendicular axis) filters the respective overlapped layers, resulting in 3 degrees of freedom (DOF) providing 6 simple filters as shown in Figure 2. Furthermore, the tablet can be tilted along up to all three axes at the same time, e.g. along the longitudinal axis and turning around the perpendicular axis. Overall, this results in a possible definition of 6 simple filters and 20 filter combinations, i.e. in total 26 different views (see Figure 3).

Additional touch gestures can even extend the number of possible interaction possibilities. For instance, we implemented a lock mechanism for each axis which allows freezing the current display content. This feature is pretty useful in case the analyst wants to place the device on a table or hand it over to a co-worker. Without the lock mechanism, the viewport will most likely accidentally change by these movements. Hence, the viewport lock can be triggered by tapping in the interaction zones as proposed in [7].

During our research, we found that the applied range of motion and discretization are the key-players for providing a high usability of our concept. Consequently, we examined those values in more detail in two pilot studies.

Range of motion

The range of motion is defined by the maximum tilt and turn angle in each direction in a way that a user is still able to handle the device comfortably. An important influence is whether the user is holding the device with one or two hands. Our first pilot study evaluated the range of motion for two-handed device control. We examined if the maximum tilt and turn angles correspond to the range of motion of the one-handed device control that was found by Rahman et al. [3]. Our pilot study also investigated if the maximum angles are depending on the tilt and turn direction.

Discretization

The subdivision of the range of motion is an important performance factor. Current devices feature accelerometers and gyroscopes that are able to measure the tilt angles with

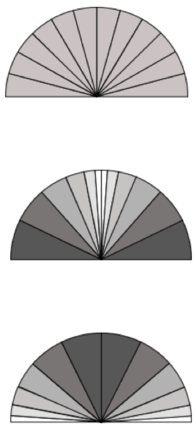


Figure 4: Linear, quadratic and sigmoid discretization of a 180° angle range as adapted from [3].

Figure 5: Picture of a participant in the first pilot study.

high precision. In fact, these measurements are so precise that the tilt angles change even though the user thinks that the device is in a stable position. Hence, for our purpose, the values of the range of motion need to be discretized.

Rahman et al. [3] tested three types of discretization: linear, sigmoid, and quadratic (Figure 4); they found, that the quadratic discretization is the optimal choice for one-handed interactions in terms of user performance. In our second pilot study, we investigated if this result can be confirmed for two-handed device interactions.

Experimental User Studies

The waggle interaction technique needs a good and intuitive definition of the maximum angle in each direction, the minimal interval size of the steps and the discretization of the range of motion. Therefore, we conducted two pilot studies. The first pilot study evaluated the maximum angle of each tilt and turn direction. In the second pilot study, we investigated the minimal interval size and the optimal discretization of the range of motion.

Pilot Study 1 - Evaluating the range of motion

The goal of the first pilot study was to get insight in the maximum angle. That means, how far can the user tilt the device and is still able to look at and interact with the device in a comfortable way when holding it with both hands (Figure 5). As there are many different mobile devices nowadays with different sizes, we selected four devices to evaluate if differences related to their size exist: iPhone 4 (3,5"), iPhone 6 + (4,7"), iPad mini (7,9") and iPad2 (9,7").

The 15 participants of the first pilot study (4 female and 11 male regular smart device users) were asked to turn and tilt the device following the waggle direction that was displayed as an arrow on the device (longitudinal, lateral, or perpendicular axis). The users were asked to stop when they do not feel comfortable anymore looking at the screen. To save that maximum angle, the users performed a single tap anywhere on the screen. Then, they should return to their normal device position and tap again, to gather the initial position. We asked them to sit in their usual working position and not move their head, keep both hands on the device, and tap with one of their thumbs.

The participants had to tilt or turn each device five times in each direction where the order in which the participants used the devices was random. Thus, each participant had to perform 30 tasks per device; 120 tasks overall. For each task, we stored the start and maximum angle values of all three axes of the device leading to six values per task.

Results

Before we were able to analyze the data, we had to post-process it to get explicit results. Depending on the predefined Waggle direction, we calculated the difference between start and maximum angle of the appropriate coordinate, i.e. x-coordinate when tilting up and down (longitudinal axis), y-coordinate when tilting left and right (lateral axis), and z-coordinate when turning the device clockwise and counterclockwise (perpendicular axis). We computed the median and the 25%- and 75%-quartiles (Q1 and Q3) for each direction and device. The analysis of these results (Table 1) shows the median maximum angle per direction.

The differences in the x-coordinates (Table 1a) could be explained by remembering the "normal" position of the device. For "normal" position, the participants were asked to sit in regular working position and hold the device in their hands. In this position, we observed in the data that the device was already slightly tilted down when starting the tasks. This has led to a bias of around 8 degrees in average. Therefore, the device could be tilted more in the up direction (28 degrees) than in the down direction (8 degrees). For getting

		iPad	iPad mini	iPhone 6+	iPhone 4	min
	Q1	15	17	19	20	15
up	median	**29**	**29**	**28**	**31**	**28**
	Q3	46	46	46	44	44
	Q1	2	1	1	2	1
down	median	**8**	**8**	**11**	**15**	**8**
	Q3	34	36	33	29	29

(a) lateral axis (up and down).

		iPad	iPad mini	iPhone 6+	iPhone 4	min
	Q1	5	7	6	5	5
left	median	**23**	**28**	**23**	**23**	**23**
	Q3	49	53	46	45	45
	Q1	24	30	24	20	20
right	median	**42**	**46**	**42**	**38**	**38**
	Q3	51	61	53	54	51

(b) longitudinal axis (left and right).

		iPad	iPad mini	iPhone 6+	iPhone 4	min
	Q1	6	5	8	5	5
clock-wise	median	**15**	**17**	**24**	**21**	**15**
	Q3	38	43	47	39	38
	Q1	7	3	5	4	3
counter-clock-wise	median	**21**	**25**	**26**	**24**	**21**
	Q3	47	49	50	40	40

(c) perpendicular axis (clockwise and counterclockwise).

Table 1: Results of pilot study 1: medians of the maximum angle in degree for each waggle direction.

the range of motion related to the 0-position (the device lies flat on desk), we added the bias so that the maximum angle for tilting down became 16. This phenomenon could not be observed for the other two axes.

However, the most interesting results were the large differences in the y-coordinates for tilting the device left and right (23 vs. 38 degrees, see Table 1b). Looking back at the original data, we can provide a first guess: 13 of the 15 participants are right-handed. Analyzing only the data of the two left-handed participants, we got different values for the left and right tilting compared to the right-handed participants (31 and 24 degrees instead of 23 and 38 degrees). We are aware of that this is not the complete opposite of the median right-handed results, but it may be the reason. And it may explain the slight difference when turning the device clockwise and counterclockwise. In either case, the disparity between left- and right-handed users needs further investigation.

Concerning the results for the z-coordinate (Table 1c), the resulting values were 15 and 21 degrees for clockwise and counterclockwise turning, respectively.

Overall, to make our approach as applicable as possible, we set the maximum angles for both directions of the same axis to the same minimum value to not exclude left- or right-handed people and included a buffer where possible. This leads to the following ranges of motion:

- Lateral axis (Up-Down): ± 16
- Longitudinal axis (Left-Right): ± 20
- Perpendicular axis (Turning): ± 15

Pilot study 2 - Evaluating the discretization

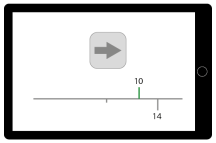
In pilot study 1, we could observe that the results regarding the single devices are similar enough to assume that the further investigation will not get falsified if we merely use one device type. We decided to use the iPad mini, which holds the average display size of all used devices. With the second pilot study, we wanted to investigate what is the minimal interval size, i.e. what is the minimal size of one interval so that the user can still reach a specific angle by tilting or turning the device. Therefore, we used the results of the first pilot study to define the range of motion.

Based on the work and results of Rahman et al. [3], we applied linear discretization as well as a quadratic like and a sigmoid like discretization in our second pilot study. Overall, we evaluated five different discretizations (Figure 4):

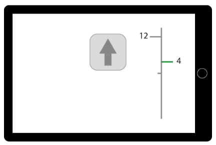
- **linear1**, **linear2**, **linear4**: The size of the intervals is 1, 2, and 4 degrees, respectively, over the whole range of motion.
- **sigmoid**: The interval size differs depending on the angle. The intervals around 0 are larger and becoming smaller the more they are away from 0.
- **quadratic**: The interval size also depends on the angle, but is the opposite way of the sigmoid discretization, i.e. the greater is the distance to 0, the greater the interval.

Thus, we get five task groups (linear1, linear2, linear4, sigmoid, and quadratic). In each task group the participants had to tilt or turn in each of the six simple directions five times resulting in 30 tasks per task group; overall 150 tasks per participant. The order of the tasks was randomized as well as the target values (within the range of motion).

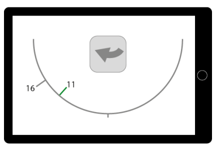
The participants were asked to tilt or turn the device to match the current and the target value shown on the screen (see Figure 6) and to hold it for two seconds. By holding the device two seconds in a specific position, we could assume that the position was stable and has been reached intentionally. We stopped the time for each task. After the experi-



(a) Tilt around longitudinal axis.



(b) Tilt around lateral axis.



(c) Turn around perpendicular axis.

Figure 6: UI-concept for the pilot study 2. Arrows show target direction, green marker represents the current angle.

	linear1	linear2	linear4	sigmoid	quadratic
x	5,13	2,44	3,05	3,05	3,43
y	4,44	2,02	3,14	3,64	3,61
z	7,10	1,89	4,25	3,70	3,75
avg	5,56	2,12	3,48	3,46	3,60

Table 2: Average time in seconds for each direction and task group.

ment, the participants answered a questionnaire for gaining subjective feedback about the preferred interval size.

Results

In the second user study, 14 participants (3 female, 11 male) took part. 10 of them were right-handed and 4 were left-handed. The overall average time per task has been 3,64 seconds. In fact, the average times per task for the different directions do not differ significantly (Table 2) except for turning around the z-axis in linear1 tasks.

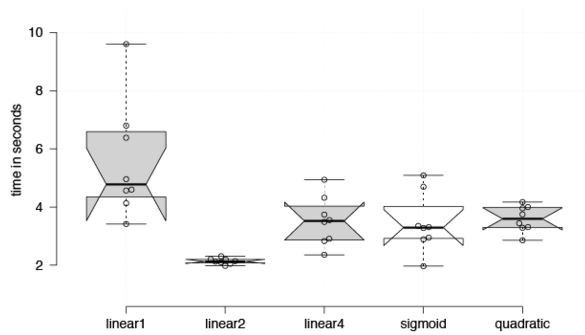


Figure 7: Boxplot of the results of the second pilot study.

As shown in Figure 7, the tasks were solved significantly faster with the linear2 discretization than with any other discretization. The task acceptance rate is 100% for each discretization which means that all participant were able to dwell on every target for 2 seconds. As observations have shown, the more the user tilted the device, the more unstable was the control. In a short informal interview, one participant said, that "the jitter in the high value areas with the smallest step size is too strong to be able to reach a value precise, fast, and stable". Based on that, we expected that the linear4 discretization has to be even faster than the linear2 discretization. However, it was not the case. Many participants were confused about the large interval size and were searching a long time for the point when values are changing. In contrast to Rahman et al. whose study returned quadratic to be best, our results have shown that linear2 is better for two-handed tablet usage.

Conclusion

In this paper, we presented an orientation-based input metaphor for two-handed mobile devices. In the studies, we investigated the range of motion and evaluated its most effective discretization to gain the optimal configuration for the two-handed Waggle interaction. Depending on the tilt or turn axis, we found different ranges of motion. While the left-right tilting offers the largest range of motion of ± 20 degrees in each direction, tilting up and down is usable up to ± 16 degrees and turning around the perpendicular axis up to ± 15 degrees. Independent from the axis, the discretization with an interval size of 2 degrees was significantly the fastest configuration. Additional information overlays like details of specific data points in data visualization or spreadsheets as well as selection of albums in a cover-flow visualization of a music library are possible applications for different types of filters. In future work, we plan to apply the Waggle technique to visual analytics tools to investigate the usability and efficiency of the technique further. Therefore, we will present our application to different experts working in visual analytics and evaluate the applicability compared to common desktop applications.

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