Implications for Design of Personal Mobility Devices with Balance-Based Natural User Interfaces

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Abstract. In this paper, we present a set of guidelines for designing personal mobility devices (PMDs) with body balance exclusively as input modality. Using an online survey, focus group and design workshop, we designed several PMD prototypes that used a natural user interface (NUI) and balance as its only form of user input. Based on these designs we constructed a physical and functional PMD prototype, which was tested using a usability test to explore how the balance interface should be designed. In conclusion, we discuss whether the guidelines from the literature could apply when designing PMDs and present a set of implications for the design of PMDs with balance-based NUIs based on both the guidelines and our own findings.

Keywords: Personal mobility · Embodied interaction · Natural user interface

1 Introduction

In July 2014, personal mobility devices (PMDs), such as self-balancing vehicles, were legalized on public roads by the Norwegian government. With the introduction of PMDs, a new market of cheap, environmentally friendly, and personal transportation vehicles would be available to the public. However, more than two months after the legalization the adoption rate was still very low [1], which suggested that the current vehicles had failed to meet the requirements of the public. This potential need for a redesign was the main motivation for our study on improving PMDs using a Natural User Interface (NUI) interaction approach. As such, we gathered user requirements through an online survey and designed several PMD prototypes using a focus group and design workshop. This was followed by a usability test on one of the designs to identify possible implications for the design of balance-based PMD interfaces.

This paper is structured as follows: We start by presenting related work on balance as input and user experience (UX) of movement-based interfaces, and use this literature to propose a list of design implications for the prototype and its interface. Next, we present the methods used to collect requirements, design and test the prototype using these implications. We then present the results from each of the methods, and finally discuss the proposed implications based on our findings.

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2 Related Work

Within Human-Computer Interaction (HCI), much of the research on balance-based interfaces so far revolves around balance as input in a virtual environment. In a study by Fikkert et al. [2], the authors compared the use of lower-body input to traditional hand held controllers using a Wii Balance Board and Wii Remote. They found that while using the remote to navigate was significantly faster, the balance board was both easier to learn and use and felt more intuitive to the users, and the users strongly indicated that they enjoyed using the balance board more. These results indicated that while a balance-based interface may not be as precise as a traditional button-based interface, it could still be easier to learn and provide a more fun and intuitive user experience.

Wang & Lindeman [3] conducted a study comparing two modes of balance control; isometric and elastic (tilt), with a leaning-based surfboard interface in a 3D virtual environment. The authors found that participants preferred the elastic board because it was more intuitive, realistic, fun and provided a higher level of presence. However, they found no significant difference in user performance, indicating that people prefer elastic balance interfaces over non-elastic, but that this preference has no impact on performance.

Haan et al. [4] demonstrated different scenarios where balance could assist traditional hand-operated input in a virtual reality (VR) setting. They tested the use of a balance interface as an interaction supplement in three different interaction modes (3D rotation, navigation and abstract control), both while sitting and standing. They found that all three modes worked well, but noted that side-to-side motion was slower and required more effort on the user's part in all modes. The authors concluded that the balance board was effective and easy to use, suggesting that the balance could easily be used in a wide variety of applications, even outside of VR.

Research on user experience is often concerned mostly with graphical interfaces and screens, but the rapid development of small integrated processors in the last decade has opened the door for UX research on embedded computers without any graphical or screen-based interface. In a study by Moen [5] the authors present the design process and user explorations of a wearable movement-based interaction concept called the BodyBug. This was created to explore full-body movement, as the interaction modality. Through their observations of users interacting with the BodyBug, they identified that the success of embodied user experience relies on having movement-triggers as well as a social excuse or reason to move, i.e. that these movement patterns are socially and culturally accepted in their context. Additionally, the authors observed large individual differences regarding which movements felt comfortable to the participants, suggesting that enforcing a set of pre-defined gestures or strict rules for a successful interaction may limit the user experience for users that feel uncomfortable with these kinds of body movements.

In a study by Larssen et al. [6] exploring movement-based input using a Sony Playstation2® and Eyetoy™, the authors used two existing frameworks for conceptualizing the interaction: *Sensible, Sensable, Desirable: a Framework for Designing Physical Interfaces* [7] and *Making Sense of Sensing Systems: Five Questions for*

Designers and Researchers [8]. The frameworks were used to categorize the movements of the participants during play, and look at how movement as input would hold as communication in the interaction. The authors found that both frameworks were valuable tools to aid researchers and designers in understanding the specific challenges that new interaction and input options present. They conclude that when movement is the primary means of interaction, the forms of movement, enabled or constrained by the human body together with the affordances of the technology, need to be a primary focus of design. Additionally, an intuitive and natural interaction through movement relies on appropriate mapping between movement and function.

Table 1. Our design guidelines for a PMD with a balance interface based on related work

Guidelines	Related work
1. Elastic interfaces increase user experience over isometric	[3]
2. Leaning from side-to-side requires more effort	[4]
3. A movement based interface relies on movement-triggers and a social excuse to move	[5]
4. There are large individual differences in which movements feel natural	[5]
5. The device must be designed around the forms of movement as allowed by the human body	[6]
6. Intuitive and natural interactions relies on appropriate mapping between movement and function	[6]

2.1 Design Guidelines from Related Work

Based on this literature we have assembled a set of guidelines for the design that we have attempted to incorporate in the design process of the prototype (see Table 1). We will return to these guidelines following our results to evaluate and discuss whether they can be used as design implications for future PMD interfaces.

3 Method

The aim of the study was to identify opportunities for improving PMDs using a NUI and lower-body input approach. We used Blake's definition of NUI *"A natural user interface is a user interface designed to reuse existing skills for interacting appropriately with content."* [9], and focused on designing an interface that: Would reuse existing skills to ease the learning curve, was "invisible" in the sense that it allowed input through direct manipulations of the device without any use of buttons, dials or switches etc. as metaphors, and finally that took advantage of the users' own intuition through tacit knowledge within a given context – in our case, motor skills and balance. In this paper, we present three of the methods used during the study; a survey to gather requirements, a focus group to generate design concepts and a formative usability test conducted before the implementation of the balance interface.

3.1 Survey

We conducted a quantitative online survey (N = 248) with the purpose of identifying user requirements and needs in the prototype. We used the following three PMD product categories as a way of framing the questions around familiar designs: Self-balancing/Segway, e-bike and electric kick-scooter. The users were asked to assess various attributes such as size, weight, safety and speed in order to identify what people like and dislike about each device category. This resulted in a list of good and bad attributes for each category that would lay the foundation for the requirement specification and become the basis for the design of the prototype.

The target group was adult Norwegians with a daily transportation need, and particularly people living in urban areas. The timeframe was set to two months. Participants were mainly recruited using online forums, had a fairly even age distribution (Mean = 37.83, SD = 3.19), but a gender distribution skewed towards males (81 %).

3.2 Focus Group and Design Workshop

To create a set of initial design ideas from the survey results and requirement specification, a focus group was chosen. This is a common method to use in combination with surveys and the pairing of these two methods are one of the leading ways of combining qualitative and quantitative research methods [10]. Additionally, because of the easy access to students with previous HCI experience at our department, it allowed for the collection of multiple perspectives in a group of people who are ordinary users in relation to PMDs, but have years of experience in conducting user-centered design and research. As a result, the focus group was coupled with a design workshop, allowing the participants to create simple paper prototypes from the generated ideas.

The focus group was conducted over approximately 2 h and included 7 participants. All participants were master students associated with the Department of Informatics at the University, and 5 of them were students of the Design, Use, Interaction program with years of experience in fields such as HCI, UCD and UX. The focus group did not have a structured set of questions, but instead used the survey results to fuel the discussion and encourage the participants to discuss if and why they agreed or disagreed with the results, adding a qualitative layer to the survey findings. Following this discussion was a brainstorming stage, where the participants generated ideas based on existing man-powered means of transport. These ideas were then discussed in relation to the survey results, the opinions of the participants, and the balance user interface. The participants formed groups of two or three and created prototypes from the two ideas that were found to be the best match with post-it notes of different colors to represent the added components for motorization; motor, battery, and electronics. Each group then presented their design to the others and explained their thoughts on how the prototype would be controlled. In the weeks following the focus group, the participants were contacted via e-mail to evaluate additional prototype iterations.

3.3 Usability Testing

Drawing on the results from the two previous activities, we continued with the design of a skateboard prototype. The paper prototypes from the workshop were unified and improved though multiple iterations with the help of the participants from the workshop. The resulting prototype was then built as a functional and testable electric skateboard design.

Initial user testing of the design included simulating the balance control with an app on a mobile phone as a formative usability test. The test (N = 14) was conducted inside a long hallway at the department over the course of three days with the purpose of learning how the balance interface should be designed and implemented, as well as getting early feedback on the design. The participants were recruited from the students that were studying in close proximity to the hallway. The prototype gained much attention from bystanders, but many were too afraid to try it themselves and only wanted to watch. The participants were observed while executing a set of basic tasks such as acceleration, maintaining a constant speed, turning and breaking. After the test, they completed a short, one-page form about their thoughts on the design and balance interface. Each test took only about a minute to complete, but many participants wanted to try it for longer. All participants were students at the department (both bachelor and master students), aged between 20 and 31. The simulation of balance was carried out by asking participants to lean forwards to put weight on the front of the board to accelerate. The actual acceleration was accomplished using a slider control on a Bluetooth connected mobile phone controlled by the user.

4 Results

4.1 Results from the Online Survey

Of the 248 respondents, only 15 (6.0 %) reported that they currently own a PMD. The same number of people reported having good prior experience with PMDs, followed by 24.6 % having tried PMDs once or twice, 36.3 % had only seen them in use and 33.1 % had no prior experience. This show that even with few PMD owners, there is a fair share of people who have tried riding a PMD at least once (30.6 %).

There was a significantly higher acceptance for the use of e-bikes than for Segways or electric scooters. Table 2 shows the willingness to use the three vehicles as a daily means of transportation.

Table 2. Distribution of people who could see themselves use a Segway, e-bike or electric scooter daily

PMD	Would use	Would not use	Don't know	Already owns
Segway	13.7 %	78.6 %	7.3 %	0.4 %
E-bike	51.6 %	32.7 %	13.7 %	2.0 %
Electric scooter	19.0 %	69.4 %	10.9 %	0.8 %

Based on the respondents answer in the previous question, they were divided into groups of positive (for answers "would use" and "already owns") or non-positive (for answers "would not use" and "don't know") and asked about which attributes they found the most positive or the most negative for each device type. These questions were not mandatory, so respondents could continue without checking any attributes.

When it comes to the Segway results (Table 3), the participants were particularly unsatisfied with the price, how they are perceived by others, size and weight, and safety. They were most satisfied with ease of use, range and the environmental aspects. Additionally, people who are positive to Segway use, mostly checked the opposite reasons, compared to those asked to list negative attributes. The exception is the ambiguous "Replaces alternative transport" vs. "Prefer alternative transport", which is frequently cited by both groups (see Table 3). The positive reasons given in "Other" were related to the enjoyment and fun of riding the Segway, while negative reasons were mostly related to health and elaborations on how people are perceived.

Table 3. Positive (left) and negative (right) citied attributes of the Segway

Most positive Segway attributes		Most negative Segway attributes	
Ease of use	60.0 %	Price	68.1 %
Replaces alternative transport	57.1 %	How I'm perceived	44.6 %
Range	28.6 %	Prefer alternative transport	38.5 %
Environmental	22.9 %	Size and weight	28.2 %
Speed	20.0 %	Safety	23.9 %
Size and weight	17.1 %	Other	22.5 %
How I'm perceived	14.3 %	Speed	10.3 %
Other	11.4 %	Range	8.0 %
Safety	2.9 %	Ease of use	4.2 %
Price	0.0 %	Environmental	2.8 %

Interestingly, all positive attributes were cited more frequently with the e-bike compared to the Segway, and almost all the negative attributes were cited less frequently. Beyond this, the most notable differences were that "how I'm perceived" was

Table 4. Positive (left) and negative (right) citied attributes of the e-bike

Most positive e-bike attributes		Most negative e-bike attributes	
Replaces alternative transport	70.7 %	Prefer alternative transport	40.9 %
Ease of use	69.9 %	Price	34.8 %
Range	56.4 %	Other	33.0 %
Speed	47.4 %	How I'm perceived	16.5 %
Environmental	41.4 %	Size and weight	15.7 %
Price	28.6 %	Speed	5.2 %
Size and weight	21.1 %	Safety	4.3 %
How I'm perceived	17.3 %	Range	3.5 %
Safety	13.5 %	Environmental	2.6 %
Other	12.0 %	Ease of use	1.7 %

much more rarely cited as a negative attribute, and that “range”, “speed”, “environmental”, and “price” were cited much more frequently as positive e-bike attributes. The full list of e-bike results can be found in Table 4.

When it comes to electric scooters (Table 5), the results show that “size and weight”, “ease of use” and “price” were rated the most positively while, “prefer alternative transport”, “how I’m perceived” and “safety” were the most negative.

Table 5. Positive (left) and negative (right) citied attributes of the electric scooter

Most positive electric scooter attributes		Most negative electric scooter attributes	
Size and weight	63.3 %	Prefer alternative transport	41.2 %
Ease of use	53.1 %	How I’m perceived	36.2 %
Price	46.9 %	Safety	28.6 %
Replaces alternative transport	38.8 %	Other	19.6 %
Speed	28.6 %	Price	17.6 %
How I’m perceived	20.4 %	Range	13.6 %
Environmental	20.4 %	Size and weight	9.5 %
Other	16.3 %	Ease of use	8.0 %
Range	6.1 %	Speed	5.5 %
Safety	4.1 %	Environmental	0.0 %

4.2 Focus Group and Design Workshop Results

Only one of the participants had personal experience riding a PMD (during a Segway sightseeing tour), but all others were familiar with the concept. In general, all participants were in agreement with the main findings of the survey, stating that the e-bike was the most useful of the three because it operates and looks like a normal bike, and because it doesn’t stand out as much as devices with an unique look. One participant said: “The only one I’d use personally would be the e-bike. The Segway looks like it’s for obese or lazy people.” They also found the e-bike to be the safest option of the three and liked that it can be used even with a depleted battery. “If the battery runs out on a Segway, I’m basically stuck, but if it runs out on an e-bike, it turns into a normal bike”. The participants found the Segway category to be clumsy and impractical mostly because of its large size and weight, making it difficult to transport or use in combination with public transit systems, as well as difficulties related to parking. One participant asked, “What am I going to do with it when I go to buy groceries? It’s too big to go inside the store, right?” The participants all found the Segway to be better suited in specialized tasks and used for in-doors transport of large buildings like airports, shopping malls, hospitals and schools, and agreed that it “looks way too silly” for normal urban transportation. Regarding electric kick-scooters, the participants were less vocal, but expressed concerns regarding the safety and stability of the vehicle at high speeds. “Is it really stable at high speeds? I don’t think I would feel comfortable going 20 km/h on a kick-scooter.” Otherwise, they agreed with the results, that the smaller size and weight was a plus, but that an e-bike or normal bike is still a better choice in most situations. They also noted that PMDs in general would probably benefit substantially from better facilitation in the cities, like more dedicated bike roads.

The brainstorming stage resulted in a long list of ideas such as electric skateboards or longboards, rollerblades, roller skis, snow racers, snake boards and more. Out of this list, the participants found the skateboard/longboard and rollerblades concepts to be the best fit for the requirements and chose to continue with these in the paper prototyping stage. The participants formed groups and discussed the optimal location of the various components, represented using post-it notes, as they created the paper prototypes (see Fig. 1). The participants discussed various design concerns as they made decisions, such as initiatives to hide the components as much as possible, keeping the device lightweight and distributing the weight equally on the front and back of the vehicle. Some of the groups also made minor alterations to their designs when they saw what the others had created (Fig. 2).

Fig. 1. Pictures from the focus group (left) and design workshop (right)

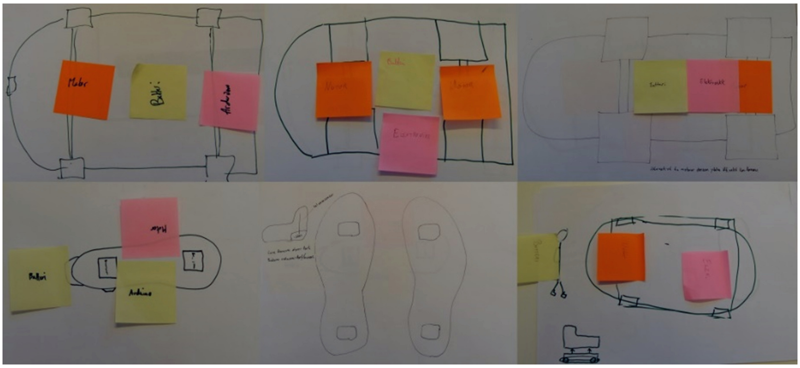

Fig. 2. Paper prototypes of the skateboard (top row) and roller blades (bottom row). Post-it note colors: Orange = motor, yellow = battery, pink = electronics (Color figure online).

4.3 Results from the Usability Test

In spite of several technical difficulties with the prototype during testing, virtually everyone who tried expressed how much fun it was to ride. The participants had mixed previous experience with skateboards and longboards (see Table 6), and those with little experience in particular had difficulties with keeping their balance and turning during their first few seconds on the board. However, they learned quickly and after only a minute you could see a noticeable difference, which was visible as they kept a straighter and more confident posture, showed improved turning ability and willingly increased the driving speed. Several of the participants wanted, on their own initiative, to ride the board back to the starting point after completing the test. Many of the participants also kept riding for longer than necessary, and some actually came back for more after a few minutes because they wanted to try again.

Table 6. Ratings of various attributes from the user test

Rating from 1 (very low) to 7 (very high)	Mean	Median	SD
Previous skateboard/longboard experience	3.29	3	1.94
Overall prototype satisfaction	6.14	6	0.84
Observed amount of leaning forwards and backwards	1.71	2	0.73
Observed ability to turn left and right	4.57	4.5	1.87

During the simulation, the participants were asked to lean forwards on the board to accelerate as if it was their body weight distribution that controlled the speed of the board. The amount of visible lean did not vary substantially between the participants (see Table 6). Some participants hardly showed any visible lean at all, and others leaned only a little bit. Thus, we did not witness large individual differences. The amount of lean on toes and heels (to turn the board) varied slightly more, but could have been related to the participants' previous board experience. Those with more experience leaned from side to side more visibly than those with less experience (Fig. 3).

Fig. 3. Participants standing on the prototype board

Next, the participants were asked how they would prefer the device to tilt elastically as they shifted their balance, between the choices: side-to-side (turning), front-to-back (accelerating/breaking), both or neither. 78.6 % of the participants said they wanted side-to-side tilt only, i.e. elastic when turning and isometric when accelerating and breaking, similar to a traditional longboard. Further, we asked how much weight should be applied on the front of the board before the vehicle starts accelerating. All participants gave values in a range between 60 % and 80 % of body weight (mean = 67.59, SD = 7.76). Finally we asked for suggestions on design improvements, and with the exception of two participants that called for balance as input rather than a simulation, all suggestions were related to various technical issues, mostly motor stuttering at slow speeds due to the use of an underpowered motor in the prototype (Fig. 4).

Fig. 4. Participants riding the prototype board during usability test

4.4 Design Implications

Revising our list of guidelines based on the results from the study, we present a list of design implications for PMDs using balance as input. We summarize these implications in Table 7. Most of the guidelines showed to be useful when designing a balance-based PMD interface. However, implication #1 was found only to be partially true while for implication #2 and #4, our results were inconclusive and further research is required.

Table 7. Design implications for balance-based PMD interfaces

Implications	PMD applicable
1. Elastic interfaces increase user experience over isometric	Partially
2. Leaning from side-to-side requires more effort	Unconfirmed
3. A movement based interface relies on movement-triggers and a social excuse to move	Yes
4. There are large individual differences in which movements feel natural	Unconfirmed
5. The device must be designed around the forms of movement as allowed by the human body	Yes
6. Intuitive and natural interactions relies on appropriate mapping between movement and function	Yes
7. Familiarity increases design acceptance	New
8. The interface should encourage visible body-movements	New

5 Discussion

As we have only simulated balance control, it is too early to draw any conclusions on the usability of the interface itself. Instead, we will evaluate the guidelines according to how well we found them to apply for the design of balance-based PMDs based on our results. When it comes to elastic vs. isometric interfaces (Table 7, implication #1), we found that for this form factor, maintaining the traditional skateboard design with elastic sides for turning and isometric front and back for accelerating and breaking was preferred by the vast majority of the participants. This could indicate that designing for familiarity in an interface is valued more than the added feedback gained from elasticity, and that a traditional skateboard design is preferred over a board with an elastic front and back, such as a self-balancing skateboard. However, this is not necessarily the case with other form factors. Similarly, we observed a lower amount of leaning on each foot (on the front and back of the board) compared to leaning on toes and heels to turn, which could indicate that side-to-side movement requires more effort (implication #2). On the other hand, it is certainly possible that this is simply a result of the participants knowing that any leaning on the front and back foot did not actually produce an effect during simulation. Furthermore, visible leaning is not required for changing ones distribution of balance between the feet, so this should be tested more thoroughly with a fully implemented balance interface.

As our design used an existing vehicle as a base and was kept as close to its original design as possible, users are given the same socio-cultural excuse to move while interacting with it as people riding traditional longboards (implication #3). Longboard riders certainly move while traveling, so these movement-triggers will transfer over to riders of electric boards. We witnessed only small individual differences in movements during the test, so we were unable to verify this implication (implication #4). There could be multiple reasons for this. First, operation of the board did not necessarily encourage large movements, thus it is expected to only see small movements being made by the participants. Had the design encouraged larger movements, the differences between participants may have been more noticeable when some of them were uncomfortable with performing large movements. Additionally, it is probable that people will be performing larger movements as they become more comfortable with the device. The participants only tested the vehicle for a few minutes, and most of them did not have extensive experience with a skateboard or longboard.

The proposed interface is designed to accelerate when the user leans on the front foot. We argue that this interaction is both appropriate and natural (implication #5 and #6) because it is what humans do instinctively to keep their balance when standing on an accelerating platform, thus the movement of the vehicle and user are working together to keep the user balanced and on the board. The opposite (leaning back to accelerate) would likely make the user lose their balance as the accelerating platform and the users balance would both contribute towards pushing the user off the board. Because of this, we consider both implications relevant for designing PMD interfaces.

Adding to the guidelines, we found it necessary to introduce a few additional design implications not covered in the literature. Both in the survey and focus group we found that the acceptance of a PMD would greatly increase if the design and interface was familiar (implication #7). Most people seem to be quite self-conscious when riding a PMD and they prefer to use vehicles that “blend in” in the urban landscape. We also found that devices where the rider has a static posture were perceived very negatively (implication #8). We would therefore encourage designers of future PMDs to take this into consideration and design interfaces that encourage some form of body movement. Whether this stems from a need for improved health or mere esthetics remains a question.

6 Conclusion

In this paper, we have presented a set of guidelines based on related work for the design of balance-based PMD interfaces. Using a survey, focus group, design workshop and usability test, we designed and tested a PMD prototype to evaluate our guidelines. Based on our results, we have verified and extended the guidelines to a list of design implications for PMDs with balance-based user interfaces. We found that most of the guidelines were applicable in our context. Additionally, we found that design and interface familiarity is essential for the acceptance and willingness to use a PMD, and that the interface should encourage visible body-movements in the interaction. As we have only simulated the interface in our tests, future work should further investigate these implications with a fully implemented balance interface.

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