PRACTICAL EXPERIENCES WITH THE PV POWERED COMPUTER MOUSE “SOLE-MIO”

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ABSTRACT: The research objective of the SYN-Energy project is to improve the understanding of solar-powered electrical devices. One of the activities has been the design and technical realization of a PV powered wireless computer mouse. In total, 15 “Sole Mio” PV powered mice have been manufactured. In this paper, we describe how test-users experienced working with the “Sole Mio” prototypes and discuss the rather bad energetic performances of some of the prototypes. Amongst these technical aspects, particularly user expectations and satisfaction with the Sole Mio concept are presented, and possible improvements of the design are evaluated. Finally, an attempt is made to extend the lessons learned for the specific “Sole Mio” case to a more general level of the design and testing of solar-powered consumer products. Here, it is found that future user related research should focus on quantitative investigations rather than qualitative evaluations: in how far and to what extent users are willing to expose device integrated PV (DIPV) devices to solar radiation pro-actively.
Keywords: Stand-alone PV Systems; Battery Storage and Control; Consumer Product; Device Testing, DIPV

1 INTRODUCTION

Within the framework of the SYN-Energy project [1], one of the focuses has been the design and technical implementation of a PV powered wireless computer mouse [2][3]. A realistic design for the PV mouse, named “Sole Mio”, was drawn up in which a solar cell was placed under a transparent cover within the mouse, with a NiMH battery providing storage capacity.

15 SoleMio prototypes were tested by a group of users during their daily work routine. User experiences and satisfaction were evaluated through interviews and user logs. In addition, electrical measurements were performed under light conditions at the desks as well as at the window sills of each use location. Also mouse power demands, PV charge currents and battery voltages were logged for a number of days.

In this paper, we describe how test users experienced working with the Sole Mio and evaluate user satisfaction with the product. In addition, possible improvements of the design are discussed.

2 THE SOLE MIO

2.1 General concept and design

The flat, rigid solar cell incorporated into the Sole Mio is placed underneath a double-bent, transparent plastic cover. Curved lines and double bent surfaces dominate, which is advantageous from the design perspective. At the same time, this PV incorporation allows for a relatively large solar cell area (approximately 27 cm^2, see Fig. 1). This is important, because estimated energy balances show that frequent use of the Sole Mio makes pro-active re-charging the device a neccessity (for example by exposing the Sole Mio to natural light at a window sill). Clearly, the larger the cell area is, the shorter required re-charging durations will be.

Figure 1: Photographs of three Sole Mio prototypes, each equipped with a different solar cell type.

It is no surprise that natural light offers much larger energy densities compared to artificial light. It is therefore required to re-charge the Sole Mio batteries by solar energy. The energy density of energy efficient artificial lighting simply is insufficient.

For this, we introduced the term “sun-bathing” [4]. However, the term remains to be further defined in future studies, because direct sunlight exposure may not necessarily be required; however, one may associate direct sunlight with “sun-bathing”. Nonetheless, exposure of PV to only diffuse fractions of solar radiation may be sufficient for specific applications.

2.2 Electronic configuration and Sole Mio components

The different components of the Sole Mio mouse itself (excluding the support structure) are depicted in Fig. 2. Users received their test-mice in a professional looking retail box including a manual to create a setting of a professional product testing.

The actual Printed Circuit Board (PCB) of the SoleMio mouse was extracted from commercially available wireless mice. Here, market research found charge demands of commercial products to vary by a factor of 4 to 5. The commercially available product with the lowest power demand at the time of the Sole Mio design (end of 2005), indicated in Table 1 as 'Wireless Optical 1', was sold by Microsoft as 'Intellimouse'. Meanwhile, energetically more economic mice operating with a laser instead of a light emitting diode (LED) have been introduced. However, the Sole Mio is based on 'Intellimouse' electronics and consequently LED technology.

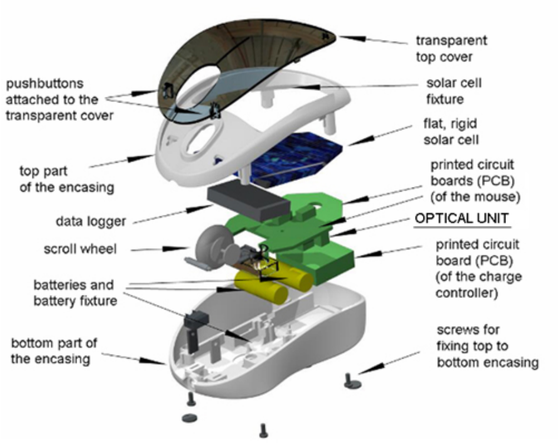

Figure 2: Sole Mio composition

The electronic configuration of the Sole Mio is based on a voltage converter (DC/DC voltage up-conversion) that charges the battery (NiMH type of AAA size and 800 mAh capacity), when the PV voltage is above 0.3 V. The voltage converter applies maximum power point tracking by measuring the IV curve of the incorporated c-Si or mc-Si solar cell every 10 seconds and adopting pulse-width-modulation based switching frequency. The voltage converter is incorporated on the PCB of the additionally incorporated charge controller, which protects the batteries from both deep discharge and overcharge. Should defined voltage thresholds be exceeded, either the solar cell or the mouse PCB is disconnected from the battery. Further, it is possible to recharge the battery incorporated into the Sole Mio by connecting the mouse to a USB port. This allows test users to continue working with the mouse should PV generated charge be insufficient.

2.3 Energy balance: Theory

Charge demand ranges can theoretically be calculated based on expected device use times between 4 and 27 hours mouse motion per week (Percept Technology Labs, 2004). The MS 'Intellimouse' uses three energy management system (EMS) levels to minimize energy consumption. Additionally, battery runtime is increased by underlay material dependent LED intensity. A DC/DC converter provides the mouse circuitry with sufficient voltage (3.5 V) with (primary) battery voltages as low as 0.6 Volt. Surprisingly, this product is not equipped with a simple energy-saving 'on/off'-switch, which enables users to completely switch the device off, but relies on 'sleeping mode' activation. When mice are transported (e.g. with a laptop), no 'sleeping' mode will be activated. The user cannot prevent the device wasting energy.

The amount of PV generated charge depends on a number of factors. Primarily, solar cell area, effective cell efficiency and the amount of available irradiation determine charge yield. However, lower irradiance levels indoors and the sheer endless variety of indoor environments, make energy balance estimations of the Sole Mio rather challenging. To this end, complexity can be reduced by omitting factors such as battery self discharge, and only considering required "sun-bathing" durations required to fully charge the Sole Mio batteries. Particularly as the differing charge demands of the Sole Mio prototypes imply rather uncertain energy balances, the theoretical power demand specifications are used to calculate required sun-bathing durations, listed in Table 1. For this, battery charge efficiency and efficiency of the electronic circuitries is assumed 90 % constant, lowering the charge generated by an assumed 10% efficient solar cell.

Table I: Required daily sun-bathing durations to fulfill light, medium and heavy device use by PV charge.

Window sill orientation and assumed irradiation		Daily sun-bathing [h] to fulfill light, medium and heavy use		
South	[500 W/m^2]	< 0.1	0.1	0.2
East/West	[250 W/m^2]	< 0.1	0.2	0.4
North	[100 W/m^2]	0.2	0.7	1.1

This energy balance estimation is of course oversimplifying matters. Influential factors such as e.g. battery self discharge are omitted, however, leading to relatively easily assessable sun-bathing benefits. Of course, also the assumed irradiation intensities at window sills facing south, east/west and north can be argued: both much higher and lower values of irradiation than listed will be present in practice. However, how (over-) simplifying the above calculation is, it shows that the Sole Mio "sun-bathing concept" is principly feasible, as observed "sun-bathing" behavior evaluated in the next section shows.

3 USER TEST RESULTS

User tests with the Sole Mio were carried out in the period September-December 2007 at three locations (Universities of Delft, Twente and Utrecht as well as at the KNMI). Some test users belonged to scientific staff (not involved in the project), others to the secretarial staff so that all users usually used their computer for most of their working day. In total, 14 people used the mouse for several weeks in their daily practice, some doing a short test (5-6 weeks), others a longer test (10-12 weeks).

Users received advance instructions regarding mouse use. Each user kept a log to provide insight into their behaviour and experiences. Halfway through the test and at the end the logs served as a basis for an interview with each user to extract further relevant information. At the end of the test a collective interview was held with all users at one location to extract further information regarding the interaction between the users themselves.

3.1 User assessment of the overall design

Almost all users found the mouse rather big and poorly adapted to the shape of the hand. The shape of the mouse (especially width and height) clearly needs redesign. However, about half of the users liked the transparent cover as it gave a clear view of the solar cell. One user suggested to make a larger part of the mouse transparent to make the cell catch more light. In some cases the optical part of the mouse (the movement tracker) did not function well, making users even more aware this was a protoype. This contributed to an overall feeling of not working with a commercial, fool-proof product.

Some users suggested to detach the PV cell from the mouse and integrate it in the support that stood in the window permanently. By placing the mouse in the support occasionally it could be charged from a battery in the support. This could be designed as a modular system.

Nonetheless, the majority of users had faith in the overall design and believed the problems, related to the prototype stage of the SoleMio device, could be solved. Interestingly, two users, independently from each other, indicated that this was a good product to stimulate awareness on energy use and possibilities for alternative forms of energy (generation).

3.2 Overall user expectations

Most users did not have a clear idea about what to expect when they started the test. Everybody participated enthusiastically and pursued their own charging tactics.

Across the whole testpopulation the varied performance of the mice clearly had a negative impact on the overall valuation of the concept. Still, as has been indicated above, users also expected that the problems could be overcome by further development. This made it difficult to assess to what extent users had developed an attachment to the mouse.

3.3 Sun-bathing

Positive judgments regarding sun-bathing were especially related to the fact that the mouse performed well when treated well. However, users differed in their tolerance regarding whether the mouse functioned well in principle (see discussion of the energetic performance in the following section). The vast majority of users indicated they expected the mouse to always perform flawlessly. Positive reactions could be increased by a proper instruction on the charging procedure: how often, the best time, recharging speed of the mouse under different weather conditions, etc.

A charging tactic followed by virtually all users (independently from each other and without having been instructed to do so) was to place the mouse in the window at the end of each working day. When left there over the weekend and during those days the user was not working at the office, this led to flawless operation of the mouse for quite some time. This approach may have been provoked by the fact that the test period being during the darker part of the year: a real challenge for the mice's performance. During this time it was crucial to sunbath the mouse as much as possible.. Some users indicated that they felt the mouse should require charging only once a week, i.e. over the weekend.

For an improved definition of sun-bathing requirements, the following issues were deemed to be important:

- Required frequency of charging must be clear;
- Signalling when charging is required;
- How charging should take place must be clear;
- Reliability of working with the PV powered product once charging has been done.

Negative judgments regarding sun-bathing were particularly related to the former issue, the unreliability of the mouse after sun-bathing. In some cases the mouse was insufficiently charged, even after placing it on a brightly illuminated window sill for entire weekends.

Regarding the above described circumstances of the user-tests, it was unfortunately not possible to determine user willingness related to acceptable sun-bathing durations quantitatively. The required sun-bathing frequency differs from location and Sole Mio prototype (see sub-section 2.3 and section 4 for details), so that sunbathing durations cannot be evaluated by the different users by measuring battery capacity before and after testing. In addition, a significantly larger number of test users than the 14 involved in this study would be necessary for quantitative analysis.

3.4 User feedback on charging signal

Also on this issue users gave varied feedback. Two users indicated that it was unclear to them whether the signal indicated that charging was taking place or that charging was required. The LED-signal functioned quite differently across the test-mice, ranging from almost continuously blinking (and still being able to use the mouse for days) to hardly ever blinking (and flawless operation as well).

Users united in their desire for a more differentiated type of feedback, asthe percentage of remaining charge in the battery. Many referred to the state-of-charge indicators on mobile phones or laptops. Most users preferred the indicator to be as simple and energy efficient as possible. One user would also like to have seen the impact charging had on the battery status. Most users were not in favour of using intelligent software which they considered either too complicated or unreliable. One user suggested that rather than using a low state-of-charge battery indicator, the signal should signify the mouse to be sufficiently charged for use.

3.5 User willingness to buy a SoleMio

Based on this test and on interviews we held earlier in the project to identify user needs, we distinguish two relevant types of customers:

- A group appreciating a PV mouse but prefering reliable, wired mice that are as cheap as possible
- A group that seriously considers buying a PV mouse that would cost about € 10 extra

Many users indicated to be willing to spend a total of approximately €50 for a Sole Mio mouse. Whether test-users would actually purchase the Sole Mio, if it was available, or whether the user-tests stimulated the interest into this type of product, however, remains relatively unclear.

4 DISCUSSION

4.1 Analysis of the energetic mice performances

It appeared that the tested mice prototypes varied in their technical performance. This was not just due to differing charge demands and power ratings, respectively, but also down to the different testing locations, as illustrated in different colors in Figures below.

Figure 3 shows the frequency of occurrence of charging power obtained by shunting the Sole Mio incorporated cells and measuring the voltage drop. Therefore, however, the differences in charging power are not only related to differences in irradiation conditions at the specific testing sites, but mostly due to differences in the technical performance of the solar cell/MPPT combination in each mouse.

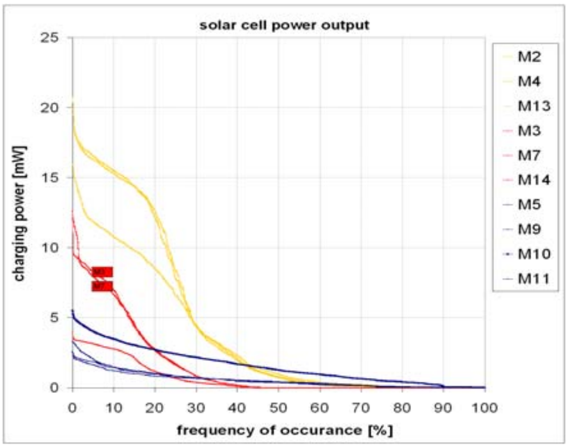

Figure 3: Charging power density for 10 Sole Mio mice placed at the window sill for 5 days

Even more important, however, is the fact that the power ratings of the original mouse electronics together with the additionally incorporated charge controller very much differed from those power demands measured for the manufactured prototypes (see Table 2).

Clearly, the additional incorporation of a separate charge controller implies that the power demand of the original mice electronics increases. However, as listed in Table 1 we measured up to 30mW Sole Mio device power demand, or relatively speaking: up to 4 times the power demands stated (and measured) for the original mice electronics. Here, we found that the much higher than expected power demand, was related to the optical unit of the mice electronics (see Fig. 2 for the location on the PCB). If the Sole Mio was exposed to mechanical blows, the transparent plastic lens which incorporates the LED possibly become loosened.

A fully loosened lens leads to a continuously shining LED, not only wasting charge but actually emptying the battery in rather short periods (roughly one day for a fully charged 800mAh AAA battery as incorporated into the Sole Mio prototypes). Re-manufacture of the optical unit did reduce the power demand, although not to the expected level regarding the power ratings of the original electronics but only to those figures in Table 2.

Due to this mechanical flaw, some of the prototypes have very differing power rating, which may change during the course of time (e.g., a lens loosened to a greater extend automatically increases LED intensity).

Table II: Theoretical and actually measured power ratings of the Sole Mio electronics and charge controller

Power rating in EMS-modes 1-active, 2-sleep, 3-deep sleep	*Demand [mW]*		
	1	*2*	*3*
Original mice electronics	*7.0*	*0.57*	*0.09*
Sole Mio – theoretically resulting power demand	*9.2*	*2.8*	*0.02*
Sole Mio – with malfunctioning optics	*10-30*	*5-20*	*0.5-10*
Sole Mio – with Re-manufactured optical unit	*10-15*	*5.5-15*	*0.3-15*
Charge controller electronics	*0.5*	*0.5*	*0.01*

Taking into account differing stand-by power demands of each prototype, battery voltages as shown in Fig. 4 consequently show a very large spread, despite the rather short period shown of only five days.

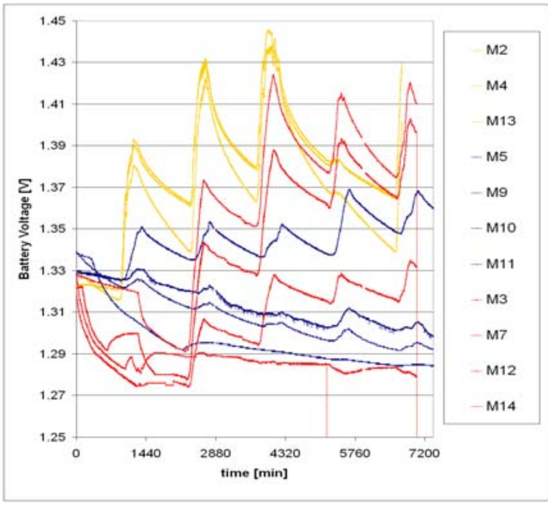

Figure 4: Battery voltages for charging 10 Sole Mio mice at the window sills for 5 days.

4.2 Design optimization: re-configurating the electronics

Aside of possible improvements of the design-concept (i.e., a design users would perceive as less “big and bulky”) the previous section shows that a re-design of the electronics would be greatly benefitial for the overall charge balance of the Sole Mio. Note that this is partly also owed to the fact that rather recently chip manufacturers started to offer dedicated Integrated Circuits (ICs) for Device Integrated PV (DIPV) applications, which when designing the Sole Mio mice electronics (in 2005-2006) was not yet the case. For example the TPS61200 chip from Texas Instruments offers seamless integration of both PV and storage unit. If this trend continues, future ICs can be expected to allow for easier electronic integration including improved SOC indication for PV powered electronic systems.

On top of charge controlling, the electronics should provide a battery status indication It was decided to only use battery voltage as battery SOC indication. Here, the selected NiMH battery type only allows indicating battery SOC as either 'full' or 'almost empty', due to rather SOC independent voltage potential of NiMH batteries. It would be desirable to indicate battery SOC through a bar graph composed of four or more elements. Moreover, indicating the positive influence of "sun-bathing" may encourage users to "sun-bath" the mouse more regularly.

4.3 Lessons learned for DIPV product design

When aiming to extend the lessons learned for the specific "Sole Mio" case to a more general level of DIPV product design, we found that two different problem categories in DIPV product design can be distinguished.

The first problem, however, is related to product design in more general terms, rather than PV technology was explicitly concerned. The sheer endless variety of DIPV products that is theoretically possible simply inherits a high diversity in applications. Therefore, "learning from scratch" is required regarding the specific DIPV product case, as long as no product-specific experts are involved in the design process. In the specific case of the Sole Mio this has been the imporance of the optical unit and its sound mechanical incoorporation, respectively (see sub-section 4.1). However, this problem would be the same if no PV was incoorporated, and designing the product encasing from scratch. Therefore, the involvement of not only PV experts but also experts in the specific field of the specific product application may of course help avoiding bad functioning (DIPV) products.

The second problem we see is related to remaining uncertainty regarding user behavior. It is found that "pro-active sun-bathing" a DIPV product that operates in the mA power range is *the* performance parameter, not only influencing but actually determining the overall energy balance. However, how much users are willing to sun-bath a DIPV product how often is not known. Thus the energy balance remains uncertain. This is very much in contrast to DIPV devices that require functioning at energy densities of artificial lighting conditions (i.e., at spectral compositions of energy efficient lighting). Consequently, such DIPV products can grant PV powered product operation anytime, anywhere, as long as a minimum illumination intensity defined as design-cornerstone during the design process (and accordingly dimensioned PV size) illuminates the DIPV solar cells. However, such DIPV applications have charge demands in the order of magnitude of µA, as otherwise solar cell areas would be unreasonably large.

Therefore, future user related research on DIPV devices operating in the mW power regime should focus on quantitative investigations rather than qualitative evaluations: in how far and to what extent users are willing to expose device integrated PV (DIPV) devices to solar radiation pro-actively.

5 SUMMARY AND CONCLUSIONS

This paper presented how test-users experienced working with the "Sole Mio" prototypes and discussed the rather bad energetic performances of some of the prototypes. Amongst technical aspects, particularly user expectations and satisfaction with the Sole Mio concept are presented, and possible improvements of the design are evaluated.

It is difficult to extend the lessons learned for the specific "Sole Mio" case to a more general level of the design and testing of solar-powered consumer products, as very product-specific problems were encountered. However, at the same time this suggests that involvement of not only PV experts but also experts regarding the specific product type may help the industrial design engineers to successfully create fully functioning DIPV appliences not dis-sattissfying the end user.

Finally, it is found that future user related research should focus on quantitative investigations rather than qualitative evaluations: in how far and to what extent users are willing to expose device integrated PV (DIPV) devices to solar radiation pro-actively.

ACKNOWLEDGEMENT

We would like to thank all test-users who participated in the Sole Mio user tests, Martin Verwaal for work on the electronics, and SenterNovem/NWO for funding the SynEnergy project and therefore financing this work.

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