A SOLAR POWERED WIRELESS COMPUTER MOUSE: DESIGN, ASSEMBLY AND PRELIMINARY TESTING OF 15 PROTOTYPES

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ABSTRACT: The concept and design of a solar powered wireless computer mouse has been completed, and 15 prototypes have been successfully assembled. After necessary cutting, the crystalline silicon cells show satisfactory efficiency: up to 14% when implemented into the mouse device. The implemented voltage conversion unit that is needed to increase the solar cell voltage for charging one single or two series connected NiMH batteries, has a conversion efficiency of up to 50%, which leaves room for further improvement. In the coming months, an extensive user test will be conducted, including user-related aspects such as the willingness to pro-actively sun-bath the mouse.
Keywords: Stand-alone PV Systems; Battery Storage and Control; Consumer Product

1 INTRODUCTION

Photovoltaic (PV) cells have been introduced in consumer products as early as the mid-eighties and have found many applications in consumer products since then, although only a few *mainstream* products exist, e.g., calculators and wristwatches. The present knowledge base, especially for product designers, however, does often not cover the knowledge base necessary for the design of PV-powered consumer products in daily practice [1]. We therefore have embarked on a study (the SYN-Energy project [2]) that aims to fill these gaps with the development of data, tools and methods that support the developers and designer of PV-powered products. Like any industrial product development project, the SYN-Energy project has a multi-disciplinary character, bringing together natural, technological and social scientists from three Dutch Universities, i.e., Delft University of Technology, Utrecht University, and the University of Twente.

As a challenging case to investigate incorporation of solar cells into consumer products, a solar powered wireless computer mouse (SPM) was selected [2] and evaluated [3] in previous papers. In the current paper, we will focus on 15 SPM prototypes assembled in the meantime. First, we will introduce the developed “SPM” product concept [4] and describe the functional principle of the SPM prototypes. Thereafter, we investigate component performance, i.e., the efficiency of incorporated solar cells and the efficiency of a voltage stepping unit integrated into the charge controller. Finally, we present measured time series of generated charge at a selected, “typical” indoor use environment (office desk).

The findings of this paper show the required technical improvements yet to be achieved for the case of the solar powered mouse we developed, and lead to recommendations of issues to be investigated during product user tests that are planned in the coming months [5].

2 THE SPM PROTOTYPES

The SPM prototypes make use of a newly designed encasing and commercially available wireless computer mouse electronics. The additionally implemented solar cell charges secondary batteries, protected from deep discharge and overcharge using a voltage regulated charge controller. The flat, rigid solar cell incorporated into the mouse encasing is placed behind a double-curved, transparent cover. This concept eases the integration of the rigid solar cells into the SPM’s encasing, and maximizes solar cell aperture area at the same time. The different components of the SPM are depicted in Fig. 1.

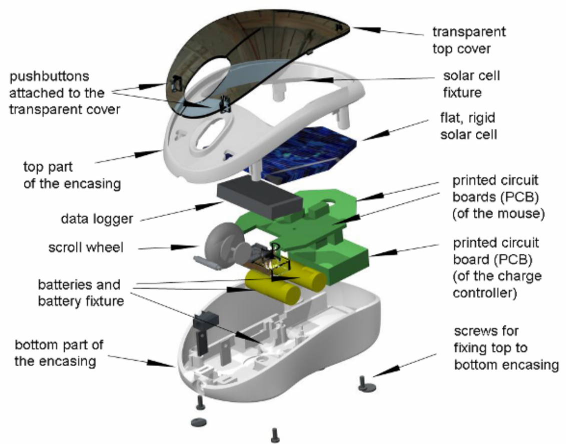

Figure 1: Final design concept of the SPM prototypes

From the design-perspective, curved lines and double bent surfaces dominate the SPM design concept. Straight lines and flat surfaces are avoided as much as possible, accounting for identified user desires during qualitative focus group user interviews [6]. Fig. 2 shows photographs of three assembled prototypes, each equipped with a different solar cell type.

The three different solar cell types implemented into the 15 SPM prototypes are five multi crystalline silicon (mc-Si), five mono crystalline silicon (c-Si) and five hydrogenated amorphous silicon (a-Si:H) solar cells.

The crystalline silicon solar cells are not commercially available in the desired shape. Therefore, cutting these cells was required, performed by laser scribing at the Energy research Centre of the Netherlands (ECN), followed by subsequently breaking the cells into the desired shape. In order to prevent cell breaking once the cells are implemented into the mouse, a thin plastic layer was attached to the cells’ back side. This also

Figure 2: Photographs of three SPM prototypes each equipped with a different solar cell type

successfully prevents breakage of cells, if the SPM accidentally falls from a desk. We did not apply any front side protection, accepting lowering cell efficiencies due to accidentally scratching / touching cell surfaces though keeping the visual appearance of the cells "as is", and limiting required production effort at the same time.

The battery unit incorporated into the mouse originally consisted of 2x 2/3rd AAA batteries of NiMH type, providing a capacity of 600 mAh if fully charged (parallel configuration). In the meantime, the design is feasible to be powered by a single AAA sized NiMH battery as well. Note that a battery capacity of around 600 mAh is *much* smaller than the capacities commonly used in ordinary wireless computer mice measuring around 5000 mAh (i.e., 2 AA sized batteries).

The charge controller protects the newly implemented secondary batteries from deep discharge and overcharge, realized by a rather simple, voltage regulated device. Therefore, also the concept of battery state of charge (SOC) indication is simple as well, i.e., not enabling *sophisticated* user interactions. However, an implemented LED is switched into blinking mode, if the battery voltage drops below a specific voltage threshold. As a result, users are encouraged to "sun-bath" the SPM, i.e., to place the SPM at a bright place at or close to the windowsill. Voltage thresholds applied within the charge controller unit are listed in Table 1.

Table I: Voltage thresholds of the charge controller

	Applied voltage thresholds	
Overcharge protection	1.35 V	1.40 V
Empty battery warning	1.10 V	1.15 V
Deep discharge protection	1.00 V	1.05 V

3 EVALUATING COMPONENT PERFORMANCE AND OPTIMIZING MOUSE ELECTRONICS

In this section, we will evaluate the energetic performance of the crystalline silicon cells and the performance of the voltage conversion unit implemented in the charge controller electronics.

3.1. Crystalline silicon solar cell performances

The efficiency of the commercially available crystalline silicon cells we started with was well above 16% (at standard testing conditions (STC): intensity 1000W/m^2, AM1.5 spectrum, 25º C), i.e., solar cell efficiency at no record but well at state-of-the-art performance concerning today's industrially produced crystalline silicon solar cells.

However, a number of technical issues lower cell performance in practice. First, the non-rectangular shape of the SPM cell causes the front metallization pattern to induce much higher series resistance related losses. Efficiency is measured at STC conditions, thus at high intensity of one sun. As the mouse is to be used indoors, at lower irradiance, an efficiency decrease caused by the increased series resistance will not be very relevant in practice. Second, irradiance that reaches the cells is lowered due to absorption within and reflection of the plastic interface(s) of the transparent cover, which has been one important doubt during investigation of design concepts of the SPM [2]. Therefore, the short circuit current decrease with and without the plastic cover attached to the prototypes has been measured (see Fig. 3). Third, the plastic encasing slightly lowers the active solar cell area by masking the edges of the implemented cells.

Fig. 3 shows measured absolute cell efficiencies of the 10 crystalline silicon cells and measured short circuit current ratio (with and without plastic cover), representing the transmission of relevant radiation fractions through the transparent plastic cover.

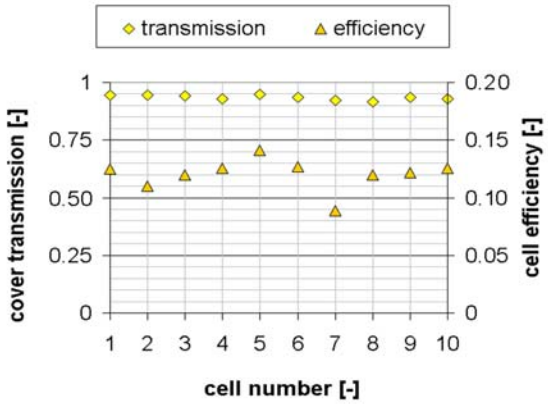

Figure 3: Measured transmission of the transparent cover and efficiency of the (mono and multi) crystalline silicon solar cells.

As depicted in Fig. 3, reflection and absorption losses are around 5-8% only, however, measured at a solar simulator where light originates directly from above (with correlated low reflection at vertical incident angles). Cell efficiency is around 12% for 7 out of the 10 cells; only one single cell shows 14% efficiency. Cell number 7 has been accidentally broken from underneath (i.e., curled connecting cables actuating from the backside) during SPM assembling, explaining the very low 9% efficiency (disassembling the cell would very likely destroy it, so we decided keeping the few spare cells untouched).

3.2. Voltage conversion unit performance

The voltage conversion unit has been realized in a boost converter topology and is implemented into the charge controller electronics. The voltage stepping unit is required in order to provide battery charge at a sufficient voltage level for re-charging the secondary batteries (i.e., at 1-1.5 V) by only a single solar cell (i.e., 0.2-0.5V and 0.3-0.6V for c-Si and a-Si:H cells, respectively). Note that battery voltage depends on a specific battery state of charge (SOC) and solar cell voltage depends on specific irradiance levels available for charge generation.

In order to supply the charge controller electronics with sufficient voltage, the original concept used two batteries connected in series. This implies that a very high voltage difference had to be handled by the switching device (i.e., battery voltage between 2.0-2.8V). Several aspects, however, led to an updated electronic design, making it possible that also a single battery can be used as energy storage unit. Here, the battery voltage range will consequently be a factor two lower (i.e., battery voltages between 1.0-1.4V depending on battery SOC).

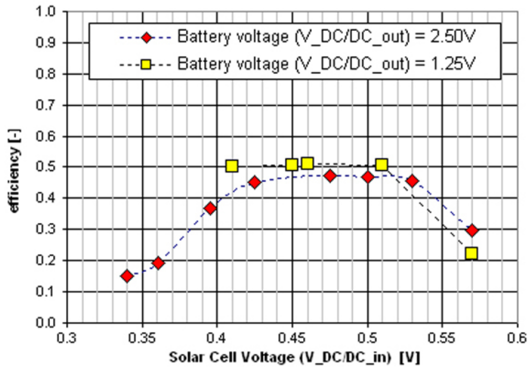

Figure 4: Very low voltage conversion efficiency (max. 50%) of the first voltage conversion unit

Figure 4 shows measured efficiency of the voltage conversion unit as a function of solar cell voltage for the two cases, a single battery and two batteries connected in series as the power supply of the mouse. Obviously, a maximum efficiency of only 50% has been obtained. Efficiency was determined by measuring voltage and current at both solar cell and battery with a time resolution much higher than the duty cycle of the switching device (using an oscilloscope, thus including transient peaks of voltage and current).

3.3. Maximum power point tracking (MPPT)

In addition, the voltage conversion unit realizes a maximum power point tracking (MPPT) feature. The MPPT feature will lead to rather high energetic benefits due to better matching solar cell voltage, because it is very likely that irradiation conditions will heavily vary during practical device use (i.e., the computer mouse will be used indoors at rather low irradiance, but may occasionally be "sun-bathed", see section 4). Solar cell voltages will vary accordingly. Due to the very low power domain that a wireless computer mouse device is operated at (see section 4), a very low own consumption of the MPPT feature is especially important. Here, the MPPT algorithm executes only each 10 seconds, as a trade off between better matching the operation point of the solar cells more often and the charge demand per duty cycle of the MPPT feature.

4 ENERGY BALANCE

The electronics of the commercially available wireless computer mouse applied in the SPM prototypes proved to have the lowest power demand of that kind of products at that time (end of year 2005). According to quoted figures by the mouse producer [7] we determined the power demand of the mouse product, listed in Table II.

Table II: Power demand of the mouse electronics

Power-Mode	1	2	3
Power demand	7.0 mW	0.57 mW	0.09 mW

With an active solar cell area of 25 cm^2, a satisfactory power output is obtained: testing the mouse at a solar simulator up to 350 mW power (at 14% conversion efficiency) is generated by the crystalline silicon cells to charge the secondary batteries of the mouse.

However, the incorporated PV unit will of course not be operated at a solar simulator and in practice the energy yield will be *much* lower [8]. Only very little irradiation may be available in the indoor use environment. One also has to account for spectral effects, because thermally high efficient glazing systems [9] will filter those spectral fractions of sunlight at which especially crystalline silicon cells show high performance. Finally, efficiency of especially crystalline silicon solar cells decreases logarithmically towards lower irradiation intensities (i.e., below 100 W/m^2) [10].

4.1 Use and user related aspects

Users need to be informed on the requirements to place the SPM at illuminated spots, i.e., to place the mouse at or close to the windowsill, if the device is not used for some time. Therefore, we distinguish two main irradiation scenarios based on the *location* the SPM is used at, to encourage the user to pro-actively "sun-bath" the SPM. As depicted in Fig. 5, we distinguish two scenarios: (1) @Sun Bathing and (2) @Office. The width of the arrow thereby corresponds to available irradiation, which of course also depends on the current weather situation outside.

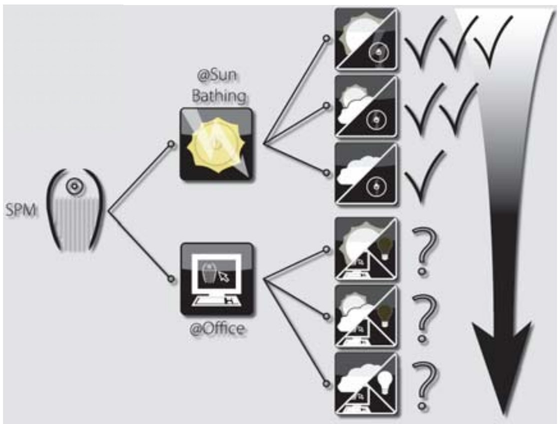

Figure 5: Place the mouse at illuminated spots regularly!

As depicted in Fig. 5 by question marks, irradiation conditions at the actual location where the mouse is used is uncertain (i.e., a specific desk where the computer is located can be situated in all kind of architectural surroundings). If the considered office place receives much daylight, however, here sufficient charge can be generated by the solar cells implemented into the mouse. We illustrate this by depicting measured charge flow for a SPM situated at a regular office desk at Delft University of Technology. Here, we measured the power output delivered by the solar cells and the power with which a separate battery (i.e., not serving the current charge demand to operate the SPM) is charged by using the sun's energy. Figure 6 depicts the measured time series (10 seconds sampling rate, minutely logged values, time period of three hours).

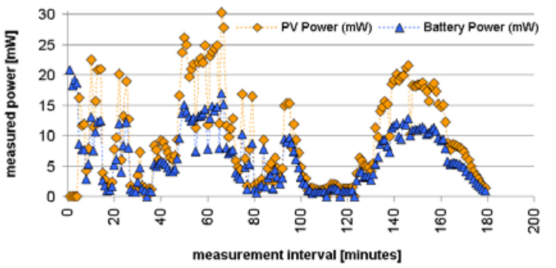

Figure 6: PV and battery power measured for 3 hours of a SPM located at a desk at TU Delft, The Netherlands

As shown in Fig. 6, the battery connected to the PV unit charges with more than 10 mW for considerable amounts of time. Note that between minutes 100 and 120 the device is actively used (i.e., the mouse is used in order to perform work on the computer), with solar cells of course being covered by the hand of the user. Consequently, this lowers battery charging to almost zero. However, although the mouse is not placed directly at a windowsill but is actively used as a regular computer mouse, battery SOC increases by around 8 mAh during the 3 hours that have been measured (not shown).

4.2 User tests to be conducted

In the coming months, the 15 SPM prototypes that have been assembled will be tested by actual users. Figure 7 shows the first prominent test person of the test phase, Mrs. Jacqueline Cramer, Minister of Housing, Spatial Planning and the Environment in The Netherlands.

Figure 7: The very first SPM prototype handed over for testing to the Minister of Housing, Spatial Planning and the Environment of The Netherlands, Mrs. Jacqueline Cramer

It is very difficult to estimating required irradiation conditions that grant 100% solar powered operation. Several aspects and many uncertainties makes calculating the energy balance a difficult task. Therefore, it is difficult to ascertain user specific "sun-bathing" requirements that grant 100% solar powered operation as well, especially if the exact location of device use is not known. The user test phase should, besides investigating the experiences of the users and user satisfaction, especially focus on user willingness to pro-actively "sun-bath" the SPM. In addition, the irradiation conditions of the specific test site are important and will be measured with reference cells at the window and the desk.. Here, especially such locations at which downtimes of the SPM occurred (i.e., a lack of energy not provided by the solar cells), should be reported together with a technical description of daylight conditions at the specific site. Three SPM prototypes that are equipped with miniature sized data loggers will help evaluating energy balance related aspects in greater detail.

5 CONCLUSIONS

We presented the concept, design and the successfully assembled prototypes of a solar powered mouse. The crystalline silicon solar cells show satisfactory efficiency: up to 14% when implemented into the mouse device. The implemented voltage conversion unit that boosts solar cell voltage in order to charge a single or two series connected NiMH batteries has a maximum efficiency of 50%, thus needing further efficiency improvement.

Extensive user test will be conducted in the coming months, investigating user related aspects. Besides technical aspects, we will focus on user willingness to pro-actively "sun-bath" the SPM.

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