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An Energy-Neutral, WiFi-Connected Room Display with Hand-Crank–Based Energy Harvesting

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Abstract

The use of electronic door displays has evolved over the last years at the Friedrich-Alexander-Universität Erlangen Nürnberg (FAU). This trend comes with two major problems regarding energy efficiency when installing new displays: 1) The retrofitted installation of displays requires power supplies for each display, 2) installed displays continuously waste energy.

In this proposal, we present the HanDi prototype, a hand-cranked display that is connected to the Internet via WiFi and can easily be installed at any door to visualize the room plan or other information. Using the university's central room-management infrastructure UnivIS, HanDi periodically updates the shown information. The electronic-ink–based display is equipped with an energy-harvesting mechanism using a hand crank to enable energy-neutral operation without the necessity of stationary power supply. Since HanDi is aware of its internal state of charge, it encourages users to refill the battery with the attached hand crank when the available energy is low. The energy-harvesting mechanism solves the energy-supply problem of information displays and, additionally, raises the user's energy awareness that services they have grown used to do not necessarily come for free. Our evaluations with the first HanDi prototype show the applicability of our approach.

1 Motivation & Problem Statement

The use of electronic, remote-controlled displays provides a convenient means to present information at the university, for example, room plans at doors. Unfortunately, standard LCD or LED displays continuously consume energy, even though their active service is required only for a limited period of time each day. However, recent technology advances put electronic ink (also e-paper, or e-ink) displays into focus [4], since they preserve the currently shown image without steady power consumption, making them ideal for room displays where information changes infrequently (i.e., on a day-to-day basis). Inside HanDi, we use a low-cost e-ink display with sufficient resolution for the use of displaying room information.

Nevertheless, even if the display does not continuously consume energy, once the image is installed, the update mechanism requires energy in order to receive updated room information. In our usage scenario, we allow room-plan updates every third day. Usually, a power supply is not available at existing room entrances and the installation of such power supplies is cost-expensive. Even when having 230 V AC available, transforming it to the required 5 V DC leads to continuous energy loss. The approach of using (rechargeable) batteries is also no ideal option, since removing the displays for exchanging the batteries is labor-intensive when considering hundreds of displays. In our approach with the HanDi display, we use a small hand crank allowing users to recharge the display when energy is low, thereby solving the problem of stationary power supply in an energy-neutral (i.e., energy-self-sufficient) way.

Our idea proposal is structured as follows: We first provide details on the HanDi approach and its implementation in Section 2. In Section 3, we evaluate HanDi's energy efficiency to validate the approach. We discuss related approaches and future work in Section 4 and Section 5 concludes.

Figure 1 *Left image*: Per default, the display shows the current room plan and system's remaining runtime with the current state of charge (see *Laufzeit*). *Right image*: Once the level of charge does not allow for an update, the display shows a message indicating that turning the attached crank will deliver updated room information.

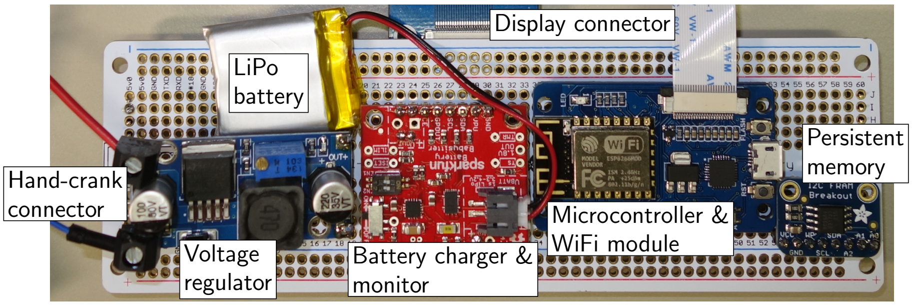

Figure 2 The electronics of the current HanDi prototype include components for energy harvesting, state-of-charge assessment, data collection via WiFi, and displaying the room plan.

2 The HanDi Approach

Figure 1 shows the two modes in which HanDi operates. When enough energy is available in the integrated (rechargeable) battery, HanDi collects new data from the UnivIS server, which is the university's central infrastructure for room information. Additionally, calendars (in iCal format) are a second source of information for the room display. HanDi displays room information of the current and the following two days (see left image in Figure 1). The system has a mechanism to precisely assess the current state of charge (see Section 2.1) and has knowledge of the energy consumption of specific actions (i.e., collecting data from server, refreshing display). When the state of charge is low, HanDi uses these prior determined energy-consumption values to decide whether to display a message that indicates that users have to turn the crank in order to receive updated information (see right image in Figure 1).

The design of HanDi comprises efficient energy management, both from the hardware side (i.e., hand-crank–based energy harvesting) and the software side (i.e., forward-looking energy planning). Additionally, we designed and manufactured a 3D-printed enclosure for all components that shows the individual room number and that is also stable enough to withstand the forces involved while turning the integrated hand crank. We go into further detail on the hardware (see Section 2.1) and the software (see Section 2.2) in the following two sections.

2.1 Hardware Design: Zero Standby Cost

Figure 2 shows the main electronic components of HanDi: the hand-crank generator is connected to a voltage regulator, protecting the system from malicious behavior (i.e., cranking extremely fast). The

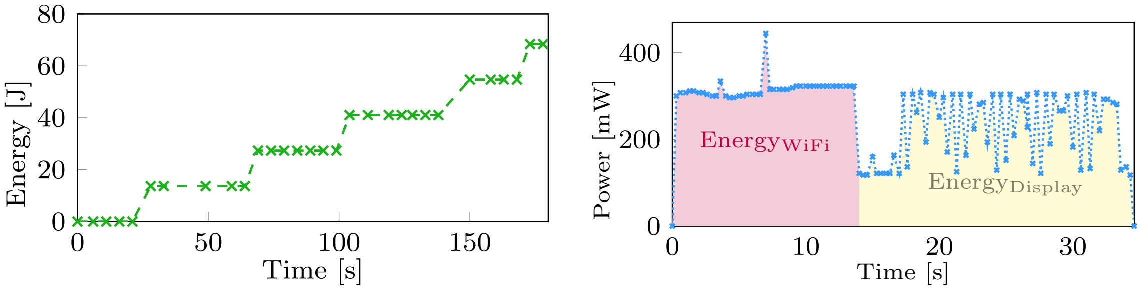

Figure 3 *Left plot (harvested energy)*: Turning the crank at medium speed for 30 sec extends the runtime for approximately 3 further days in the first HanDi prototype. *Right plot (energy of operations)*: The energy consumption (area under power consumption) for every operation (i.e., receive data, update display) is conservatively determined prior to runtime in order to allow forward-looking energy management.

generated energy flows into the LiPo battery with the help of a battery charger [2], which also monitors the current energy level [3]. The main design goal of HanDi was to have a system that ideally only consumes energy while updating. In order to achieve this, we chose a microcontroller that has a low standby power consumption [5] and take advantage of the most prominent feature of e-ink displays, the possibility to display content without consuming energy at all. Our used persistent memory with ferromagnetic technology has the same characteristic of not needing any power while standby [1]. We designed HanDi's software to benefit from these hardware properties.

2.2 Software Design: Forward-Looking Energy Management

The main idea of HanDi's software design is being aware of energy costs and the current energy level of the system: We always have to make sure that enough energy is left to start a new update cycle or otherwise show the message encouraging users to turn the crank. Guaranteeing the completion of operations is especially important when the battery is close to depletion, or else the system risks showing outdated information. To solve the problem of providing guarantees, we conservatively determined the *worst-case energy consumption (WCEC)* [7, 8] of all operations (i.e., data transmission via WiFi, update of display). That is, HanDi decides whether enough energy is available to start an update or display the message for cranking. Using this forward-looking energy-management strategy based on WCEC values together with knowledge on the current state of charge, we never leave the system in an undefined state.

3 Evaluation

In this section, we discuss two evaluation scenarios that validate the applicability of HanDi. The results are summarized in Figure 3. In the first experiment (see left part of Figure 3), we evaluated the energy-harvesting mechanism attached to the display: We turned the crank at a medium speed and monitored the harvested energy using the state-of-charge–assessment chip [3]. The steps in the curve are due to the chip's resolution of stored energy in relation to the battery's energy (2000 mAh in this scenario). We observed an increase in available energy of around 14 Joule each 30 sec turning the crank.

This value of harvested energy needs to be considered in relation to the required energy consumption for receiving updated room information from UnivIS and displaying it: The right part of Figure 3 shows a power trace of these two operations. For forward-looking scheduling, we determined the worst-case energy consumption also of about 14 Joule (i.e., 9.5 J for information update via WiFi, and 4.8 J for updating the e-ink display), which upper bounds the actually used energy in this experiment. Since the display updates every third day, these values indicate that during this period a user needs to turn the crank for around 30 seconds to keep the system continuously operational. Since this evaluation was conducted on the very first prototype of HanDi, which does not include any optimizations so far, we argue that the effort to keep the system operational is manageable (30 sec cranking for 3 further days runtime). Several aspects of our future work on HanDi will help to decrease this effort, which are presented as follows.

4 Related Approaches & Future Work

To our knowledge, HanDi is the first energy-neutral hand-crank–based e-ink display. A related product is Joan [6] to display room plans. This solution also benefits from zero-standby e-ink displays and, being battery-operated, can be effortlessly installed at any door. HanDi additionally offers a hand-crank mechanism and thus energy-neutral operation. Furthermore, having already an interface to the centralized room-management system UnivIS, HanDi is already adapted to the needs of the university. The commercial solution Joan comes, besides the cost for the display, with monthly hosting fees. HanDi instead is publicly available under an open-source license and thus free of any usage fees.

Although the first HanDi prototype indicates the validity of the proposed idea, we have several ideas to enhance our approach as part of future work:

Instant Feedback: We experienced that an instant feedback on how much energy has just been harvested encourages users to crank. Thus, displaying the achievement while cranking and a message thanking for the energy after cranking helps to raise the acceptance for such energy-harvesting systems.

Enhanced Energy Efficiency: The first HanDi prototype is based on a low-cost hand crank intended to teach children electricity. In order to improve HanDi's energy efficiency, a more sophisticated hand crank with a more suitable gear ratio is necessary. Furthermore, the prototype has no means to adapt to the input's maximum power point, which is known to significantly improve energy-harvesting approaches.

User Input: HanDi benefits from advances of e-ink displays and their availability at low cost. Recent advances also enable colored displays and, even more interesting, displays with touch input. Using such displays HanDi could advance from a room display to a booking system for rooms, while, in contrast to other solutions, still being energy neutral.

5 Conclusion

As we started developing the HanDi prototype for the FAU Ideenwettbewerb, we see the current status as a working proof for this concept. We believe that energy awareness is of major importance to achieve long-term energy sustainability, thus thinking outside the box is necessary. Even though raising awareness for this daily convenience scenario, HanDi helps making visible energy problems on a larger scale. Furthermore, we solve the problem of power supply at door-plate placements, enabled through both the energy-efficient hardware and software design. Our evaluations indicate that the HanDi approach is feasible and is fully operational with minor action from users.

All resouces (source code, electrical/mechanical design) of HanDi are publicly available under an open-souce license: `https://gitlab.cs.fau.de/handi`

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