4TU.NIRICT Community Fund 2021 – Final Report:

Human-Centered Sustainable IoT

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16 February 2022

In this 4TU.NIRICT project "Human-Centered Sustainable IoT", we aimed to strengthen an active research community on Computer-Human Interaction on IoT Applications in the Netherlands, formally called CHIIoT Group (https://chiiot.org/). This proposal continued with the successful collaboration between TU Eindhoven (TU/e), TU Delft (TUD), and the University of Twente (UT) attained through a prior 4TU.NIRICT grant "Self-Sustainable Computing" in 2020. The proposal was granted on October 14th, 2021.

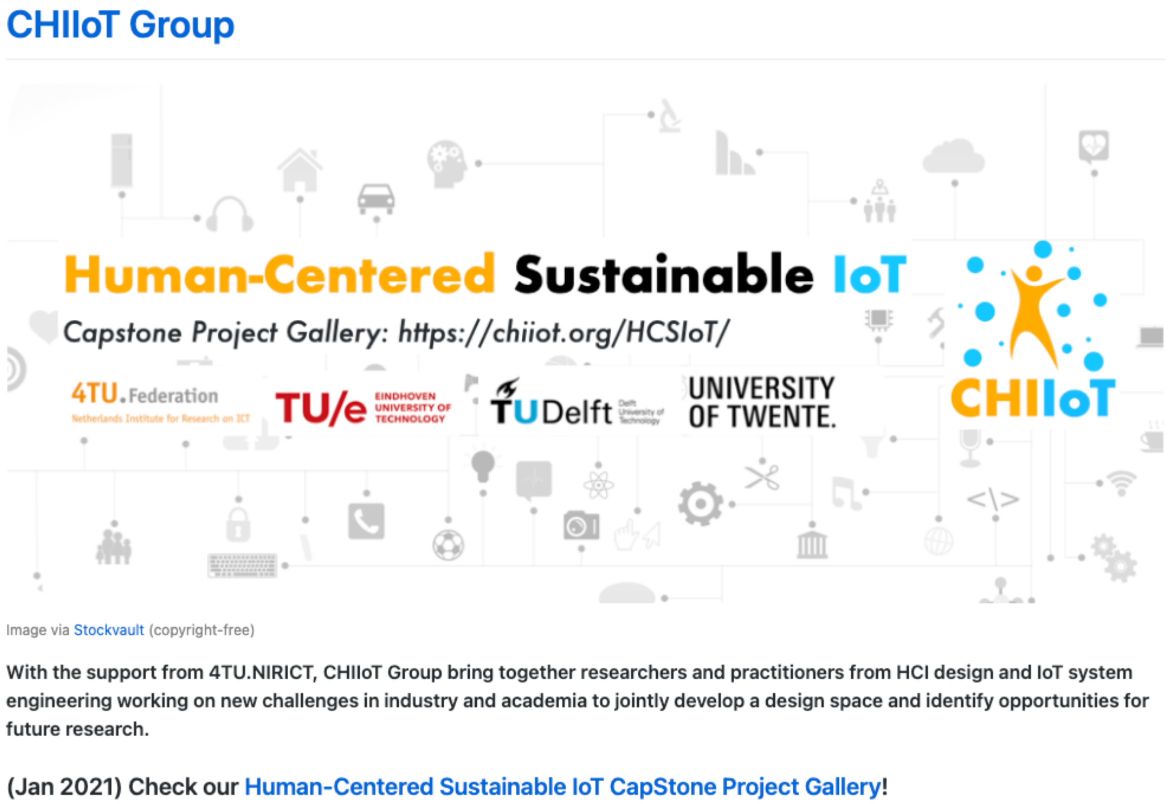

Figure 1. Official website of CHIIoT Group (https://chiiot.org/)

Towards the end of October, we first formed two regular workgroups in the CHIIoT community: user experience and systems. Each workgroup consists of members from at least 2 TUs. Then, we invited the research teams in TU/e, TUD, and UT to submit their 1-page research proposal, which can stimulate a common interest for further collaboration. A total of 11 proposals were received before the deadline. The proposal was reviewed by a committee formed by members from both workgroups based on the relevance to our topic "Human-Centered Sustainable IoT" and their scientific quality and societal relevance. As a result, 6 proposals (54%) were selected by the committee as the HCSIoT Capstone projects (Figure 2). The PI of each project received a 1K euro budget for developing its demonstrator, which will highlight the use of toolkits, educational and research artifacts to inform ICT researchers, educators, and practitioners in the 4TU.NIRICT community about cutting-edge technologies and methodologies for building user centered sustainable IoT applications. All these projects' description can be found in the Appendix.

Figure 2. Six HCSIoT Capstone projects and their gallery of demonstrators (https://chiiot.org/)

In November, both workgroups organized several online meetings and offline discussions to align the mutual interests and highlighted opportunities for future collaboration. A few new proposals were also kicked off during their discussions. At the same time, the organization of the 1st CHIIoT Human-Centered Sustainable IoT Symposium (HCSIoT '21) (https://chiiot.org/HCSIoT/2021/) was kicked-off. We invited Dr. Anke van Oosterhout, an expert in designing shape-changing interfaces in IoT as the keynote speaker. We planned the symposium as a physical event in Blauwe Zaal @ TU/e and set the date on Dec. 15, 14:30 - 17:00. The promotion is shown in Figure 3. The half-day event was planned as follows:

Figure 3. Venue and information of the 1st CHIIoT Human-Centered Sustainable IoT Symposium (HCSIoT '21) (https://chiiot.org/HCSIoT/2021/)

Program (Timezone: CET)

- 14:30-14:35 Opening: Dr. Rong-Hao Liang, TU/e
- 14:35-14:55 Keynote Talk: Designing Shape-Changing Interfaces in IoT - Dr. Anke van Oosterhout, TU/e
- 15:00-15:10 Demo #1 - IoT Sandbox, Dr. Joep Frens, TU/e
- 15:15-15:25 Demo #2 - SunBox, Dr. Marco Zuniga, TUD
- 15:30-15:40 Demo #3 - OOCSI@Home, Dr. Mathias Funk, TU/e
- 15:45-15:55 Demo #4 - Battery-free prototyping platform, Dr. Przemysław Pawełczak, TUD
- 16:00-16:10 Demo #5 - IoT Communicators, Dr. Yaliang Chuang, TU/e
- 16:15-16:25 Demo #6 - Multimodal smartphone-based localization, Dr. Alessandro Chiumento, UTwente
- 16:30-17:00 Closing Remarks and Live Experience

Towards December, unexpectedly, the covid situation hit us in two phases. In the first phase (before Dec 6), the national COVID-19 measure discouraged us from organizing group events and traveling. Since organizing a physical event became no longer convenient for people in Delft, UT, and WUR, we had to move the entire planning to an online event while using the physical venue, Blauwe Zaal, for live streaming, which was still possible and arranged. Unfortunately, in the second phase (after Dec 6), several PIs and organizers of the events were in quarantine, making their physical presence and demo impossible. With the growing concerns in the organizing committee, we consulted the 4TU office on Dec. 6 and confirmed that the event can be moved to the year 2022 on Dec. 7.

Since a physical event organized in 2022 can no longer be covered by this project, the committee decided to revisit the previous proposals and fund one more project for future events, using the budget originally reserved for the venue, video streaming, and catering costs of the symposium. The rest of the budget was also used for covering the additional costs of every capstone project and building an online gallery (https://chiiot.org/HCSIoT/) on the CHIIoT website and facebook page for a public dissemination. The results of dissemination can be seen from Figure 4.

In summary, until Feb 15, the investment on 7 capstone projects successfully turned into 6 exhibition-ready demonstrators, which is on the high side of the proposed numbers (4-6). The requested budget was reasonably spent on the planned activities under the restrictions of the COVID situation. **We appreciate the 4TU.NIRICT community fund for supporting these activities**. The team will seek further opportunities to share the demonstrators and the knowledge in these practices in engineering and technology development, and innovation in education by bringing 4TU people together.

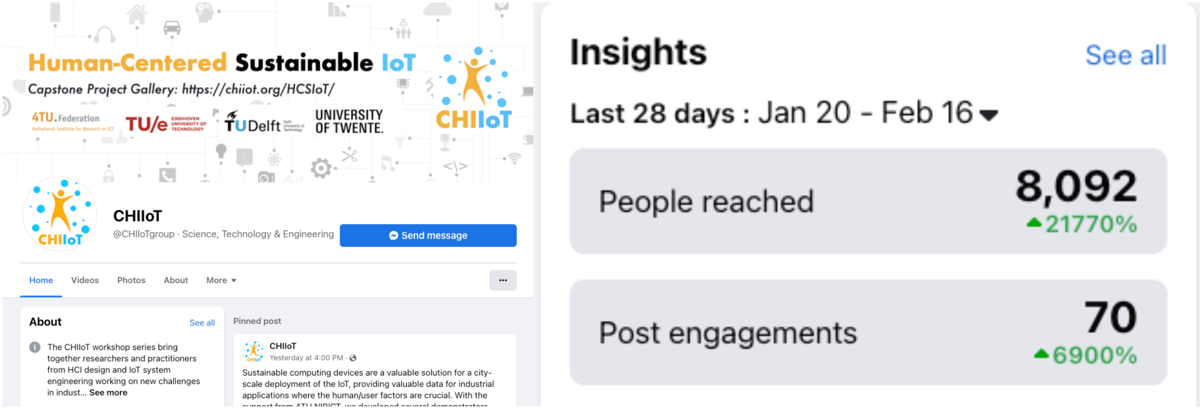

Figure 4. The CHIIoT facebook page and the quantitative results of online dissemination

Appendix: Descriptions of the 7 capstone projects (text captured on Feb 16)

Project 1 - BFree: Battery-Free Prototyping Platform

PI: Przemysław Pawełczak, TU Delft

The battery-free (BFree) prototyping platform allows unskilled electronic hobbyists to prototype, in easy-accessible Python programming language, systems that are battery-free while harvesting energy from the ambient sources.

Project Page: ***https://chiiot.org/HCSIoT/BFree/***

BFree is a hardware-software system enabling intermittent computing applications (i.e. computing that is accurate and makes progress despite power interrupts) for Adafruit Metro M0 (https://www.adafruit.com/product/3505) hobbyist-grade embedded platform that is (a) battery-free (i.e. energy is stored in a less-polluting and better maintainable capacitor, instead of a battery) and (b) powered from renewable energy sources. Power interrupts are the result of insatiable energy coming from energy harvesting sources, such as vibrations or solar power. Programs for such intermittency-protected Adafruit Metro M0 boards are written in a regular CircuitPython language. This means that the end user does not need to learn any domain-specific programming language. BFree (in the background) takes care of saving intermediate program state to a non-volatile memory of the BFree shield (i.e. red PCB shown in the photo above) and restores the program state (when the harvested power is again available) from the last moment the system lost power from insufficient harvested energy.

Project 2 - IoT Sandbox
PI: Joep Frens, TU/e
This project shows that IoT can be approached as a dynamically growing system and demonstrates a physical, growing interface to operate it. This demonstrates that there are possibilities to rethink IoT interaction styles beyond the touchscreen.
Project Page: https://chiiot.org/HCSIoT/IoTSandBox/

This demonstrator operates in the home environment and builds on two observations. First, we observe that IoT artifacts are very different from traditional (interactive) products in that they are designed to form IoT systems that are composed in the homes of the end user out of offerings from different manufacturers rather than bought as complete systems. Second, we observe that IoT artifacts are predominantly operated through touch screen and voice interaction. We are interested in understanding the dynamic nature of IoT systems and particularly in diversifying the interaction style of IoT artifacts beyond the touchscreen. The IoT sandbox is a research demonstrator designed to show that also physical interface can be used to control systems that are as dynamic as home IoT. The tiled interface can be adapted to control an ever-expanding set of interconnected IoT artifacts in the IoT Sandbox by adding new tiles. Next to this, pre-sets can be programmed that offer user defined functionality that can be projected in new tiles.

Project 3 - SunBox
PI: Marco Zuniga, TU Delft
Sunbox uses a natural source of energy (sunlight) to communicate wirelessly.
Project Page: https://chiiot.org/HCSIoT/SunBox/

A recent development in wireless communication is the use of optical shutters and smartphone cameras to create optical links solely from ambient light. At the transmitter, a liquid crystal display (LCD) modulates ambient light by changing its level of transparency. At the receiver, a smartphone camera decodes the optical pattern. This LCD-to-camera link requires low-power levels at the transmitter, and it is easy to deploy because it does not require modifying the existing lighting infrastructure. The system, however, provides a low data rate, of just a few tens of bps. This occurs because the LCDs used in the state-of-the-art are slow single-pixel transmitters. To overcome this limitation, we introduce a novel multi-pixel display. Our display is similar to a simple screen, but instead of using embedded LEDs to radiate information, it uses only the surrounding ambient light. We build a prototype, called SunBox, and evaluate it indoors and outdoors with both artificial and natural ambient light. Our results show that SunBox can achieve a throughput between 2 kbps and 10 kbps using a low-end smartphone camera with just 30 FPS. To the best of our knowledge, this is the first screen-to-camera system that works solely with ambient light.

Project 4 -IoT Communicators
PI: Yaliang Chuang, TU/e
IoT communicators enable smart IoT devices and systems to provide users with perceptible feedforward and feedback that can convey systems' intentions with semantic visual languages and let users feel in control of the settings without interrupting their jobs.
Project Page: [***https://chiiot.org/HCSIoT/IoTCommunicators/***](https://chiiot.org/HCSIoT/IoTCommunicators/)

IoT products and systems are becoming ubiquitous in many people's everyday lives. They simplify and amplify users' private and professional jobs by monitoring users' behaviors and proactively activating or switching particular settings, optimizing users' activities. In the conventional designs, those systems communicate to users with every tiny data on the digital interfaces. However, they fail to inform people through direct interaction when people encounter the devices in the physical world. Without getting the feedback and feedforward at the right time in the right place, users can't establish a good mental model to assure the system will work as they wish nor react to the unexpected situations properly without interrupting their primary tasks. To fulfill the communication gap, we developed a communicator component that could be incorporated in or attached to any IoT device. It consists of a low-cost lighting interface with multiple LEDs arranged in a ring form. We used the morphological method to generate variant patterns and investigated their semantic expressions by interviewing 10 participants' free interpretations of each design. As a result, we produce ten types of lighting patterns, and each could convey particular meanings, including greeting users, announcing upcoming system automation, guiding users to intervene if they don't need it, indicating the system or devices' status, etc. We believe that our IoT communicator could provide users glanceable information for assuring the system is operating as they expect. If they want to know more, they can use the AR interface to see the detailed information on digital devices. In the next step, we will conduct a usability study to investigate the interaction and user experiences with multiple devices working together in a physical environment.

Project 5 - OOCSI@Home
PI: Mathias Funk, TU/e
This project integrates the OOCSI prototyping middleware with the HomeAssistant smart home automation system to enable faster, more realistic and more integrated prototyping in the smart home IoT domain.
Project Page: [***https://chiiot.org/HCSIoT/OOCSIatHome/***](https://chiiot.org/HCSIoT/OOCSIatHome/)

When prototyping new IoT device and interaction concepts we can make use of prototyping middleware such as OOCSI. However, integrating new connected experiences into a smart home context, often with off-the-shelf commercial IoT products, is difficult due to protocols, communication standards and complex connectivity. The OOCSI@Home project designed and developed an extension for the popular open-source HomeAssistant system which allows for an easy integration of newly designed prototypes into a smart home setup via OOCSI. As part of this integration, we also developed a protocol, heyOOCSI, to announce device types, properties and features. This protocol is transparently implemented on top of the standard OOCSI protocol and it is available on all supported platforms. This allows for controlling and integrating prototypes and other smart devices into a HomeAssistant setup. As HomeAssistant has a lot of integrations, this makes designed prototypes compatible with even more data and actuators for you to work with. For instance, one can create a new light switch for a Philips Hue bulb or use solar energy data to control a designed prototype.

Project 6 - NFCe: Body-Centric Interaction with NFC Devices
PI: Rong-Hao Liang, TU/e
This project explores a sustainable way of faciliating human-centered interactions with IoT devices, smart environment, and others using passive NFC extenders worn on users' body with a smartphone.
Project Page: [***https://chiiot.org/HCSIoT/NFCe/***](https://chiiot.org/HCSIoT/NFCe/)
The application of interactive technology seems to be more and more inseparable from smartphones, so many times we have to take out mobile phones to interact, such as NFC-based interaction. In this project, we proposed a body-centric interaction design space, and a design of wearable NFC relays that enable body-centric interactions for a commodity near-field communication (NFC) device. The passive extenders worn on the body can extend the operating range of the NFC reader/writer of a smartphone to the reach of the wearer's hand, arm, or foot. These NFC devices can capture the near-field interactions between the human body and NFC-tagged objects. We explored the design space and elucidated the applications in human-computer interaction as well as IoT lifestyle. Our implementation demonstrated the proposed applications' technical feasibility and aroused more ideas in the co-creation workshop to be generated. We also release an open-source library called OpenNFCSense, a system for detecting the movements of near-field communication (NFC) tags using a commodity, low-cost RC522 NFC reader. With a user-defined tag profile, the users can use its application programming interface (API) to obtain the NFC tagged objects' motion speed, motion frequency, and motion type while recognizing these tagged objects.

Project 7 - Multimodal smartphone-based localization
PI: Alessandro Chiumento, UTwente
The ability for people to find themselves inside building and navigate safely and surely to an objective is a very necessary objective of this project. We aim to bring indoor navigation to any building, any situation and for everyone.

A major challenge in indoor localisation is to provide good navigation tools to users that are not invasive, cheap to install, easy to maintain, and able to work in many different conditions. It is not possible to use a GPS indoor so creative solutions have to be developed. Many different technologies can be used to achieve good indoor localisation, from Bluetooth beacons to Infrared. Most of the solutions rely on an active tag emitting a signal and different base stations spread over an environment receive this signal and triangulate the location of the tag (by using either the received power or time-difference of arrival of the signal at the base stations). But, technologies used normally for communication can also be used for navigation as well. As an example, we have successfully built a Wi-Fi fingerprinting solution, relying on machine learning, which uses the signal received by Wi-Fi access points to localise a mobile user in a building. This solution does not require new infrastructure to be installed solely for navigational purposes but relies on the very same Wi-Fi we all use for connectivity.