Scientific Report

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Nationality	British
Name of the *Host Organisation*	SICS
First Name / family name of the *Scientific Coordinator*	Thiemo Voigt
Period of the fellowship	09/09/2013 to 09/07/2015

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

Over the course of my fellowship I participated in many strands of research and student supervision in my institute's Networked Embedded System Group. Primarily, and in chronological order of undertaking, these included:

- IEEE 802.15.4 wireless communication corruption study.
- SicsthSense sensor data storage platform development.
- Visible Light Communication research.
- GreenIoT research project proposal.
- Seasonal Affective Disorder monitoring research.
- Science Museum research demonstration and MegaMind display.

At the beginning of my fellowship I completed research studying the nature of corruption in IEEE 802.15.4 wireless communication transmission. The analysis of one year's data from an outdoor sensor network deployment showed that packet corruption follows a distinct pattern that is observed on all links. We explained the pattern's core features by considering implementation aspects of low-cost 802.15.4 transceivers and independent transmission errors. Based on the insight into the corruption pattern, we proposed a probabilistic approach to recover information about the original content of a corrupt packet. Our approach vastly reduces the uncertainty about the original content, as measured by a manifold reduction in entropy. We concluded that the practice of discarding all corrupt packets in an outdoor sensor network may be unnecessarily wasteful, given that a considerable amount of information can be extracted from them. This work was published at the European Conference on Wireless Sensor Networks and received the best paper award.

I also developed and released new versions of SicsthSense, SICS' cloud platform for the Internet of Things. SicsthSense enables low-power devices such as sensor nodes and smartphones to easily store their generated data streams in the cloud. This allows the data streams, and their history, to easily be made permanently and globally available to users for visualisation, processing and sharing. Moving sensor data computation and monitoring into the cloud enables centralisation of control and redistribution of collected data.

The newest release includes the addition of user definable functions to operate on inserted data and so shifts processing of data values into the cloud and avoids the need for sensor reprogramming. The ability to set triggered actions to occur on inserted data and function outputs was also added so arbitrary behaviours can be automatically performed when user-defined conditions arise (e.g. turn on heater when temperature goes below 20C). A user-oriented documentation portal was also launched to enable easier interaction with the service for normal users. Contiki code was released that demonstrates sending data directly from IPv6 sensor nodes to the cloud storage over 6LoWPAN without the need for a gateway, enabling the development of full end-to-end encryption. This software is in use by other researchers in SICS and KTH University as a easy-to-use yet powerful mechanism to store their data. Now that SicsthSense has reached a state of maturity we are researching the addition of end-to-end security protocols to give sensor systems privacy, trust and safety.

A major component of my time over the last year was spent designing, building and testing a new system of visible light communication. As the distinction between the physical and the digital world begins to blur, it is increasingly useful to associate physical objects with digital data. This is commonly achieved with machine-readable barcodes, such as QR codes. However, the receivers' channel qualities—which are dominated by camera resolution and distance from the code—differ widely. Consequently, existing barcode schemes either support the transmission of small payloads over long distances, or they support large payloads at the cost of requiring short distances or high-resolution receiver cameras. We built a system (Focus) that does not require the explicit trade-off that previous work makes between code capacity and the receivers' channel quality. Instead, by encoding data in the frequency domain of images, Focus enables receivers to decode as much data from a code as their channel supports: a nearby, high-resolution receiver can decode all data from a code, whereas a low-resolution receiver that is farther away can nonetheless partially decode the data. Focus also supports transmission of arbitrarily large payloads through videos containing sequences of codes. We evaluated Focus over a range of distances, receivers, and displays. Our evaluation showed that decoding performance scales smoothly with the distance between code and receiver, and with the resolution of the receiver's camera. This work is currently under review at HotNets International Conference.

I have also built a personal mobile sensing system that exploits technologies on smartphones to detect light exposure, mood, and activity levels of individuals efficiently and accurately. People's health, mood and activities are closely related to their environments and the seasons. Countries at extreme latitudes (e.g. Sweden, UK and Norway) experience huge variations in their light levels, impacting the population's mental state, well-being and energy levels. Advanced sensing technologies on smartphones enable non-intrusive and longitudinal monitoring of user states. The collected data makes it possible for healthcare professions and individuals to diagnose and rectify problems caused by seasonality. I conducted a two year experiment to test the functionality and performance of our system. The results showed that we can obtain accurate light exposure estimation by measuring light data opportunistically on smartphones, tracking both personal light exposure and the general seasonal trends. An optional questionnaire also allows insight into the correlation between a user's mood and energy levels. Consequently, it was possible to not only quantitatively inform users with winter blues how little light they were experiencing but also correlate this with their reduced mood and energy, providing evidence for lifestyle changes.

Recently, I have also been performing some communication of SICS' research to the wider community through the Stockholm Science museum "Tekniska Museet". Specifically about personal health sensing and data processing. A new wing of the museum called MegaMind is opening shortly and aims to show the way in which technology can interface with humans to enable creativity and learning. I have helped build a display showcasing sensors and how they can monitor our bodies and the outside world.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

- "*All is not Lost: Understanding and Exploiting Packet Corruption in Outdoor Sensor Networks*", Best Paper at European Conference on Wireless Sensor Networks 2014
- "*Transmitting Data over Heterogeneous LCD/Camera Links*", Best Poster Runner up at International Conference on Information Processing in Sensor Networks 2014
- "*Focus: Scalable Visual Codes for Embedding Data in the Physical World*", Hot Topics in Networks Workshop 2015 (pending)
- "*SADHealth: A Personal Mobile Sensing System for Seasonal Health Monitoring*", IEEE System Journal special issue (pending)

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

- European Conference on Wireless Sensor Networks, February 17-19, 2014, University of Oxford, Oxford, UK
- SICS Open House, 27th March 2014, Stockholm
- Uppsala University SicsthSense Seminar, 13th October 2014, Uppsala
- Tekniska Museet Demo, 16th November 2014, Stockholm
- SICS Open House, 19th March 2015, Stockholm
- Deep Learning Workshop, 15th June 2015, Sweden

IV – RESEARCH EXCHANGE PROGRAMME (REP)

NTNU Trondheim, Norway: 10th-16th March 2014
Dr. Sverre Hendseth - Department of Engineering Cybernetics
My visit to NTNU allowed me to present my work on the SicsthSense system and IoT data collection. This lead to discussion of the challenges faced by distributed sensor data collection over unreliable links.

FORTH Crete, Greece: 8-14th June 2015
Prof. Maria Papadopouli - Mobile Computing Activity
Presenting my visual data encoding research lead to discussion of previous work they had undertaken in image acuity and data reception. We also discussed Prof Papadopouli's work on home network monitoring and similarities to the work have recently begun using embedded hardware.