ERCIM "ALAIN BENSOUSSAN"
FELLOWSHIP PROGRAMME

ERCIM
European Research Consortium
for Informatics and Mathematics

Scientific Report

First name / Family name	Naveed Anwar Bhatti
Nationality	Pakistani
Name of the *Host Organisation*	RISE SICS AB
First Name / family name of the *Scientific Coordinator*	Thiemo Voigt
Period of the fellowship	01/04/2018 to 01/04/2019

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

The main research activities followed during my ERCIM Fellowship are summarized here:

Efficient Transiently-powered Embedded Systems:

Transiently powered embedded systems are becoming popular because of their self-sustainable, no maintenance and easily deployable nature. However, there is an intrinsic challenge with these systems: they can be unpredictably interrupted, as energy harvesting by no means can ensure a predictable supply of energy.
During the fellowship, we have devised efficient ways to save application state onto non-volatile memory when power fails. We have also optimized the checkpoint size by saving only those data structures which are being shared among different segments of the program. In the end, we managed to publish two papers ([1] and [2]).

Smart Implicit Interactions:

This project is built around developing a new interface paradigm for IoT called "smart implicit interaction". Implicit interactions stay in the background thriving on data analysis of speech, movements and other contextual data, avoiding unnecessarily disturbing us or grabbing our attention. This project is a collaborated work between researchers from RISE SICS, Stockholm University and KTH Royal Institute of Technology.
During the fellowship, we created Soma-pixels. Soma-pixel is about the simplicity of motion emerging from the complexity of the computational world. Each Soma-pixel is motorized using a linear actuator which allows us to raise or lower it. A pressure sensor embedded on top of each pixel let you control their position in real-time. You can increase or decrease their height by just applying the force on top. Each pixel can double (or halve) its height in just a few seconds. Also, each pixel can share its position with other pixels via radio.
Placing these Soma-pixels together can reconfigure the space in a myriad of combinations. One of the combinations can result in the smart mattress. A mattress is normally static. We wanted to give it some life form so to explore the interplay of static and dynamic which we can achieve with these soma-pixels that react to an applied force. A smart mattress using soma-pixels can replicate the unique shape of the body to have a versatile and accessible postural.

Internet of Things Security:

IoT is now becoming an integrated part of our society's infrastructure. As we become increasingly reliant on IoT systems to perform critical functions, it becomes apparent that security and safety concerns must be taken seriously. An important step is to enable memory isolation, by means of compiler tools, OS mechanisms, and building on a memory-protection unit (MPU) and/or Trusted Execution Environments (TEE).
During the fellowship, we investigated security aspects for intermittent computing systems, which form the foundation for the next generation battery-less Internet of Things by using energy harvesting to power their operation. These systems compute intermittently, as energy is available, and employ persistent state; for example, through checkpointing, to ensure forward progress.
In this area, we experimented with the Microchip SAML11 microcontroller, which comes with TrustZone security extensions. Our goal has been to secure the checkpoint state using TrustZone by placing it in the secure world. For comparison, we evaluated our approach with current common practice, which includes encrypting the checkpointed data using AES before saving it to non-volatile memory.
We had planned to use Atmel Studio's built-in "Data Visualizer" for energy measurements. However, we realized that "Data Visualizer" from Atmel Studio does not provide an essential

functionality (like logging to CSV) and has limited accuracy. On the other hand, using physical equipment such as oscilloscopes is too impractical. As power measurements will be essential to the rest of the project, we need to repeat the measurements using different AES settings and benchmark applications. It was thus necessary for us to extract information out of Data Visualizer and automate the whole experimental procedure. After some research, we were able to find out an open source implementation of the DGI library from Atmel that the "Data Visualizer" uses to extract current values from SAML11 board. We build a Python library that provides bindings to the DGI library with built-in plot functionality for energy measurement.
We ported the whole mbedTLS suite (including different modes of AES) to the SAML11 board. Using the Python library, we developed, we were able to repeat the power measurements on four different benchmark applications: Kalman, Fast Fourier Transform (FFT), Quick Sort, and Bitcount, using both our approach (TrustZone based) and common practice (AES based). Early results we gather show that the energy overhead of the TrustZone-based approach is almost negligible in comparison with the AES-based one. We also verified the security constraints of the checkpointing process. We tried to read/write the secure flash from the normal world and could not do so.

Other Activities:

I was also involved in other professional activities.

- I served as a member of the technical program committee of the following Conferences/Workshops:
    1. The IEEE 25th International Conference on Parallel and Distributed Systems (ICPADS)
    2. 1st International Workshop on Intelligent Systems for the Internet of Things (ISIOT)
    3. ACM/IEEE Conference on Internet of Things Design and Implementation (IOTDI) Poster/Demos

- I served as a reviewer for the following journals:
    1. Springer Swarm Intelligence
    2. IEEE Transactions on Sensor Networks (TOSN)

- I served as a Web and Social Chair for ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN) for year 2018 and 2019

- I delivered tutorial (along with other researchers) on Transiently-powered Systems at ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN) 2018, Porto, Portugal

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

[1]. Saad Ahmed, **Naveed Anwar Bhatti**, Muhammad Hamad Alizai, Junaid Haroon Siddiqui and Luca Mottola," Efficient Intermittent Computing with Differential Checkpointing", Languages, Compilers, and Tools for Embedded Systems 2019 (LCTES '19), June 2019.

> **Abstract:** Embedded devices powered off ambient energy harvesting compute intermittently, as energy is available. System support ensures forward progress of programs through state checkpointing in non-volatile memory. Checkpointing is, however, expensive in energy and adds to execution times. To reduce this overhead, we present DICE, a system design that efficiently achieves differential checkpointing in intermittent computing.

Distinctive traits of DICE are its software-only nature and its ability to only operate in volatile main memory to determine differentials. DICE works with arbitrary programs using automatic code instrumentation, thus requiring no programmer intervention, and may be integrated with both reactive (Hibernus) or proactive (MementOS, HarvOS) checkpointing systems. By reducing the cost of checkpoints, performance markedly improves. For example, using DICE, Hibernus requires one order of magnitude shorter time to complete a fixed workload in a real-world settings.

[2]. Saad Ahmed, Abu Bakar, **Naveed Anwar Bhatti**, Muhammad Hamad Alizai, Junaid Haroon Siddiqui and Luca Mottola," The Betrayal of Constant Power × Time: Finding the Missing Joules of Transiently-Powered Computer", Languages, Compilers, and Tools for Embedded Systems 2019 (LCTES '19), June 2019.

Abstract: Transiently-powered computers (TPCs) lay the basis for a battery-less Internet of Things, using energy harvesting and small capacitors to power their operation. This power supply is characterized by extreme variations in supply voltage, as capacitors charge when harvesting energy and discharge when computing. We experimentally find that these variations cause marked fluctuations in clock speed and power consumption, which determine energy efficiency. We demonstrate that it is possible to accurately model and concretely capitalize on these fluctuations. We derive an energy model as a function of supply voltage and develop EPIC, a compiletime energy analysis tool. We use EPIC to substitute for the constant power assumption in existing analysis techniques, giving programmers accurate information on worst-case energy consumption of programs. When using EPIC with existing TPC system support, run-time energy efficiency drastically improves, eventually leading up to a 350% speedup in the time to complete a fixed workload. Further, when using EPIC with existing debugging tools, programmers avoid unnecessary program changes that hurt energy efficiency.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

Conference: ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN) – in Porto, Portugal.
Seminar: Humanising AI – in Stockholm on 31st May and 1st June 2018, Sweden
Seminar: RISE SICS and Ericsson Security Day – on 28th November 2018, Sweden
Seminar: Developing Secure Internet of Things Applications: Tutorials and Hackathons – in Stockholm on 5th June 2018, Sweden.

IV – RESEARCH EXCHANGE PROGRAMME (REP)

Duration: 1 week
Research Group: VTT, Finalnd
Scientific contact: Harri Hyvari
Description: The nature of work included:

- Delivering a technical talk on: “Transiently-powered Embedded Systems: Applications and Challenges”
- Technical meetings with the head of team, post doctorates and PhD students. The meetings were mostly focused at presenting the work done in VTT and the general discussion on the area of research.