Scientific Report

First name / Family name	Prasant Kumar Misra
Nationality	Indian
Name of the *Host Organisation*	SICS Swedish ICT
First Name / family name of the *Scientific Coordinator*	Prof. Thiemo Voigt
Period of the fellowship	01/11/2012 to 31/10/2013

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

Location awareness is an essential feature of many commercial, public service, and military wireless networks. Information collected or communicated by a wireless device is often meaningful when combined with location (and time) as it provides valuable context in its interpretation. During the fellowship, my research activities were mainly focussed on the design and development of energy efficient location sensing systems, with a *primary* focus on the Global Positioning System (GPS).

Activity-1: GPS is the *most* pervasive technology that provides the fundamental service of location. The ubiquity of GPS has, henceforth, grown beyond billions of smart phones to embedded devices for enabling many novel outdoor applications across several domains. GPS receivers have, therefore, become more versatile in terms of cost, size and weight; but are *still* demanding in energy usage. It is an artifact of the computationally intensive GPS receiving operation, which accounts for more than 80% of the total energy expenditure of the sensing platform on which it is coupled. The latest solution in this category has shown that *significant* energy savings can be achieved by exploiting the coding nature of the GPS signal, and splitting the post-processing mechanism into local and cloud computation. While such a data acquisition and processing model is preferable, the *task* of offloading data to the cloud introduces an *additional* cost in energy. Motivated by the need to limit this expenditure, I developed Sparse-GPS.

Sparse-GPS (or, S-GPS) is based on a *mechanism* to compress and transmit the condensed GPS data to the offloading device; wherein the coarse information of the Doppler shifts and time delay of the satellite signals can be efficiently recovered to determine the visible satellites. Cross-correlation is the *conventional* method of obtaining these parameters; but, given its sparse information content, I made use of the theoretical results in sparse approximation to achieve similar performance. The underlying information theory suggests that it is possible to accurately and efficiently recover the information of a high dimensional signal from only a small number of compressed measurements, when the signal-of-interest is sufficiently *sparse* in a certain transform domain. I proposed a *new* dictionary that combines the information sparsity along all search dimensions, and achieves up to two order of magnitude better sparse representation than standard dictionaries. I demonstrated the GPS acquisition capability and energy gains by empirical evaluations on real GPS signals. I showed that S-GPS is twice as energy efficient than offloading uncompressed data, and has 5-10 times lower energy cost than a standalone GPS; with a median positioning error of 40 m (Section 2, Publication no. [5][6]).

Activity-2: During this period, I was involved in a number of projects being undertaken in the network embedded systems group. Within the scope of these projects, I contributed towards: (I) evaluation of RF-based indoor localization solutions for the future Internet (Section 2, Publication no. [4][7]); and (II) robust localization in industrial environments with inertial measurement units (IMU). I also provided logistical support to some of these projects by: (I) attending project

meetings on three occasions at the Universiteit Gent Belgium, Technische Universitat Berlin, and Indian Institute of Technology Mumbai; and (II) helping in the selection and interview process for summer internships.

Activity-3: I was also involved in other professional activities.

- I served as a member of the technical program committee of the following conferences:
  - The 34th IEEE Real-Time Systems Symposium (RTSS'13)
  - The 8th IEEE Workshop on Practical Issues in Building Sensor Network Applications (SenseApp'13)
  - The 5th Workshop on Real-World Sensor Networks (REALWSN'13)
  - The 9th IEEE International Conference on Distributed Sensor Networks (DCOSS'13)
  - The 8th International Conference on Intelligent Sensors, Sensor Network and Information Processing (ISSNIP'13)
- I served as a reviewer for the following journals:
  - IEEE Communication Magazine 2013
  - IEEE Transactions on Parallel and Distributed Systems (TPDS) 2013
- I delivered tutorials (along with other researchers) on:
  - "Foundations of Sparsity and Compressed Sensing" at SICS Swedish ICT, Stockholm
  - "COOJA/Contiki for Wireless Sensor Networks" at Robert Bosch Centre for Cyber Physical Systems in the Indian Institute of Science, Bangalore
- I was invited to contribute an article (Section 2, Publication no. [1]) to the special issue on Cyber Physical Systems in the Journal of the Indian Institute of Science Bangalore (publishing since 1914).

Activity-4: Alongside working on the research agenda outlined for my fellowship, I continued to work on some of my unfinished projects and reports initiated during the tenure of my Ph.D. candidature in UNSW, Sydney (Section 2, Publication no. [2][3][8]).

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

[1] P. Misra, L. Mottola, S. Raza, S. Duquennoy, N. Tsiftes, J. Hoglund, and T. Voigt. *Supporting Cyber-Physical Systems with Wireless Sensor Networks: An Outlook of Software and Services*. Special Issue on Cyber Physical Systems, Journal of the Indian Institute of Science, 93(3):441-462, Sep. 2013

Abstract: Sensing, communication, computation and control technologies are the essential building blocks of a cyber-physical system (CPS). Wireless sensor networks (WSNs) are a way to support CPS as they provide fine-grained spatial-temporal sensing, communication and computation at a low premium of cost and power. In this article, we explore the fundamental concepts guiding the design and implementation of WSNs. We report the latest developments in WSN software and services for meeting existing requirements and newer demands; particularly in the areas of: operating system, simulator and emulator, programming abstraction, virtualization, IP-based communication and security, time and location, and network monitoring and management. We also reflect on the ongoing efforts in providing dependable assurances for WSN-driven CPS. Finally, we report on its applicability with a case-study on smart buildings.

[2] P. Misra, N. Kottege, B. Kusy, D. Ostry, and S. Jha. *Acoustical ranging techniques in embedded wireless sensor networked devices*. *ACM Transactions on Sensor Networks* (To Appear: Feb. 2014 in Volume 10, Issue 1)

Abstract: Location sensing provides endless opportunities for a wide range of applications in GPS-obstructed environments; where, typically, there is a need for higher degree of accuracy. In this article, we focus on robust range estimation, an important prerequisite for fine-grained localization. Motivated by the promise of acoustic in delivering high ranging accuracy, we present the design, implementation and evaluation of acoustic (both ultrasound and audible) ranging systems. We distill the limitations of acoustic ranging; and present efficient signal designs and detection algorithms to overcome the challenges of coverage, range, accuracy/resolution, tolerance to Doppler's effect, and audible intensity. We evaluate our proposed techniques experimentally on TWEET, a low-power platform purpose-built for acoustic ranging applications. Our experiments demonstrate an operational range of 20 m (outdoor) and an average accuracy 2 cm in the ultrasound domain. Finally, we present the design of an audible-range acoustic tracking service that encompasses the benefits of a near-inaudible acoustic broadband chirp and approximately two times increase in Doppler tolerance to achieve better performance.

[3] P. Misra, S. Kanhere, and S. Jha. *Sparse Representation based Acoustic Rangefinders: From Sensor Platforms to Mobile Devices.* IEEE Communications Magazine (Under Review: Apr. 2013)

Abstract: Acoustic rangefinders are a promising technology for accurate proximity detection, a critical requirement for many emerging mobile computing applications. While state-of-the-art systems deliver robust ranging performance, the computational intensiveness of their detection mechanism expedites the energy depletion of the associated devices that are, typically, powered by batteries. The contribution of this article is threefold. First, it outlines the common factors that are important for ranging. Second, it presents a review of acoustic rangers and identifies their potential problems. Third, it explores the design of an information processing framework based on sparse representation that could potentially address existing challenges, especially for mobile devices. Finally, it presents μ-BeepBeep: a low energy acoustic ranging service for mobile devices, and empirically evaluates it benefits.

[4] N. Wirstrom, P. Misra, and T. Voigt. *A multi-modal localization system for stationary WSN deployment*. In the 11th European Conference on Wireless Sensor Networks, EWSN '14 (Under Review: Sep. 2013)

Abstract: We present a localization system that targets rapid deployment of stationary WSN. The system fuses measurements from multiple localization modalities, e.g. RF ranging, neighbor information, or maps, to obtain position estimations with higher accuracy than that of the individual modalities. The type of available modalities varies between different environments and scenarios. It is, therefore, important to make different modalities independent of each other, such that they can be excluded or included independently to tailor the system to a specific scenario. The system accomplishes this by separating different modalities into separate components. A particle filter is then used to fuse together the results from the individual components by allowing each component to generate particles (based on the measurements of their corresponding modalities) to represent possible node locations, and subsequently, weighting the particles generated by all the components. We show that position estimations can be improved with our system by combining multiple modalities. We evaluate the performance of the system in both an indoor and outdoor environment using combinations of 5 different modalities. Using 2 anchor nodes as reference points, and combining all 5 modalities, we obtain RMS (Root Mean Square) estimation errors of approximately 2.5 m in both cases, while using the components individually results in errors within the range between 3.5 and 9 m.

[5] P. Misra, W. Hu, Y. Jin, J. Liu, A. Paula, N. Wirstrom, and T. Voigt. *Energy efficient GPS Acquisition with Sparse-GPS.* ACM/IEEE Information Processing in Sensor Networks (Under Review: Oct. 2013)

Abstract: Following rising demands in positioning with GPS, low-cost receivers are becoming widely available; but their energy demands are still too high for long-term operation. For energy efficient GPS sensing in delay-tolerant applications, the possibility of offloading a few milliseconds of raw signal samples and leveraging the greater processing power of the cloud for obtaining a position fix are being actively investigated. In an attempt to reduce the energy cost of this data offloading operation, we propose Sparse-GPS: a new computing framework for GPS acquisition via sparse approximation. Within the framework, GPS signals can be efficiently compressed by random ensembles. The sparse acquisition information, pertaining to the visible satellites that are embedded within these limited measurements, can subsequently be recovered by our proposed representation dictionary. By extensive empirical evaluations, we demonstrate the acquisition quality and energy gains of Sparse-GPS. We show that it is twice as energy efficient than offloading uncompressed data, and has 5-10 times lower energy cost than standalone GPS; with a median positioning accuracy of 40m.

[6] P. Misra, W. Hu, Y. Jin, J. Liu, N. Wirstrom, and T. Voigt. *Poster abstract: SparseGPS: Energy Efficient GPS Acquisition via Sparse Approximation*.
In Proceedings of the 11th ACM Conference on Embedded Networked Sensor Systems, SenSys '13 (To appear: Nov. 2013)

Abstract: The global positioning system (GPS) system is a dominant wireless technology that enables reliable location sensing for a diverse range of outdoor mobile sensing applications. Following rising demands for location sensing, low-cost GPS receivers are becoming widely available; but their energy demands are still too high to be useful for many of these applications. For energy efficient GPS sensing, the possibility of offloading a few milliseconds of raw signal samples and leveraging the greater processing power of the cloud for obtaining a position fix is being actively investigated. In an attempt to reduce the energy cost of this data offloading operation, we propose SparseGPS: a lightweight GPS acquisition mechanism based on sparse approximation.

[7] N. Wirstrom, P. Misra, and T. Voigt. *Poster abstract: Spray, Embracing Multimodality*. In the 10th European Conference on Wireless Sensor Networks, EWSN '13

Abstract: We present Spray, a localization system that compensates for low accuracy of individual localization measurements by combining measurements from multiple localization modalities.

[8] G.S. Sidhu, A. Kamboj, P. Misra, S. Kanhere, and S. Jha. *Poster abstract: µ-BeepBeep: Low Power Acoustic Ranging on Mobile Devices*. In the 10th European Conference on Wireless Sensor Networks, EWSN '13 [Awarded: Best Poster]

Abstract: We present µ-BeepBeep: a low energy acoustic ranging ser- vice for mobile phones. µ-BeepBeep combines the efficacy of the basic BeepBeep ranging mechanism with a light-weight cross-correlation mechanism based on sparse approximation.

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

- **Project meeting/Tutorial delivery**: January 14-20, 2013 in IIT Mumbai and IISc Bangalore, India
- **Conference**: The 10th European Conference on Wireless Sensor Networks, EWSN '13: February 13-15, 2013 in Ghent, Belgium
- **Project Meeting:** February 15, 2013 in Universiteit Gent, Belgium
- **Project Meeting:** May 13-15, 2013 in Technische Universitat Berlin, Germany
- **Seminar**: "Intellectual Property Protection in India", October 3rd, 2013 in Stockholm, Sweden
- **Seminar**: "Regional Global Seminar on Cooperation in Education and Research", October 15, 2013 in MDH in Västerås, Sweden

IV – RESEARCH EXCHANGE PROGRAMME (REP)

First period: 1 week at Universiteit Gent, Belgium
Research Group: iMinds-IBCN
Scientific contact: Prof. Ingrid Moerman
Email: ingrid.moerman@intec.ugent.be
Description:
Description: The nature of work included:

- Understanding the w-iLab.t testbed
- Evaluating a RF-indoor localization solution developed in our group

Second period: 1 week at ETH Zurich, Switzerland
Research Group: Networked Systems, Computer Engineering Group
Scientific contact: Prof. Lothar Thiele
Email: thiele@ethz.ch
Description: The nature of work included:

- Technical discussion on developing a localization service in Glossy, a state-of-the-art network flooding and synchronization protocol in wireless sensor networks
- Delivering a technical talk on: "Energy-efficient ranging and detection with sparse cross-correlation"