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Intelligent Mobile Sensing and Analysis Research Network in South Africa – Building a base at the CSIR

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Abstract

Intelligent capturing and secure communication of physiological and environmental data to central point of presence in large magnitude is crucial in the design of accurate models of natural and man-made systems or processes. The research network aims to utilise ubiquitous mobile phone devices, integrated with built-in or externally connected sensor units to achieve this. Furthermore, as sensor signals are more noisy and mobile device capabilities are improving, the initial sensor signal enhancement can be done at the mobile device itself, reducing the need for large-bandwidth communication channels and increasing the security of signal transmission to a central applications server database. At the central server data base sensor data enhancement, artificial intelligence methods such as data mining and expert systems modelling can be applied to extract intelligence and statistical inference. Currently sensor data acquisition is often limited in magnitude, poorly organised and is dedicated to equipment with specific locations, which can reduce the usefulness of the data for model building and decision making based on model-based signal processing.

Mobile devices are suitable platforms for geographically and time unlimited acquisition, enhancement and secure communication of sensory data in large magnitude to a central database. The applications of such an intelligent mobile sensor system can be:

1- Remote mobile health and environmental monitoring, where non-invasive sensors integrated with mobile phone devices can help in ambulatory and continuous monitoring of patients, natural environment monitoring and medical processes. The CSIR thematic research areas of Health, Biosciences and the Natural Environment can benefit from the research and development by this research network.
2- Biometric sensor-based secure voting, census data survey, modelling of public transport systems, mobile library access and mobile financial services can benefit from the research spin-offs of the intelligent mobile sensor data platform.
3- Mobile multi-sensor systems are also becoming increasingly important in a variety of fields. A mobile sensor network is composed of a collection of nodes that has sensing, computation, communication and locomotion capabilities. These networked sensors have many potential civilian and military applications.

1. Introduction

The combination of sensors with ubiquitous mobile computing devices and associated mobile communication networks will lead to applications supported by the next generation technology in the thematic areas in which the CSIR is focusing its strategic research. Advanced and intelligent data acquisition in large magnitudes can be performed by combining sensors with mobile devices carried by over four billion people in the world. Two important developments are the main drivers: the widespread deployment of mobile devices and their increased capabilities of integrating sensors. By combining sensors and mobile devices, the strategic research network aims to build intelligent sensor data acquisition platforms, advanced statistical sensor signal modelling and analysis algorithms, secure mobile sensor data communication protocols and service delivery platforms for the thematic applied research areas at the CSIR. The research network, in collaboration with tertiary education institutes, further plans to promote research and human capital development in mobile computing and sensor technologies, sensor signal modelling and analysis with the aim of making the project sustainable, and make a lasting impact on society.

Future smart mobile devices are expected to be integrated with different sensors to make possible a natural interaction with our environment and people [1, 2]. The original concept of mobile computing and communications embodies embedded sensors, computing and communication. This is clear since the microphone and camera are the sensors detecting voice, picture and video signals; speech and video enhancement and coding represent the signal processing; and the radio interface communicates with the outside world. A variety of mobile hardware sensors are being planned for integration with mobile chipsets. Therefore in the long term the developed models, platforms and techniques can contribute to innovation and applications in public and private enterprises to improve the life of people in South Africa and elsewhere in the world.

Internationally, the network will gain from collaboration with MIT media lab, the EPROM.MIT.EDU initiative collaborative linkage. MIT media labs [3] has used mobile phone-generated CDR (call data register) information for town planning and disaster warning. The University of California's CENS@UCLA centre is also involved in research on embedded networked sensing using mobile devices for ecological observation systems, remote patient monitoring and urban planning [4]. Locally the university of Johannesburg's Artificial Intelligence group (www.uj.ac.za) will be a collaborative network partner.

Example: When a small earthquake hit the city of Los Angeles a student at a California university programmed his mobile phone to capture readings from its built-in accelerometer, a **sensor** originally intended to support features such as games. He then transferred the data to a computer and plotted the result. Success! His phone had become a mobile seismometer.

2. Sensors and mobile computing devices

Modern mobile devices are already equipped with a number of sensors: accelerometers, biometric (finger print) sensors, cameras, GPS positioning sensors, pressure and haptic sensors and gyroscopes.

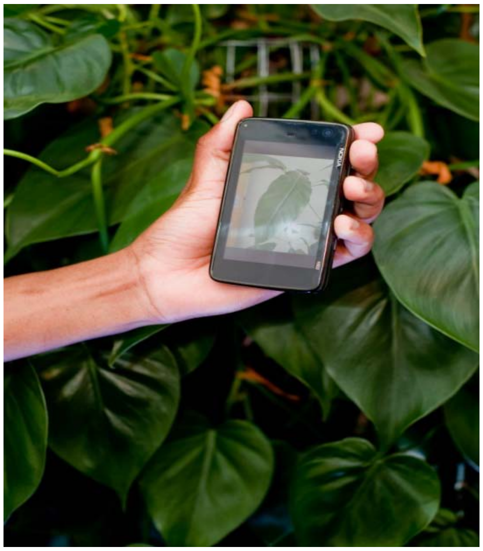


Figure 1: Environmental monitoring

At the same time external sensors can be connected through various interfacing methods to mobile devices to utilise the pervasive deployment, mobility and geographical independence of mobile computing, information transmission, access and delivery. Estrin [1] states that “in the world there has never been a technology other than human observation, that is as pervasively deployed as the mobile-phone”. It then becomes natural to integrate mobile devices with sensors to build a location- and time-aware global sensory network. Already mobile phones are regarded as eyes and ears in urban and rural societies because of the cheap video camera and audio recording sensors integrated in mobile devices. For example, spectacular media footage recorded by mobile phone has appeared in big media such as the BBC and CNN of the shooting of students at Virginia Tech in April 2007.

In this paper the research network will consider both embedded and external sensors to achieve mobile intelligent sensor data collection in large magnitude for improved societal and environmental services. Adding computing to services such as mobile health monitoring, mobile biometric sensing, environmental monitoring, traffic and urban planning and sensor network-based disaster prevention will benefit from the application of mobile integrated sensor systems. The intelligence in such a mobile sensor data collection and processing system comes from the exact GPS/Cell-ID positioning and time tagging of the collected data, and the expert system that will be used to analyse the collected sensory data.

3. Mobile sensory health monitoring

One important application of the sensor and mobile integrated system is in remote health monitoring. Remote monitoring of patients in ambulatory the situation, where vital physiological signals can be sensed and sent to a medical centre before the ambulance reaches the medical centre, can be crucial to save the lives of patients.

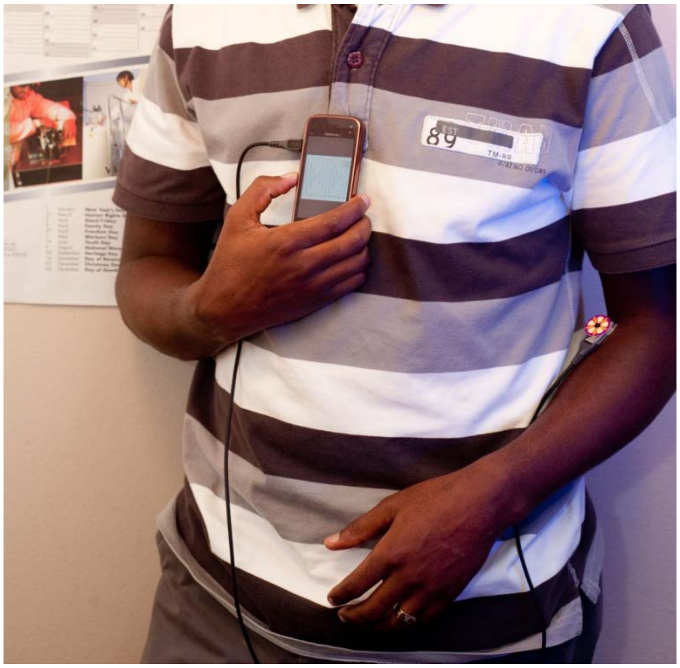


Figure 2: Mobile sensing of physiological signals

Continuous remote monitoring of chronic patients is another area that can be supported with such a system. A mobile health monitoring system involving a non-invasive physiological sensor and a mobile phone for secure wireless transmission or storage of sensitive medical information is considered here. The system could be designed as a wearable and alerting tool (Figure 2). A non-invasive sensor based on PPG (photoplethysmography) and digital signal processing (DSP) is described in [5]. The sensed PPG signal is enhanced with DSP as described, and the enhanced sensor signal is made ready for analysis and decision making.

Such a system as described here has the added advantage that we can now transmit the sensed and enhanced sensor signal to a remote location using mobile wireless technologies. Figure 3 illustrates the components of a mobile health application for remote sensor-based health monitoring. It is composed of a non-invasive sensor to measure a physiological parameter from a patient’s body, a digital signal processing unit (DSP) to enhance the noisy sensor signal, and transmission to a central server. Signals obtained from non-invasive sensors often are very noisy (with 0 dB SNR), therefore the required signal processing (see section 9) could be intensive to extract the correct physiological information. Depending on the type of mobile device connected to the sensor and the type of sensor signal (1D or 2D multimedia), the signal processing can be performed inside the sensor unit, the mobile device or through support of the cloud. The application server is the final destination of the required health information.

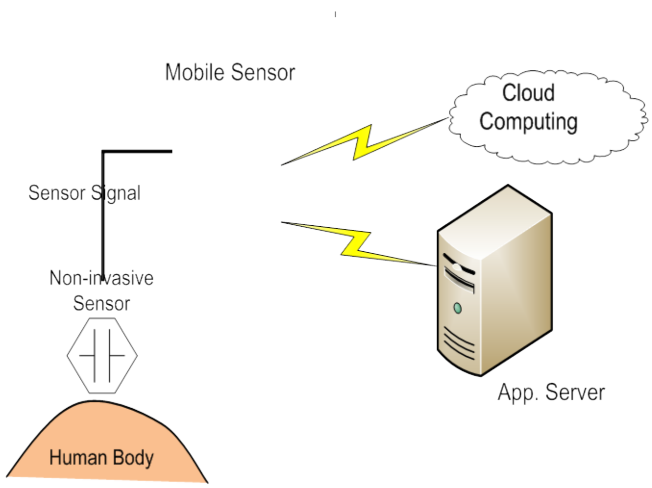


Figure 3: Mobile sensor health monitoring system

A varied-layer security model is imperative at the applications layer to meet the security needs of each application. This is normally hosted by the mobile health provider company. The service provider can also subscribe and request secure storage services from the cloud as shown in Figure 3. This allows a secure back-up of mobile health information. In order to provide these services in a standard open platform, the next generation network IP multimedia subsystem (NGN-IMS) platform with standard and open signaling and authentication, authorisation and accounting (AAA) functions is considered here.

4. Mobile cloud computing

In "Beyond the Internet" discussion of next generation networks and services, several research organisations pointed out that mobile wireless devices will be the predominant Internet access platforms by 2015 [1]. Therefore cloud computing is envisaged as the future computational and storage offloading resource for mobile wireless computing devices. This will reduce the limitations of battery life, computational capacity and storage requirement, which are typical of mobile devices. Cloud computing is defined as Internet-based computing, whereby shared resources such as storage, software and information are provided to computers and other devices on demand, like a public utility. Mobile devices can make use of these resources to compute and process advanced sensor signal applications. In mobile cloud computing, mobile phones offload computationally intensive multimedia applications to a cloud computing resource. This in turn will also enable the possibility of low-end mobile devices carried by the masses to be used for applications requiring advanced computational requirements.

Sensor-based continuous mobile health data collection and processing, environment monitoring, and biometric-based mobile financial applications and mobile sensor networks requiring high-performance computing will benefit from a mobile cloud computing R and D network [3, 7].

5. Mobile sensor data analysis

Statistical modelling and inference based on acoustic, image and physiological sensor signals obtained from ubiquitous mobile devices are an important artificial intelligence research area [3]. Extracting intelligence and statistical indicators based on collected sensory information will enhance decision making and applications development in the thematic areas of the CSIR. The emphasis is mainly on statistical modelling and application of data mining algorithms on various types of sensor signals with applications in enhanced prediction and estimation of societal and environmental problems. Research interests include: Bayesian estimation, optimisation, model selection, wavelets and multi-resolution signal processing, information theoretical methods, regularisation, and adaptive methods and neural network learning methods.

Availability of location information through Cell-ID and GPS-integrated mobile devices add time and position intelligence to the collected mobile sensor data. Therefore continuous time series monitoring of human mobility in metropolitan areas is possible. Sustainable planning of emerging cities and transportation systems can benefit from the research network. Information-rich time series mobile sensor data about moisture on the road and in unmonitored areas outside the highway system can be used for efficient planning of road transport systems. Continuous time remote monitoring of environmental health and water contamination is another area that can benefit from the mobile sensor research network. Large data base identity management multimodal biometrics is very hard to steal, share or compromise. We envision an environment where a service vendor (a bank, identity issuing authority, a voting station or a utility payment unit) can trust and authorise the mobile user to their services. The research network aims to develop reliable mobile multimodal biometric identity mechanisms possible by biometric signal capturing and processing capabilities integrated in a mobile device. The work on mobile biometrics will benefit government and law-enforcement authorities [8, 9]. The research network is also investigating R&D collaboration with the European mobile biometrics research network [6].

Large data base identity management through biometric sensors described in the next section also will benefit from an expert system designed on top of the collected sensory data base information.

6. Sensors and mobile biometric identity

Modern mobile devices are integrated with technologies capable of signal capture and analysis for multimedia processing. Taking into consideration that mobile devices are more ubiquitous than normal desktop PCs, it makes sense to give mobile devices the ability to recognise the user and in doing so allow a third party to have confidence in the mobile device and the user request for services.

Figure 4: Mobile biometric identity

An ideal and reliable method of recognising, authenticating and authorising a user for a service is thus through a combination of biometric identities. These are typically voice, fingerprint, facial picture and iris identifiers. Mobile devices with varying resolution can record or sense these biometric identities. Externally pluggable modules, as shown in Figure 4 [9] can also act as biometric sensors until the deployment of widespread biometric sensors and integration in mobile devices.

7. Mobile sensor networks

A mobile sensor network is composed of a collection of nodes that has sensing, computation, communication and locomotion capabilities. Mobile sensor networks (MSNs) are formed by a large number of sensory mobile nodes, distributed in such a way that they collaborate to achieve a common purpose. The purpose of the MSN could be to sense and monitor physiological, environmental or man-made processes. MSNs are good candidates for utilisation in intelligent object tracking, intrusion detection, environmental monitoring, disaster area monitoring and recovery, hazard and structural monitoring, traffic control, inventory management in factory environments and health-related applications. Secure communication protocols between MSN nodes and a central sensor data repository and decision support are also areas that the research network will tackle [10].

8. Mobile Sensor Lab at the CSIR

A mobile laboratory has been established with fundamental hardware device platforms and software tools required for mobile sensor software and hardware development and testing. The laboratory is equipped with a number of mobile platforms donated by Nokia R&D and open-source mobile applications software development hardware and tools. These will be used for research in modelling mobile security and sensor systems, and the development and testing of mobile sensor applications in the above-mentioned areas.

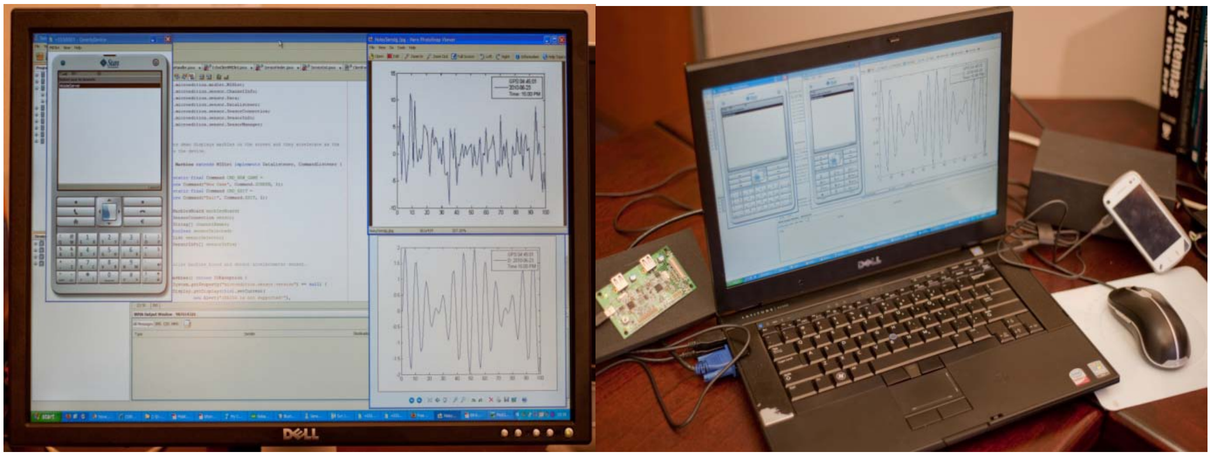


Figure 5: Mobile sensor research and modelling environment

9. Sensor signal processing

Sensor signals are mostly captured in combination with environmental noise signals, which makes the sensor signal unusable without signal enhancement and extraction to remove the unwanted additive noise signal. The signal-to-noise ratio (SNR) can typically be in the region of 0 dB SNR for many real-world applications. Hence digital signal enhancement and extraction are crucial components of a mobile sensor-based system since the physiological or important information parameters are embedded in the waveform of the sensor signal. Accurate and non-distortive sensor signal waveform extraction requires digital filter models which give a high magnitude attenuation for out-of-band frequencies and unwanted additive noise signal while preserving the linear phase characteristic of the filter to avoid distortion in the important sensor signal waveform. Such a digital filter transfer function characteristic is defined by:

$$H(f) = |H(f)|e^{-j\varphi(f)} \quad \text{………………. (1)}$$

Where |H(f)| is the magnitude or attenuation function of the filter, and $\varphi(f)$ is the phase function with respect to frequency.

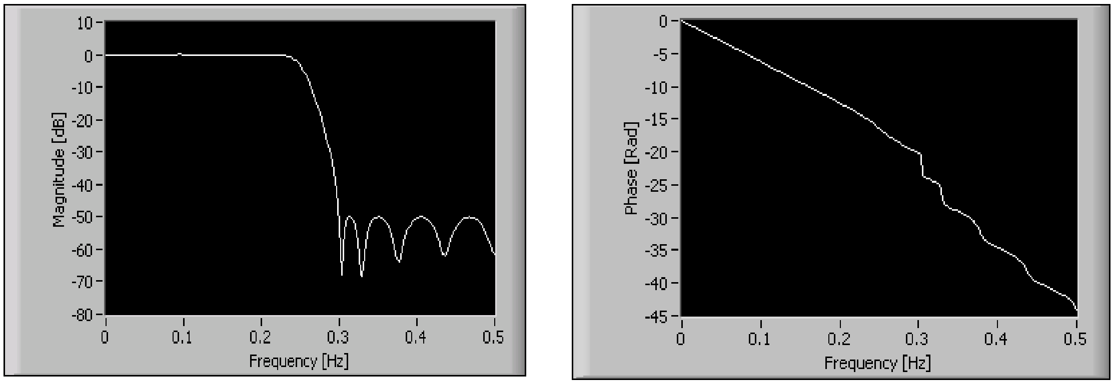
An ideal transfer function plot of a low-pass filter, with a normalised cut-off frequency of 0.3 Hz is shown in Figures 6 a-b. The filter characteristic depicts a 60 dB attenuation of out-of-band frequencies, while the phase characteristic is maintained linearly within the pass-band (0-0.3 Hz). Such a filter characteristic can be obtained by using one of the two digital filter design methods, namely the Infinite Impulse Response (IIR) architecture described by equation (2), or the Finite Impulse Response (FIR) model given in equation (3).

$$y(n) = \sum_{\mathbf{k=0}}^{\mathbf{N}} a_k \mathbf{x}(\mathbf{n}-\mathbf{k}) - \sum_{\mathbf{k=1}}^{\mathbf{M}} b_k \mathbf{y}(\mathbf{n}-\mathbf{k}) \quad \text{………….(2)}$$

$$y(n) = \sum_{\mathbf{k=0}}^{\mathbf{N}} a_k \mathbf{x}(\mathbf{n}-\mathbf{k}) \quad \text{……………………………….(3)}$$

Where a_k and b_k are the filter coefficients, x(n) is the input and y(n) is the output of the filter. M and N are the sizes of the recursive and non-recursive parts of the filter respectively.

As shown in Figure 3, we assume that such signal enhancement filters can run either in the mobile sensor device in the case of smart phones, or the operation is offloaded to the cloud for processing in the case of limited capacity client mobile devices.



(a) **(b)**

Figure 6: Ideal sensor signal filter characteristics

10. Conclusion

- Mobile intelligent sensing is an emerging research area internationally in which South Africa should participate.
- Large-scale mobile sensor-based data collection is crucial for accurate modelling of man-made and artificial systems or processes.
- The building of a mobile-sensor security lab is ongoing.
- The CSIR can play a central role in developing intelligent mobile sensor platforms and networks for addressing crucial research requirements of CSIR thematic units, and development of government, industrial and societal services.
- The research network would like to collaborate with interested CSIR units, research institutes and industry that are willing to contribute to the advancement of science and technology in the area.

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