Overview of Progress in Smart-Clothing for Health Monitoring and Sport Applications

Luís M. Borges, Andreia Rente, Fernando J. Velez, Luisa R. Salvado, António S. Lebres, J. Martinez Oliveira, Pedro Araújo and João Ferro

***Abstract*—Smart-Clothing is a project that combines research in textiles materials and wireless sensor and actuator networks in the context of human body monitoring with statistical methods for the data analysis and treatment. This project aims mainly to aid in the monitoring of the foetal movement in the last four weeks of pregnancy. Besides the integration of sensors in the garment there will be needed a hierarchical communication system that allows the delivery of the data collected from the garment that the pregnant is wearing to the doctor. The pregnant can be either at home or in the hospital. In the first stage of the project tests are being made using several types of sensors integrated in a belt in order to choose the one that is more reliable for the detection of foetal movement. Another sensing task is the manufacture of the electrodes for the electrocardiogram (ECG) system. At this point, the electrodes for the ECG are already made and working. The testing of the sensor for the detection of foetal movement is still being done.**

***Index Terms*—Smart Textiles, Hierarchical Wireless Communications, WSAN, Tele Medicine, Sports.**

I. Introduction

The main objective of the Smart-Clothing (Smart Clothing for Health Monitoring and Sport Applications) project is to boost the regional economy in the area of knowledge and technological innovation by using materials for the smart textiles and embedded advanced communications systems. This project has a specific objective of covering the market of healthcare and sports. The development of Smart textiles prototype, such as the one proposed by the Project Smart-Clothing, combines investigation in functional textiles materials and wireless communications networks in the context of human body and statistical methods for the data analysis and treatment. A hierarchical communication system is employed to deliver the data from the Wireless Body Area Network (WBAN) that is installed in pregnant woman. Although the main focus of Smart-Clothing is to produce the sensors integrated into the clothes and to integrate them into the WBAN, broader Wireless Sensor and Actuator Network (WSAN) solutions are being envisaged. e.g., in the context of high competition teams, where the objective is to design and develop instrumentation to support clinical intervention for the rehabilitation of neuro-muscular and muscular-skeletal functions caused by traumatic injuries that occurred either during sports activity. As the biomechanical analysis of the human movement needs a use of complex hardware and software systems, there is an opportunity for wireless communications and instrumentation and measurement research to integrate these devices into tiny wireless sensor devices, with simplified network capabilities, that will enlarge amplitude and freedom of the movements.

The remaining of the paper is organized as follows. Section II presents the overview of the project. Section III presents the description of the project. It includes the main areas of the project and the tasks overview for the Smart-Clothing project. Section IV presents preliminary results of of movement and ECG sensing. Finally, Section V presents the conclusions and suggestions for further work.

II. SMART-CLOTHING

This Smart-Clothing project is an iCentro project approved by CCDR-C with FEDER funding and will end on December of 2008.

The methodological specifications applied in this project will allow for quantifying the precision of the experimental measurement with the new device for signal acquisition, develop algorithms to extract the parameters that show clinical relevance and to establish strategies for efficient data mining in the context of medical diagnostic of foetal health in the pregnant women, and real-time monitoring of sport activities. From the conventional sensors and electronic circuits for data acquisition and storage point of view, the objective is to

Manuscript received July 30, 2008. This work was supported by Unidade de Detecção Remota, Department of Physics, and by Unidade de Materias Têxteis e Papeleiros, both from University of Beira Interior, by Instituto de Telecomunicações, by COST 2100 (Pervasive Mobile & Ambient Wireless Communications), by the PhD FCT (Fundação para a Ciência e Tecnologia) grant SFRH / BD / 38356 / 2007, and by the Smart-Clothing project, an iCentro project approved by CCDR-C with FEDER funding. Authors acknowledge the contributions from Doctor Miguel Castelo Branco.

Luís M. Borges, Fernando J. Velez, and João Ferro are with the Instituto de Telecomunicações, Department of Electromechanical Engineering, University of Beira Interior, 6201-001 Covilhã, Portugal (phone: +351275329953; fax: +351275329972; e-mail: lborges@lx.it.pt, fjv@ubi.pt, ferro@lx.it.pt).

Andreia Rente and Rita Salvado are with the Department of Textile Engineering, University of Beira Interior, 6201-001 Covilhã, Portugal. (e-mail: rente.andreia@gmail.com; rita.salvado@ubi.pt).

António S. Lebres is with the Department of Physics, University of Beira Interior, 6201-001 Covilhã, Portugal. (e-mail: lebres@ubi.pt)

J. Martinez Oliveira is with the Centro Hospitalar Cova da Beira, 6200-251 Covilhã, Portugal. (e-mail: jmo@fcsaude.ubi.pt)

Pedro Araújo is with the Department of Informatics, University of Beira Interior, 6201-001 Covilhã, Portugal. (e-mail: paraujo@di.ubi.pt)

develop a set of electronic microcircuits associated with textiles materials in order to measure relevant biomedical and biomechanical parameters through an easy-to-use telemedicine gear, e.g., in the form of a belt. One example of how this theme of pregnancy monitoring is gaining importance in the research is the mentioned by the authors in [1], which describes an innovative, remote monitoring decision support system, utilised in the early diagnosis of pregnancy complications, through the effective and non-invasive monitoring of maternal and foetal electrocardiograms.

A hierarchical communication system, Fig. 1, will be needed to deliver the data from the WBAN that is installed in pregnant woman. Note that, although the main focus of the Smart-Clothing is to produce the sensors integrated into the clothes and to integrate them into the WBAN, the consideration of aspects of data aggregation, routing and Medium Access Control (MAC) protocols are important whilst allowing for the integration of wireless sensor networks (WSNs) into the hierarchical network.

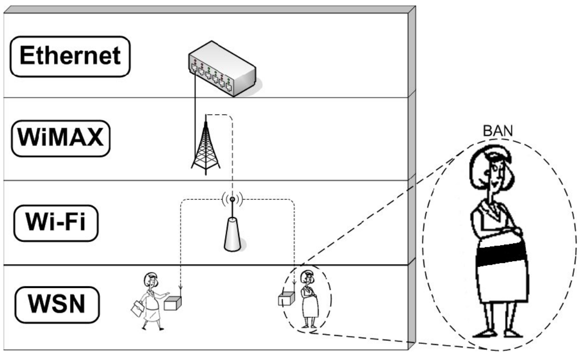

Fig. 1. Hierarchical communications considering the WBAN and other communications networks

New algorithms and protocols are being developed to optimize the trade-off between energy consumption/ processing and communication capabilities, namely in the MAC layer. Hierarchical communications can be a solution to obtain a network of networks, e.g., by using internet protocol (IP). A bottom-up architecture formed by i) WSNs, ii) Wi-Fi, and iii) Ethernet (or WiMAX) will be explored to allow for healthcare monitoring anyway, anywhere and anytime.

The interest in the coexistence among several wireless communication systems, , is increasing because the possibility of using unlicensed frequency bands. In Europe, there are two unlicensed frequency bands specifically available for wireless networks: i) The Industrial Scientific and Medical (ISM) band, which includes the 433MHz, 900MHz, 2.4GHz and 5.8GHz frequency bands; ii) the Unlicensed National Information Infrastructure (UNII) band, which includes the 5.2GHz frequency band. It is nevertheless important to note that users of unlicensed bands can equally affect the quality and the use of the frequency spectrum. Hence, one of the principal disadvantages of unlicensed frequency bands is frequency sharing and resulting interference.

III. FIELDS OF STUDY

A. Main areas

The main areas addressed by the Smart-Clothing project are the following:

- **Sports Activity:** In the context of high competition teams, the objective is to design and develop instrumentation to support clinical intervention for the rehabilitation of neuro-muscular and muscular-skeletal functions caused by traumatic injuries that occurred either during sports activity or due to cardiac stroke (or even originated from the neurological forum). As the biomechanical analysis of the human movement needs a use of complex hardware and software systems, the methods normally used are still limited, mainly due to the laboratorial conditions imposed by the amplitude and freedom of the movements, and by the portability of the systems. In Smart-Clothing, wireless communications and instrumentation and measurement researchers are integrating these devices into tiny wireless sensor devices with simplified network capabilities.

- **Obstetrics:** In low risk pregnancies, the monitoring of the foetal health in the periods between the medical sessions based in traditional protocols for counting the foetal movements felt by the mother is very important [2]. Besides the maternal perception being a relevant characteristic for the evaluation of the foetal health, the monitoring is hard to accomplish and could induce to errors, where such errors could be the mother's anxiety and concentration. Between the medical sessions that occur weekly during the last five weeks of pregnancy, the foetal health can change suddenly. As a consequence, the majority of foetus fatalities in the end of pregnancy verifies in the low risk group. Therefore, it is important to obtain an obstetric tracing, allowing for the identification of sudden changes in the foetus health, by monitoring the foetus movements and the foetal heart rate (FHR).

The foetal monitoring in the hospital is done by using equipment called TocoCardiographie, which records the FHR and the uterus contractions. The FHR is determined by using an ultra-sound Doppler sensor (f= 1 to 3 MHz), while the uterine contractions are detected with a pressure sensor. The foetal monitoring can be done by the pregnant at her home, counting the foetus movements (the pregnant feels 80% of the movements), which should be registered in a form for posterior analysis of the medic. There is in the market low cost portable equipments, based on the Doppler technology, which allow the FHR monitoring and the foetal movements, by the pregnant [3]. It can be used beyond the 12 weeks and allows recording the cardiac sounds. The use of equipments based on the ultra-sound technique poses for possible effects over the foetus, but their effects are not well known. One of the problems responsible by the appearing of pregnancy complications is the failure of the monitoring rules by the pregnant. Frequently the pregnant do not take account of the foetus movements as it is done by the health services or even they do not attend to the medical sessions. The main reason for the developing of this project is because the pregnant woman does not give special attention to the monitoring and there is not a harmless device to do this type of monitoring. This results in the need for developing automatic systems for foetal monitoring. As a consequence, the development of easy to wear tele-medicine gear will allow for remotely monitoring the pregnant women, and the health of the baby she carries.

B. *Work packages*

The project Smart Clothing has five main work packages (WP), as follows.

WP 1- Scenarios

A gathering of the health, and sports technician's needs that could be satisfied by Smart-Clothing, as well the solutions and technologies that exist in this area is being performed. The main Smart-Clothing scenario is presented in Fig. 3. It consists of four main actors, i.e., the WBANs, the WSN, the gateway and the remote agents. The WBAN is attached to the pregnant women and collects the data from temperature sensors the electrocardiogram (ECG) monitoring and the foetal movement. The WSN is itself responsible by the aggregation of the data collected by the WBAN, and its correct delivery to the gateway. The gateway has got a decision system that chooses the better way to deliver the data to the gateway located at the Hospital. The Hospital gathering has the same decision system and is used for the interconnection of a wireless sensor network with remote agents through a geographical network, to collect, aggregate and eventually pre-process data received by the WSN.

Finally, the remote agents can be either a collector of information (through a server where the information is stored and could be accessed later on) or a nurse that monitors the foetus in the pregnant women and a doctor that closely monitors the foetus by using his/her personal digital assistant (PDA), or his/her laptop or even his/her tablet PC or Ultra-mobile PC (UMPC).

WP 2- Sensors, Communications and Textile Materials

As a starting point for the sensing task different sensors will be studied with different sensing capabilities. Two types of sensors will be used, some totally produced with textile materials but others already sold on the market, which can be integrated onto the textile structures. The parameters to be measured are being identified, and a detailed study of solutions versus requirements will allow for deciding about the size and the location of the sensors. This activity is being followed by the experimental verification of all sensors, to see if they are able to capture the intended physiological signals. If this actually happens, the circuits will have to be developed and improved for a better integration into the Smart-Clothing garments. The textile raw materials sensors considered within the project are the electrical sensors – electrodes, and sensors of pressure. For the production of such sensors, it is essential to have conductive textile materials. The most often used ones are the metal alloys and carbon ones owing to their high conductivity. For the production of both types of sensors, it is possible to choose a tissue or a conductive mesh already produced.

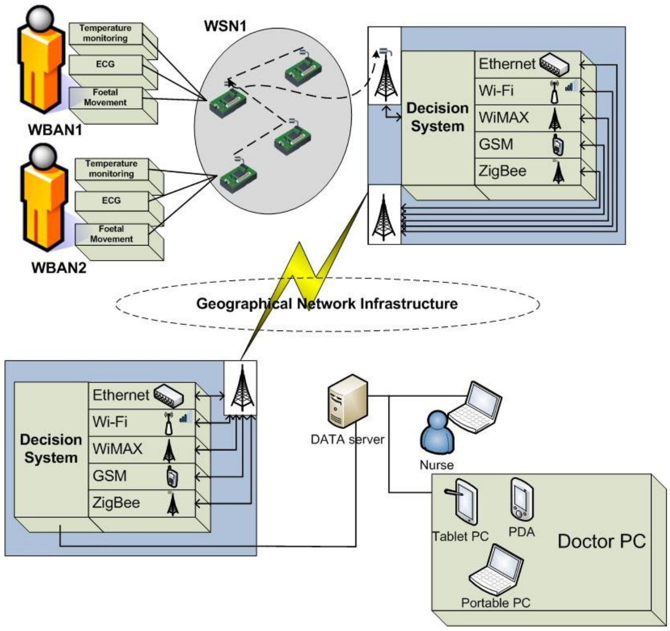

Fig. 2. Smart-Clothing main healthcare scenario.

Another alternative is to buy the raw material in the shape of wire or filament, and to produce the structures. In both cases, the sensor needs to be manufactured.

Electrodes capture the electrical signals from the body, such as electrocardiogram, electroencephalogram and electromyography signals. To collect results with these sensors, direct contact with the human body is needed, with some pressure on the skin. The implementation of these sensors requires two raw materials, a non conductive material that is used as a support and a conductive material that is going to produce the sensitive part of the electrode. A fabric is being produced with several electrodes integrated or they can be made individually through techniques such as patchwork.

The resistance of the pressure sensors varies according to the pressure suffered by them, which helps the detection of some movements. The use of pressure sensors in the Smart Clothing project is important for the detection of movements such as the muscle movements or the movements of the foetus.

The other sensors being tested are the extensometers and potentiometers. Extensometers operate similarly to pressure sensors, i.e., when pressed the strength of the material is changed. The potentiometers have the bending as a principle of work, i.e., when the sensor is bended the current increases and the resistance decreases. The variety of size and thickness of these sensors allow their integration into textile structures. This integration can be achieved through the application of the sensors, holding them onto the fabric. Another possibility is to produce a fabric with spaces suitable for the placement of the sensors. In all these sensors, there is a change in the value of resistance as a consequence of the event of touch or bending. This variation of the resistance will detect a movement or a change relatively to the previous state.

The added value of having textile materials with sensory capabilities comes from the simplicity of integration into textile structures, such as garments. This will maximise the comfort because the sensors thus become soft, thin, light and flexible, and better adapt themselves to the human body in a way their implementation does not interfere on the daily life of its users. The research is based on the capture of biological signals by using textile materials, which are having a huge development in the last years [4]. The main issues focused are the technical functionality (capture of signals with high quality) and fashion clothing.

Another important issue is the cleaning or noise reduction which causes interference within the signal. This noise is due to various causes such as the biological signals of the pregnant woman, e.g., MECG-Maternal ECG [5], or the mechanical movements such as the breathing, talking or walking. Ultra-sound are not being considered. Bluetooth or ZigBee are used for communication [6], [7], [8]. Some patents on foetal monitoring are presented in [9], [10], [11].

WP 3- Micro-electronic Integration

The concepts of energy saving in WSANs will be deeply explored by having into account the interactions among physical, MAC and network layers in a cross-layer approach. Innovative energy-aware MAC protocol solutions and routing algorithms will arise from this research. These energy-aware solutions will be integrated into the motes. Hence, the main task is to miniaturize some of the electronic components in order to consume less power while decreasing its size.

Several amplifiers, multiplexers and converters are also being implemented, according to the type of signal, signal level, frequency range and the equivalent Thévenin source.

WP 4- Communications Management and Routing

The correct data delivery to the destination (sink nodes) is a paramount. In WSNs, in an initial phase of the project, the option for the pregnant woman is to choose which system should use in order to reach the Ethernet of the hospital, where the gynaecologist is. The delivery method is chosen by the decision device and the choice can be either the Wi-Fi system or the WiMAX system, or even the Global System for Mobile (GSM) system from a hierarchical network. This decision device should be incorporated between the WSN and the networks that this device can choose. Later, automatic selection procedures for the best radio access technologies (RATs) will be incorporated. The decision device, Fig. 3, should be capable of detecting and evaluate which network is more reliable in terms of quality of service (QoS) issues [12] and should implement energy-aware techniques.

When a delivery method is chosen the nodes form the others RATs will not necessary be in the active mode, and they should in fact be in a sleep or idle mode. More than one optional delivery system can be used in order to deliver the data to the doctor, Fig. 3.

WP 5- Validation and Field Tests

Once the sensorial *hardware* is integrated into the textiles materials, the microelectronics integration of the system and the support *software* to communication developed, the validation of the devices becomes necessary. To achieve this goal, the devices will be tested in real environments, and the results will be compared with results available for existing equipments.

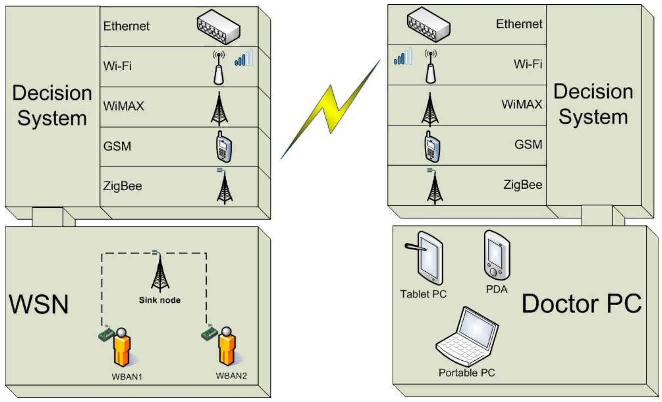

Fig. 3. Hierarchical communications and coexistence in the context of WBAN.

IV. PRELIMINARY RESULTS OF MOVEMENT AND ECG SENSING

After the scenarios had been defined the next step was to identify which type of sensor will be incorporated into the Smart-Clothing belt. To achieve this goal, several belts were made to see which sensors are capable of detecting the foetal movement. All these belts are currently being tested and results will soon popup from the tests.

The first Smart-Clothing belt was based on pressure sensors built up with conductive and semi-conductive tissues, according to the original idea exposed by the author in [13].

Fig. 4. First Smart-Clothing belt with fabric pressure sensor.

The production of this belt Fig. 4 is made with two different types of conductive tissues; some are conductive in all surface and others are only conductive in some areas. Tissues are deployed in layers so that the fabric, with conductive areas, stays in the middle of the other layer. This will act as a switch when the outer layers of tissue is pressed letting the current to traverse from one to the other, according to the value of the resistance.

The board used to acquire and send the signals to the software is shown in Fig. 5 and the software developed to count the movements of the foetus automatically is shown in Fig. 6. The results obtained by using the belt with fabric pressure sensor are similar to the ones presented by the authors from [4] in similar studies.

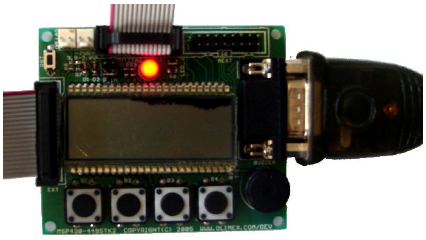

Fig. 5. Acquisition and interface board for the first Smart-Clothing belt.

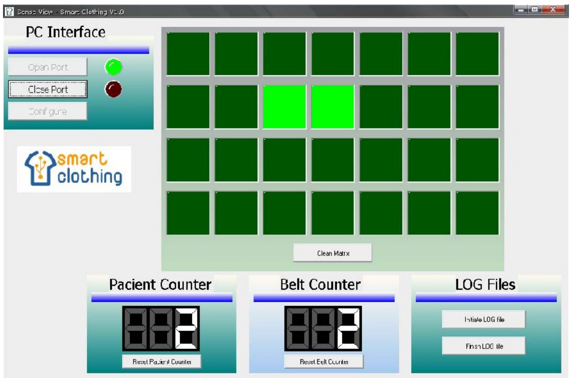

Fig. 6. Print Screen from the software used with the previous belt to show the movements of the foetus.

The second Smart-Clothing belt has a piezoelectric film sensor, Fig. 7, placed against the abdomen of the pregnant, in order to detect slight movements/ deformations caused by the moving of the foetus. The piezoelectric sensors are commonly used for the detection of biological signals. Compared with other sensors this one presents a high sensibility, reduced dimensions and do not need power supply to operate.

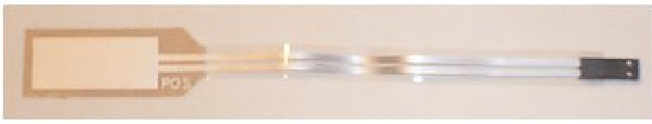

Fig. 7. A piezo film sensor used in the second Smart-Clothing belt.

This belt uses a piezoelectric sensor which is pressured against the pregnant abdomen, in order to capture the movements of the foetus. Besides the capture of these signals the breath movement of the pregnant is also captured and the movements due to the displacement of the sensor (motion artefacts). These movements represent a noise signal which should be eliminated [5], and are represented upon the curve from Fig. 8.

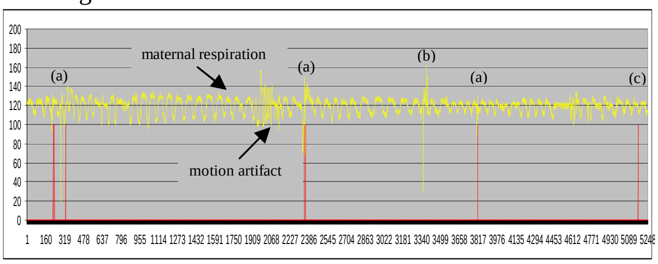

Fig. 8. Fetal movements: [upper=belt, lower=mother] (a) – detected by mother and belt (b) – detected by belt only (c) – detected by mother only.

The pregnant woman holds a pressure switch which is switched on when a foetal movement is felt by her; results are shown in the Fig. 8. In the developed prototype only one sensor was used, which was placed in several positions in order to detect the foetal movements.

The third Smart-Clothing belt uses a flex sensor Fig. 9, which measures the deformation angle when the foetus moves in the area which the flex sensor is placed.

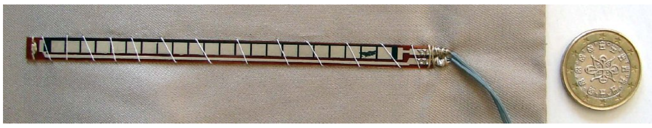

Fig. 9. Flex sensors used in the third Smart-Clothing belt.

Besides the belt, the software was also developed, Fig. 10. It allows for presenting the evolution in time of the deformation angle for each flex sensor, and counting how many movements it detects.

Fig. 10. Print Screen from the software used with the third belt to show the deformation angle in each flex sensor .

Besides the Smart-Clothing belts, the electrodes for the ECG system have already been conceived and produced. The electrodes are made with carbon wire and have the aspect presented in Fig. 1111, where the black ECG electrodes can be observed.

Fig. 11. The electrodes for the ECG exam where the black shape ones (the conductive filaments can be seen behind).

These electrodes were tested by using the circuit whose acquisition diagram for the reading of the ECG signals is presented in Fig. 12, where the band-pass filter as a band that varies from 0.4 to 35Hz.

The ECG signals captured using these electrodes, Fig. 13, were compared with the ones captured by using an electrocardiograph from the local hospital, Fig. 14.

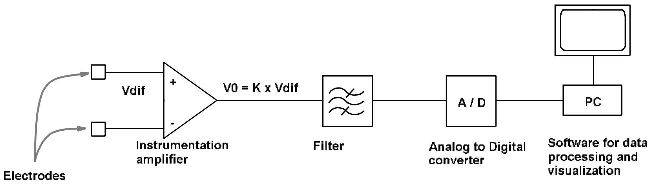

Fig. 12. Acquisition diagram of the circuit for testing the ECG system.

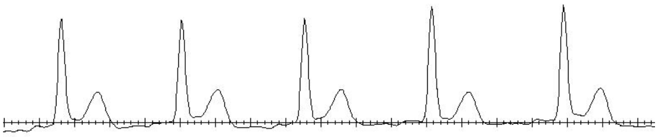

Fig. 13. ECG signal captured using the Smart-Clothing electrodes.

Fig. 14. ECG signal captured using the ECG machine from the local Hospital (Pero da Covilhã).

The electrodes used with electrocardiograph from the local hospital are presented in Fig. 15.

Fig. 15. Standard electrodes used in the electrocardiograph from the local hospital.

Besides the sensing and textiles integration tasks, the objectives of the communications task from Smart-Clothing are also being pursued. There are currently researchers working on WSANs (Crossbow motes and our own motes), WiMAX, Wi-Fi and GSM networks for the support of hierarchical communications.

V. Conclusion

The aim of this paper was to describe of the objectives and main tasks of Smart-Clothing. Preliminary results were discussed for foetal movement monitoring and ECG sensing that uses sensors based on smart textiles, and the framework for the experimental work has been described. The first trials good hints for the envisaged solutions and new experiences will certainly lead to innovative solutions. The tests of the various Smart-Clothing belts are currently being performed, and soon there will be additional results. The electrodes used in the ECG system allowed for obtaining results similar to the ones while using electrodes commercially available. The next step will be its integration with system that detects the foetal movement. The hierarchical communication system that includes the WSAN layer is also being implemented and tested.

References

[1] E. C. Karvounis, C. Papaloukas, M. Tsipouras, P. Bougia, I. Dimitrios and K. Naka, “Remote maternal and fetal health monitoring during pregnancy”, in *Proc. IEEE Information Technology Application in Biomedicine (ITAB)*, 2006, Ioannina, Greece.

[2] C. Gribbin and D. James, “Assessing fetal health”, *Current Obstetrics & Gynaecology*, Elsevier, Vol. 15, Issue 4, pp. 221-227, 2005.

[3] Angel Sound Fetal Doppler Available at: http://www.hi-baby.co.uk/acatalog/Angelsound_Fetal_Doppler.html

[4] E. Strazdiene, P. BlaŽevic, A. Vegvs and K. Dapkuniene, “New Tendencies of Wearable Electronics Application in Smart Clothing”, Electronics and Electrical Engineering, ISSN 1392-1215, No. 1(73), 2007.

[5] R. Vullings, C. Peters, M. Mischi, R. Sluijter, G. Oei, J. Bergmans, “Artifact reduction in maternal abdominal ECG recordings for fetal ECG estimation”, in *Proc. 29th Annual International Conference of the IEEE EMBS*, Lyon, France, 2007, pp. 43 - 46.

[6] C. Rodriguez, S. Borromeo, R. Prieta, J. Hernández and N. Malpica,”Wireless ECG based on Bluetooth protocol: design and Implementation”, in *Proc. IEEE Information Technology Application in Biomedicine (ITAB)*, 2006, Ioannina, Greece.

[7] D. I. Shin, S. J. Huh and P. J. Pak, “A Patient Monitoring System using Sensor Network Based on the ZigBee Radio”, in *Proc. 6th International Special Topic Conference on Information Technology Application in Biomedicine (ITAB)*, 2007, Tokyo.

[8] Y. Sakaue and M. Makikawa, “Development of Wireless Biosignal Monitoring Device”, in *Proc. 6th International Special Topic Conference on Information Technology Application in Biomedicine (ITAB)*, 2007, Tokyo.

[9] *Maternal Fetal Monitoring System*, US 7,333,850 B2, Feb.19, 2008

[10] *Fetal Wellbeing Monitoring Apparatus and Pad Therefor*, WO 2008/010215 A2

[11] *System and Method for Fetal Monitoring*, WO 2004/016163 A1, Feb. 2004

[12] E. Felemban, C. Lee and E. Ekici, “MMSPEED: Multipath Multi-SPEED Protocol for QoS Guarantee of Reliability and Timeliness in Wireless Sensor Networks”, *IEEE Transaction on Mobile Computing*, 2006, Vol. 5, No. 6, pp. 738-754.

[13] Flexible Pressure Sensor Available at: http://www.instructables.com/id/Flexible-Fabric-Pressure-Sensor/