Sensor Validation within a Pervasive Medical Environment

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***Abstract*—Pervasive patient sensing devices generate large quantities of wireless data. This data needs to be transmitted to central medical servers or mobile practitioners for real-time analysis. Various factors can affect the "quality" of our patient data. These include: wireless interference (e.g. access point or radio failure) and/or Sensor failure. Vital patient data packets may be lost resulting in an incorrect diagnosis. Patient sensor failure is a reality. It is imperative that sensor failure is detected as soon as possible to ensure a higher QoS is provided. Presented is a Data Management System-Validation Model (DMS-VM). It is designed to manage wireless interference and sensor failure in a controlled and intelligent manner. The DMS-VM samples multiple patient vital sign readings and intelligently filters this data to verify its integrity based on an agent middleware platform. This novel approach provides higher QoS within context aware medical environments. The DMS-VM experimental prototype is presented**

I. INTRODUCTION

One of the core design features of the DMS (Data Management System) [1] is to provide a higher QoS within a pervasive environment. The DMS-MV includes two validation protocols to ensure medical practitioners receive accurate patient datasets. The first protocol is an isolated sensor validator (e.g. where a single sensor is sampled and compared against a set of predefined ranges). The second protocol is a cross sensor validator (e.g. where two patient sensor types are compared against each other i.e. an ECG sensor R-R interval against a pulse sensor). These protocols are especially effective as packet loss is likely to occur within a heterogeneous wireless broadcasting environment. The loss of transmitted signals within the medical community is unacceptable. [2] Demonstrated that transmitted ECG signals from WPANs (Wireless Personal Area Network) suffered poor reliability due radio interference. Sensor failures are an additional concern which may result in poor patient care. The DMS-VM protocols provide a robust solution for sensor validation within a medical environment by utilising the context capabilities of autonomous reasoning software agents.

In section II the DMS-VM architecture is presented. This section will describe the agent-based architectural framework and the data validation techniques employed. The technologies utilised to realise the overall system will also be outlined. A problem domain and evaluation of the DMS-VM model is given in section III. Finally, section IV will conclude with a summary on the DMS-VM and future research.

II. DMS-VM ARCHITECTURE

A logical overview of the DMS-VM architecture is presented in figure 1. If the patient monitoring device does not contain sufficient processing capabilities, data is transmitted onto the mobile device or central server. Isolated sensor validation may be executed within the patient mobile device (e.g. PDA, mobile phone). Cross sensor validation is executed within the DMS-Server. Here two separate patient vital-sign datasets are compared against each other. For example, two pulse sensors may be attached to a patient. Here the DMS-VM will be able to determine if they are producing similar results.

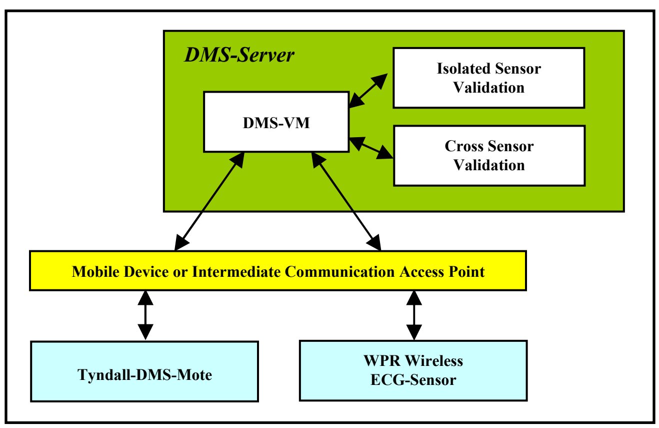

Figure. 1. The DMS-VM agent within the DMS-Server provides two validation protocols to manage our sensor readings. 1) Isolated sensor validation, where a single sensor value is measured against a set of predefined ranges 2) Cross sensor validation. The DMS-VM agent compares the Tyndall-DMS-Mote pulse rate readings against the WPR-ECG R-R intervals to ensure they are providing similar pulse readings.

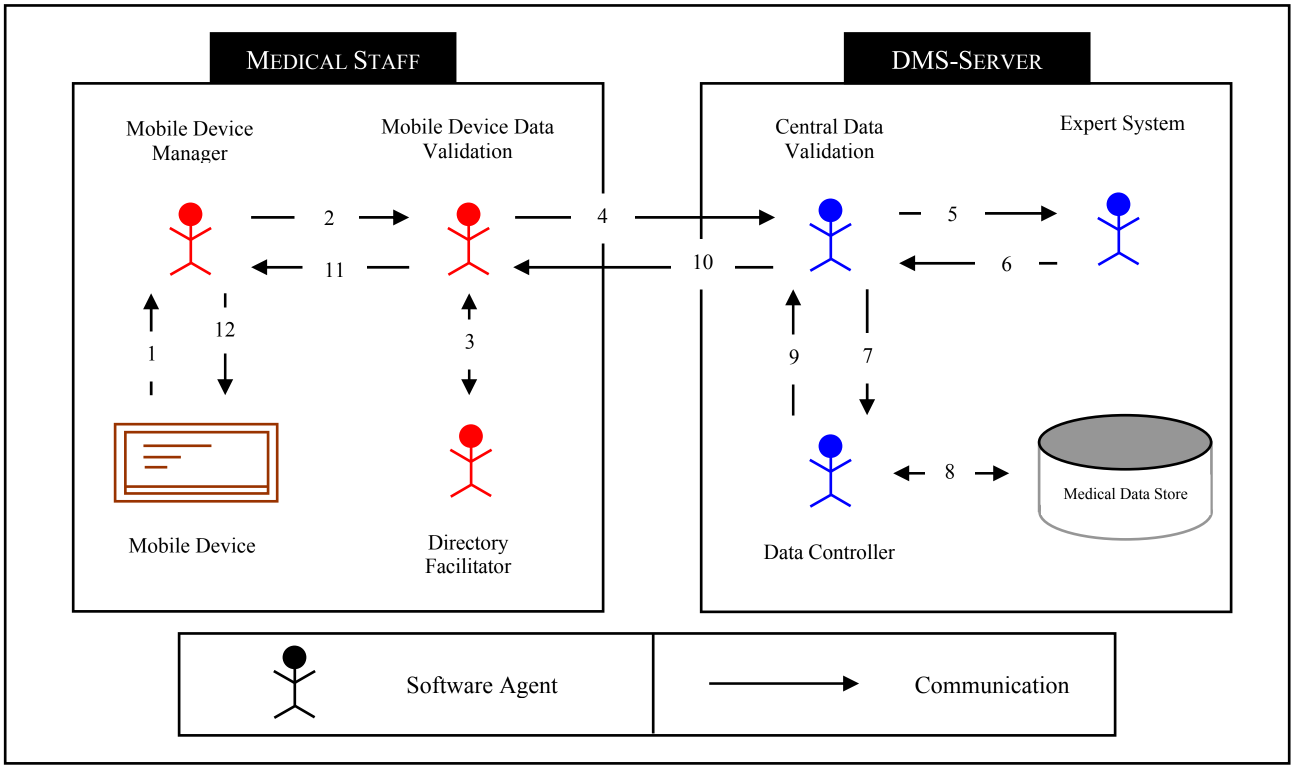

Figure. 2. The DMS-VM Agent Based Architecture.

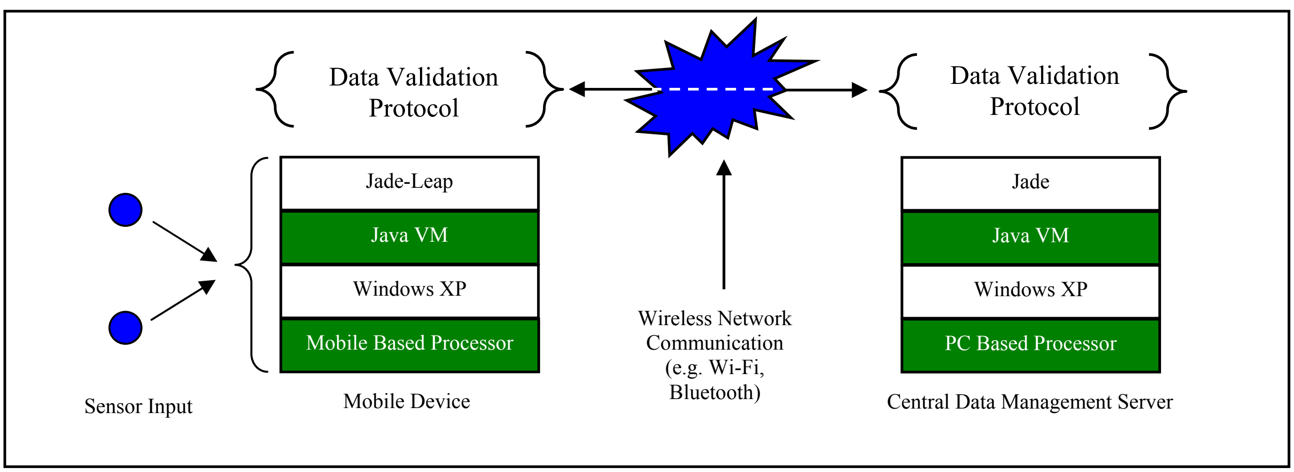

Figure. 3. The DMS-VM Implementation Overview.

An outline of some of the key software agents and their interaction between medical staff and specific datasets is presented in figure 2. These include:

1) Mobile Device Manager Agent (MDMA)

A resident JADE software agent. It is designed to arbitrate between the central DMS-Server and medical practitioner. This agent deals with medical staff requests and incoming server updates. The MDMA interacts with the Mobile Device Data Validation Agent for pre and post validation checks.

2) Mobile Device Data Validation Agent (MDDVA)

Incoming and Outgoing datasets to and from the mobile device pass through the MDDVA. This agent is responsible for ensuring that the current dataset resident on the mobile device is within a set of predefined sensor ranges. It achieves this by associating each sensor type with a collection of sensor type parameters.

3) Directory Facilitator (DF)

A JADE multi-agent management facility. It maintains a continuous view of all JADE agents within its local platform. The DF continuously examines the services each mobile agent provides, their location and current state. If a JADE agent is created or terminated relevant JADE agent domains will be notified.

4) Central Data Validation Agent (CDVA)

The CDVA manages all real-time sensor data streams and medical practitioner request/updates. All of the CDVA executions are based on the central expert system, which contain a formal set of data validation rules.

5) Expert System Agent (ESA)

The ESA associates incoming sensor types with a set of predefined validation rules.

6) Data Controllor Agent (DCA)

The DCA populates the medical data store with incoming medical practitioner request/updates and sensor values.

The DMS-VM prototype enables single or multiple sensor readings to be validated. It is built on a software agent middleware JADE [3] (cf. Figure 3). JADE is a Java-based open source development framework aimed at developing multi-agent systems and applications. JADE a software agent middleware platform resides within the DMS-Server. JADE-LEAP [4] is designed for mobile devices with limited processing and memory capabilities. For example it is able to function on the medical practitioner's mobile device (e.g. PDA, mobile phone). Communication between the mobile devices and central server is achieved over wireless protocols including: Wi-Fi and Bluetooth.

By implementing automated agent software in the Hand-Held-Device capable of detecting sensor information, it is possible to compare information sampled from different sensors to ensure sensors validation. This can give a more reliable measurement, where the automated detections may act with a higher degree of confidence, resulting in fewer false alarm conditions.

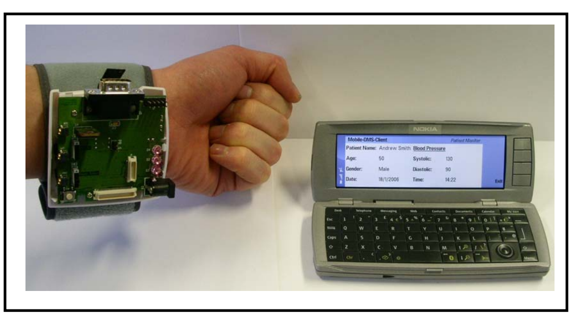

Figure. 4. A Tyndall-DMS-Mote attached to a patient's wrist. Pulse rate readings are sampled and returned to the DMS-Server for real-time Validation. Here the Nokia 9500 is utilised to transfer data back to the DMS-Server.

Three sensory products are currently under review. These include: the Tyndall-DMS-Mote (cf. Figure 4), the WPR wireless ECG-Sensor [5] (cf. Figure 5) and a desktop based bio data acquisition system, PowerLab 4/25T [6]. The Tyndall-DMS-Mote contains ECG, Pulse, Blood Pressure and Body temperature sensors. The WPR solely measures ECG while the 4/25T may attach medically certified patient sensors including ECG, Blood Pressure and Pulse etc.

Figure. 5. The WPR wireless ECG-sensor attached to a patient's chest. It is transmitting vital sign recordings to the DMS-Server through a Hand-Held-Device.

III. PROBLEM DOMAIN AND EVALUATION

Existing solutions for 24/72 hours arrhythmia detection are normally based on a cabled connection from several ECG electrodes to a recording unit, carried in a belt. There are well known problems related to missing contacts between the electrodes and the patients skin, which can lead to miscalculations. In Figure 6, a time series of recorded ECG is shown, using a "Holter monitor", obtained from a 3-channel recorder. As it can be seen from the recordings, electrodes looses from skin contact, whereas the curves enters a saturated level, the R-wave detection is not able to correctly identify the heart beats. This leads to an erroneous calculation of prolonged RR-interval, which normally will give an alarm condition.

Existing solutions are used by the patient for a predefined recording time, and the unit is returned to the hospital for analysing of the recordings. As this requires manual inspection by trained personnel, situations like the one showed in Figure 6 will normally be overruled as incorrect recorded events. The consequence of this incorrect event situation is thus limited.

Figure 7 presents a situation where a test person wearing the wireless ECG-sensor from WPR Medical is moving away from the receiver unit to a distance where package loss occurs, due to an out-of-range situation. However, similar types of packet losses can occur because of transmission errors due to influence between the wireless sensor system and other wireless systems.

The fusion of multiple sensor datasets, enable the automated reasoning model (e.g. intelligent software agents) to aggregate heterogeneous information data pools [7]. Two key areas of interest include uncertainty at various levels of decision making and reactions to temporal changes in our pervasive environment.

The Tyndall-DMS-Motes (cf. Figure 4) and the Wireless Patient Recording Electrocardiogram (WPR-ECG) [5] (cf. Figure 5) were utilised. Our results are based on deploying a JADE agent middleware within the DMS architecture. Contained within this agent platform the DMS-VM was developed (cf. Figure 2 and 3). Interaction between mobile practitioner devices and patient WPANs were channelled through the DMS-Server for real-time analysis (cf. Figure 1). Pre-validation results show (cf. Figure 6, Figure 7) the DMS-VM filtering valid data from multiple input streams.

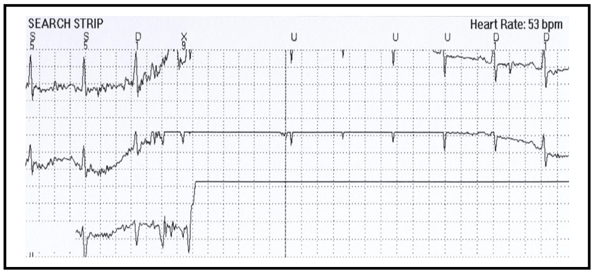

Figure. 6. A time series of ECG recordings obtained from a "Holter Monitor", RR-intervals are erroneously sampled due to intermittent sensor failure.

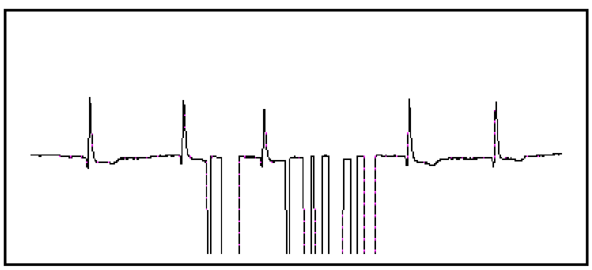

Figure. 7. Packet loss due to an "out-of-range" situation (shown as "negative-ECG lines). This is a form of communication failure.

IV. CONCLUSION

The DMS-VM prototype is presented. It is designed to validate large quantities of static (medical data store) and dynamic (mobile devices and patient sensors) datasets. As sensor failures occur within our pervasive medical environments, early detection is paramount. A key problem with automated error detection systems are the number of false alarms based on incorrect information. This may result in a lack of trust towards the system. Similar to sensor failure radio interference/disconnection generate similar outcomes.

Presented are pre-validation sensor readings (cf. Figure 6 and Figure 7), which highlights the DMS-VM problem domain. The current DMS-VM prototype operates in off-line mode (where ADInstruments and Tyndall-DMS-Mote biosensors are connected to the PowerLab 4/25T, readings are stored and analysed after the sampling period). The 2nd generation DMS-VM version will be designed to perform real-time analysis on multiple sensor types in real-time (i.e. WRP wireless ECG-Sensor R-R intervals with the Tyndall-DMS-Mote pulse output). This will be achieved by utilising the Object Linking and Embedding (OLE) feature of PowerLab bio-based applications. By fusing multiple sensors of similar types/meaning an improvement in overall performance will be indicated by the reduction in the number of false alarms.

The 3rd generation of the DMS-VM will incorporate user profiles and real-world context variables including, patient location and schedule. This will add greater meaning to our raw sensor readings, thus enabling the DMS-VM to filter out erroneous or irrelevant datasets.

ACKNOWLEDGMENT

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