SIXTH: A Middleware for Supporting Ubiquitous Sensing in Personal Health Monitoring

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Abstract. For an arbitrary event, a lack of the prevailing context compromises understanding. In health monitoring services, this may have serious repercussions. Yet many biomedical devices tend to exhibit a lack of openness and interoperability that reduces their potential as active nodes in broader healthcare information systems. One approach to addressing this deficiency rests in the realization of a middleware solution that is heterogeneous in a multiplicity of dimensions, whilst supporting dynamic reprogramming as the needs of patients change. This paper demonstrates how such functionality may be interwoven into a middleware solution, both from a design and implementation perspective.

Keywords: Middleware, Ambient Assisted Living, WSN.

1 Introduction

Two key perspectives characterize pervasive healthcare. The first concerns the application of mobile computing and sensing technologies to the provision of remote healthcare services, frequently using a variety of wearable biomedical sensor devices. The second concerns the objective of making healthcare truly pervasive both in the spatial and temporal dimensions [3]. A key motivation for pervasive healthcare is its potential as an enabler of preventative medicine. One popular interpretation of pervasive healthcare is that of Ambient Assisted Living (AAL). AAL envisages a home environment capable of monitoring and appropriately supporting the resident. The raison d'être of AAL is to enable older adults to live in their preferred home environment for longer than would normally be the case with all the personal, health, societal and financial benefits that accrue from this. AAL envisages embedded sensors dispersed throughout the home that continuously monitor inhabitant behavior and evolve as the circumstances of the inhabitant change, possibly due to increasing infirmary for example [7].

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A cursory analysis of the literature will indicate that significant research is taking place in wearable Body Area Networks (BANs) as well as embedded sensor networks for AAL. Much of this is progressing in parallel but independently, with little cross over. It is conjectured that harnessing both research streams could lead to better and more robust outcomes. In particular, the potential of harnessing AAL technologies as a basis for determining prevailing contexts would be particularly beneficial. For example, if a wearable sensor should detect an increased heart rate, it can only report this in the usual way. There may well be an organic reason for this, and one that requires urgent medical intervention. However, it could just be the case that some extra physical exertion is taking place. AAL configurations offer significant potential for determining prevailing contexts at arbitrary moments in time. This paper illustrates how a generic middleware architecture offers potential for fusing these disparate information sources, leading to more informed decision making on the part of the health professional.

The remainder of the paper is structured as follows: Section 2 provides a breakdown of relevant related work. Section 3 discusses the design of our system for combining sensed data streams. Section 4 showcases by way of example code how the design is built and how similar systems could be built within a generic framework. Section 5 identifies prudent future work and concluding remarks are provided in Section 6.

2 Related Work

Within this Section a breakdown of some related work is enumerated, in particular a discussion of AAL and BAN/Wearable Sensing Middleware is given.

Examples of middleware developed for AAL include SAM [10], OASIS [1], GAL [2] and openAAL [12]. openAAL is a flexible component based middleware showcasing variant behavior based upon installed bundles. The openAAL workflow moves from event detection to an invocation of a service controlling actuation in response to an identified situation. GAL is a service-oriented middleware which integrates BAN sensors with environmental sensors and combines the information from these sources to provide context to identified events. The SOPRANO Ambient Middleware (SAM) shares a common goal of providing a loop from sensory input to actuation. The OASIS project is an agent based offering attempting to facilitate the sharing of content between services in domains relevant to elderly patient care.

Middleware architectures are also an important consideration for a BAN; we look at two such relevant examples: Personal Wireless Body Area Network (PWBAN) [11] and Self-Managed Cell (SMC) [4]. The PWBAN offering is designed to acquire sensed data and deliver to user level applications. Elements of security, node (re)tasking, and resource detection are supported. SMC describes an architecture akin to a software agent in which each SMC is autonomous and is reactive to current user activity. A discovery module maintains contact between neighboring SMC's. A policy service governs the SMC reaction to identified events.

Through this spectrum of related work the need for the continued development of platforms supporting heterogeneous sensor devices in such a way that new devices can be easily incorporated (as within GAL) is evident. Through support for heterogeneous devices we can bridge the divide between a typical AAL home scenario and a BAN within a single system to empower applications to reason about this unified data set. There must be movement towards dynamic configurability of sensor resources, as is supported within PWBAN notably. The modularity of openAAL is attractive and such capability to inject services into the system is key when system uptime is crucial as in patient monitoring systems.

3 An Integrated Middleware Approach

SIXTH [8] is a modular, extensible and scalable sensor middleware which has been developed within the CLARITY research centre in University College Dublin. SIXTH is built on the Open Services Gateway initiative framework (OSGi) [1]. SIXTH aims to provide uniform access to sensing resources by abstracting the details of connection to the sensing apparatus. Extensibility is a core tenet of the SIXTH philosophy and is supported by its OSGi basis thus accommodating the dynamic addition of new functionality at runtime. The connection mechanisms to sensor networks are implemented as plug and play components termed *Sensor Adaptors*. A simplified description of the SIXTH system architecture is shown in Figure 1, this shows how adaptors connect to the SIXTH core, the architecture is described in detail in [8].

SIXTH is open, allowing for the replacement of functional components, such as the data dissemination policy, with a more tailored solution to suit application requirements. Support for heterogeneity of data source is key to a successful middleware solution; this is why SIXTH has been designed to provision support for any data provider through the introduction of a new adaptor. Adaptors have been developed for Tyndall iWSN nodes, TinyOS nodes, Oracle SunSpots, Shimmers, Arduinos and a multitude of web-based sources such as Twitter, Cosm and Foursquare.

To be reactive to the shifting demands of user applications, such as the applications monitoring the home environment and wearable sensors, there is necessity for dynamic sensor reprogramming e.g. to sample for light when no movement has been detected. SIXTH supports dynamic reprogramming; this is handled through the *RetaskingMessage* class and the passing of these messages to the nodes is handled by their *Sensor Adaptor*.

For our purpose herein we utilise Shimmer sensors as wearable sensors and Tyndall iWSN [6] nodes as those located within the home environment. These sensors are shown in Figures 5 and 6 respectively.

[1] OSGi: `http://www.osgi.org/Main/HomePage`

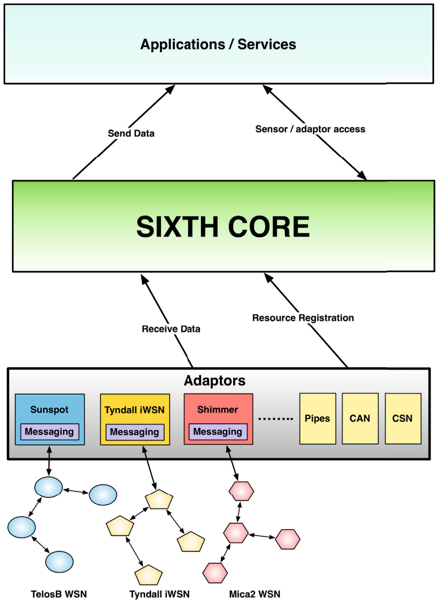

Fig. 1. The SIXTH Architecture

4 Adaptors for Heterogeneous Sensing

In this Section we discuss the implementation of SIXTH adaptors making reference to the implementation issues of the Tyndall iWSN and Shimmer adaptors. We convey our intention that heterogeneous sensor resources appear as like entities to the user application after SIXTH has isolated the heterogeneity of interaction within the adaptor layer. A showcase is provided of the data handling element of the middleware wherein we show how any component can be set up to receive data.

4.1 Creating An Adaptor

A Sensing Adaptor is created by implementing the *ISensorAdaptor* interface and enacting the required methods. As a means of relieving the burden of programming the *AbstractSensingAdaptor* has been defined with default functionality for handling component registration and data dissemination. Each adaptor is responsible for the connection to its external source(s) e.g. via USB to a WSN base station, when data is received from a source it must be translated to the *ISensorData* standard and the *send(ISensorData)* method invoked to disseminate the data to the registered listeners. Figure 3 shows the creation of a skeleton Adaptor extending *AbstractSensingAdaptor*. The *AbstractSensingAdaptor* is utilised as a common basis for both the Tyndall iWSN and Shimmer adaptors. The connection mechanism of each is different; the Shimmer adaptor is coupled with

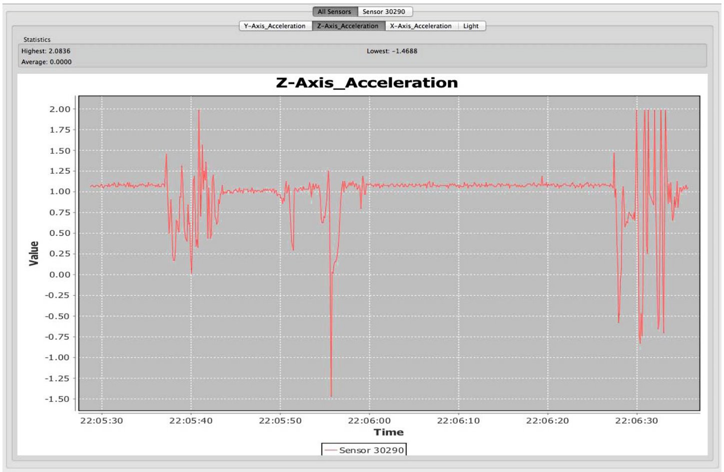

Fig. 2. Accelerometer values from a Tyndall iWSN sensor

a Bluetooth bundle for communication, whereas communication to the Tyndall motes is done via a USB connected base station. In both cases message translation must be performed to achieve a unified end result. Both adaptors support translation of *RetaskingMessage* instances to device messages for runtime device (re)tasking, this system is flexible allowing an adaptor to reject an invalid request i.e. for too high a frequency, or for an unsupported modality.

4.2 Receiving Data

The simplest method of receiving data is to implement the *IDataReceiver* interface and register the class as such on the OSGi service registry, this class will then be notified of all data which is produced by sensing entities. Figure 4 illustrates an example of a simple *IDataReceiver* implementation

To receive a filtered data stream an *INotifiier* implementation can be utilised typically with some set Query which specifies rules for the set of Sensor Data which is passed on to its associated *INotifiable* e.g. the application. Figure 2 shows a visualisation of accelerometer data from a Tyndall iWSN node. The code driving this is implemented as an *IDataReceiver* which creates a visualisation element for each numerical piece of sensed data for each newly identified sensor node.

4.3 The Wider AAL Context

SIXTH empowers connection to heterogeneous sources allowing their data to be easily combined in a single system. By utilizing Tyndall motes as door contact sensors we can reason as to where the patient is when unusual acceleration values are detected from the wearable sensor, giving inference as to an activity that might be taking place. Utilizing a wider toolkit of internal room sensors we could, for instance, discern if a patient was sitting from pressure mat data.

```
package ie.ucd.sixth.core.adaptor;

import org.osgi.framework.BundleContext;
import ie.ucd.sixth.core.RetaskingMsg;

public class ExampleAdaptor extends AbstractSensorAdaptor {

    public ExampleAdaptor(BundleContext bundleContext, String type) {
        super(bundleContext, type);
    }

    @Override
    public boolean retask(RetaskingMsg message) {
        return false;
    }

    @Override
    public String getSpecification() {
        return null;
    }

}
```

Fig. 3. Example of A sketeton Sensor Adaptor

```
package ie.ucd.sixth.core;

import ie.ucd.sixth.core.receiver.IDataReceiver;
import ie.ucd.sixth.core.sensor.data.ISensorData;

public class DataReceiverExample implements IDataReceiver {

    public DataReceiverExample(){
        Activator.getContext().registerService(IDataReceiver.class, this, null);
    }

    @Override
    public void receive(ISensorData data) {
        // perform operation on data
    }

}
```

Fig. 4. IDataReceiver implementation example

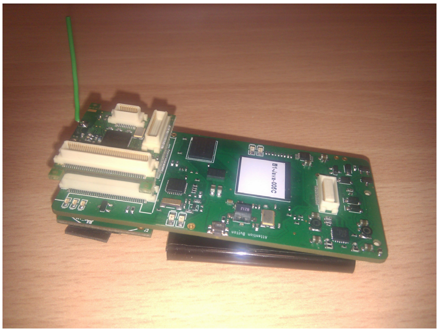

Fig. 5. Tyndall iWSN Sensor Node

Fig. 6. Shimmer as a wearable sensor

5 Future Work

In future, to provide a means for automatic event detection, while taking into account all contextual information, an agent driven solution will be utilized. This would be realised via a deep integration with the agent programming framework Agent Factory [5], and, in certain cases, adopting agile agents [9]. To further illustrate this solution, we plan to instrument a home environment and perform a large battery of tests with many sensors. We also plan to develop SIXTH adaptors for a range of smart clothing products, for example, the StatSports vest [2], so as to provide more fine grained information on patient health.

6 Conclusion

We have motivated the development of SIXTH, looking at the importance of context identification in an AAL configuration and how this can be best achieved through the convergence of multiple heterogeneous data sources. We provided a overview of the state of other initiatives and how these important issues are dealt with. SIXTH was showcased as an open, extensible middleware offering the integration of typical AAL configurations and wearable sensing devices.

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[2] Stat Sports: `http://www.statsports.ie/`

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