

Controlling Networked Devices in Ubiquitous Computing Environments using Biofeedback

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Abstract - With the advent of service oriented computing, device miniaturisation and wireless communications, it is evident that common household appliances are becoming more ubiquitous and pervasive. We are experiencing a transition from dedicated electrical appliances to devices designed to publish the functions they have as independent network-enabled services. Devices and the services they offer will be seamlessly integrated within the environment as soon as they are switched on. Such flexibility will allow us to discover, compose and execute service configurations using conventional user interfaces or autonomic reactions in the body. In this paper we describe our Biofeedback Device Control System (BDCS) and illustrate how service-enabled devices can be controlled using biofeedback information received from human subjects. We have developed a prototype to illustrate how the BDCS system works, which demonstrates how a heart monitoring service can discover and control camera devices when sharp increases in heart rate are detected.

Keywords: Biofeedback, Networked Devices, Ad Hoc Services, P2P Networking, Discovery, Dynamic Service Composition.

I. INTRODUCTION

With the advent of service oriented computing, device miniaturisation and wireless communications, it is evident that common household appliances are becoming more ubiquitous and pervasive. We are experiencing a transition from dedicated electrical appliances to devices designed to publish the functions they have as independent network-enabled services [1]. Devices and the services they offer will be seamlessly integrated within the environment as soon as they are switched on. Such flexibility will allow us to discover, compose and execute service configurations using conventional user interfaces or autonomic reactions in the body – autonomic reactions are physiological changes in the body that occur when specific conditions are present.

Imagine the home of the future forming a two-way interaction between the devices it contains and biofeedback information provided by the human body. Monitoring services, whether they are located on the

person or within the home itself, would monitor the physiological states within the body to determine whether the person is awake, tired, sleeping, alarmed, angry or sad, and automatically control context-dependent services. For example you may be within your home and you hear an intruder, which has a physiological effect on your body, i.e. there is a sharp increase in your heart rate, your breathing becomes more rapid and your palms begin to sweat. In this instance the data received from the Electrocardiogram (ECG) sensors, the Respiration Pneumogram (RP) sensors and the Galvanic Skin Response (GSR) sensors [2], possibly located with the your clothing or bed linen, detect these changes and attempt to discover and control security monitoring devices to ensure that activity within the home from that point on is recorded. The security monitoring devices would remain in a controlled state until the physiological conditions in the body returned to some normal baseline state, after which security services would be instructed to stop recording.

Creating services to control devices based on isolated biofeedback responses is simplistic, however the real challenge presents itself when trying to control devices based on contextual information. For example biofeedback services will need to communicate with other biofeedback services such as electroencephalograph (EEG) sensors to determine the context in which changes occur. In our intruder scenario, if the heart monitoring service determines a sudden increase in your heart rate it may first pre-process this condition in conjunction with other biofeedback services to determine the context surrounding the change. If the EEG service reports that the person is asleep then the change may be the result of a bad dream, and therefore decide that there is no need to instruct the security monitoring devices to record. However if the EEG service reports that the person is awake, then the heart monitoring service can conclude that this is not the result of a bad dream and instruct the security monitoring devices to begin recording. This scenario itself is problematic – for example the person may have just returned home after their daily run. In this instance the heart rate is high and the person is awake, therefore we would not want the security cameras to start recording.

In this paper we describe how biofeedback systems can be used to discover and control service-enabled devices

based on context-dependent situations. We achieve this using the advances we have made in dynamic service composition [1] and our research efforts in distributed ad hoc services [3]. We have developed a prototype to illustrate our findings, which uses real-time biofeedback information received from sensors connected to the human body.

We begin in Section 2 by describing some background work relating to context-aware service discovery and invocation. In Section 3 we describe how the Biofeedback Device Control System (BDCS) works and in Section 4 we describe and criticise the prototype we developed. We present our conclusions in Section 5 and describe what issues we will address in our future work.

II. BACKGROUND WORK

A number of research communities are actively involved in trying to understand how state changes within the body's physiology can be used to consciously and unconsciously control devices. Considerable advances have been made in a number of disciplines such as medicine [4], game playing [5], wearable computers [6], cybernetics [7], brain-computing communication [8], and ubiquitous computing [9]. However little research has been applied to the area of ubiquitous computing and Networked Appliances in order to control devices based on contextual physiological state changes. We begin by describing some notable research being carried out within several key disciplines and argue that it is paramount that we consider how these technologies can be combined to create new and novel solutions.

Schmidt *et al.* [10] describe how situational data can be used in a real world situation to approximate particular contexts. They describe how context-aware systems must decide what contexts they are interested in and what sensing technologies are required to achieve this. Contexts can then be determined by analysing the sensing technology, either by using simple if-then-rules or some other algorithm, to determine when a specific context has been realised.

Badr *et al.* [11] attempt to solve similar problems to Schmidt *et al.* [10] using a policy-based model for evolving a self-managed autonomic control service. Their Control Service is used to perform a number of self-healing functions such as self-detect, self-repair and self-reconfigure to resolve any conflicts that may occur. Although Badr *et al.* [11] do not explicitly talk about context, their system takes a number of factors into consideration, which enables the system to continually reflect on its internal state and resolve conflicts as and when they occur. In this instance the Control Service understands its own context in which services are executed.

Understanding context is an important requirement, however context alone is not sufficient. It is paramount that developers of context-aware systems within ubiquitous computing environments consider a number of other key research areas, such as internetworking, interoperability, service discovery and semantic services, if convincing results are to be produced.

Many other industry efforts have evolved to create interworking solutions, which include the Home Electronic System (HES) [12], Home Audio-Video Interoperability (HAVi) [13], Universal Plug and Play (UPnP) [14] and its Intel Digital Home implementation [15], the Digital Home Working Group (DHWG) [16] and the Open Services Gateway Initiative (OSGi) [17]. Additionally some notable research efforts have evolved to discover services, provided by networked appliances, which provide explicit solutions and define scenarios that create classic network configurations [18-21]. Moreover the provision of home monitoring and controlling systems from within TV sets and their set-top boxes has advanced rapidly in recent years because the TV is considered the central appliance within a typical home environment [22-24]. However despite the advantages they provide, several challenges need to be considered, more notably, interoperability [25, 26] and the difficulties associated with the integration of combined functionalities. Furthermore these solutions do not consider machine-processable semantics – service descriptions and services requests need to be described using ontological structures to allow context-aware systems to discover and use services based on their capabilities.

Paolucci *et al.* [27], in part, address some of these limitations by describing a service ontology matching engine [28] that determines the similarity between a service request and a service description based on the inputs and outputs they define. Paolucci *et al.* explain that there is a need to allow matching engines to perform flexible matches based on the degree of similarity between the service request and the service description. They use a term called “sufficiently similar”; in its strongest sense a service description and a service request are sufficiently similar when they describe exactly the same service.

McIlraith *et al.* [28] support this idea and state that there is a need to describe services in terms of their capabilities in an unambiguous computer-interpretable language. They describe how advances made in Web Service technologies and research carried out by the Semantic Web community could provide a means to achieve this vision by combining these technologies together to produce Semantic Web Services.

Maedche *et al.* [29] extend the ideas described in [27, 28] by providing an assessment of service-driven systems and describing the need to converge three separate technologies – Web Services, P2P technologies and the

Semantic Web. They argue that combining these technologies will allow services to be identified, located and invoked. They also point out that this new paradigm is important to the development of service-enabled systems, however they also state that this is not an easy task and the integration process itself gives rise to new complexities such as locating and integrating services on the fly, semantic interoperability, data heterogeneity and process mediation. These areas of research describe a number of interesting approaches that address a number of fundamental requirements – the challenge is to develop mechanisms that link these efforts together.

In our own research we are addressing these challenges by developing a framework that allows us to automatically publish, discover, compose and execute semantic services within peer-to-peer (P2P) networks [3]. The framework provides services that address semantic interoperability and evolve distributed knowledge structures based on general consensus [30]. It also provides a semantic matching algorithm that discovers services based on the capabilities described in service requests and service descriptions. We believe that such a framework could effectively provide a middleware solution to bridge the gap between context-aware systems and the semantic services distributed within P2P networks.

It is clear that no one solution described above will enable us to create an efficient context-aware system designed to control networked devices within ubiquitous computing environments. However by combining these efforts and developing threads that link the main ideas together will give rise to new and novel solutions that will make controlling networked devices within ubiquitous computing a reality.

III. THE BIOFEEDBACK DEVICE CONTROL SYSTEM (BDCS)

In this section we describe how we have designed the Biofeedback Device Control System (BDCS), which enables devices to publish the shared functions they provide as services within a P2P network. All BDCS devices implement the P2P Interface, which allows them to connect to the network, and zero or more application specific services that allow the shared functions they provide to be controlled. A simple configuration, which describes three peer devices, is illustrated in Figure 1.

The services within the BDCS system are described using machine processable semantics and are implemented as peer services. The BDCS system does not concern itself with the type of services used, i.e. Web Services, Java RMI or CORBA; furthermore it does not concern itself with the underlying P2P implementation – these decisions are left to the device manufacturers. However BDCS enabled devices must implement several core interfaces to ensure that the services provided by the device are described using ontological structures and that messages

distributed within the network are described using machine processable semantics.

Although resource limited devices are not required to implement a number of optional core services, such as semantic interoperability bridges, the BDCS system will try to discover and use these services within the P2P network. Such services will be used as though they were implemented on the device itself, however the service's location is unknown and method invocations are based on the remote procedure call paradigm.

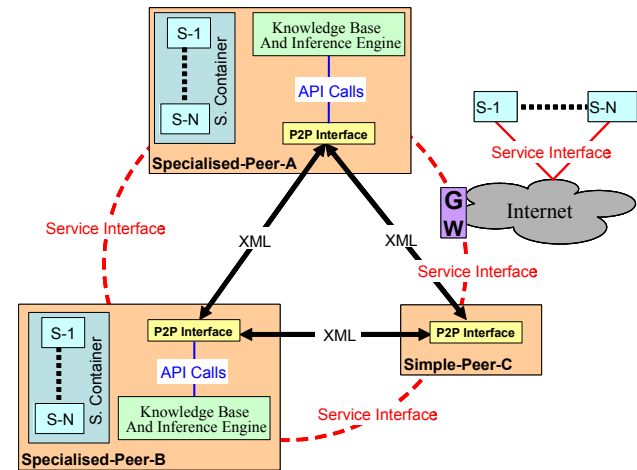


Figure 1 Peer-to-Peer architecture for service-enabled devices

The BDCS system continually monitors the real-time data streams received from sensors connected to devices and using simple rules, it determines whether an alarm condition should be raised. For example a heart monitoring service will continually monitor the heart sensors to check for any unusual electrical activity. If this device discovers that the person's heart rate has suddenly increased it will discover other services within the P2P network such as EEG monitoring services or GSR monitoring services to try and determine any contextual information surrounding this sudden change.

Services within the network need to be published and effectively discovered using advertisements therefore peer services must have a Service Class Advertisement, a Service Specification Advertisement and a Service Implementation Advertisement. The Service Implementation Advertisement is extended to implement semantic descriptions that describe the service from a number of view points. These semantic descriptions are the Service Description, the Service Profile, the Service Process Model, the Service Grounding and the Service Interface. The advertisements and the service descriptions describe how semantic services can be developed, which enable devices to discover them based on their capabilities – a typical peer service is illustrated in Figure 2.

There is also a requirement to implement security within the BDCS system to ensure that all devices and the services

they provide are authenticated and authorised. Furthermore the messages passed between devices must be effectively encrypted and decrypted to ensure that they are not intercepted and altered during transmission. Within the BDCS system we do not place any constraints on the security models used but a number of interfaces must be implemented to ensure the above requirements are addressed. This is an active area of research that is being addressed within the Networked Appliances Laboratory [31] at Liverpool John Moores University.

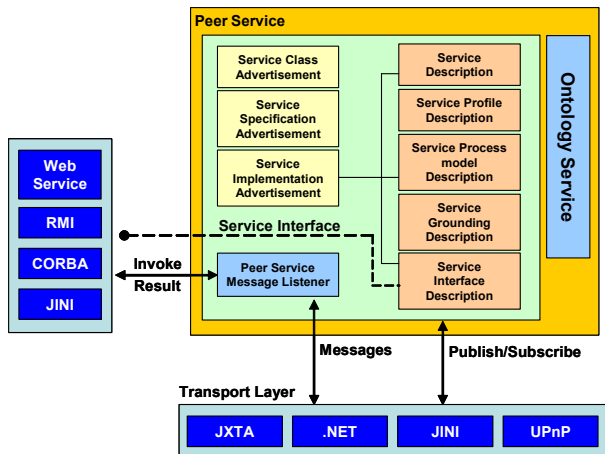


Figure 2 Semantic Peer Services

The following section provides an overview of the prototype and describes how our system controls devices within ubiquitous computing environments using biofeedback information.

IV. PROTOTYPE

We have designed and built a prototype to demonstrate how state changes in the human body can control devices using biofeedback. To achieve this we have developed two simple services. The first service is used to monitor a person's heart rate to detect unusual electrical activity using ECG heart monitoring sensors and the second service is implemented on a TINI microcontroller [32], which controls a camera. The camera was simulated as a Java application on a notebook computer, which is controlled by the TINI microcontroller using serial communications.

We used a BIOPAC MP150 data acquisition workstation [2] to read the electrical activity produced by the heart in real-time, which was received using electrode sensors (LEAD1102-R, LEAD110S-W and LEAD11) [2], connected to a MEC110C extension cable [2]. The electrode sensors themselves are connected to a Biopotential amplifier (ECG100C Electrocardiogram Amplifier) [2] and the human body using Vermed SilverRest Electrodes.

Communication between the MP150 and the heart monitoring service is achieved using a standard straight through RJ45 Ethernet cable. The heart monitoring service communicates with the TINI microcontroller in ad hoc mode using a wireless 802.11b access point. The access point is directly connected to the TINI board using a straight through RJ45 cable, which simulates an on-board wireless interface, which to date is not implemented on TINI microcontroller boards. The microcontroller is connected to the camera using a straight-through serial cable, which is used to control the device using serial commands. The described configuration is illustrated in figure 3.

In the prototype the human body is connected to the BIOPAC MP150 via the heart monitoring electrode sensors. The values received from the sensors are analogue values between 0 and +10 volts, which are measured by the ECG 100C device and converted into digital values using the MP150. This digital data is transmitted to the Heart Monitoring Service, which is written in Microsoft C#, via the RJ45 connection and processed using two algorithms. The first algorithm analyses the digital data received from the BIOPAC and calculates the global maximum in the heart beat signal as illustrated in Figure 4. When processing the data we avoided local maximums by only processing peaks above 5 volts. The peaks in the data are determined by calculating the increasing values – when the value starts to decrease we know that we have reached the maximum point.

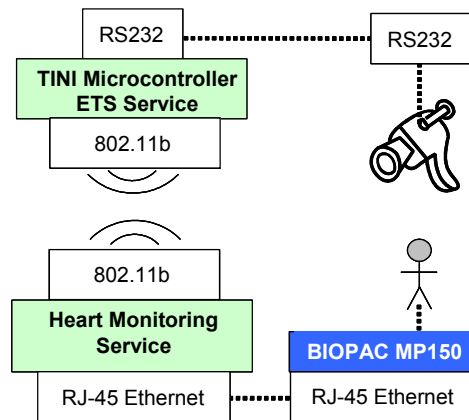


Figure 3 The Prototype Hardware Configuration.

The second algorithm calculates the time between two peaks as illustrated in Figure 4, and calculates the number of beats per minute (bpm). The bpm value is then used to determine if an alarm state has been reached. For experimental purposes, values between 50bpm and 75bpm are classed as normal heartbeat activity and values above or below this range indicate an alarm state has occurred. In this instance a counter is invoked and incremented by one for each heartbeat out of range. If this counter reaches a predetermined value (for experimental purposes this value

was set to 5), the Heart Monitoring Service generates an “enable-alarm-message” and sends it to the TINI microcontroller. The converse of this is also true – if the heartbeats remain within range for 5 consecutive beats an “alarm-disable-message” is sent to the TINI microcontroller. Using a counter in this way enables the service to avoid triggering alarm conditions if spurious spikes in the data occur. For example it is possible for a spurious heartbeat to spike above 75bpm, therefore counting 5 consecutive beats ensures that an alarm condition is definitely present, or not present as the case may be.

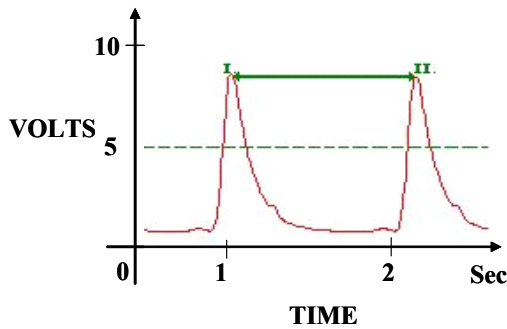


Figure 4 Heart beats signals received from the ECG 100C

Messages are sent to the TINI microcontroller using 802.11b communications and are processed by an Ethernet to Serial (ETS) converter service, which was written in Java, in order to control the underlying functions provided by the camera. In reality the TINI microcontroller and the camera would be one self-contained unit, however in the prototype the TINI microcontroller is connected to the camera using a straight through serial cable. Upon receiving control messages from the Heart Monitoring Service the TINI microcontroller instructs the camera to start or stop recording by sending serial commands to the camera.

In the following section we present our conclusions and illustrate what areas of research still need to be addressed in our future work.

V. CONCLUSION AND FUTURE WORK

In the paper we describe how common household appliances are becoming more ubiquitous and pervasive with the advent of service oriented computing, device miniaturisation and wireless communications. We proposed a system called the Biofeedback Device Control System (BDCS) and describe how it uses biofeedback information to control service-enabled devices based on different situations. We describe how this may be achieved using the advances we have made in our previous work [3, 30] and highlight key requirements that still need to be addressed.

We tested the BDCS system by developing a simple prototype to evaluate our ideas. The prototype

demonstrates that we can control service-enabled devices using biofeedback information based on physiological state changes in the body. It illustrates the technologies used to achieve this and highlights the limitations we had to deal with. It allowed us to understand how to process real-time data received from different sensors and create filtering algorithms to allow us to interpret this data. Although the algorithms we developed were single, because they only process on data channel, they proved that we could successfully filter real-time data and control wirelessly connected devices.

Furthermore the prototype enabled us to move away from simulated environments and develop a real world solution. Using microcontrollers and high-end medical equipment we were able to successfully capture signals from the human heart and control devices, which provided an interesting reality. However the downside to our prototype was the fact that it was only capable of processing a single data channel as described above. Decisions cannot be made based on isolated events therefore the data signals received from devices at any one time need to be analysed in parallel. Mechanisms need to be developed that allow patterns within these signals to be extracted and explicitly mapped onto contexts or situations. The more information we can reason over surrounding a particular event the better we can discover and control the most appropriate devices. We believe that this is a difficult challenge to address, however the ideas presented within this paper may provide a foundation on which to build.

We believe that controlling devices within ubiquitous computing environments poses the most significant challenge and there are still many requirements that still need to be addressed such as syntactic and semantic interoperability, locating and integrating on-demand services, data heterogeneity, priority mandating and process mediation. Biofeedback systems may provide an interface to ubiquitous devices, but without addressing the above mentioned problems, they will have no real value.

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