An Activity Monitoring Application for Windows Mobile Devices

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Abstract

Obesity is rising at an alarming rate. A great challenge facing the health community is to introduce population-wide approaches to weight management as existing health and medical provisions do not have capacity to cope. Technology is fast becoming an important tool to combat this trend. The use of activity monitors is becoming more common in health care as a device to measure everyday activity levels of patients as activity is often linked to weight. This paper outlines a research project where Bluetooth technology can be used to connect a commercial wrist-worn activity monitor with a Windows Mobile device to allow the user to upload the activity data to a remote server.

1 Introduction

Obesity is a pan-European epidemic presenting a major barrier to the prevention of chronic non-communicable diseases. It is becoming an epidemic affecting the life of over a billion citizens globally [1], [2], [3]. According to the World Health Organization (WHO), a majority of men are obese or pre-obese in most European countries except for Belgium, Denmark and Italy [4][5]. In the UK, two thirds of men and 50% of women are overweight. If current trends continue, the year 2010 will witness over three quarters of the British men being overweight (Obesity is also rapidly rising among children with estimates of 12 million children overweight, of which 2.9 - 4.4 million are clinically obese [6][7]. A great challenge facing the community is to introduce population-wide approaches to weight management as existing health and medical provisions do not have capacity to cope. Technology nowadays is an essential tool to provide worldwide healthcare especially for those who are not able to visit their physicians or healthcare providers more often. The encouragement of taking preventative measures to the upward trend in chronic diseases is getting through and more people are self-managing their health. That makes an opportunity for companies to develop medical devices and services to empower individuals to manage their own healthcare [7].
Current common methodologies for measuring the activities of daily livings (ADL) such as direct observation, self-report questionnaires and diaries, Doubly Labeled Water (DLW) - the measurement of energy expenditure- and heart monitoring can be inaccurate in measuring physical activities and are inconvenient for their time consumption. In addition they are unreliable since it could depend on the subject’s memory and intrusive for the patient/user [42][43][44].

Over the past few decades, the need for smart applications and devices that sense, classify and provide automated feedback related to the user’s physical activities has relatively increased with the awareness level of the communities about health and physical fitness. However, such advanced technologies are still a challenge for the market to cohere because of the limitations that small monitoring devices could have such as the processing speeds, storage and display results. Nevertheless, companies are developing platforms for the sake of providing the next generation with medical devices to connect seamlessly to one another. This achieved by making these platforms act as enabling tools for the integration of devices with co-developed systems and through the promotion of the transmission of care beyond the hospital and doctor’s office to the consumer’s home. Such devices will offer services in many aspects including disease management and monitoring products that can measure and monitor different changes in the patient’s vital signs like heart rate, blood pressure, blood oxygen levels, blood sugar levels and blood cholesterol levels. However, products monitoring vital signs are mainly targeting patients with chronic diseases, elderly patients and overweight and obese people but can also be used for fitness training programs in general for users even with no medical life threatening conditions [8].

Evaluating clinical patients can be obtained by physical activity monitoring systems. This motion sensor technology is a great help for rehabilitation programs’ quality improvements. Various devices are being used which differ with respect to technology, size and mode of expression of activity, all depending on the aim of the study or use of the system [9][10].

Nevertheless, technology progression within the past decade and the adaptive and programmable user interface have made the development of inexpensive digital monitors and mobile technology advancement possible as well as support the creation of smart embedded applications. In addition, a plethora of such devices and applications ranging from a simple pedometer to a complex web-based tracking and coaching program have surfaced for physical activity monitoring. Such devices with improved sensitivity, awareness and faster processing capabilities are more suitable for medical and research purposes [42][45]. However, proactivity and reactivity specification of the physical actions performed by the user are still required [42].

Here in this paper, we present a study of the physical activity systems and the Bluetooth technology with an embedded Windows mobile application developed to be connected and used for data upload to the web-based health monitoring system (MiLife) that is intended for round-the-clock use by a patient/user. This windows mobile application connects with the MiLife system’s wrist band - Personal Activity Monitor (PAM) - via Bluetooth wireless connection to transfer the data to the upload device and then upload it to the system’s server to be able to display one’s progression and statistical results.

2 Activity Monitoring

In order to accomplish this project and develop the application it is essential to understand What, Why and How! What exactly is activity monitoring, why is it needed nowadays! and how is it possible to wirelessly access them! The following study will explain What is activity monitoring, why they are becoming widely needed and commonly used, how it basically works and the different types of activity monitoring. Also, a complete research about Bluetooth technology, why it is applicable to connect it with the MiLife system and Windows Mobiles that are chosen for this project, why Bluetooth profiles and protocols needed for it and how the connection is actually established.
Obesity is defined as having an excessive amount of body fat. It is more than a cosmetic concern. It is a serious matter that increases a person’s risk of having chronic non-communicable diseases and health problems such as: osteoarthritis, sleep apnea, asthma, high blood pressure, gallbladder disease, cholesterol, several forms of cancer, cardiovascular disease, stroke, type II diabetes, social stigmatization, depression and low self esteem [9]. There is also increased risk of dyslipidaemia, insulin resistance, breathlessness, gout and hyperuricaemia, reproductive hormone abnormalities, polycystic ovarian syndrome, impaired fertility and of course lower back pain.

BMI (Body Mass Index) correlates with body fat in a person and can help predict the development of health problems related to excess weight [11]. It is important to note that although BMI correlates with the amount of body fat, it does not directly measure it. That shows for example in athletes that may have a BMI that identifies them as overweight even though they do not have excess body fat. Weights that are greater than what is generally considered healthy to a given height are labeled as “Overweight and Obesity”. Overweight and obesity are determined in adults by using the BMI because of its correlation to the person’s body fat. When the BMI is between 25 and 29.9, an adult individual is considered overweight and when the BMI is calculated as 30 or over, an adult is considered obese [12][13]. Causes for obesity can be categorized into lifestyle, lack of physical activities or medical reasons [14][15]. Physical activity is measurable. It is defined as increased energy expenditure (EE) by any body movement produced by skeletal muscles. In other words, the energy expenditure is a consequence of the behavior (movement). To be able to define how physical activity mediates in health effect and to quantify the amount of physical activity it is essential to know its components like; intensity, frequency and duration, where the type of the activity is not required for the assessment yet it is still used for other health applications (e.g. Bone health) [16][17].

2.1 Energy Estimation Measurements

There are four levels of physical activity intensity; low, light, moderate and vigorous. Each of these levels has a defined energy expenditure result. The results are obtained by relating the total energy expenditure to resting energy expenditure. Metabolic Equivalents is a term used for the measure of a single activity and expressed as (MET = Total Energy Cost of an Activity / Resting Energy Expenditure “REE”), or by taking the Physical Activity Ratio (PAR = Total Energy Cost of an Activity / Basal Energy Expenditure “BEE”). Whereas the average intensity for a whole day is considered as the Physical Activity Level (PAL = Total Daily Energy Expenditure / Basal Energy Expenditure). Tables of intensity measures have been extensively compiled for adults and highly used for physical activity surveillance studies which identify the threshold for each level of the physical activity as 3 METs for the moderate level and for the vigorous physical activity it is at 6 METs. As these measures were originally developed for adults they were applied on children as well. However, the MET-value can be applied in children but only when discarding walking and running from the activities performed by individuals because age can play a great role in increasing the MET-value since children spend more energy than adults which can be verified as the decline in the REE and energy cost of locomotion (The ability to move from one place to another) by age is not at a proportional rate. Hence, MET may not be the best measure when it comes to age and size. Although when adjusting the resting energy expenditure REE and when adjusting the Stature (an approximate for body-size difference in number of steps taken) children will have similar energy cost for locomotion (walking and running) as adults and a large part of this difference will disappear despite the age variance [47].

Another EE measurement method is the Heart Rate (HR), which is the most frequently indirect method used for three main reasons: 1. Heart rate is easy to measure; 2. EE is easily obtained from HR data; and 3. HR-based EE-estimates are relatively accurate in steady exercise conditions. Nonetheless, with all its advantages, heart rate measurement method has its limitations. The inconsistencies in the heart rate and EE relationship is not taken into account when assuming a steady state condition. Individual laboratory is needed for best accuracy in relating HR level to the EE. Traditional method could assume a constant level of energy expenditure at low physical activity intensity which makes it inaccurate sometimes. Also non-metabolic (e.g. Mental or emotional stress) increase in HR could influence the EE results. And finally, prolonged physical activity could develop changes in body’s metabolism which are not taken into account [24].
To estimate the EE, it undergoes two stages: estimation of oxygen consumption (VO2) then deriving the EE based on information of the VO2 estimation and the body’s metabolism. The VO2 estimation method utilizes HR information and information on respiration rate where VO2 on/off-kinetics are derived from the time interval between two consecutive heart beats (R-R intervals) [19].

Direct and Indirect Calorimetry and the Doubly Labeled Water (DLW) techniques are the most accurate methods for metabolism level measurement and they validate most other methods [21]. Calorimetry is defined as the science of measuring the heat eliminated or stored of chemical reaction or physical changes [22]. The human body produces heat as a by-product to the metabolism process in the cell which can be represented as shown in Table 1:

\[
\text{Food} + \text{Oxygen} \rightarrow \text{ATP} + \text{Heat} \\
\downarrow \text{cell work} \\
\text{Heat}
\]

**Table 1**: Heat is generated as a by-product to the metabolism process

Hence, the rate of heat produced and the metabolic rate are directly proportional. That said, Calorie which is defined as the amount of heat required to raise the temperature of one gram of water by one degree Celsius, is the common unit to measure heat energy; and since it is a very small unit, EE and energy value of foods are measured with Kilocalorie. One Kcal is equal to 1000 Calories, whereas 1 Kcal is equal to 4.186 Kilojoules (KJ). This process of measuring the body’s heat energy is called Direct Calorimetry. But when this method is not applicable for any medical or technical reason an Indirect Calorimetry method can be used which in order for it to measure the amount of heat produced in the body; it exploits the direct relationship between the amount of oxygen consumed and the heat produced in the body, so by measuring the oxygen consumption an estimation of the metabolic rate can be provided. A representation of the indirect calorimetry method is shown in Table 2 where the type of nutrients plays a role in this method (Carbohydrate, Fat or Protein) and each should be calculated solely while actually the caloric expenditure during exercise is often estimated to be approximately 5 Kcal (21 KJ) per one litter of O2 consumption:

\[
\text{Food} + \text{oxygen} \rightarrow \text{heat} + \text{carbondioxide} + \text{water} \\
\text{Indirect calorimetry} \quad \text{Direct calorimetry}
\]

**Table 2**: A representation of the indirect calorimetry method

Open-Circuit Spirometry is a technique that uses computer technology to measure the oxygen consumption as the most common indirect calorimetry technique. A gas volume measuring device is used to measure both the volume of air inhaled during the physical activity and the expired gas from the individual when it is channeled to a mixing chamber to be analyzed for O2 and CO2. The computer is then able to calculate the VO2 (volume of O2 consumed per one minute) and the VCO2 which is the volume of CO2 consumed after converting the fractions of O2 and CO2 by the analyzer. The results will be obtained at the end using this simple equation [21]:

\[
\text{VO2} = [\text{volume of oxygen inspired}] - [\text{volume of oxygen expired}]
\]

A third biological approach to measuring the energy expenditure and considered the gold standard method is the Doubly Labelled Water (DLW). Activity level is directly proportioned to the energy expenditure estimates from the loss of isotopes. The individual drinks water with stable isotopes that contain Hydrogen and Oxygen elements (2H2O) and (H218O). This equilibrates with their body water in a few hours. Two different excretions developed from oxygen isotope are (C18O2) and (H218O) and only one hydrogen isotope excretion (2H2O). The rate of CO2 can be assessed from the difference of excretion in the saliva, urine or blood. Finally, to calculate the energy expenditure from the excretion difference in addition to the amount of oxygen consumed, Weir’s algorithm is used [19, 48].

However, indirect calorimetry and doubly labelled water techniques are not easy to use and very costly. They require laboratories, expensive analytical equipments (specially the 18O) and skilled reliable technical staff. Another drawback for the DLW method is that it only assesses average EE over the 4 to
21 days of the analytical period and variation information is not obtainable within this period. Aside the fact that these two methods serve as criterion to other methods in development, they are most feasibly to be used in epidemiological researches [19, 48].

2.2 Monitoring Systems

When direct observation is not feasible for a case or a study of low frequent body movement a portable device is attached to the individual’s body to record and measure his/her motions [42]. Activity monitoring systems have progressed in the past few years, specifically 1990s, from a simple pedometer to a multi-sensor accelerometer. Storage of raw digitized movement data, or average of data can be stored in selected epochs of time, usually 2, 15, 30, 60 or 120 seconds [18][24]. They are traditionally used to measure calories burned and energy expenditure after some physical activities have been performed. Physical activity monitors are commonly small and easy-to-use by children and adults [20].

A pedometer (Stepometer) is typically worn on the belt or waistband to calculate the distance that an individual has walked. It works by sensing the movement and counting the steps then converting them into distance. They perform this by determining the individual’s stride length by detecting vertical acceleration of the hip during gait cycle. They are however limited in their discrimination of activities and posture [9][17][18][19]. Many of them use a simple spring sensor that makes contact with ambulation by moving up and down. An electrical circuit closes with each step and the accumulated step count is displayed digitally on an LCD screen. A pedometers main problem is that they do not measure how hard (cannot differentiate between walking and running), how long or how often (intensity, duration or frequency) a physical activity occurs. They also tend to underestimate the number of steps taken during higher intensity activities and consistent errors occur in say, a slow walking activity. On top of these limitations, pedometers do not have the ability to store or recall single-day values over a period of days; therefore it needs a daily written report before it resets itself. Finally, the most important limitation concerning pedometers is that they are incapable of measuring static movements, non-locomotor activities, upper body exercises or cycling [20].

Nevertheless, advances in technology have made accelerometers a feasible option for physical activity assessment [21]. To have a clear measurement of a movement which is less than 20Hz frequency, an activity monitoring system containing an accelerometer should be used. For a significant accuracy increase of frequency reading in an accelerometer device the system should filter the high frequent vibrations. To achieve this filtering purpose, a low pass characteristic sensor is used. Read-out electronics can be used to perform extra filtering to the frequency data (e.g. Σ∆ modulator and digital filtering techniques) [9]. An accelerometer could be placed on different parts of the user’s body, by being embedded within wrist bands, bracelets, adhesive patches, or belts, to relay acceleration data using integrated transceivers. Software is necessary for acceleration data to be collected to recognize user activities and run real - time applications [22]. Three common types are uniaxial, biaxial and triaxial accelerometers. The uniaxial monitor records the amount of physical activity performed by the individual between two predefined periods of time [23]. A uniaxial monitor was the first accelerometer that was used for epidemiological purposes that indicated feasibility and productivity. It is the size of a wrist-watch and consists of a cylinder with a mercury ball which connects with a mercury switch during body movement. Caltrac, ActiGraph, and the Biotrainer are examples of uniaxial monitoring systems [18][23].

Two of the uniaxial accelerometers are equivalent to one biaxial accelerometer [19] which can measure a full range of body movements from sedentary to intense physical activity. The biaxial accelerometer architecture is intended for microfabrication in single-crystal silicon, whereas millimeter-scale fabrications are intended to be by uniaxial and triaxial accelerometer [23]. The difference between the uni- and triaxial accelerometers is that the latter accelerometer measures accelerations along three planes; vertical, anterior- posterior and mediolateral, while a uniaxial accelerometer measures the acceleration in a single plane when it is attached to the trunk or limbs. A Triaxial accelerometer then samples the signals from analog to digital usually (10 to 40 Hz) by signal conversion. Tritrac, RT3 and MiLife are examples of monitoring systems that contains a triaxial accelerometer.
3 Bluetooth

Bluetooth is an industry-standard protocol that enables a short-range wireless connectivity [25][26]. This technology is used for transferring data between different devices intended to replace the cables connecting portable and/or fixed devices such as phones, laptops, PCs, PDAs and any other handheld devices while maintaining high levels of security in a range of about 15 meters and with data transfer rates of around 2 to 3 Mbps [25][26][27]. A Bluetooth connection allows electronic devices to communicate in a short-range wirelessly via piconets (a.k.a ad hoc networks). Piconets are small computer networks that use Bluetooth protocols. Hence, as Bluetooth enabled devices enter and/or leave radio proximity piconets are dynamically and automatically established. Simultaneously each device can belong to several piconets in addition to its ability to connect and communicate with up to seven other devices within a single piconet. Innovation in Bluetooth solutions is enabled by a fundamental strength in the Bluetooth technology which is the ability to simultaneously and homogeneously handle both data and voice transmissions; and this includes hands-free headset for voice calls, printing and fax order capabilities, synchronization between PDAs, laptops and Smartphones along with some mobile phones applications [27][28].

Bluetooth profiles in devices are similar to Internet protocols in that they define general behaviors that allow Bluetooth enabled devices to communicate and therefore benefit from this wireless technology. A wide range of profiles defined by Bluetooth technology can describe different types of use cases. Developers are able to create and build applications to work with, communicate and connect devices with each other by following the Bluetooth specifications guidance. Hence the variety of devices and advances in technology are growing and spreading widely, Bluetooth technology is being developed to cope to this digital evolution yet it is backwards compatible. Significantly, different products support different Bluetooth standards – versions 1.0, 1.1, 2.0 and 2.1. For example a mobile phone supporting a Bluetooth of version 2.0 has the ability to connect with a hands-free headset supporting Bluetooth standard version 1.0. Each profile specification contains information at least on the following three topics: 1. Other profiles dependencies. 2. User Interface formats suggestions. 3. A profile doesn’t use the whole Bluetooth protocols stack. However, each profile uses specific options and parameters at each layer to accomplish its task. Profile dependencies are considered when a profile implicitly or explicitly re-uses parts of another profile for example the Object Push Profile is dependent on another three profiles; the OBEX, Serial Port Profile and Generic Access profile, as Figure 2 illustrates [25][26][29].

Figure 2: A profile containing another profile- direct or indirect dependencies [30][36]

Bluetooth generic procedures that are related to other Bluetooth devices discovery when devices are 'Idle' which is called 'Idle mode procedures’ and the management aspect of linking and connecting these Bluetooth devices ‘connecting mode procedures’, in addition to procedures definitions to the use of different security levels are all achieved by the Generic Access Profile (GAP). In other simpler words, the description of lower layers usage (LMP* and Baseband) along with few other higher layers (L2CAP, RFCOMM and OBEX) of the Bluetooth protocol stack is made by the GAP [30][31][36][37].
GAP includes the Service Discovery Application Profile (SDAP) which locates available ON Bluetooth devices in the surrounding area of an enabled Bluetooth device, then a user may select one or more of these available services and communicate/ connect with them. However, Service Discovery Protocol (SDP) is not directly involved in accessing services but it facilitates it by properly conditioning the local Bluetooth stack to access the desired service using the information retrieved via the SDP. Yet, the SDP is used to locate services in other Bluetooth enabled devices after being located via protocols and procedures defined by the service discovery profile by using a service discovery application on the device. Nevertheless, it is sometimes needed to enable another services such as RFCOMM or any other transport services or a particular usage profile (for example file transfer, cordless telephony, LAN AP ... etc) over the two devices as a result to the fact that SDAP is a specific- user- initiated application which makes this profile become in contrast to other profiles and consequently the service discovery interactions between two SDP entities in two different Bluetooth enabled devices. TCS-BIN-Based Profile - or it can also be referred to TCS Binary System is based on the Bluetooth Telephony Control protocol specifications and it will be used for cordless telephony profile. However, the Cordless telephony and Intercom profiles use the same protocol stack as shown in figure 2. The TCS-BIN-Based profile defines two main roles in a Bluetooth connection: Gateway (GW) or Terminal (TL) where a topology of one GW and up to seven TLs are supported by the cordless telephony profile but on the other hand there are no specific roles defined for the intercom profile, it is totally symmetric [30][31][32][33][36][37].

The foundation of the Bluetooth profile structure is the Serial Port Profile (SPP) that defines the procedures and protocols that are to be used by a Bluetooth-enabled device for RS232 (or similar) serial cable emulation. The SPP deals with legacy applications to communicate and connect wirelessly using Bluetooth as a cable replacement through a virtual serial port abstraction (which is operating system-dependent in itself). This profile carries four main profiles dependencies: Dial-Up Networking Profile, Fax Profile, Headset Profile, LAN Access profile and Generic Object Exchange Profile [33][34].

Object Exchange (OBEX) is the Bluetooth adaptation to the infrared OBEX (IrOBEX). It is a transfer protocol that defines binary objects as well as a communication protocol that facilitates the exchange of those objects between two devices. OBEX and HTTP (Hypertext Transfer Protocol for the Internet) have a similar design and function that it is a client – server communication method that uses a reliable transport. In Transmissions HTTP is able to provide human-readable texts on a PC or a Laptop, but since OBEX is implemented in devices with limited sources, it is easier for it to parse by using “Headers” which are binary-formatted type-length-value triplets to exchange information about a request or an object. HTTP transactions are inherently stateless; generally a HTTP client opens a connection, makes a single request, receives its response, and either closes the connection or makes other unrelated requests. In OBEX, a single transport connection may bear many related operations. In fact, recent additions to the OBEX specification allow an abruptly closed transaction to be resumed with all state information intact [27][30][31][32][36][37][29].

3.1 Bluetooth Technology on Windows Mobile OS

Windows mobile is a compact operating system combined with a suite of basic applications for mobile devices on the Microsoft Win32 Application Programming Interface (API). Increasingly, Windows Mobile phones are using Bluetooth technology more and more and most of Windows Mobile OS versions 6 and 6.1 have built-in Bluetooth capability - version 6.1 was used for implementing and installing the application. Bluetooth is supported by Microsoft for Windows XP with Service Pack 1 and later, Windows Embedded XP and on Windows embedded CE which operates Windows Mobile devices. Therefore, any Bluetooth application that runs on Windows XP should appropriately run Windows CE core services that are similar to those exposed by Transmission Control Protocol (the TCP part of TCP/IP protocol). Using common Windows Sockets programming techniques and specific Bluetooth extensions will enable the devices, applications and programmers to obtain Bluetooth connectivity and data transfers, like many networking protocols and services. Nevertheless, in order for an application to operate properly in a wireless environment, Bluetooth provides extensions such as Service/Device Discovery (SDP), notifications and also extensions that precede simple porting to similar technologies to Bluetooth such as IrDA. These extensions are used because of significant differences between fixed, wired and wireless ad-hoc networks.
4 A Mobile Device Activity Monitoring Application

As previously mentioned, in a clinical setting there are benefits to face to face coaching and remote coaching. Both have been proven to be effective in behavioral change, but face to face can be time intensive and expensive, whereas remote coaching can be more affordable and consume less time. The primary attributes of remote monitoring systems are to: (a) Record key information at the point of care, eliminating errors and duplication of effort and providing completeness of data. (b) Automate processes and information sharing. (c) Provision for clinical decision support. (d) Ensure secure acquisition and storage of patient data. (e) Provide reliable performance and (f) Assist patients in management of their own health from their own home.

The system chosen for this trial was Milife. MiLife\(^1\) is an online, personalized coaching system along with a Bluetooth weighing scale, wrist band and Bluetooth adaptor. The wristband and weighing scales both communicate with a Bluetooth PC or MAC which is running the milife software. The wrist band needs to be ‘paired’ with the host pc every 10 days or less to ensure that all the activity data held on the wrist band can be uploaded onto the milife online system. The system also allows for the setting of targets with regards exercise and diet. Once the user has defined their diet and training plan, there is the option to receive reminders via email or SMS text to assure adherence to the plan is being followed. The entire system consisting of the hardware, software and online account cost £150 UK sterling.

![Figure 3: Illustration of the main use cases of the MyLife system with all its actors - showing their involvement with the PAM firmware.](image)

The components of the MiLife system - also called Actors- are essentially linked and connected together to deliver optimized service to the user. Starting from the Personal Activity Monitor (PAM) that acquires data and retain it for certain amount of time to the PC where the data is transferred via Bluetooth then uploaded to the MiLife web server. However, the PAM was the main focus of this project (see Figure 3). The principle system elements are:

- **Accelerometer:** A LIS3LV02DQ triaxial accelerometer (3-axis) from STMicroelectronics. It acquires data on a firmware running on a Microchip PIC18LF2520 microcontroller (*PIC firmware*).

- **MMI:** Controlled by the PIC firmware. The Man-Machine Interface (MMI) consists of a LED and an MFB - a Light Emitting Diode and a Multi-Function Button.

- **Power Management Circuit:** It identifies the PIC while its battery is charging and when it becomes fully charged.

\(^1\) http://www.milife.com
• **PC:** A Bluetooth-enabled PC that runs the MiLife application software. Which is for this project will be substituted with a Windows Mobile Phone Version 6.1 that will adopt the application being developed.

The application is developed in c#.net on the .Net Compact Framework 2.0. It transfers the data that has been retained in the PAM to a Bluetooth-enabled Windows Mobile and then uploads it to the MiLife central server. The flow of work with the different states and events that the system goes through to reach the ultimate goal of allowing the user to explore his/her results online is shown in Figure 4 [38].

![Figure 4: PAM state diagram illustrating state and events of the MiLife Windows Application.](image)

### 4.1 Monitoring

After setting a valid time in the PAM, it will directly start to monitor acceleration measured in three orthogonal directions X,Y and Z once every 100ms. The measurements after that will be passed to the PIC to be stored in three 12-bit long, two’s complement binary numbers form. Earth’s gravitational acceleration plays a scale factor - appointed as \( \lambda \) - linking these binary values given by the accelerometer datasheet. So an absolute acceleration of 340 per g is obtained if the PAM is not subjected to any acceleration other than gravity [38].

Using (Equation 1) enables the PIC to calculate the magnitude of the PAM’s acceleration from the three directions acceleration measurements. Dividing it by scale factor (\( \lambda \)), would give the 1g result expected.

\[
a_{abs} = \sqrt{X^2 + Y^2 + Z^2}
\]

Equation 1: Converting the three orthogonal acceleration measurements into an absolute acceleration value by the PIC

Using (Equation 2) in each epoch (an epoch is two minutes in time), the PAM sums all 1200 absolute acceleration values, as it is sampled once every 100ms. By that, a single 32-bit long value that is proportional to the average absolute acceleration is produced.
Equation 2: Summation of the absolute acceleration values over one epoch, where $N=1200$.

Afterwards, the PIC will convert the 32-bit epoch total into a single 8-bit binary value using a non-linear algorithm for the conversion. Progressively the epoch total value is compared to larger terms of the sequence specified by (Equation 3). The index of the term that is just larger than the epoch value is selected as the 8-bit representation.

$$V_N = V_{N-1} + \left( \frac{V_{N-1}}{256} \right)$$

Equation 3: The 32-bit epoch total is compressed into 8-bits for storage by using this sequence.

Using the PC software (GetStatus command), an overlapping data situation can be detected. This could happen if the PAM’s flash memory was full and not yet uploaded; the old values are wrapped and overwritten with the new data [38].

4.2 Discovering and Pairing Bluetooth Devices

Inquiry requests are sent from a device to discover other Bluetooth-enabled devices by using the inquiry scan channel of these devices even though when the requesting device can not know the exact characteristics of the inquiry scan channel because it has no prior knowledge of the devices that are to be discovered around it [26][27][29][36][37].

Nevertheless, Windows maps the Bluetooth SDP onto the Windows Sockets namespace interfaces to facilitate the discovery of Bluetooth devices and services. The main functions that can be used for this mapping are the WSASetService, WSALookupServiceBegin, WSALookupServiceNext, and WSALookupServiceEnd functions in addition to the WSAQUERYSET structure. However, it is important for a person studying it or for a programmer to understand that SDP registration is separate from socket control. the WSASetService function is responsible to register a Bluetooth SDP record that corresponds to the server application that is prepared to accept client connection or when closing to deregister it [26][40].

Despite the small differences in specific user interfaces between one device and another that are implemented by manufacturers, there are still very basic steps that all devices go through in a first Bluetooth connection between two devices. Which is the **Pairing** process that should always be conducted in a secure environment. Steps have to be taken by both devices:

1. Turning the Bluetooth functionality On.
2. Make the devices visible for discovery.
3. Place both devices in the Connection Mode.
4. Enter the Passcode.
5. Delete or Disconnect trusted device.

These are typically how a user can pair two Bluetooth-enabled devices, however, the embedded functions used for the pairing process can be a bit more complicated but can be summarized as following:

The Windows Embedded CE device calls the SetBTDiscoverable function to put itself into Discoverable Mode. The Passcode or the PIN code will be passed to the SetBTDiscoverable function is the PIN code the user must enter to the device. After the user has dwTimeout milliseconds to enter the PIN code into the Bluetooth device using the device User Interface (UI). The PIN then must be
associated with the Windows Mobile’s ‘Discoverable Name’. Before the SetBTDiscoverable function the Windows Mobile can obtain a handle to the BTPAIR_API_DISCOVERY_ACTIVE event using the CreateEvent function. Then, after the SetBTDiscoverable is called, the Windows Mobile can use WaitForMultipleObjects function to poll the event objects and finds out what happens afterwards, including whether Discoverable Mode was activated, whether pairing event occurred, and when Discoverable Mode became inactive again [26][27][29][36][37].

4.3 Juice Upload

Here we describe the uploading process of the data (Juice) to the PC. The application is responsible for storing and uploading the data to the Juice central server system of MiLife. After activating the Bluetooth Mode on the PAM by the user using the MMI actions (will be defined in the Implementation section) and the non-zero value user ID provided after the Juice Association (A one time process where it defines the PAM with the PC application via Bluetooth and gives it the non-zero value user ID). The application now is able to create a Bluetooth connection to the PAM since it is Bluetooth connectable. Once the connection is established, the PAM will respond the upload data requests from the application for the epoch and scale readings (Scale is not included for the Windows Mobile application). The status of the epoch readings availability for uploading can be obtained by using the (GetStatus) message. However, the PAM will eventually treat the corresponding memory location (Flash memory) as empty as soon as the data sample has been completely uploaded and the application sends a ‘disconnect’ request message, then, a Bluetooth SPP disconnection will be initiated by the PAM [38].

4.4 Data Upload to Server

A sequence of events take place when uploading data from the PAM to the Windows Mobile upload device. The following Sequence Diagram (Figure 5) illustrates these events and each will be explained afterwards along with the programming (c#.net) codes used to achieve each point.

Figure 5: Sequence of events that takes place when the PAM uploads data
By referring to the libraries that MiLife has provided to build up this application in addition to their recommended free online library “32feet” [39] that has been used to build the PC software for the MiLife system, these events took place sequentially [26][38][41][46]:

- The MFB allows the PAM to enter the ‘Bluetooth Active’ Mode.
- The PIC will then attain a connectable mode.
- A SPP connection will be initiated by the windows mobile device to the PAM’s incoming SPP service. When the connection is completed the PAM will send a ConnectIndication message including the stored UserID which will be received by the WM application.
- ‘GetStatus’ is the function used by the application to which the PAM responds with its current status giving the number of epochs available for upload.
- The PAM updates its clock value by using the ‘SetTime’ function issued by the WM application.
- The PAM then sends the epochs data record as response to the ‘ReadEpochRecord’ function that the WM application issues.
- The epoch record will be marked as read in the PAM after the WM application has dealt with the data record and issued an ‘AckRecord’ function.
- When the PAM have an empty response to the ReadEpochRecord request after a number of ReadEpochRecord/AckRecord sequence, that indicates that the PAM has no data remaining to upload.
- The WM application would not be able to an AckRecord function if the Bluetooth connection got lost (e.g. the user walks out of Bluetooth range during upload process) then the PAM will not be able to mark the current upload record as ‘Read’. However, the data will not be lost, the PAM will be able to upload the data from where the connection was lost next time the user attempts a connection.
- The WM application the issues a DisconnectRequest and the PAM disconnects the Bluetooth connection with the WM device.
- Finally, the PIC firmware puts the BT firmware in the PAM into ‘Sleep Mode’ once the link has disconnected.

4.5 Application Screenshots

What follows is an overview of different screenshots of the application running on a Windows Mobile CE operating system, version 6. Figure 6 shows the Windows Mobile application at its first page before discovering any Bluetooth Devices in its range.

![Figure 6: Prior to pairing](image1)

![Figure 7: PAM’s Bluetooth](image2)

![Figure 8: Verification](image3)

Figure 7 illustrates discovering the PAM’s Bluetooth. Here we can see that the “Connect” button appears to enable a connection between the PAM and the Windows Mobile device. Figure 8 shows the
application prompting for the user’s ID and Password to authorize data transfer from the PAM to the Windows Mobile application. After entering the user’s ID, the application gets connected and the ‘GetStatus’ function would display the PAM’s status and readings.

5 Conclusion

Obesity levels in populations are on the increase throughout the world. Due to the range of health problems associated with this medical condition, significant pressure is placed on health care provision budgets. Remote Monitoring of patients outside of clinical environments is beginning to have an impact and much research has been conducted into the benefits associated with keeping patients in their home environments. Activity monitors are useful devices for gauging various levels of intensities of activities and are becoming more widely used in clinical trials into obesity. This research examined the use of a windows mobile application which paired with a commercial activity monitor.

This paper demonstrated a Windows Mobile application for the MiLife monitoring system where the connection between the PAM and the Bluetooth-enabled WM device was crucial to implementing functionality on the windows mobile device. The application can be connected to the MiLife “Juice” central server to upload the collected data from the PAM and therefore allow the users to read their status and follow their scheduled progression.

6 References


