The Well Mannered Wearable Computer

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Abstract: In this paper we describe continuing work being carried out as part of the Bristol Wearable Computing Initiative. We are interested in the use of context sensors to improve the usefulness of wearable computers. A `CyberJacket` incorporating a Tourist Guide application has been built, and we have experimented with location and movement sensing devices to improve its performance. In particular, we have researched processing techniques for data from accelerometers which enable the wearable computer to determine the user's activity.

We have experimented with, and review, techniques already employed by others; and then propose new methods for analysing the data delivered by these devices. We try to minimise the number of devices needed, and use a single X-Y accelerometer device.

Using our techniques we have adapted our CyberJacket and Tourist Guide to include a multimedia presentation which gives the user information using different media depending on the user's activity as well as location.

Keywords: GPS; Location Sensing; Accelerometer; Movement Sensing; Wearable Computer

1. Introduction and Background

Our interests in wearable computing are centred around determining the context of the user and developing applications which make use of this information. In particular, we are exploring the concept of situated computing [1][2] by using sensors to provide data which can help determine facts such as the location – indoor or outdoor; the activity; and/or the well-being of the user.

The first application that we developed – a Tourist Guide - used GPS as a location sensor to trigger the display of web-pages giving information about our current location which would be useful, and of interest, to a visitor to the area covered.

Similar projects in this field include the Cyberguide [3] by GeorgiaTech and the GUIDE project [4] at the University of Lancaster both focusing on context awareness using location sensing. We tested our application using a ‘CyberJacket‘ equipped with an x86 processor programmed with a web server and the event managed application. Also included in our CyberJacket specification is a sound card for audio cues; a differential GPS receiver; and a Jornada palmtop providing a web browser and display. This configuration was extensively tested and two main criticisms arose – the inadequacy of the location sensing, and the distraction caused by untimely rendering of the web pages and audio cues.

The positional accuracy of within 10m which should have been achieved using a basic differential GPS service was not achieved due to the difficulties associated with receiving an adequate signal using body mounted antenna. Two different services were experimented with – RadioBeacons operating at around 300kHz and FocusFM at 100-102MHz. Neither of these could be satisfactorily received without the use of separately carried aerials i.e.not as an integral part of a wearable computer design. A considerable improvement was experienced when GPS Selective Availability was turned off [5] and the positional accuracy improved to a theoretical 15m, though we have recorded a worst case error of 25m due to ionospheric variations.

The other criticism of our initial application was distraction caused by inappropriate rendering. We addressed this by investigating the use of accelerometers to provide activity awareness, and hence to modify the behaviour of our application and improve the interaction with the user.

Previous research into the use of accelerometers, such as the wearable Context-Awareness Component [6], and Sensor Badge [7] employed these devices to detect basic activities such as sitting/standing/walking/running. These designs used a low level analysis in a small form factor. More complex projects included the Acceleration Sensing Glove [8] using multiple hand mounted accelerometers, and Technology for Enabling Awareness [9] which combined accelerometers with a variety of other low-level sensors. These projects required a higher level of analysis and hence more sophisticated hardware.

In our project we have researched data processing techniques which provide a high level of activity analysis and in which complexity, size and power consumption are minimised. We describe our research into the use of accelerometers as movement sensors and the effectiveness of their integration into our CyberJacket based Tourist Guide. By doing this we give our wearable computer the ability to determine what the user is doing in addition to the who and where of the user.

2. Architecture

The Crossbow ADXL202 Accelerometer Evaluation Board is designed specifically to help the designer understand these devices and provides a compact module which can be interfaced to any PC with a RS232 serial interface. It provides outputs corresponding to the X and Y G-forces applied to the board.

To enable testing to take place for long periods with a minimal infrastructure we have interfaced this with a Matsucom onHand PC (see Figure 1). The sensor is worn in a trouser pocket.

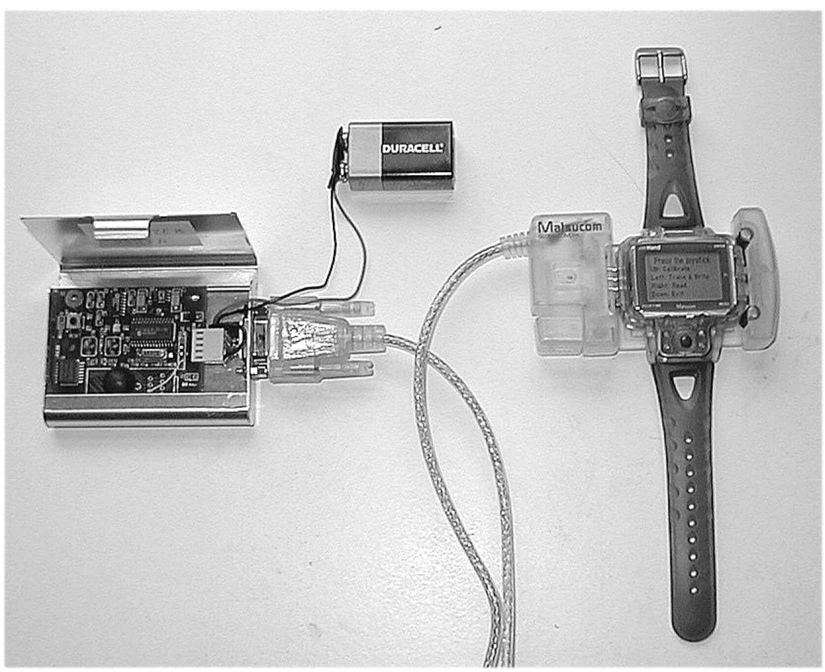

Figure 1: Accelerometer with onHandPC.

Our planned wearable architecture consists of a small computer connected to a variety of sensors using an event manager. In a steady state the main processor is switched off and the sensors are the only active parts. The sensors are programmed by the main processor to power-up the main processor when an interesting situation occurs. In order to program the sensors, the main processor combines the requirements from the various application programs, and programs each sensor to send an event in a particular case [10].

We embed our accelerometer in this architecture so that the accelerometer sensor analyses the user's behaviour, and outputs the states `Sitting', `Walking', etc. For example, an application program could register an interest in the event that the users activity changes from Walking to Sitting. It would then wake up the main processor, and because the user is now be able to look at a screen, display relevant information.

3. Data Processing

After experimenting with different sampling rates, and analysing the data to measure various features, we decided that it was only necessary to collect samples at a relatively low frequency (5 Hz; to aid in low power design), and from only two data sources - the X and Y axes of the accelerometer. From these samples we extract 4 features. These features can be calculated cheaply; they can work across a range of people; and are robust. We then use a clustering algorithm - a neural network - in order to infer what the user is doing.

In order to experiment with the various features and clustering algorithms, we have first collected data for 10 people performing various activities: **Walk**ing, **Run**ning, **Sit**ting, walking **Up**stairs, **Down**stairs, and **Stand**ing. We use part of this data as a ground truth to train our system, and evaluation is then carried out using the remainder of the data.

3.1 Feature Extraction

As can be anticipated some activities are easy to distinguish, however distinguishing between walking and walking upstairs is more difficult. We have studied various features that can be extracted from the sensor data cheaply. It turns out that extracting a total of 4 features from the 2 sensors is sufficient for our purposes: the Root Mean Square and integrated values of both sensors over the last 2 seconds. We have determined that using this technique it is unnecessary to carry out any further analysis such as determining frequency components.

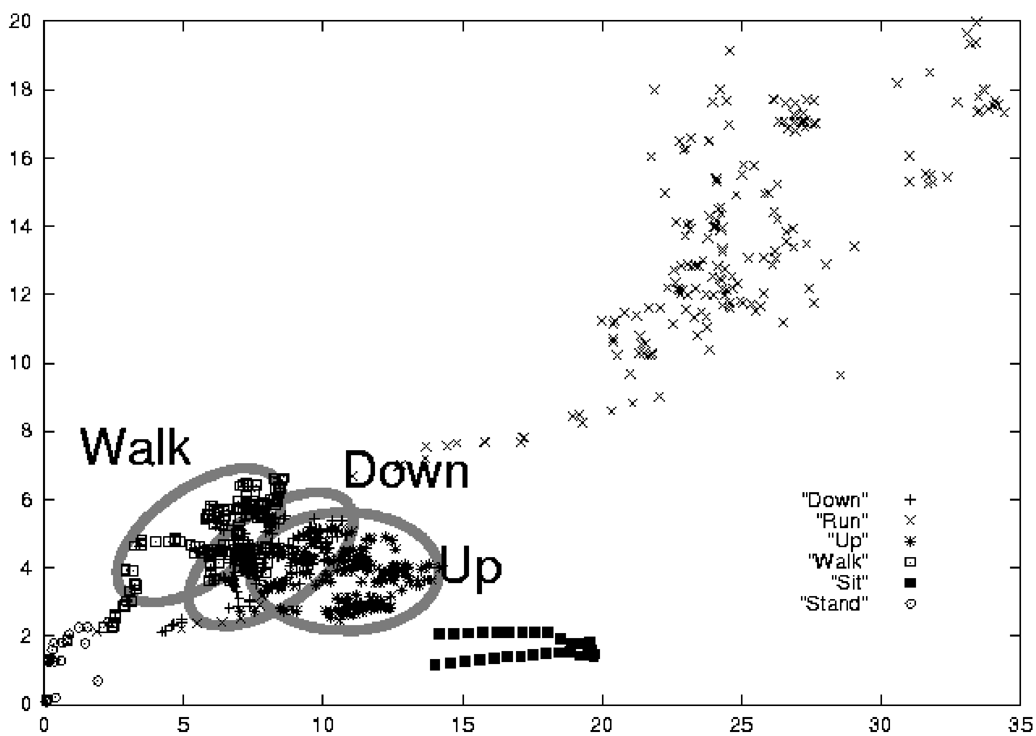

Figure 2: RMS X vs Y for six activities

Figure 2 shows a scatter plot of 6 types of activities. The X-axis is the RMS of the X-sensor, the Y-axis is the RMS of the Y-sensor. By plotting the RMS values we observe a lot of overlap between Walking, and going Up and Down stairs. There is a clear distinction between Running, Sitting and Standing enabling them to be easily determined.

Further analysis using the integrated or mean values, as shown in Figure 3 - a scatter plot of the same activities, also clearly identifies Running, Sitting and Standing. However, by plotting the RMS values against the mean values there is again overlap in the walking activities, but the overlap is different, and in a 4 dimensional dataspace, these activities also turn out to be well separated clusters.

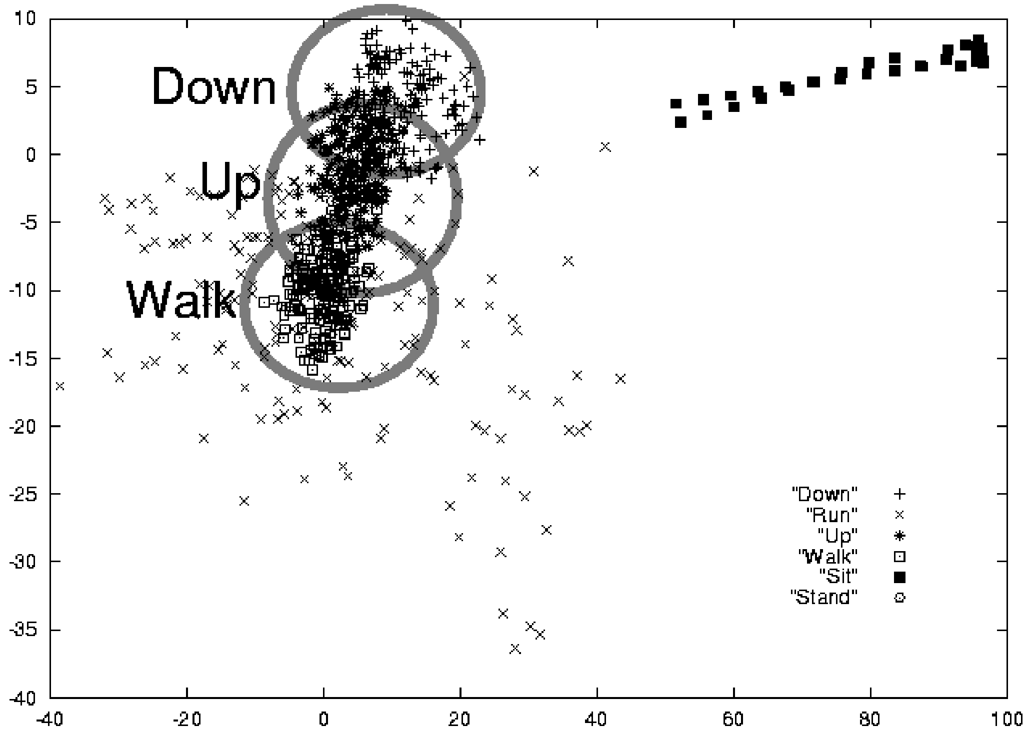

Figure 3: Integrated X vs Y for six activities

It is important to stress that the features discussed are person and clothing specific. The strength of these features is that for every person that we have data for, these four features allow the recognition of the particular user's activities. However, one person walking can give the same results as another person running. Repeated testing has also shown that different results are obtained with the same person wearing different clothing e.g.tight jeans or baggy chinos. For each test we have calibrated the accelerometer to compensate for the inclination and orientation of the device in the user‘s clothing. It may be possible to further calibrate for the type of clothing and typical activity level of the user though this has not yet been attempted.

We speculate that for particular activities for which movement analysis is of special interest e.g. sports, accelerometers could be integrated into dedicated clothing items. It is not unusual for an athlete to wear a heart-rate monitor, and if this was combined with an accelerometer sewn into the athlete‘s shorts, further useful training information would be obtained.

3.2 Neural Network Analysis

To determine the nature of the clusters, we use a neural network with 4 inputs and single layer of neurons. Outputs were taken for each activity we are interested in. Back-propagation was used to adjust the values of the network using the following transfer function between the output and the input medial layers:

$$z = \frac{1}{(1 + e^{-z})}$$

This provided a simple arrangement which could be incorporated into the onHand PC, and later transferred to our Cyberjacket.

We initially trained our network on a ground truth, and analysed the results after further person specific training. Our initial results shown that we can infer the user's activity with a high accuracy (85-90\%). Verifying which 10-15\% is ``wrongly" classified, we observe that this is often the person going upstairs via a small landing. Landings are difficult to resolve: the real activity is walking, whereas it is labelled as going upstairs in our ground truth. A temporal filter can take those errors out, but this will make the system sluggish in its response. The actual accuracy of detecting peoples activities is around 95%; with a temporal filter we can increase that further.

3.3 Final Sensor Implementation

In order to implement our sensor we propose to connect our accelerometer up to a small neural network chip [11] and a PIC microcontroller. We will trigger a measurement and calculation every 200ms, and the PIC will send an event over the event bus to the main processor if the activity has changed. The sensor package should consume well under 10mW.

This sensor can be programmed in two ways:

- The main processor can order the sensor to train (given that the main processor has told the user to perform a certain activity).
- The main processor can order the sensor to monitor the user's activity, and to only inform it when the activity changes for more than t seconds.

While our experimental package used a RS232 serial interface, we are investigating the relative merits for wireless body networking using Bluetooth, low power UHF and other short range electromagnetic solutions.

4. Application - the Well Mannered Wearable

The potential for wearable/mobile computer Tourist Guide applications has previously been explored by the University of Lancaster with their GUIDE project [3] utilising a notebook computer and WaveLAN cells for location finding. In particular they considered some of the potential rewards and pitfalls of utilising context in the design of interactive systems [12]. Columbia University has experimented with an extensively equipped backpack with handheld and head mounted displays – the Touring Machine [13]. Our CyberJacket Tourist Guide, see Figure 4, provided a simple GPS based arrangement which could be easily adapted to enable the testing of our movement sensor design.

As a first example of the potential use of a single accelerometer, we control the media rendering to ensure that the presentation of information is appropriate to the user's activity and consistent with the sensed event. For example, we do not wish to render any information if the user is running; we also know that if the user is not moving then an event triggered by a change in location cannot be generated. A simple set of rules can thus be formulated to form an etiquette for our wearable computer.

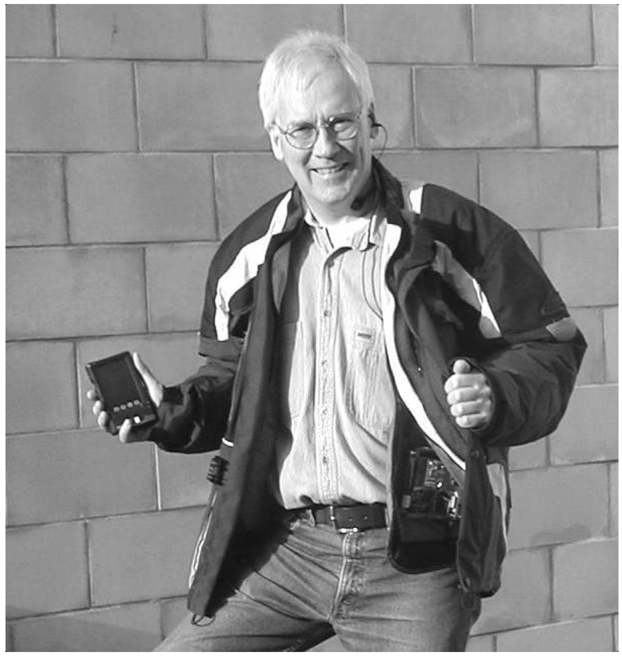

Figure 4: The Bristol CyberJacket

We designed our application to operate according to the user‘s activity. Events signifying interesting locations with associated web pages and/or commentary can only be triggered while the user is walking. The commentary is played to alert the user to the place of interest, and the web page is only displayed once the user has stopped walking. The application is suspended when the user is running.

This arrangement improves our user interface and reduces the irritation factor caused by the untimely and inappropriate rendering of information. We are now considering the potential of developing a more complex set of rules which could be implemented with additional sensors such as a microphone to determine when the user is speaking and/or being spoken to.

Our previous testing involved visiting tourist sites around the Clifton district of Bristol. With our new configuration we were able to carry out tests in the new Millenium Square and around the @Bristol complex – a much smaller area - with acceptable results. The behaviour of the application was found to be particularly improved in busy environments such as in city streets where the user‘s attention is focused on interaction with pedestrian and vehicular traffic. The audio message when walking was found to be more agreeable than requiring the user to look at a display screen.

By constructing the application to use the audio prompt to alert the user to the proximity of a point-of-interest and then requiring the user to stop walking to be able to view further information, a predetermined pattern of walk-stop-go activity was promoted. This was particularly evident in quieter areas and was perceived to be somewhat artificial. We plan to experiment further with different content to try to determine a balance between the audio and visual data which will provide a more natural experience.

The power saving when running was not quantifiable over a test period of several hours, particularly as the CyberJacket does not encourage vigorous activity. Nevertheless, the authors believe this to be a useful feature where battery life is critical.

5. Results and Conclusions

We have demonstrated that with a single X-Y accelerometer it is possible to distinguish various activities of the user, even very similar activities. We have experimented with many features, but stuck with two that can be calculated cheaply: RMS and integration of the last 2 seconds of measurements. We then use a clustering algorithm, a neural network, to infer the user's activity.

As an initial application we have added the activity sensor to our Tourist Guide in order to use the appropriate output mechanism i.e. be quiet when the user is running; enable events and only use audio when the user is walking; use graphics when the user is standing or sitting. We will incorporate walking up/downstairs when guiding the user around. This will give us vital clues as to where the user is going on a small scale, and giving them immediate feedback that they are going the wrong way.

The incorporation of the movement sensor, along with recent improvements to the GPS system, has enabled us to significantly improve our Tourist Guide application. As a result we have been able to attempt more ambitious scenarios and achieve greater user satisfaction. We have thus shown that the use of context sensors to determine the user's activity can provide a valuable source of data which has the potential to improve the behaviour of wearable computers.

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