Journal of Mobile Multimedia, Vol. 1, No.2 (2005) 161-177

VISUALIZING PAIN DATA FOR WHEELCHAIR USERS: A UBIQUITOUS APPROACH

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Received April 29, 2005
Revised June 22, 2005

We describe a wireless enabled solution for the vizualisation of pain data. Our approach uses pain drawings to record spatial location and type of pain and enables data collection with appropriate time stamping, thus providing a means for the seldom-recorded (but often attested) time-varying nature of pain, with consequential impact on monitoring the effectiveness of patient treatment regimes. Moreover, since the implementation platform of our solution is that of a Personal Digital Assistant (PDA), data collection takes place ubiquitously, providing back pain sufferers with mobility problems (such as wheelchair users) with a convenient means of logging their pain data and of seamlessly uploading it to a hospital server using WiFi technology. Stakeholder results show that, notwithstanding problems related to PDA data input, our approach is generally perceived to be an easy to use and convenient solution to the challenges of anywhere/anytime data collection.

Key words: Wireless computing, Personal Digital Assistant (PDA), Visualization, Pain, Healthcare
Communicated by: D Taniar

1 Introduction

Many wheelchair users (hereafter referred to as 'users') experience pain – especially back and buttock pain – as well as discomfort in their daily lives [1,2]. This can arise from many body sites including the spine and limbs [3,4]. In the UK for instance, twenty-six percent of Electric Powered Indoor/ Outdoor Chairs (EPIOC) users admit to pain or discomfort when sat in their chair at four months after delivery [5], and this rises to 46% at two years [6]. Although the frequent usage of the term 'wheelchair discomfort' in the literature suggests that such pains are mild [1,4,7], our experience suggests that they may be severe for some EPIOC users. These individuals are profoundly dependent, often sit in their wheelchair all day and therefore might be expected to experience intrusive posture-related pain. Furthermore, many users have musculoskeletal conditions which may contribute towards their pain e.g. spinal pain following failed spinal surgery or osteoarthritis in addition to those with neurological conditions giving rise to neurogenic pain e.g. Multiple Sclerosis [8]. The use of pain drawings and visual analogue scales to demonstrate the site and severity of wheelchair users pain has been demonstrated to be acceptable to wheelchair users, and to support the view that it increases over the duration of sitting. This preliminary re-search thus supports the view that at least some of the pain experienced by wheelchair users is postural and thus potentially remediable given appropriate seating [8].

The integrated use of telecommunications and information technology in the health sector leads to new challenges in organizing, storing, transmitting and presenting health information in both a timely and efficient manner for effective health-related decision-making. Innovations range from routine hospital information systems [9] to sophisticated AI-based clinical decision support systems [10].

Whilst clinicians are eager to exploit advances in telecommunication technology in order to put in practice new methods of data gathering and patient monitoring and the use of the Internet in this respect is by now traditional [11], it is only recently that wireless technologies have been harnessed to act as tools coming to the aid of patients and clinicians alike. However, to the best of our knowledge, no studies have used wireless technology to monitor the sites and severity of the pains experienced in EPIOC users.

In this paper, we present the implementation and experiences of a wireless-enabled monitoring system for wheelchair users. The motivation behind our work lies in the fact that, whilst the pain experienced by these users is part of a worldwide problem of spinal pain with considerable implications on countries' healthcare budgets and national economies, there is a relative paucity of tools for the collection and digitization of back pain data. Moreover, the disabling pain experienced by wheelchair users means that in many cases such data collection cannot take place unless additional personnel are present at the patient's domicile, a situation which is usually both unrealistic and impractical. The consequence of this state of affairs is that there is under-reporting of back pain data, as well as an almost total lack of available, continuously-polled back pain data, notwithstanding the evidence in support of the fact that, for chronic back pain sufferers, pain has a time-dependent nature [12], and that this relation is as of yet still not completely understood. Thus the majority of individuals with back pain experience pains that vary in relation to physical activity, commonly noted after pronged sitting, standing or walking. Accordingly, the structure of this paper is as follows: Section 2 presents an overview of the area of back pain, while Section 3 and 4 review work done on the visualization of back pain data and use of wireless technology in medicine respectively. Such work provides the foundation for our project, which is described in detail in Section 5. Lastly, Section 6 presents the results of an evaluative study of our back-pain tool, while the implications of our work are elaborated upon in Section 7, where conclusions and possibilities for future work are identified.

2 Back Pain

Back pain is considered to be a health problem of epidemic proportions in the UK [13], Western [14] and other industrialized countries [15], with enormous economic consequences due to sickness absence with loss of productivity, cost of associated state benefits and healthcare costs. Estimates of costs to the UK economy may be as much as £10.6 billion in benefits and £480 million in healthcare, and in the industrialised world it is the second leading reason of physician visits, second only to the common cold [16,17]. Recent reviews suggest that spinal pain utilises between 1-2% of Gross National Product in OECD countries [18]. The issue is that whilst back pain is a universal experience, disabling back pain seems to be a feature of caring societies that are able to use benefit systems to substitute income for those with back pain influencing their ability to work.

Moreover, the impact of back pain in developing countries should not be underestimated, as it potentially affects livelihoods and even lives. Without treatment, back pain can prevent sufferers from doing essential daily activities central in maintaining their homes and livelihoods [19]. Indeed, routine

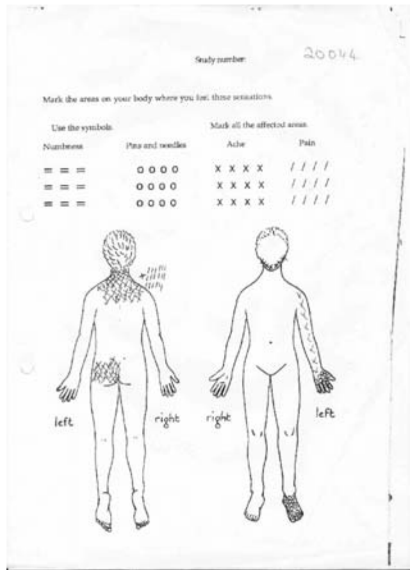


Figure 1 Example Pain Drawing

activities for people in developing countries such as collecting water, harvesting, and carrying heavy objects, including children, increases the risk of lower back pain. Furthermore, back pain does not affect solely the adult population: studies across Europe [20] show that back pain is very common in children, with around 50% experiencing back pain at some time.

Treatment for patients with back pain is notoriously unsuccessful [21]. This may reflect an approach by clinicians that focuses more on the cause rather than on the person [22]. However, the characteristics of people referred with back pain are poorly described and recent surveys are lacking. Thus, the initial symptoms that present from back pain are somewhat generic. It is only through further analysis of these symptoms that the cause can be specifically identified. Back pain diagnosis is rarely simple and clear-cut (besides cases of breaks/fractures, tumours and infections). In medical practice an agreement between physicians for a diagnosis can often be difficult and especially so with cases involving debated psychological factors. An even greater differing opinion between physicians exists over the best treatment for a case of back pain [23].

In most cases the only visual aid to assist medical staff with their assessment are pain drawings (Figure 1). Pain drawings are a two-dimensional figure of the human body where the patient marks the type and distribution of the pain being suffered [24]. As patients may have developed psychological and emotional problems, due to having to deal with the pain, pain drawings in conjunction with a psychological evaluation allow the physician to assess whether the pain is anatomic or non-anatomic. Indeed, in some patients, the psychological problems may have aided the cause of the back pain, by adding stress to the body, or the stress of the back pain may have caused psychological problems [25]. If the assessment of pain intensity and distribution could be assessed in more accurately, a faster diagnosis could be achieved translating as patients receiving the correct treatment sooner leading to a decreased recovery period. To this end, pain drawings represent an invaluable clinical tool.

3. Pain Drawings and Visualization

The size and complexity of medical data sets makes it increasingly difficult to understand, compare, analyse and communicate the data. Visualisation is an attempt to simplify these tasks [26]. While the recent inventions of medical imaging modalities such as computerised tomography and magnetic resonance imaging have revolutionised radiology, the use of visualization in other areas of medicine has remained relatively limited.

In the particular case of back pain, one major area of ambiguity in its diagnosis of back pain is in determining whether or not the cause of back pain is being experienced due to physical reasons (i.e. fractures, tumours, slipped disc etc) or psychological reasons (i.e. stress, anxiety, depression etc). One of the key developments in this type of diagnosis occurred in 1976 with a technique developed by Ransford et al. [24]. The technique involved the use of body outlines where patients were asked to mark on the type (usually ache, pain, pins and needles, and numbness) and distribution of the pain being experienced – diagrams which are know in the literature as pain drawings.

Ransford at al.'s research and testing were an extension of theories explored by [27]. The latter indicated that the Hypochondriasis (Hs) and Hysteria (Hy) scores of the Minnesota Multiphasic Personality Inventory (MMPI) were the best prognosticators to out come for disc disease and Ransford et al. [24] subsequently suggested that 'pain drawings' could be used as an approximate predictor of the Hs and Hy scores.

Whilst pain drawings were initially introduced by clinicians in an attempt to identify patients in whom psychological issues were felt to be a dominant component in the experience of that person's pain, however, current practice utilizes pain drawings to identify sites of pain and the presence (or absence) of typical geographical patterns for pain referral. Psychological issues are now addressed using specific questionnaires [28] – in this paper, we focus on pain drawing as aids to clinicians in determining the site(s) of pain.

Pain drawings, as depicted in Figure 1, act as a simple self-assessment technique, originally designed to enable the recording of the spatial location and type of pain that a patient is suffering from [29]. They have a number of advantages including being economic and simple to complete, and can also be used to monitor the change in a patient's pain situation [29].

Pain drawings have along the years proven to be a versatile tool for recording information as diverse as psychological distress, type of pain, and disability [30]. In order to link the pain drawing to either psychological, emotional or causes of pain; several scoring systems have been developed and described in the literature. These broadly fall into four categories: grid methods, body region methods, penalty point system and visual inspection methods. Whilst the first two record the presence or absence of pain within defined regions, the last two do require subjective interpretation.

With the grid method [31] an overlay of a grid is placed over the pain drawing. The grid is designed so that each cell is approximately the same size (Figure 2a). By using the grid, unskilled testers could calculate the amount of surface area that was in pain. Body region methods, on the other hand, break down the surface of the human body in very simple regions, in order to indicate areas that are in pain (Figure 2b). Thus, in a study exploring lumbar discogenic pain, Ohnmeiss et al. [32] used five general regions: low back and buttocks, posterior thigh, posterior leg, anterior thigh and anterior leg. Other ways of regionalising the human body can also be used, such as based on dermatomes have also been employed [33].

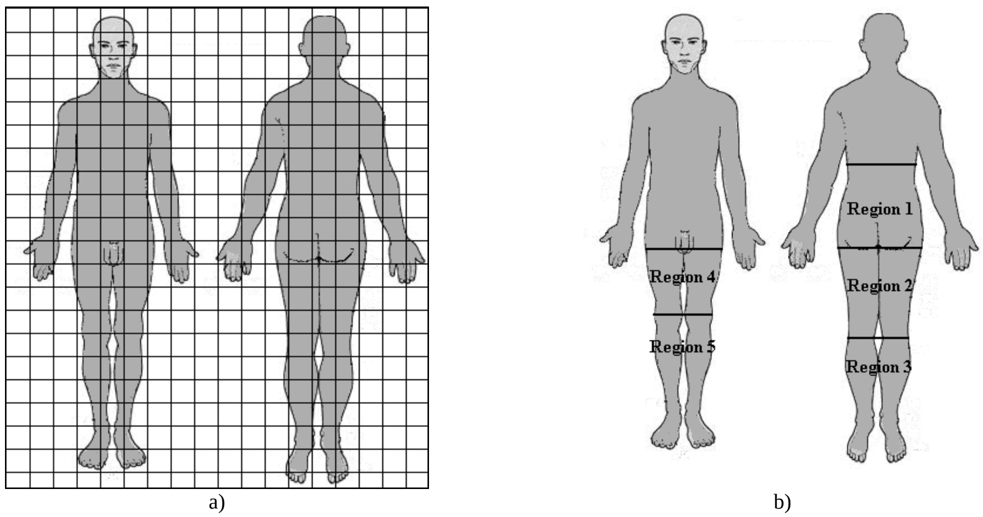


Figure 2 a) Grid method; b) Body region method

Penalty point systems, such as the one described by Ransford et al. [24], work by awarding points for every unnatural placement of pain on a pain drawing. Different areas and rules are made so that there is a weighting depending on the irregularities in the drawing. If more points are scored than normal, then that person may have a psychological problem that needs addressing. In this particular case, pain drawings are used not only as a recorder of pain location, but also as an economical psychological screening instrument to see if a patient would react well to back pain treatment [24], for, as previously mentioned, back pain can be caused by psychological and emotional problems, as well as occupational factors, and hence medical treatment itself may not remove the cause of the pain. Whilst psychological screening for back pain treatment usually entails patients completing costly, time-consuming and difficult to understand questionnaires, by using a penalty point scoring method, it was found that pain drawings could predict 93% of the patients that needed further psychological evaluation just by looking at their completed pain drawing, a conclusion later corroborated in [25].

Visual inspection methods use trained evaluators, who look at the pain drawings and from their experience are able to say what they believe to be wrong with the patient, or if psychological testing is needed [34]. Thus, Uden and Landin [35] have used this method for to identifying patients with lumbar disc herniation. In their approach, drawings were classified as indicative or non-indicative of symptomatic disc disease. If pain was primarily in a radicular pattern from the back into one or both lower extremities, the drawing was classified as indicative. The drawing was classified as non-indicative if pain was indicated to be restricted to the low back only, was indicated to be widespread in a sporadic pattern, or was indicated by extraneous marks made inside and outside of the body to show pain or other sensations.

Most of the methods described can be and are used in practice in conjunction with sensation type approaches, which allow not only the placement of pain to be noted but also the particular type of pain encountered. This is done using a key, therefore allowing more information to be collected and acts as an aid to the clinic as to what the cause of the pain is.

The consensus of the literature seems to be that the pain diagram is a powerful tool in the role that it is designed for, namely to record the spatial location and pain type. However, pain drawings are usually stored in a paper format, which allows no further evaluation of the data that is stored upon it and makes searching through the data somewhat an arduous task. To compound the issue, when information from the pain drawings is digitized, it invariably results in loss of information, since current systems that are used for analysis of the pain drawings and the associated questionnaires revolve around statistical packages, such as Excel and SPSS, incapable of handling diagrammatic data. Thus, although diagrammatic data is collected, it is not used as the key component to the data analysis tools. This is somewhat a problem, as people will find it easier to show through a diagram the way that they feel, instead of answering closed questions in questionnaires. Such data cannot therefore be used to its full potential and, in particular, cannot be used in helping with queries within the dataset. Lastly, the paper-based solution of existing methods makes it impractical to record pain variations over time, in spite of the time-dependent nature of pain in chronic sufferers [12].

4. Uses of Wireless Technology in Medicine

The advent of wireless communication technologies such as the General Packet Radio Service (GPRS) and WiFi have enabled ubiquitous interconnectivity, access to the Internet and World Wide Web, and opened up a realm of new possibilities for telemedicine solutions.

Thus, a study on evaluation of clinical response to wireless technology by Seckman, Romano and Marden [36] focused on measuring perceived usefulness, easy of use and impact of wireless technologies among clinical staff. Their results show that the nurses were the most frequent users of the wireless laptops, with 86.9 percent, and staff feedback show that the new technology is easy to use with no interference with medical devices. From a different perspective, Grasso [37] explored the characteristics of portable point-of-care data entry devices with respect to user interface design and wireless access. As part of their proposed solution they developed a prototype point-of-care database network, namely Clinical Trials Information System, was implemented and evaluated by 5 participants. The results of the study were generally positive, with the average acceptability index being 5.2 on an ascending scale of 1 to 7.

Chu and Ganz [38] examined a portable teletrauma system that assists healthcare centres in pre-hospital trauma care. In this study, simultaneous transmission of a patient’s video, medical images and electrocardiogram signals, which is required through the pre-hospital procedure, is demonstrated by coupling a laptop computer with a commercially available GPRS data service. The evaluation of the system revealed that the tool has the potential in reducing patient mortality when it is used by emergency services personnel to provide immediate care to the patient. However, the quality of the images and video transferred is reduced significantly due to the jitter and the delays caused by the wireless network limitations. For a similar context, [39] implemented a wireless PDA-based physiological monitoring system for patient transport. The PDA-based tool enables the emergency personnel to acquire and upload the patient’s vital signs, including heart rate, three-lead electrocardiography, and oxygen saturation by pulse oxymetry. Patient’s bio-signals are transmitted, through WLAN (802.11), in real-time to a remote central management unit, and authorized medical staff can access the data and make the relevant preparations prior to the patient’s arrival to the hospital. The evaluation of the PDA-based prototype during intra-hospital transport of patients showed a high degree of satisfaction – with an average of 4.64 on an ascending scale of 1 to 5. In related work, a patient-monitoring system that utilizes wireless mobile access terminals is described in [40]. Using this system, authorized users, hospital personnel and patients' relatives, can access a patient's physiological data stored on the hospital's computer, thus speeding up the clinical decision making process. For the same purposes [41] implemented a prototype image browser to display medical 2D/3D images and waveforms on mobile phones and PDAs. The evaluation results of the prototype image browser application were more than satisfactory, but the time required to download an image off the server was too long – up to 30 minutes per image – to make it a widely used medical tool.

Another example of the use of wireless technology in telemedicine is the remote health care monitoring of cardiovascular conditions [42]. Here, for instance, a body-worn electrocardiograph monitor transmits a patient's electrocardiogram to a PDA, from where this data is subsequently uploaded to a hospital mainframe using cellular technology. Indeed, the use of body-worn wireless-enable equipment has also been put forward to monitor a full spectrum of conditions, ranging from cognitive decline to cancer.

On the other hand, a context-aware hospital mobile prescription system that can identify and react according to the location of tagged items (PDAs, beds, hospital trolleys), prescribing the correct medication to patients based on their bed identification number is detailed in [43], while a context-aware messaging system, which can download the appropriate data to a doctors' PDA according to its location was depicted in [44]. From a different perspective [45] examined the use of small-screened mobile devices for healthcare services and showed no significant difference between the use of PDAs and laptops when they are used for nursing documentation. We are not, however, aware of any use of wireless technology in back pain care and monitoring, and this forms the primary focus of our paper.

5. Implementation

5.1 Aim

In our work, we have sought to alleviate the problems identified above and have developed a wireless-enabled, ubiquitous solution that uses the pain drawing as an actual user-friendly visual aid to the input and analysis of back pain datasets. Whilst our solution is generic and applicable to all back pain sufferers which have access to wireless technology, we have specifically targeted wheelchair users due to their severe mobility limitations (which might mean that they might not, for instance, easily have access to a desktop-based computer) and their dynamic pain patterns, which are now easily logged by the developed application. In so doing, we specifically address the issue of pain variability in time, as identified by Gibson and Frank [12], and our application can thus also be used as a data gathering tool for this still incompletely understood phenomenon, the solution of which has potentially important implications in the monitoring of the effectiveness of back pain treatment and medication.

5.2 Data Collection

In order to function as an effective data gathering tool, the developed application, in keeping with previously identified best practice [46] incorporates a questionnaire complemented by visual input of pain location and type, via a pain drawing.

The questionnaire was elaborated in consultation with clinicians from Stanmore Specialist Wheelchair Service in London and representatives of the UK National Forum of Wheelchair User Groups. Clinicians were interested in recording data pertaining to a patient's medical background as well as that which captured the variation of pain patterns with the time of day. On the other hand, the wheelchair users were interested in the usability, flexibility and privacy aspects of the application. Both stakeholder groups agreed that a wireless solution would be beneficial for the added versatility that it offers.

It was agreed that the pain drawing should incorporate four different pain types, namely numbness, pins & needles, pain and ache and that grid scoring should be used. As opposed to traditional methods [31], in which transparencies of the grid are made, and the drawings are scored by placing the grid over each and counting the number of squares in which the patient indicated symptoms, our approach conceptually slices the body contour into squares. The advantage brought with this approach was that we were able to code the pain location with its coordinates from an image to a database, and vice versa (Figure 3).

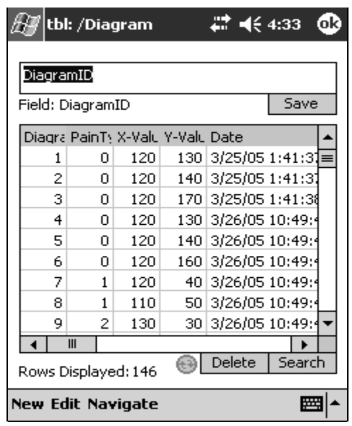


Figure 3 Pocket PC local database

5.3 Application Structure

The underlying structure of our application is based on a three-tier wireless system model where the three main components are: a mobile, wireless-enabled device, a web server with scripting capability, and a backend database.

In this model (Figure 4), the patient inputs on a wireless-enabled device (in our case, a PDA), pain information. This is done at specific time intervals, as requested by clinicians, and the information is saved to a local backend database. Whenever the user is within a wireless-enabled zone, s/he then connects to a web/database server via a wireless access point, using the Hypertext Transfer Protocol over Secure Socket Layer (HTTPS). Moreover, the connection between the PDA and the wireless access point is itself secured through the use of 128-bit Wired Equivalent Privacy (WEP) encryption.

Upon receiving such requests, the server responds back and asks for appropriate authorisation. After this has been successfully completed, the data is then uploaded to the hospital server. The clinician then uses his/her computer to logon to the Web server and downloads information regarding any specific patient and their pain pattern from the database for further analysis.

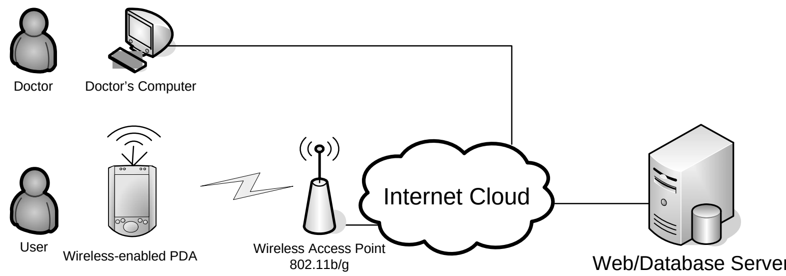


Figure 4 Application structure diagram

5.4 Application Architecture

The developed Pain Application is designed and implemented using Microsoft Embedded Visual Basic, a language specifically geared to help developers build applications for the next generation of communication and information-access devices running Windows CE.

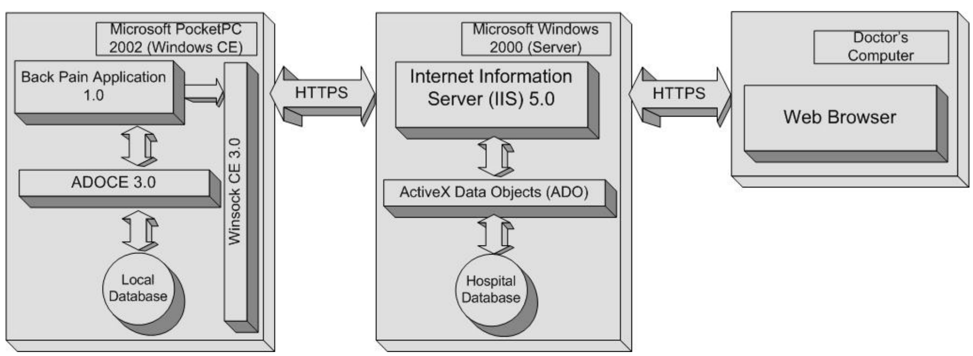


Figure 5 System architecture diagram

The system architecture diagram (Figure 5) shows the main components that make the wireless model system model work. Accordingly, the Pain Application was implemented on an HP iPAQ 5450 PDA with 16-bit touch-sensitive transflective thin film translator (TFT) liquid crystal display (LCD) that supports 65,536 colour. The display pixel pitch of the device is 0.24 mm and its viewable image size is 2.26 inch wide and 3.02 inch tall. It runs Microsoft Windows for Pocket PC 2002 (Windows CE) operating system on an Intel 400Mhz XSCALE processor and contains 64MB standard memory as well as 48MB internal flash ROM. The Web server was implemented on an Intel Pentium III running at 1 GHz, with 512MB RAM and a 50GB hard disk. In our work, a 10Mbps D-Link DWL-700AP wireless access point was used.

The application reads the coordinates of the pain locations from the touch-sensitive screen and using ADOCE 3.0 (Active Data Objects for CE) connects to a local Microsoft Pocket Access database file. Through this connection, the application saves the pain coordinates and patient questionnaire data to the database. When the user is within wireless Internet coverage, the application uses Winsock CE 3.0 (Windows CE Sockets) to send a connection request to the server. The server runs Windows 2000 operating system and Internet Information Server (IIS) 5.0, with Open Database Connectivity (ODBC) to connect to the hospital database.

The doctor's interface is made of dynamically created Active Server Pages (ASP), which can be accessed using any conventional web browser running on a computer connected to the Internet. Thus, after successful authorization, medical personnel can download a particular patient's data to their personal computer. This is achieved through the ASP code dynamically creating an SQL query to the database, the results of which are presented dynamically on the viewed Web page.

5.5 Application Walkthrough

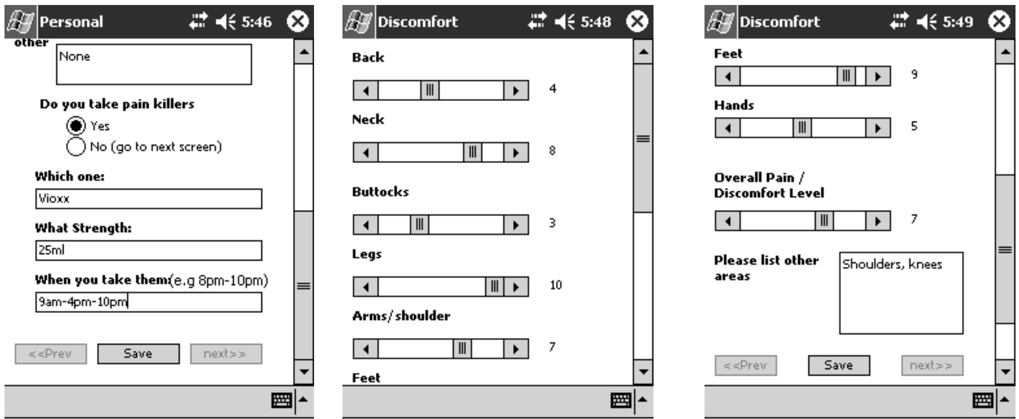
The prototype application is designed so that it provides maximum functionality with a minimum of stylus-tapping. Each screen has a simple structure in order to help the user accomplish his/her task efficiently and swiftly. Moreover, the colour scheme used in the application was created as a result of experiments with the elderly and visually impaired (colour blind) to reduce the visibility problems.

a) b) c)

Figure 6 a) Welcome screen; b) Personal details screen; c) Personal details screen

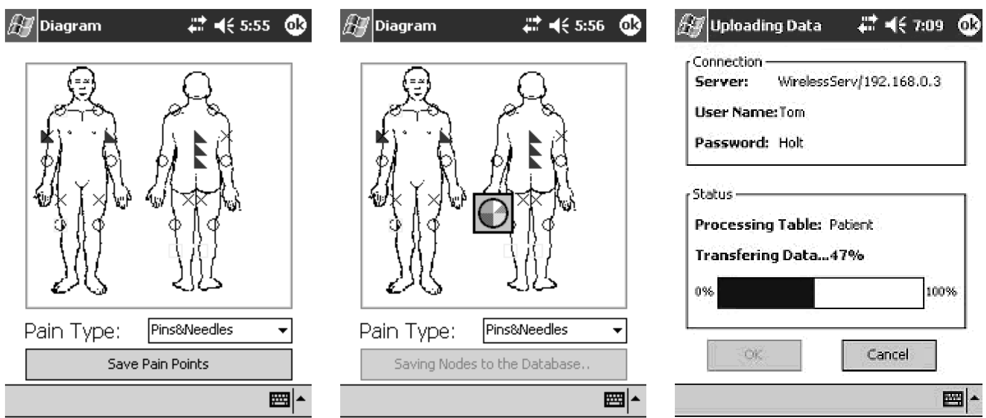
The initial screen welcomes the users to the system and lets them select their user type. The user taps on the New Subject menu and selects the appropriate type (Figure 6a). Following this input, the system forwards the user to the relevant screen. If the Doctor option selected, patient data input screen is loaded (Figure 6b), where the doctors can record the personal details of the current user and allocate him/her a login and password. Moreover, on these screens (Figure 6c and 7a), the practitioners can store information about discomfort causing factors, comfort causing factors, prescribed medical treatment and medication frequencies.

If the User option is selected, then after successful login, the application will load up a discomfort screen, where users of the system can input their discomfort levels for various parts of their body (Back, Neck, Buttocks, Arms/Shoulder, Feet and Hands) using horizontal scrollbars (Figure 7b). After consultations with clinicians, we employed a scale of 0-10, with 0 being "no discomfort" and 10 being "worst possible discomfort". Additionally, patients can also indicate, in a dedicated text box, other areas of their body in which they might be feeling discomfort (Figure 7c).



a) b) c)

Figure 7 a) Personal details screen; b) Discomfort scrollbars; c) Discomfort textbox



a) b) c)

Figure 8 a) Diagram screen; b) Diagram screen; c) Data transfer screen

The back pain diagram screen of the prototype application provides a simple interface for the user to record his/her pain points effectively (Figure 8a). There are three main functionalities of this screen; to enable the user to identify his/her pain type (Pins and Needles, Pain, Ache and Numbness) using a pull down menu; to enable the user to show the appropriate pain type on the diagram; and finally, to record the data to the local database using the Save Pain Points button (Figure 8b). Lastly, the collected data can be uploaded to a central hospital database by a tap of a button, using wireless network connectivity (Figure 8c).

6. Functionality and Evaluation

6.1 Pilot Evaluation

The first version of the developed application was given out, together with a brief user manual, to three wheelchair users from the collaborating group for a 5-day pilot evaluation. The feedback provided could be broadly categorized into two groups. The first concerned ways through which any potential misunderstandings of the questionnaire content could be clarified. The second grouped issues such as font size (too small in our initial prototype) and color schemes used by the application (which had to take into account users' potential color blindness). The users did not encounter navigation problems, nor were there any problems raised with regard to clarity of the pain diagram, or indeed with the saving and transferring of recorded data. All the concerns identified by the participants of the pilot study were addressed in the subsequent version of our application.

6.2 User Evaluation

The developed application was evaluated with a sample of 10 wheelchair users, members of the Hillingdon Wheelchair User Group (London). There were 6 females and 4 males in the sample, aged between 42-64 years old, each of which had varying degrees of daily wheelchair use. Each participant was given 3 days in which to evaluate the application, as well as a short (2-page) user manual, and instructions at which times of the day they should record their pain measurements.

Table 1 Evaluation Questionnaire

Effectiveness	
The PDA is easy to carry around with me	
PDA application is easy to learn	
I would have preferred instructions that were easier to understand	
I think that the process of inputting data on the PDA application could be faster	
I could use the PDA for other activities in my life	
It is useful to show how my pain varies across time	
I found it difficult to use the PDA	
Using the Program	
Screen directions are consistent and easy to follow	
I had difficulties navigating through the program	
It is easy to make mistakes using this program	
Program responds appropriately to any mistakes I made	
It is easy to add/delete pain points	
Text on each screen is clear	
Character recognition/on-screen keyboard is easy to use	
Communicating About My Pain	
It was hard to show the intensity of my pain with the scrollbars	
It was hard to understand how to use the pain identification screen	
The body diagram on the pain identification screen is easily visible	
Having different colours for each pain type is helpful	
Having different shapes for each pain type is helpful	
Pain type selection was difficult	
Showing the location of my pain on the PDA is easy	
Overall	
Summary Evaluation	Poor ☐ Fair ☐ Satisfactory ☐ Good ☐ Excellent ☐

Input of data took place mainly at the user's domiciles (or wherever they happened to be when the recording of data had to take place), with no personnel being on hand to offer help in this respect, save for the information contained in the manual. While the degree of local connectivity of each patient varied, they were told to use their own means and resources in order to upload the collected data to the hospital server. At the end of the evaluation period, participants were requested to complete a questionnaire (Table 1), in which they recorded their opinions on a Likert scale of 1-5 with respect to three categories of the developed application: *effectiveness, using the program*, and *communicating about my pain*. Lastly, patients were also asked to give an overall evaluation of the application and detail any other observations that they wished to make.

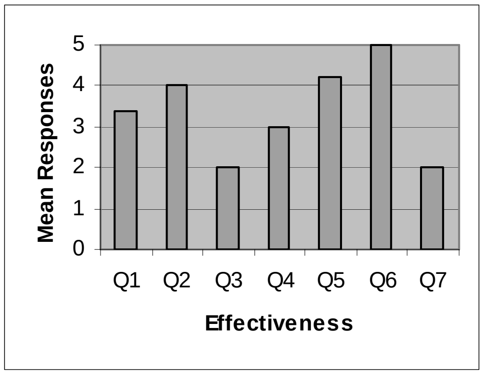


Figure 9 Effectiveness: Mean responses

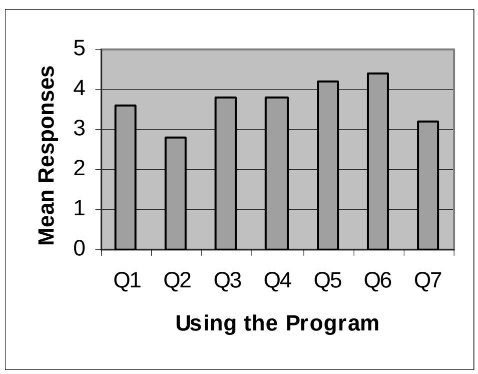


Figure 10 Using the Program: Mean responses

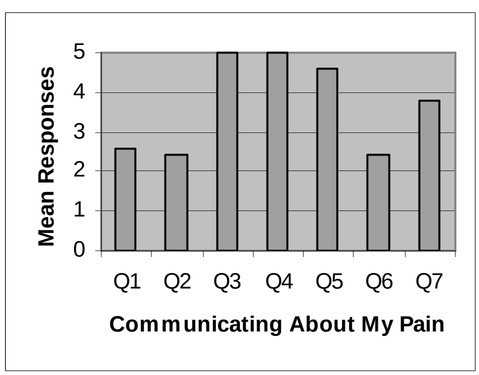


Figure 11 Communicating About My Pain: Mean responses

The results of the evaluation are given in Figures 9-11. Performing a one-sample t-test analysis of the results highlighted a general consensus that wheelchair users had in respect of the ability to record pain data on a mobile device being beneficial to their lifestyles (an observation also confirmed through informal and formal, written feedback, at the end of the questionnaires).

Accordingly, our analysis revealed that the responses collected were, for all questions of the evaluation questionnaire, statistically significant at the 0.05 level. Thus, in the effectiveness category it is noteworthy to remark that all participants in our survey strongly agreed that the ability to show how their pain varies across time was useful. Informal feedback collected in this respect highlighted that in most cases participants felt that the fact that wheelchair users are, for long periods of the day, in considerable pain is an under-reported phenomenon. Moreover, there was also unanimous participant agreement that the PDA application was easy to learn and that users could envisage themselves using the PDA in their lives for purposes other then pain monitoring. Lastly, participants disagreed that the provided user manual was not easy to understand.

As regards the using the program category of questions, user evaluations indicated that there was agreement that adding and deleting pain points on the pain drawing associated with the developed application was an easy process. Whilst users did feel that it could be easy to make mistakes inputting data, they did indicate agreement with the fact that the program does respond appropriately in such circumstances. Although some users, especially those suffering from arthritis and/or poorer eye-sight did encounter difficulties in using the relatively small interface of the PDA, as well as the character recognition software and on-screen keyboard method of inputting data, there was relatively high agreement that screen directions were consistent and easy to follow, leading to an easy navigation process in the developed application.

There was unanimous strong participant agreement that the outline body diagram of the pain drawing was easily visible and that our idea of colour-coding the different pain types was particularly helpful. There was also near unanimous strong agreement with the statement that having different shapes for each pain type (thus facilitating potential patient input of all four different types of pain on the same location, without any symbol overlap). Participants were also in disagreement with the statements that pain type selection was difficult and that showing the intensity of pain and understanding how to use the digitized pain drawing on the PDA were hard.

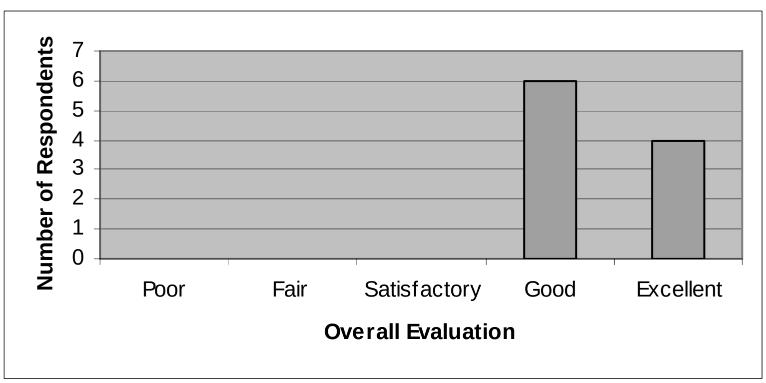


Figure 12 Overall Evaluation

As far as the overall evaluation of the developed application is concerned, all participants scored it as being either good or excellent, with an almost even split between the two opinions (Figure 12). This shows that, notwithstanding problems encountered with data input, participants felt that the application was successful in its purpose of ubiquitous monitoring of pain levels encountered by wheelchair users and in highlighting their variability with the progress of time.

Lastly, although participants did encounter barriers in respect of their attempts to upload data, with some of them using ingenious resources (such as using WiFi-enabled cafes or local shopping malls) to accomplish this task, nonetheless participants felt generally positive about ubiquitous data collection and transmission capabilities, with the feeling that proliferation of WiFi hotspots would remove such barriers in the future.

7. Conclusions and Future Work

This paper describes the design, implementation and evaluation of a wireless-enabled solution for back pain data collection and wireless transmission to a remote clinical database. Whilst the paper analyses problems in the assessment of wheelchair users' pain, the principles extend beyond Britain's 1.2 million wheelchair users to potentially facilitate assessment of many chronic pain states where pain is expected to change over time. Thus, many musculo-skeletal pains change in relation to physical activity, particularly back and neck pain, and our work has specific applicability in these areas.

Employing a user-friendly visual approach to data input, in our solution data collection activities are carried out in a ubiquitous fashion. The fact that the gathered data, including pain drawings, are digitized makes it easier for it to be collected, time-stamped and analyzed, while the fact that such input takes place on a PDA means that this can happen irrespective of the location of the user without clinical supervision. Finally, recognizing the mobility problems that wheelchair users endure, our solution is WiFi-enabled, thus facilitating remote, ubiquitous, data access and management and absolving patients of the need to actually physically hand in their completed questionnaires.

Stakeholder evaluations highlight that the application is generally perceived to be easy to use and successful in its stated intent of monitoring pain level variations during the waking day of wheelchair users. Whilst known data input drawbacks of PDAs manifested itself in our developed application, these were however felt not to be potential obstacles in the way of application adoption.

We recognize that security in the application – developed as a proof-of-concept –could be improved beyond the simple login/password authentication scheme. Similarly, issues of scale have yet to be addressed. However, both these remarks form the basis of our future endeavors. Moreover, further studies are needed to confirm the impression that the developed application could be used in the assessment of numerous pain states with variability across time, such as back and neck pain.

Acknowledgements

We are indebted to Elisabeth and Peter Kemp for their assistance in devising this application and advising on its suitability for wheelchair users. We are also grateful to the members of the Hillingdon Wheelchair User Group who kindly participated in this study.

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