

Technology Inspired Design for Pervasive Healthcare

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Abstract— Pervasive healthcare technologies are increasingly using novel sensory devices that are able to measure phenomena that could not be measured before. To develop novel healthcare applications that use these largely untested technologies, it is important to have a design process that allows proper exploration of the capabilities of the novel technologies. We focus on the technology-inspired design process that was used in the development of a system to support posture and provide guidance by nudging people, and how this has led us to explore pervasive healthcare applications.

Pervasive healthcare; vibrotactile feedback; technology inspired; hardware prototyping; sensory awareness; posture and movement; physiotherapy

I. INTRODUCTION

The advent of ubiquitous computing technologies has provided many opportunities for developing far-reaching and effective healthcare applications. Opportunities arise in the form of hospital-based solutions, supporting medical staff through novel diagnostic methods, or for use at home, enabling patients to monitor their own health.

The introduction of a range of novel sensors and mobile devices, makes it increasingly possible to measure and monitor phenomena that were hitherto not possible. Examples of such phenomena are the detection of movement in a room, changes in a person's skin temperature, or the precise angle between the upper and lower arm of a person stretching their arm. However, there are many challenges involved in the design of systems that use such technologies, particularly since the available sensing possibilities enable the development of very new experiences that are not readily comparable to healthcare scenarios that patients or designers are familiar with.

There is a growing realization that systems in the area of pervasive healthcare need to take into account the cognitive and physical abilities of the intended users of the system [1]. For example, if building a system that is intended for elderly users who are frail and suffering from memory loss in order to

support them living independently at home, then the system must be designed with those users in mind, and evaluated with these users in-situ. This is generally referred to as a user-centred approach, and often involves building prototypes that users can explore in order to reflect and engage with new technologies.

Prototypes can help designers evaluate whether such systems could work in the real world and how they can be improved. Moreover, building prototypes also acts as a way of physically exploring the possibilities of new technologies, and can even be viewed as a source of inspiration for future systems.

In this paper, we describe our approach to the design of a novel wearable system that can give real-time feedback to improve posture and to support the training of complex motor skills. We discuss how it was designed and its sources of inspiration. We then discuss how our experience has led us to consider developing other systems, in which health and wellbeing are the focus.

II. RELATED WORK

Pervasive healthcare covers a wide range of solutions to improve health and well-being. These solutions can be in the form of off-the-shelf systems, or specifically tailored solutions with specific groups of users in mind.

A. Off-the-shelf systems

There is a growing market for off-the shelf systems that allow users to monitor aspects of their health. For example, the SenseWear Armband [2] can be worn on the upper arm and collects a variety of physiological data through multiple sensors (accelerometers and temperature sensors). Its purpose is to provide the wearer with data about their energy expenditure during activities and also while resting, thus helping them maintain a healthy lifestyle. An example of another small sensing device is iPosture™ [3]. This device can be worn on the chest and is designed to help the wearer improve their posture when sitting. It alerts the wearer through haptic

feedback, by gently buzzing them, when they are slouching to encourage them to adjust their posture.

Both these systems are commercially available, are relatively cheap and offer solutions to everyday problems that can be used by the general public. The SenseWear Armband is a technology that can potentially help to combat obesity problems, by encouraging people to monitor their own life style and thus hopefully adopt a more healthy life style. However, it has been reported that a disadvantage of the SenseWear Armband is that it has to be worn day and night, and that the data, though relatively accurate, may be overly complicated for most people to make sense of [4]. Similarly, the iPosture device can potentially assist large numbers of people who suffer from bad posture due to their work in offices, working long hours on computer related activities. However, an in-the-wild study of the iPosture device, which was carried out with a small number of users who wore the device for a number of days, showed some problems [5]. The study revealed that users felt uncomfortable and self-conscious when wearing the device in social settings, as the device's buzzing could be heard by others in their vicinity, and also that users gradually stopped noticing the system as the day went on. So even though the devices appear to offer lightweight and affordable solutions to problems that affect many people, in practice their utility and efficacy is questionable, especially if they don't fit in with people's life styles and routines.

B. User centred design for tailored healthcare solutions

A user-centred approach takes the specific needs of a group of users into account, from the onset of designing a system, and works with them throughout the development of the system. The rationale for involving users is to try to ensure that the system under development is usable, comfortable and understandable. An example is DIMA – a system that was designed to enable patients with chronic renal disease to carefully monitor their fluid intake by Siek et al [6]. Such patients are restricted in the amount of fluid they are allowed to take in each day, and in order to stick to their prescribed daily amount, have to make complex calculations throughout the day. A handheld PDA system, that also included a barcode scanner, was developed to support these patients. The idea was that by pointing their PDA at products they were about to consume, patients were able to keep a very strict count of how much they had consumed that day. Early on in the development of their system, the researchers provided the patients with paper-based prototypes to ascertain whether they would be able to use the new PDA system. These revealed that a large proportion of their patient group had reading problems, and thus required non-text graphical interfaces in order to be able to work the system.

The importance of user input at an early stage was also demonstrated by the Smart project, who developed a system to encourage stroke patients to carry out their stretching exercises, using sensors attached to their arm that measure the extent of the stretching, allowing patients to monitor their own progress [7]. They organized hands-on workshops with groups of patients in order to work out how best to attach the sensor to the upper arm. That is, which type of armband, and which type of fastener, would be easiest to put on, given that these patients usually have very limited movement in their upper limbs.

Interestingly, a fastener that seemed simple to the researchers caused too much friction for patients to put on, while a solution that seemed overly complex to the researchers, was preferred by patients after trying a few times.

C. Rapid prototyping and technological inspiration

Another approach for ensuring that ubiquitous systems fit in with people's lifestyles is to use *rapid prototyping*, also sometimes referred to as *sketching in hardware*, or *physical computing* [8]. This involves building physical, partially working prototypes, to enable representative users to interact with them. Hardware prototypes offer a step-up from paper-based prototypes, as they do provide a different kind of interactive functionality. They usually do not have the aesthetically pleasing look and feel of a final product, but instead use electronic toolkits such as Arduino and various electronic components, put together through a variety of DIY techniques such as hardware hacking, modding, and mashups [8, 9, 10]. This process of rapid prototyping can go through a number of cycles, where user reactions feed into the next iteration of the prototype [11].

Apart from helping the users understand the design, prototyping is important for the designers of a system, because building the physical system is a helpful way of learning about the affordances of a system, which would be difficult to do when just thinking about a system [12]. Exploring the potential of technologies, by physically exploring their possibilities, through combining and trying out designs, can also provide inspiration. Rogers et al. [13] use the term 'technology inspired' to describe the process where the capabilities of new technologies are explored and experimented with, in order to provide ideas for conceptual development. They describe this approach in the context of a project which seeks to promote learning through novel, playful visions of technologies. They explored how RFID tags, barcodes, GPS devices, ultrasonics, beacons, handheld computers, accelerometers, pressure pads and aerials could be used and combined to create a mixed reality environment for to children explore. The approach emphasizes looking at the technology for design inspiration, investigating where and how it may be used in innovative ways. This is quite different from technology-led, where the technology effectively determines the outcome or product, denying the input of people and context during the design process.

Our approach to pervasive healthcare system design is to combine all three approaches: user studies, consultations with health care experts and a technology-inspired approach. It also draws initially from previous research using pervasive technologies from another application area.

III. FROM A WEARABLE SYSTEM FOR VIOLIN BOWING TO PERVASIVE HEALTH CARE

The starting point for our exploration of the pervasive healthcare space lies in our experience of developing a system, MusicJacket, that supported people learning to play the violin [14]. In particular, the system aimed to support the physical aspects of playing, such as how to make the complex arm movement for bowing, and how to encourage people to

maintain a good posture during playing. Some of the questions we came up against during the development of this system are considered highly relevant to pervasive healthcare systems, intended to support the training of motor skills and methods to correct posture.

A. Technology Based Nudging

The novel aspect of the MusicJacket system is that it uses *haptic feedback*, i.e. it uses the sense of touch, giving the wearer of the jacket the sensation that someone gently ‘nudges’ their arm into the correct position. The real-time feedback is delivered through vibration motors, similar to those found in most mobile phones. When the player’s bowing moves too far from the target trajectory that is set for them, the player feels a gentle buzz, whereas feeling no buzz means that they are on the correct path.

Our first foray into haptic feedback was when developing a prototype Tactile Vision Substitution (TVSS) system for determining how people experienced vibrotactile feedback. [9]. This system was in the form of a large belt with an array of vibration motors, which could be attached to a person’s abdomen. The system enabled visual stimuli to be translated into a person ‘feeling’ certain patterns of vibration on their abdomen. Parts of the software code and some of the hardware components of this system were re-used in order to build a prototype feedback system that was used to guide movement of arms.

We were interested to know whether people would be able to react to this haptic feedback, while they were involved in making music. Research had indicated that musical activities place a heavy load on people’s sensory systems, that is, their eyes are busy looking at their music or their hands, and their ears are busy listening to the sound they make. Therefore giving additional feedback in the form of visual displays or auditory sounds seems not appropriate. Tactile feedback can be a more intuitive form of feedback, that people are likely to be able to react to, just as they might when the teacher ‘touches’ their elbow to gently move it to the right position while they play.

The haptic technology and how it was worn inspired us to explore this kind of real-time nudging as a way of supporting the training of physical movements and posture.

B. Exploring Nudging more Precisely

As part of the prototyping for the MusicJacket system, it was important to know where precisely to place the vibration motors in order to make the feel for the players at its most intuitive. We consulted an expert in ‘feeling’- an Alexander Technique (AT) trainer - who spent two days with us in the laboratory. The AT trainer’s experience with violin players had taught her that when a player gets tired, they start to lean in on their left leg and their whole body starts to slough. As a result, the hand that is holding the violin also starts to lower, making the whole posture for playing very difficult. In order to provide appropriate feedback to players on this aspect, we wanted to find the best place on their body that would help them back into the right posture.

We experimented with a number of different placements for the motors. For example, placing a motor on the player’s head (to encourage the player to lift up their head and body) did not work, as it proved too distracting due to bone resonance distortion, and the player would ‘hear’ the buzzing in their head. Placing a motor under the feet of the player, so as to ‘push’ them up, and move away from the heavy leaning into the left leg, did not work either. The player’s weight was too much for the motors, which simply did not vibrate anymore. The issue was eventually resolved by using three motors for the feedback on the arm being too low: one underneath the elbow of the arm that is too low, and two on either side of the rib cage, to give that overall nudge to the player that they should lift themselves up, and stand tall. Figure 1 shows the placement of the feedback motors.

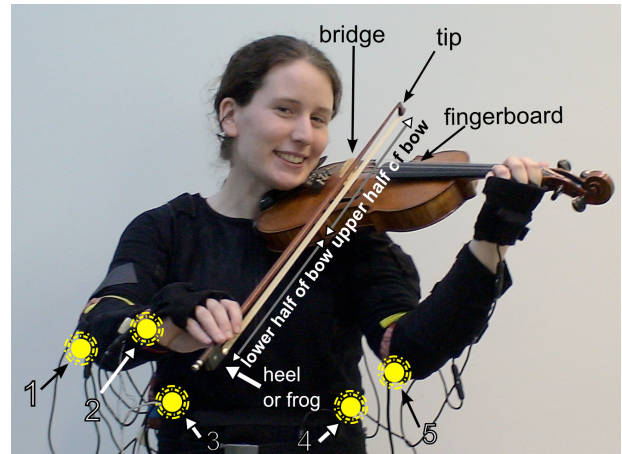


Figure 1. Motor placement in final version of MusicJacket. Motor 1 = move right arm forward, motor 2 = move right arm back, motors 3, 4, 5 = straighten up and lift violin.

While exploring the position for motors 3, 4 and 5 (in Fig. 1) the AT trainer realized that she was effectively able to feel a triangle between the three vibrating points on her body: between the left elbow and her two sides. The triangle would change shape as the player moved her arm and body. We hypothesized that using the vibrotactile feedback as training, players could gain an increased sensory awareness of where their own ‘correct’ triangle was. Thus the triangle could become a useful spatial concept for their proprioceptive sense. An awareness of one’s own body, and in particular, an awareness of where parts of the body are in relation to each other, is an important step towards learning how to sit, stand and move correctly.

The proprioceptive triangle came about as a direct result of exploring the potential of the technology, and has inspired us to think that besides providing a form of guidance for movements, nudging can also be used as a mechanism for giving people greater awareness of their own body. This is an issue that lies at the core of most treatment regimen in physiotherapy.

IV. TO PERVASIVE HEALTHCARE

Following on from the MusicJacket we are now working on pervasive healthcare projects in which we base our new designs on our experiences of developing and evaluating the MusicJacket. In particular our approach to pervasive healthcare

focuses on giving feedback to users that is easy to follow, and that uses the idea of physically nudging.

A. *iFollow Physiotherapy*

Our next step is to develop and evaluate, our new system for pervasive healthcare, *iFollow*, as a physiotherapy intervention based on novel technologies. The system is aimed at older adults who have recently come out of hospital following an orthopedic operation. In consultation with clinical experts this group has been identified as requiring intervention because patients are leaving hospital earlier than previously, well before the length of time to regain optimal functionality. A programme to exercise at home with support can be particularly beneficial [15].

The objective is to motivate and guide older people through a schedule of tailor-made physical exercises that follow interactive visualisations presented in real-time. The interactive exercises will be designed as visual movement patterns that map onto their arm/shoulder body movements. We will also develop various forms of haptic feedback to give guidance on the extent of movement and to encourage patients to reach their target movement.

We will follow an iterative design approach, involving older people who have received orthopedic surgery as well as healthy representatives of this group, physiotherapists and interaction designer at key points of the design. In particular, we will work closely with physiotherapists specialized in treating older adults to develop the requirements of individualized exercise regimes for people recovering from injuries and to set target movements. This will also involve consulting with older adults who have just come out of hospital and are starting their exercises at home.

We will adopt the *MusicJacket* approach of modeling and setting of body movement trajectories. A target movement can be seen as the ideal trajectory for the movement, and is the one the older person should be aiming to make. In order to set the target movements for each older individual, we will provide individualized exercise regimes, working closely with the physiotherapists, as the regime needs to recognize what movement patterns can be regained and what might remain permanently injured. We will then develop an *iFollow* wearable jacket prototype for the delivery of tactile feedback in conjunction with a textile consultant. The jacket needs to be easy to put on for someone who is frail and has restricted limb movement; be comfortable to wear; and customizable to accommodate different exercise regimes.

We plan to conduct two main phases of user studies. First, we will work with healthy older adults as participants, to determine how effective the addition of haptic feedback is for increasing motivation and accuracy of movement in the exercises. Our hypothesis is that the haptic feedback will increase motivation and in turn, improve well-being. We will develop measures of performance, effectiveness and enjoyment to assess levels of improvement and will also investigate the system's social potential by studying how it can be used in a social setting, allowing other people to join in. The second phase will involve trialing our *iFollow* system with patients who are in rehabilitation and will follow a case study approach.

We will also run a workshop inviting physiotherapists to get their feedback on the value of the new approach and how they would envision using it in their practice.

B. *Augmented Balance board*

A second prototype system we are developing that has drawn from a blended technology-inspired and user-centered approach is the *Augmented Balance Board*. This is a system that was designed to support musicians develop better posture while playing, and in particular to avoid playing in a cramped style. Many musicians suffer from serious health problems due to many years of intense practicing. Until fairly recently this was a hidden problem, and no training was provided for musicians on how to look after their body and how to prevent injury. There are now specialist medical clinics for musicians to attend, and an analysis of 1046 musicians seen at such a clinic of the British Association for Performing Arts Medicine (BAPAM) showed that just over half suffered from problems due to poor posture, tense neck and shoulder muscles, inappropriate practice regimes, lack of fitness and stress [16].

Most music conservatories now offer AT training to their students. The main purpose of these AT lessons is to help students find and maintain their core balance and to learn to use appropriate pressure and tension of the muscles when playing. One method used with musicians who are overly tense is to encourage them to play their instrument, or to sing, while standing on a rocking, or wobbling board as commonly used in physiotherapy practice. By gently rocking and thus continually adjusting their own body balance, a player is effectively coerced into being relaxed while playing.

We have developed the first prototype for an augmented balance board that monitors the player's rate of wobbling, and gently nudges a player to continue to wobble if they have stopped. Nudging players to continue is necessary because most players have no trouble wobbling when playing easy passages, but as soon as they come across complicated sections that they are struggling with, they tense their bodies, and stop wobbling. It is this that they need to address – that even when a passage is difficult, they must learn not to tense up and play in a cramped style.

The first prototype of the system uses Nintendo Wii technology, by mounting a standard Wii balance board atop a wooden rocking base. The balance board contains four pressure sensors. It connects over Bluetooth to a computer, with the connection being kept active by *Osculator* software [17]. *Osculator* is also responsible for reading the pressure sensor data, and converting it into the *Open Sound Control* format which can be read by *MaxMSP/Jitter*. In the manner of [18], the role of *MaxMSP/Jitter* is to interpret, store, and visualize the data, and also to communicate with an Arduino microcontroller. The nudging feedback is delivered through vibration motors connected to the Arduino microcontroller.

The prototype will be evaluated with a number of users, including students at a music conservatorium during a hands-on workshop session planned for the near future. One of the open questions for the workshop will be where exactly the feedback motors should be placed to have the most impact and to be comfortable – on the person's foot, or, for example, on

their waist? Or does the precise location depend on the instrument that is being played?

The purpose of the hands-on workshop is not only to gain feedback on how to refine the first prototype, but is also for the music students an opportunity to experience and reflect on how ubiquitous technologies can impact on their playing and their performance.

V. CONCLUSIONS

We have described a blended approach for exploring how new technologies can inspire the design of new pervasive applications that use real-time feedback to correct certain physical behaviours. This was illustrated by two proposed new systems we are currently building to enhance physiotherapy and music posture, respectively. An important aspect of our approach is also to engage with experts in the field, such as an Alexander Technique trainer who can make sense of the ubiquitous technologies we are exploring, through verbalizing her sensory experience. Another important aspect of ensuring the new solutions fit with people's lifestyles and be used, is that they are comfortable, easy to use and the benefits of using them make sense to the wearer. To assess these aspects requires evaluating them in the wild – which we are now embarking on.

REFERENCES

- [1] B. Arnrich, O. Mayora, J. Bardram, G. Troster, "Pervasive healthcare: paving the way for a pervasive, user-centered and preventive healthcare model". *Methods Inf Med.* 2010;49(1):67-73.
- [2] M. Fruin and J. Walberg-Rankin, "Validity of a Multi-Sensor Armband in Estimating Rest and Exercise Energy Expenditure", *Medicine & Science in Sports & Exercise*, 2004, Volume 36, Issue 6, 1063-1069
- [3] iPosture™, <http://www.iPosture.com/index.php>
- [4] J. Maitland, S. Sherwood, L. Barkhuus, I. Anderson, M. Hall, B. Brown, M. Chalmers, and H. Muller. "Increasing the awareness of daily activity levels with pervasive computing." In *Proceedings of the first international conference on Pervasive Computing Technologies for Healthcare*, 2006, 1-9.
- [5] R. Johnson, J van der Linden and Y. Rogers, Yvonne. "To buzz or not to buzz: improving awareness of posture through vibrotactile feedback". *Proceedings Whole Body Interaction Workshop CHI 2010*, 10-11 Apr 2010, Atlanta.
- [6] K.A. Siek, K.H. Connelly, and Y. Rogers, "Pride and prejudice: learning how chronically ill people think about food." *Proceedings CHI '06*. ACM, 947-950.
- [7] G.A. Mountain, P.M.Ware, J.Hammerton, S.J.Mawson, H. Zheng, R. Davies, N. Black, H. Zhou, H. Hu, N. Harris and C. Eccleston. "The SMART Project: A user led approach to developing and testing technological applications for domiciliary stroke rehabilitation", *Designing Accessible Technology*, 2006, Part III, 135-144.
- [8] D. O'Sullivan and T. Goe, "Physical Computing: Sensing and Controlling the Physical World". 2004, Premier Press.
- [9] B. Hartman, S. Doorley, and S. R. Klemmer, "Hacking, Mashing, Gluing: Understanding Opportunistic Design". *IEEE Pervasive Computing*, (2008) vol. 7, no. 3, 46 – 54.
- [10] J. Bird, P. Marshall and Y. Rogers, "Low-Fi Skin Vision: A Case Study in Rapid Prototyping a Sensory Substitution System". *Proceedings of HCI 2009*, 55-64.
- [11] S. Carter, J. Mankoff, S. R. Klemmer and T. Matthews(2008) "Exiting the Cleanroom: On Ecological Validity and Ubiquitous Computing", *Human-Computer Interaction*, (2008) 23: 1, 47 — 99.
- [12] S. R. Klemmer, B. Hartmann and L. Takayama, "How bodies matter: five themes for interaction design". In *Proc. DIS '06*, 140 – 149.
- [13] Rogers et al. (2002) "Things aren't what they seem to be: innovation through technology inspiration. *DIS2002* London, UK, 25-28 June, 373-377. ACM Press.
- [14] J. van der Linden, E. Schoonderwalt, J. Bird and R. Johnson. "MusicJacket: Combining Motion Capture and Vibrotactile Feedback to Teach Violin Bowing." *IEEE Transactions on Instrumentation and Measurement*, (2011), 60 (1) .
- [15] Bandolier, "Caring for older people after Acute Illness", Downloaded June 2010 from <http://www.medicine.ox.ac.uk/bandolier/booth/mgmt/careold.html>
- [16] C. B. Wynn Parry, "Managing the physical demands of musical performance", in *Musical excellence, strategies and techniques to enhance performance*, A Williamon, Eds. 2004, Oxford University Press.
- [17] Osculator, <http://www.osculator.net/>
- [18] S. Holland, A.J.Bouwer, M. Dalgelish and T.M. Hurtig, "Feeling the beat where it counts: fostering multi- limb rhythm skills with the haptic drum kit." *Proc. TEI 2010, ACM (2010)*, 21-28.