Interactive Rehabilitation Tiles

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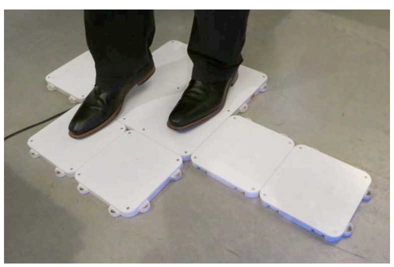

Figure 1: The sensor floor modules

Abstract
Traditional physical rehabilitation techniques are based mainly on mechanical structures and passive materials. This has certain limitations, which can be overcome by applying interactive technologies. As a team of designers, technologists and medical researchers and practitioners, we have developed an interactive sensor floor tile system for rehabilitation exercises, as part of an interactive infrastructure to support rehabilitation for stroke patients. Since 2009, the team has advanced its understanding of rehabilitation practices and problems, and designed prototypes, interventions and demonstrators in order to gain feedback on our approach. We have identified as the three critical factors affecting rehabilitation *motivation, customisation,* and *independence.* The system that we have developed is founded on the current mechanical practices, of improvisational nature, and creative use of existing materials and techniques, expanding from this way of working by applying new interactive digital technologies and 3D instant manufacturing techniques. Two sets of sensor floor modules are in use in hospitals and we are reporting in this paper the first positive effects the system has on the patients' rehabilitation.

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Keywords
Force sensing tiles, modular approach

Introduction
Traditional physical rehabilitation exercise techniques can be enhanced by using interactive technologies. After studying rehabilitation practices for several years, we have identified three key areas where improvement can be achieved. These key areas are *motivation* (offering rewarding feedback to the patients to stimulate them to participate fully in the therapies), *customisation* (the ability to adapt the systems to a wide range of needs of different patients and therapies), and *independence* (enabling the patients to follow therapies away from the hospital, when and where it suits them, under remote expert guidance of the therapists and practitioners, including the highly desirable feature of automatically logging patient exercise data). We presented these three key issues in an earlier paper [3], and they have been guiding our developments. The key issues are described in detail in another publication [6], including the design approach responses that we have developed. Particularly the

Figure 2: The Re-Ability Sleeve.

Figure 3: Tangible programming table working prototype

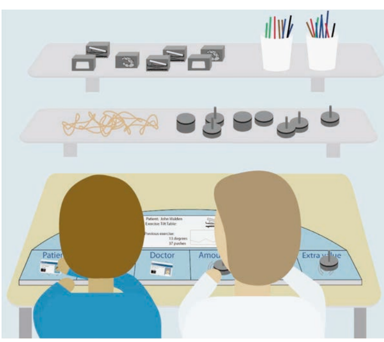

Figure 4: Tangible programming table: impression of the usage scenario

issues of *customisation* and *independence* are well suited to be approached from interaction and tangible interface design perspectives [1, 9].

Our studies focused on staff practices in the hospital ward, consisting of unobtrusive observations, appropriate interventions, unstructured interviews, and explicit requests for participation. In effect, our aim was to have the practitioners drive our research and developments, as is common practice in design research. Our proposals proceed from existing practices and our approach is inspired by actual therapies. The work is based on the current mechanical and often very creative solutions of physiotherapists and other practitioners [4]. Rather than replacing, we are *extending* their practices with digital technologies. We have also successfully applied the enabling technologies of 3D modelling design tools and instant manufacturing (such as 3D printing) in our explorations. These developments provide a fertile basis for a new paradigm and new focus on tangible interaction.

The sensor floor tiles, shown in Figure 1, form part of a larger development of additional modules which electronically link together. The development of an interactive infrastructure fits well with the notion of embedded interaction. Modules can be input (through sensors that pick up the patients actions), output (displaying feedback to the patient visually, auditory, tactually), or both, and there are active objects which are used to indicate modes and preferences. Other modules we have developed so far are a wireless interactive hand counter [5], a custom sleeve of wearable modules for wirelessly tracking of arm and finger movements (bend, pressure, orientation) developed by the fourth author (see Figure 2 and a publication [12]), and a wireless handheld reaching task module (with an RFID reader, and motion sensor and visual feedback, using RFID tagged targets) [3]. All these modules are working in real time. The mapping between modules and the settings are established through placing the modules and other objects involved (representing the patient for instance) on a programming table as depicted in Figures 3 and 4, using RFID tags and multiple RFID readers (we are using a sequential polling technique to avoid interference between readers and between tags). We are also developing ‘programming modules’, physical objects which are part of the modular system, and which enable the therapist (or care giver) to set the parameters and variables of the task through manipulating physical objects rather than screen based programming interfaces. This idea has been presented in a working prototype to the practitioners on several occasions, and we have received positive feedback.

Modular Interactive Stepping Tiles

In response to the needs of the therapies we developed balancing and stepping task tiles. The first version was developed in 2012 as an industrial design major project by Rebecca Hall, which resulted in a prototype that was tested in the rehabilitation ward of a public hospital in Sydney. This work was inspired by the exercise mat developed by the second author and colleagues at Neuroscience Research Australia [13, 14, 16], a design adapted from the DDR (Dance Dance Revolution) game paradigm. With this sensor mat, elderly or less mobile people can practice balancing and stepping tasks in their own home. In the earlier phase of our project we have looked into using game controllers for input with patients, but found the customisability too limited while we needed more freedom to design appropriate tangible interfaces [4]. Others have designed new games for rehabilitation purposes, from quite

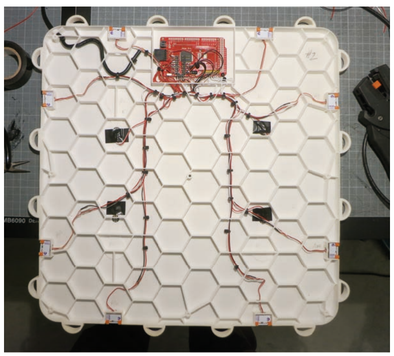

Figure 5: The 3D printed structure of the main tile with the wiring, sensors and interface.hardware

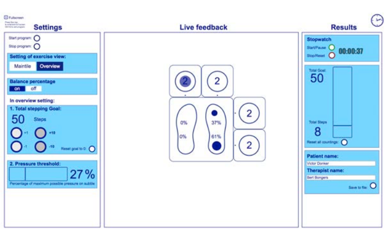

Figure 6: A screen shot of the visual interface and feedback.

straightforward feedback [10], colourful patterns [7], to programming 3D environments [8], however we focused on multimodal feedback to enhance the therapies which enabled us to find the optimal mappings between the patient's actions and the system's responses. Our sensor floor tiles are fabricated using instant manufacturing techniques. They are 20mm high to meet an important requirement for the exercises, to make it easy to step on – other products such as the entertainment robotics tiles [15] are thicker and the Wii balance board is over 50mm high. The floor consists of a main tile of 40x40cm, on which the user can place both their feet, measuring the pressure at four points under the feet, for balancing exercises. Smaller 'sub'-tiles (20x20cm) with one sensor each can be attached to the main tile on all four sides, so that stepping tasks can be carried out. Our design process was very much driven by the practitioners, who also suggested not to have visual feedback in the tiles as the patients need to not look at their feet during exercises. They asked for a surface with pressure points rather than a balance surface (such as the Wii). Between the layers of the structure an FSR (Force Sensing Resistor) is placed under a layer of foam (3mm EVA closed cell) to disperse the force of the feet. This gives a continuous electrical signal proportional to the weight applied, converted by a microcontroller circuit into digital signals. The signals travel between the tiles using the littleBit magnetic and spring-loaded contacts [2]. The tiles are connected via USB to a computer, which then provides visual feedback. The bottom of the tiles is covered with a thin layer of neoprene rubber to prevent sliding.

Early in 2013 a medical research group who are studying balancing exercises and falls prevention in Sydney [15] commissioned the development of two more sets, enabling us to further develop the design. Improvements were made to the electrical connections and the mechanical linking of the tiles, and we made all the tiles pressure sensitive (some were switches in the earlier model). The main improvement however was to address the reproducibility by applying 3D printing techniques (the first version was made using a computer controlled milling machine, which is cheap but not suitable for larger numbers). The structure is shown in Figure 5. A 'bridging' tile was developed, not containing any sensors but acting as a bridge to extend the range of the stepping task. We developed a way of sensing where the tiles are attached and what type they are (sensing or bridging) so that the on-screen layout changes dynamically in response to the actual placements of the tiles. The main tile contains a Sparkfun Arduino MegaPro which links to the host computer via USB.

Graphical interface

A graphical interface for visual feedback, information presentation and control was developed by the third author, as shown in Figure 6. The interface was created in Max/MSP/Jitter, which was already used to read and process the signals from the tiles. This system allows the therapist to control a number of parameters and settings to configure different types of exercises, using a touch screen or a mouse. The screen shows the tiles that are connected, and displays their pressure values through the size of a circle and for the main tile also in percentages (for balancing exercises). The sub-tiles show a numerical value representing the number of steps taken by the patient. On the right hand side the overall stepping count is displayed, as well as the goal to be reached. The patient's and therapist's ID are put in a field, for logging purposes. A stopwatch section of the screen allows the therapist to time activities. The left hand side of the screen is for setting the task parameters, such as number of steps and thresholds. The modular sensor floor system is currently in frequent use in a Sydney hospital (shown in Figure 7), and in the Adelaide repatriation hospital (shown in Figure 8) where a comparative test is being carried out (across various similar systems). Preliminary results and experiences are presented elsewhere [6].

Design Process

One of the key elements of our ideas for a range of products is the customisability through individual manufacturing (this is increasingly possible using 3D printing on demand schemes). While 3D printing is relatively expensive, we needed to use this technique in order to explore the flexibility and freedom of form, so that we could create customised products for the patients. There is a strong trend of 3D printing gradually becoming more affordable. The costs of such manufacturing are largely dependent on the amount of material used, so we designed the 3D printed part to be as light as possible yet strong enough to bear the load of a person standing on it. This was achieved by designing a honeycomb structure, with 1mm wall thickness. The material printed is ABS or polyamide, and depending on the quality of the printing machine the density of the material can be over 90%. Torsional stiffness is obtained by layers of acrylic, which are laser cut. The amount of this acrylic material is not an issue in this process, as it is cheap and the price of the process depends mainly on the length and complexity of the path that is cut. All this was done using the machines of the design faculty, with the final 3D print structures provided by the higher quality machines of the Shapeways Company (the major printing on demand supplier of 3D prints).

Figure 8: The interactive floor tiles in use in the Adelaide hospital, for a stepping task exercise.

The tiles were developed iteratively, we made four different versions of the structure before we had the right balance between weight and strength. A finite elements analysis was performed on the computer model which confirmed the strength of the design. The torsional stiffness was important as it influenced the working of the sensor, finding the right balance. Every new version or part of the system was taken to the hospital for feedback and adjustments were made if necessary. The design took into account the situations of and knowledge from a wide range of stakeholders, such as therapists, patients, carers, medical researchers, people responsible for technical support and IT support, physiotherapists, and occupational therapists.

Discussion and Conclusion

The sensor tiles have been in continuous use in both hospitals, and a third set is in the Interactivation Studio for development and demonstration purposes. The material costs of each set (consisting of 1 main tiles, 4 sub-tiles, and two bridging tiles) is about 1100$, plus assembly costs. This puts the system competitively between the low end mass fabricated game controllers applied for this application domain (a couple of hundred dollars) and the purpose developed solutions which commonly cost 10-20k$. Several other hospitals have requested a set. The aim has been to design the tiles in such a way that they can be assembled with minimal manual labour. The current version still requires quite a bit of skilled work to assemble, including soldering all the connections, and some mechanical bits. The easiest way to resolve this is to make the tiles entirely stand-alone, and have them connect wirelessly to each other and/or the computer. Wireless technology however also requires a battery (the current version is powered from the host computer via the USB connection), and a

Figure 7: The interactive rehabilitation main tile in use for a balancing task.

charging system. We have developed all this in one system, assembled from off-the-shelf components, including induction charging which means the tiles can be charged without wires. It becomes possible to seal the tiles, for easier cleaning. The increase in costs of the parts is justified by the potential decrease in costs of assembly, with the added benefit of a wider range of possible lay-outs. Currently this is limited to eight sub-tiles, which is enough for a wide range of therapies and exercises but further possibilities such as creating a path to walk along, and perform gait analysis, which is often required in the wards.

The interactive infrastructure approach can leverage the possibilities of the individual modules. This infrastructure consists of a number of modules and objects, each with a specific purpose such as sensing (weight, movement etc.), displaying (presenting information to the patient and therapist / trainer), or acting as tokens. The modules can communicate with each other (mostly wirelessly), so that there is a continuous flow of movement information and relevant feedback across the modules of the system.

It was interesting and rewarding to see that the tiles are used so intensively, and for many unforeseen purposes such as a sensor surface for pushing against for patients who exercise on a tilting bed, patients with prostheses, exercises which involved balancing on a thick piece of foam on top of the tiles, etc. Some of these applications call for further extensions and modules. Several further extensions of the sensor tiles are under development, mostly prompted by experiences in the rehabilitation ward. For instance, due to the modular nature of the tiles, it is possible to put a subtile on a raised surface to create a more difficult stepping task. For this and similar activities it is useful to have an extension wire. The edges of the surfaces are a bit sharp, so we are experimenting with ways to create ramps out of acrylic or foam or 3D printed material. There are further developments in the software too that we have not yet tested in practice, such as a method of visually cueing the patient's desired movements through highlighting the tiles on the screen.

We have shown in our research that the tiles fulfil the need for increasing patient's *motivation*. Furthermore, we have a lot of anecdotal evidence that it is really successful with patients, for instance a very problematic patient did not seem to be able to move by himself (in a pushing up exercise on the tilting bed), until he received the visual feedback of the system. Furthermore we are working on sonic feedback to further support the exercises. Through this approach of modularity a large part of the demand for *customisability* can be addressed, and it can be further extended by fully applying the printing on demand model where the practitioners can order the right size of the tile (within limits).

Although several designs were developed (by the third author) for graphics to put on the tiles, in the end we decided to leave them blank which allows the use of stickers and whiteboard markers by the therapists supporting a wide range of uses. The system is very easy to set up and can potentially be used by the patient in their own room in the hospital or even at home, supporting the need for *independence*. The logging system keeps track of the patients exercise results, linked to his ID and time of exercise. This data can be shared in real time with a physiotherapist through the Internet, enabling the possibility for remote rehabilitation.

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