Modular robotics for playful physiotherapy

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Abstract— **We developed modular robotic tiles to be used for playful physiotherapy, which is supposed to motivate patients to engage in and perform physical rehabilitation exercises. We tested the modular robotic tiles for an extensive period of time (3 years) in daily use in a hospital rehabilitation unit e.g. for cardiac patients. Also, the tiles were tested for performing physical rehabilitation of stroke patients in their private home. In all pilot test cases qualitative feedback indicate that the patients find the playful use of modular robotic tiles engaging and motivating for them to perform the rehabilitation. Also, initial pilot test data suggest that some playful exercises on the tiles demand an average heart rate of 75% and 86% of the maximum heart rate.**

I. Introduction

PHYSICAL training and exercising can be desirable for a number of health reasons, e.g. for upholding a healthy lifestyle, for preventing future health problems, and for rehabilitating after health problems may have occurred. Hence, physical training and exercising is often promoted amongst children, adult and elderly, and amongst both healthy and sick people. Such promotion of performing physical exercises, e.g. for rehabilitation, may be helped on the way by understanding what motivates individuals to perform the physical activity.

The underlying hypothesis for the work presented here is that it may be possible to develop playful modular robotic devices that motivate to perform physical activities, and that such devices may be of benefit as a motivating tool for physiotherapeutic rehabilitation practices. By exploiting features from the field of modular robotics, it may be possible to easily reconfigure such a tool to suit individual patients and different patient groups, e.g. cardiac and stroke patients, if modules in an easy and flexible manner can be moved around and configured for different activities.

II. Modular Robotic Tiles

We developed a system composed of a number of modular robotic tiles which can attach to each other to form the overall system. The tiles are designed to be flexible and in a motivating way to provide immediate feedback based on the users' physical interaction with the tiles, following design principles for modular playware [1].

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Fig. 1. Modular robotic tiles used for playful physiotherapy.

Each modular robotic tile has a quadratic shape measuring 300mm*300mm*33mm – see Fig. 1. It is moulded in polyurethane. In the center, there is a circular dent of diameter 200mm which has a raised platform of diameter 63mm in the centre. The dent can contain the circular printed circuit board (PCB) and the electronic components mounted on the PCB. At the center of each of the four sides of the quadratic shape, there is a small tube of 16mm diameter through which infra-red (IR) signals can be emitted and received (from neighboring tiles). Small magnets are placed on each side of the tiles. The magnets on the back provide opportunity for a tile to be mounted on a magnetic surface (e.g. wall), and the magnets on the sides provide opportunities for the tiles to attach to each other. The magnets ensure that when two tiles are put together they will become aligned by the magnetic forces, which is important for ensuring that the tubes on the two tiles for IR communication are aligned. On one side of the tile, there is also a small hole for a charging plug (used for connecting a battery charger and for reset).

There is a small groove on the top of the wall of the circular dent, so a circular cover of diameter 210mm can be mounted on top of the dent. The cover is made from a circular transparent satinice plate and a polyurethane circle in the centre.

A force sensitive resistor (FSR) is mounted as a sensor on the center of the raised platform underneath the circular cover. This allows analogue measurement on the force exerted on the top of the cover.

There are three NIMH AA batteries (rechargeable batteries) on top of the PCB. A 2 axis accelerometer (5G) is mounted, e.g. to detect horizontal or vertical placement of the

tile. Eight RGB light emitting diodes (LED SMD 1206) are mounted with equal spacing in between each other on a circle on the PCB, so they can light up underneath the transparent satinice circle.

On the PCB, there are connectors to mount an XBee radio communication add-on PCB, including the MaxStream XBee radio communication chip.

The modular robotic tiles can easily be set up on the floor or wall within one minute. The modular robotic tiles can simply attach to each other with magnets, and there are no wires. The modular robotic tiles can register whether they are placed horizontally or vertically, and by them-selves make the software games behave accordingly.

Also, the modular robotic tiles can be put together in groups, and the groups of tiles may communicate with each other wireless (radio). For instance, a game may be running distributed on a group of tiles on the floor and a group of tiles on the wall, demanding the user to interact physically with both the floor and the wall.

I. Play and Motivation

The modular robotic tiles for rehabilitation are designed to motivate patients to perform specific physical actions. Specifically, the goal is for the patients to become motivated to perform the actions needed for the recovery of their abilities. Often, rehabilitation is tedious and monotonous, which may be the case both for physical rehabilitation and also for general fitness training. With the modular robotic tiles, we try to create rehabilitation training which is interesting and fun, since the interaction becomes like a play where people forget that they are doing exercises and find the activity fun, challenging and playful.

The playful aspect is indeed important. The modular robotic tiles are part of what is termed playware, i.e. intelligent hardware and software that produces play and playful experiences [2]. By allowing the playware equipment (such as the modular robotic tiles) to respond in an appropriate manner to the patients' physical movements, the equipment is creating playful experiences for the patient, and the play motivates people to perform and forget the surrounding environment, e.g. a hospital setting. In a sense, we are taking play one level further, from the predominant view of play as a children's activity to activity for adult, and we use the qualities of play that to motivate.

Related to the role of play, Vygotsky in the early 1930'ies expressed: "Play creates a zone of proximal development in the child. In play, the child always behaves beyond his average age, above his daily behavior; in play it is as though he were a head taller than himself." [3] Vygotsky defines the zone of proximal development as "The distance between the actual developmental level as determined by independent problem solving and the potential development as determined through problem solving under adult guidance or in collaboration with more capable peers." [3]

In a similar way, I suggest that it is possible to allow the modular robotic tiles to create a zone of proximal development for the physical rehabilitation of the adult patients, and the play may allow them to perform beyond their average level of rehabilitation, above their daily behaviour.

The therapist can set levels of the games in the tiles for the different patients or patient groups, so that the patients are challenged in their zone of proximal development for their physical rehabilitation, and the patients work in collaboration or competition with other patients in a patient group (i.e. in the therapist provides "adult guidance" and the other patients may be the "more capable peers" in Vygotsky's terms in his definition of the zone of proximal development). Also, playware tool may by itself adapt to the appropriate level for the individual users to automatically create an adaptive zone of proximal development (see Discussion).

An important aspect of the modular robotic tiles, as with other playware, is that they can provide immediate feedback on the patient's actions, and this may contribute to motivate the patient to perform the actions in the right manner. This is indeed one of the reason to use inspiration from robotics to create this kind of playware rehabilitation equipment, namely that robotics provide the technological insight to how to best create a physical system that respond appropriately with immediate response to the user's interaction with the system. (Here, I define a robot as a *programmable* machine that by its *interaction* with its surroundings *autonomously* can perform a *variety* of tasks. The behaviour of a robot can be distinguished from that of a computer program by the interaction with the physical environment by sensors and actuators. *Sensors* allow the robot to sense the environment while *actuators* allow the robot to manipulate with the environment.)

It becomes important to make sure that the immediate feedback is incorporated into a playful experience that also makes the long term use of the equipment interesting, fun and challenging for the patient. Here, the creation of playful rehabilitation games is important, i.e. the different games, the levels, the individual or social use, and so on, and only extensive scientific studies with large test populations can provide us with definite understanding of how to best design the playful rehabilitation games. Nevertheless, we suggest that there is potential in combining modularity, robotics and play. Modularity provides easy set-up, customization and reconfiguration. Robotics provides immediate response on the patient's actions. Play provides motivation to perform physical actions. Combined we achieve a system with such qualities, and we have tested the system in hospital, rehabilitation centre and private home environments, and for cardiac and stroke patient's physical rehabilitation, as described briefly below.

II. Games for rehabilitation

We developed a number of games for the modular robotic tiles to be used for physiotherapeutic rehabilitation of cardiac patients who have undergone surgery and need to perform

rehabilitation (typically to some pulse level which may increase over the patient's recovery period). The games include Color race, Lunges, Stepper, and Disco. In "Color race", it is possible to choose number of participants (1-6). According to the number of players, that number of colors will show up at random locations on the structure. For instance, if three players are selected, there will be one tile lighting up in red, one tile lighting up in blue, and one tile lighting up in yellow. When one of the tiles with a color is pressed, the color will be turned off on the tile and shown at another randomly selected tile. When a player has hit his/her color 20 times as the first of the players, then that color will be shown on all tiles. The game can be used as presented here with more patients at a time, or with only one patient who then competes with only one color on how long time it takes to hit it 20 times, or on how many he/she can hit within e.g. 2 minutes.

Hence, the users will select number of participants and duration of games, and then chase one color each. The user who hits most tiles with his/her color within the selected duration of a game will win the game, indicated by his/her color lighting up on all tiles for 10 seconds, before a new game starts again. Users compete at same time on the tiles and have to navigate around each other to catch the colors. For instance, if the tiles are put as a structure on the floor, the patients will be walking, running or jumping around on the tiles to hit the ones with their individual color with the feet. If the tiles are put as a structure on a wall, the users will be moving around to hit the tiles with their hands.

In the game "Floor and Wall", the user builds two structures ("floor"-structure and "wall"-structure) that are physically separated (e.g. they are in two different rooms, or one structure is on the floor and one structure is on a wall). The game is similar to the Color race game, so that colors appear on tiles either in the "floor"-structure or tiles in the "wall"-structure. The two structures communicate with each other by radio communication (XBee), and thereby colors can be send to randomly chosen tiles on either the "floor" structure or the "wall" structure.

In the "Disco" game, a tile light up in a random color when it is pressed. If no tile is pressed for 2 seconds, then all tiles will turn off. Hence, the user can move around and continuously press the tiles to make them change color (e.g. from red to blue to yellow to magenta to green to purple, etc.). The user may choose to play external music along with playing the game.

There are also one player games such as "Stepper". In Stepper, the system will investigate the physical structure built by the user and find the longest rectangle with 2 tiles on one side (i.e. 2*2, 2*3, 2*4, 2*5,…). It will indicate by color on the first two that the user should place him/herself with a foot on each of these two. On the two tiles furthest away, light will show in colors depending on the speed with which the user steps on the two tiles where he/she is positioned. The indicator tiles will show up in yellow, green and red in this order based on the speed on the stepping. The game can be performed between two patients where radio communication between two clusters of tiles is used to indicate who of the two patients is leading in the competitive game.

Figure 2. Left: easy set-up by physiotherapist. Right: Wall and floor game.

In the "Lunges" game, the user has to reach out and touch the tiles that light up. The tiles light up in a color that may indicate that the user should use the left or right leg/arm to reach out and touch that tile. The user can also select if the touch to activate the tiles should be light, middle or hard (which is measured by the analogue FSR sensor). This may, for instance, allow physiotherapists and fitness trainers to select level for specific users. The "Lunges" game can, for instance, be used for balance training.

Also, we created numerous other games e.g. for ball games and cognitive memory games.

III. Cardiac and Stroke Patients

We performed a set of pilot experiments at the Funen Hospital in Svendborg, Denmark during 2006-2009, in which period the tiles have been in normal use as part of the rehabilitation equipment for cardiac patients. In one study in 2006, 20 cardiac patients between 50 and 80 years of age used the tiles for three months as a major part of their rehabilitation [4]. The therapists and patients were interviewed about their use of the tiles, and we provide some qualitative results from the pilot study here.

Development physiotherapist Tonny Jaeger Pedersen expressed that

> "It unites play with meaningful rehabilitation and at the same time makes it possible for the therapist to, in a larger extend, direct the rehabilitation towards the individual patients", and that "when patients enter the tiles, something happens in their facial expressions; then it is fun. The physical contact with the other patients on the tiles creates a lively atmosphere in the gym. Furthermore, it is much more motivating to do the exercises with a competitive aspect. Several of our

patients are former athletes and it has been very giving to be able to use the tiles as a rehabilitation tool".

The tiles were used in the rehabilitation gym of the hospital along with traditional equipment such as an exercise bike and a treadmill, and physiotherapist Pedersen concludes that

> "it is much more fun to exercise on the tiles. Patients forget the physical work when the lights flash and the game is on",

and as one patient stated:

> "When doing rehabilitation not everything is as much fun. Then it is nice to have a little competition. When having gone through a heart attack it is not always desired to go down to the gym and exercise. There has to be something to "spice it up", and I think that the tiles makes this possible".

Quantitatively, the study showed that as well Color race on the floor as Stepper demands a high proportion of the maximum heart rate. Both are very requiring and training for fitness and endurance as Color race on the floor demands an average heart rate on 75% of the maximum heart rate[1] and stepper demands a total of 86% of the maximum heart rate, according to this test.

In a second test, three physiotherapist students used 15 tiles for home rehabilitation of stroke patients (apoplexy patients) with the same exercise games as described above (especially Color race and Lunges). They would go with a box of tiles to the private home, set up the tiles e.g. in the living room within one minute, and then the patient would start doing the exercise games on the tiles for approximately 30 minutes. The study was limited to two patients, and both these citizens exercised on the modular robotic tiles for ½ an hour twice a week during two weeks. This physical exercise took place alongside a municipal rehabilitation programme, which the respondents participated in as well.

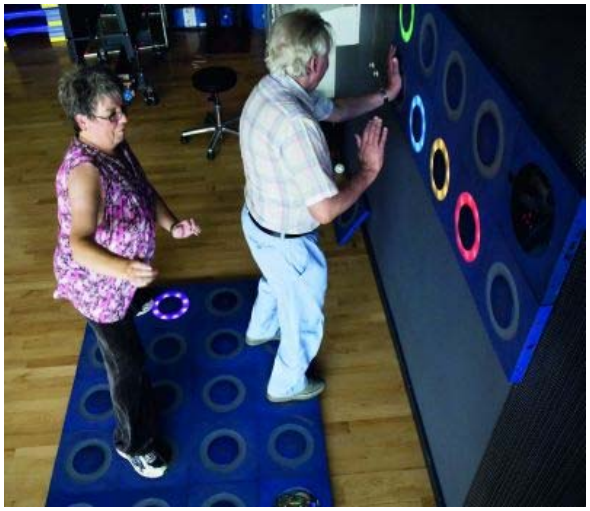

Figure 3. Two cardiac patients from Funen Hospital playing and competing against each other as part of their rehabilitation program.

[1] Estimated maximum heart rate, meaning. 220 – age.

The pilot study showed, according to the conclusions [5], that

> "Both respondents perceived the modular robotic tiles as exciting. They mentioned that it was fun to try something new and different. The element of competition when using the tile gave them a sense of challenge. Using the competitive element, they were able to compete against themselves and others. Likewise, they both experienced that the exercise benefitted them in their everyday life as it improved their balance. The respondents could imagine themselves using the tile beyond the time of intervention. Furthermore, they could imagine themselves using the tile in their own homes, but also as a part of the municipal rehabilitation programme.
>
> The observations during the intervention manifested these statements. Both respondents seemed motivated while doing their exercises, they were focused, eager and they kept a high level of intensity during the entire process.
>
> The respondents both found positive challenge when it came to their balance, coordination and circulation. Likewise, respondent B experienced that exercising on the intelligent tile had challenged his muscular system in both under-extremities. Moreover, respondent B stated that the tiles brought some cognitive challenges, as it required use of his ability to concentrate. Observations of sweat, cheek colour and an enhanced respiration confirmed the respondents' statements. Also, a progress in movement patterns on the tile was observed, e.g. the ability to use longer steps, stepping backwards and sideways during the games." [5]

It must be underlined that the above-mentioned improvements in the respondents' physical ability cannot solely be related to the exercise on the intelligent exercise tile, but can as well represent a natural part of the pathological picture and the exercise in the municipal context.

IV. Discussion and Future work

The qualitative statements from therapists and patients in the pilot studies with modular robotic tiles for physiotherapeutic rehabilitation suggest that there is a good potential for obtaining interesting results from making proper clinical tests. Such clinical tests are a necessary next step to obtain further qualitative evidence and especially quantitative evidence of a potential effect from using the modular robotic tiles with different patient groups. Here, it was only possible to report the indications from the pilot tests, which however indicate that the playful aspect of the modular robotic tiles, at least in some cases, may provide motivation to perform physical activities. Further, it was evident that the modularity provided flexibility and easy set-up for the therapists e.g. to set-up this kind of rehabilitation equipment in new environments (e.g. private homes) within one minute.

As an interesting point for future development, the work

makes a novel interpretation of Vygotsky's work speculating that it can be applied to other human development than the cognitive development, namely for the physical development of human beings. This may potentially influence also other fields of human activity, such as playgrounds, sports, fitness training, teaching, music, etc. where a similar approach with the use of playware may provide intelligent equipment that motivates people to perform specific actions. When applied to playgrounds (in order to create physical activity amongst youngsters as a response to the obesity threat), we have even seen that the modular robotic tiles allow the equipment to automatically recognize the human behaviour (with an artificial neural network) and change its behaviour dependent on the human behaviour, e.g. in the most simple case if the playware equipment recognizes that it is a heavy, slow person, then the physical game may run somewhat slower, and if the playware equipment recognizes that it is a lightweight, fast person, then it will run somewhat faster. Also, it may adjust the distance that the human being has to run to perform the game. In individual use, this can happen run-time, so the playware equipment changes itself as the user is using it, adapting itself to the user's level.

And hence, we may develop playware equipment that by itself in an automatic, dynamic way makes the appropriate zone of proximal development for the individual human being. It may adjust itself to become interesting, challenging, and motivating for the individual user, if it can give the right playful challenge for that particular individual.

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