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Modularity for Modulating Exercises and Levels – Observations from Cardiac, Stroke, and COLD Patients Therapy

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Abstract - The modular interactive tiles aim at engaging anybody (elderly, carer, hospital personnel, children) in performing playful and motivating physical activities. Inspired by modular robotics, each tile is a self-contained module with processing power and communication to neighbouring modules, and a number of these can be put together in any physical shape by the user within a minute. The tiles light up in different colors and can perceive the pressure when people press them with their hands or jump on them with their feet. Numerous games (exercises) are running on the tiles, and these games aim at providing high motivation for people to engage physically with the tiles. Therapists may use the tiles to provide treatment for a large number of patients who receive hospital, municipality or home care, although the tiles can as well be used for prevention with elderly or for fitness with normal people. In this paper, we investigate the therapeutic use. We show how the tiles are tested extensively with cardiac patients, COLD patients and stroke patients in hospitals and in the private homes of patients and elderly. We find that therapists are using the modular aspect of the tiles for personalized training of a vast variety of elderly patients modulating exercises and difficulty levels.

Keywords - Modularity, rehabilitation, playware, entertainment.

1. Introduction

We developed the modular interactive tiles with inspiration from modern artificial intelligence (e.g. [1]) and modular robotics in order to explore flexibility in activity creation for end-users. The aim is to allow the end-user (e.g. a therapist or a doctor) to utilize her professional knowledge to adjust the technology in a fast and easy manner, for instance to the physical capability, mental capability, treatment level, fatigue level, and so forth of a particular patient.

Hence, in contrast to most modular robotics research, here we do not focus on *self-reconfiguration* (e.g. self-reconfigurable modular robotics such as [2-7]) but instead focus on *user-configuration* (e.g. [8-16]) of modular technology utilizing inspiration and knowledge gained from the development of modular robotics. It is our hypothesis that the inspiration from modular robotics may lead to a highly *flexible* and *easily adjustable* system for the end-user.

In modular robotics, each module has a physical expression and is able to process and communicate with its surrounding environment. The communication with the surrounding environment is through communication to neighbouring robotic modules and/or through sensing or actuation. A modular robot is constructed from many robotic modules.

The approach inherits the behaviour-based robotics methods [17] and exploits it with the belief that behaviour-based systems can include not only the coordination of primitive behaviours in terms of control units, but also include coordination of primitive behaviours in terms of physical control units. We, therefore, imagine a physical module being a primitive behaviour. Thereby, the physical organisation of primitive behaviours will (together with the interaction with the environment) decide the overall behaviour of the system. Hence, in a similar way to the control of robot behaviours by the coordination of primitive behaviours, we can imagine the overall behaviour of a (robotic/interactive) artefact to emerge from the coordination of a number of physical (robotic/interactive) modules that each represents a primitive behaviour. In user-configurable modular robotics, it is the user who makes the coordination of the physical modules, e.g. by physically arranging the modules.

2. Modular Interactive Tiles

The system of modular interactive tiles is a distributed system where the modules 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 gaming interaction, following design principles for modular playware [10].

Fig. 1. Modular tiles used for feet or hand interaction.

Each modular interactive tile has a quadratic shape measuring 300mm*300mm*33mm – see Fig. 1. It is moulded in polyurethane. Inside, the printed circuit board (PCB) has the electronic components mounted, including an ATmega 1280 as the main processor in each tile. At the center of each of the four sides of the quadratic shape infra-red (IR) signals can be emitted and received (from neighboring tiles). On the back of a tile there are four small

magnets. The magnets on the back provide opportunity for a tile to be mounted on a magnetic surface (e.g. wall). Each side of a tile is made as a jigsaw puzzle pattern to provide opportunities for the tiles to attach to each other. The cover is made from transparent satinice.

A force sensitive resistor (FSR) is mounted as a sensor allowing analogue measurement on the force exerted on the top of the cover. On 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 so they can light up underneath the transparent satinice in a circle.

The modular interactive tiles are individually battery powered and rechargeable. There is a Li-Io polymer battery (rechargeable battery) on top of the PCB. A fully charged modular interactive tile can run continuously for approximately 30 hours and takes 3 hours to recharge – an important long battery life for the utilisation in rural areas in developing countries. The battery status of each of the individual tiles can be seen when switching on each tile and is indicated by white lights. When all eight lights appear the battery is fully charged and when only one white light is lit, the tile needs to be recharged. This is done by turning of the tiles and plugging the intelligent charger into the DC plug next to the on/off switch to recharge each tile.

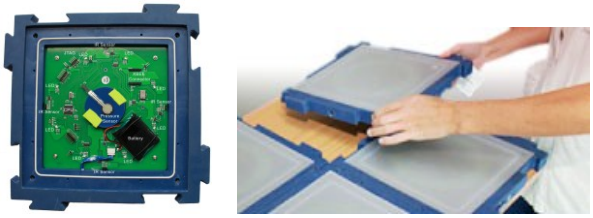


Fig. 2. Left: PCB and components of a modular interactive tile. Right: Assembly of the modular interactive tiles as a simple jigsaw puzzle.

On the PCB, there are connectors to mount an XBee radio communication add-on PCB, including the MaxStream XBee radio communication chip. Hence, there are two types of tiles, those with a radio communication chip (*master tiles*) and those without (*slave tiles*). The master tile may communicate with the game selector box (an RFID reader that reads RFID game cards) and initiates the games on the built platform. Every platform has to have at least one master tile if communication is needed e.g. to game selector box or a PC.

With these specifications, a system composed of modular interactive tiles is a fully distributed system, where each tile contains processing (ATmega 1280), own energy source (Li-Io polymer battery), sensors (FSR sensor and 2-axis accelerometer), effectors (8 colour LEDs), and communication (IR transceivers, and possibly XBee radio chip). In this respect, each tile is self-contained and can run autonomously. The overall behavior of the system composed of such individual tiles is however a result of the assembly and coordination of all the tiles. The modular interactive tiles can easily be set up on the floor or wall within one minute. The modular interactive tiles can simply attach to each other as a jigsaw puzzle, and there are no wires. The modular interactive tiles can register whether they are placed horizontally or vertically, and by themselves make the software games behave accordingly. Also, the modular interactive tiles can be put together in groups (i.e. tiles islands), 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. We developed numerous games for both physical and cognitive training. For documentation of patients' exercises and progress, it is possible to make radio connection between the tiles and a PC with a small radio (XBee) communication USB-key. The documentation software will show time and points on the PC monitor, and collect the data in a database. Hence, the patients can follow their points directly on the PC monitor, and the therapists/doctors can collect and view the data for each patient.

3. Experiments

The modular interactive tiles have been tested as playful physiotherapy, which is supposed to motivate patients to engage in and perform physical rehabilitation exercises, with special focus on elderly training. The modular interactive tiles were tested for an extensive period of time (5 years) in daily use in hospital rehabilitation units e.g. for cardiac patients [18]. Also, the tiles were tested for performing physical rehabilitation of stroke patients both in hospital, rehabilitation centres and in their private home. In the test cases qualitative feedback indicate that the patients find the playful use of modular interactive tiles engaging and motivating for them to perform the rehabilitation. Also, test data suggest that some playful exercises on the tiles demand an average heart rate of 75% and 86% of the maximum heart rate [18].

The modular interactive tiles have been used in the following places and periods:

Place	Period	Patient group	Estimated number of patients
Sygehus Fyn Hospital	2006-11	Cardiac	>200
Svendborg Municipality	2007	Home rehab	>10
Svendborg Municipality	2009-10	Stroke	>20
OUH Svendborg Hospital	2009-11	Stroke	>30
Ringe Neurorehabilitation center	2009-11	Stroke	>60
UH Hospital Kiel, Germany	2010-11	Bone marrow transplant	>20
Neema Rehab Unit, Tanzania	2009-11	Physiotherapy	>30
Odense Municipality	2007-08	Rehab	>30
OUH HCA Children's Hospital	2007-11	Children therapy	>100

There are many challenges to prevention and rehabilitation of elderly. For instance, fall incidence rates currently pose a serious health problem for older adults. Among those who are 65 or older, it has been estimated that 35 percent to 45 percent of otherwise healthy, community-dwelling adults fall at least once a year. The

modular interactive tiles games and exercises enforce activities that combine physical training with sensory tasks and cognitive tasks. Based upon scientific findings with relation to elderly training, some of the games are designed to promote unpredictable, sudden movements, and the games allow a gradual increase of difficulty. The gradual increase of difficulty is provided in a very easy manner to the therapists and the elderly users who can simply change the difficulty level by changing the physical structure of the tiles construction, e.g. a smaller platform of tiles often provides an easier level than a larger platform of tiles for the same exercise. An example is the "Color race" game, where patients have to chase 'their' color (i.e. one patient is red, another patient is blue, and so forth) which appear at random tiles. As soon as the patient hit a tile with the color on, then the color will turn off and appear on another tile, where the patient will move to hit the color. The game can be on time or on number of tiles hit (e.g. the patient who first hit 10 tiles with his/her color wins the game).

The tiles exercises address the challenges of elderly with relation to balancing, fall risk, muscle strength, reactivity, memory, attention, and concentration. There are numerous different exercises that each targets different challenges for the elderly and for specific patient groups, i.e. some exercises for cardiac patients, some exercises for stroke patients, some exercises for COLD patients, some exercises for private home rehabilitation, some exercises for brain training, etc.

For a specific patient group, the tiles exercises should be used in practices that match the individual aims of the therapist and patient. The tiles and exercises should allow set up in a flexible manner to target the individual patient needs and aims. Experiments with the therapeutic use of the modular tiles for stroke patients, COLD patients, cardiac patients and home rehabilitation patients is set up to try to verify if this is the case in the daily therapeutic practice, and the experiments are summarized below.

In 2009 we started a project with three departments of rehabilitation placed at three different hospitals in Denmark. The tiles have been part of these departments of rehabilitation from May 2009 and until now (March 2011). The new intelligent exercise-equipment is systematically used and assessed by therapists and patients connected to the three departments of rehabilitation. The purpose of this study was to investigate how the tiles work as a tool in these specific practices by gathering information about the users' opinions and experiences.

In this study we have been focusing on capturing both the patients' and the therapists' opinions and experiences. We have observed how the patients and therapists interact with each other and with the tiles in different training sessions. After each training session we have interviewed both the patients and the therapists and asked them questions in relating to an unstructured interview-guide and the just ended training session. We have collected data by video recording, taking notes, writing log books and by using a Dictaphone.

The target groups in this particular study have been physiotherapists and their patients who are cardiac, stroke and COLD patients. The tiles have been used for training individuals and groups of 3-4 patients with apoplexy or different heart diseases at the departments of rehabilitation at the three hospitals. The therapists have also used the exercise-tool for training groups of 9 patients at a time with chronic obstructive pulmonary disease (COLD) two times a week. For the study presented here, the exercise-equipment has been used by 9 therapists, of whom we have interviewed five.

4. Observations

We have investigated how the tiles have become part of the rehabilitation praxis by following the interaction between the physiotherapists and the patients during different training sessions. Through the analysis we have found some characteristic pattern of adjustments between the physiotherapists' knowledge, the patients' individual goals and the tiles. In this section we will start by introducing one empirical case where we describe a process of adjustments. This will lead us to an overview of the different exercises we have found.

An empirical case:

The physiotherapist Mette has organized a training session for her patient Marie who is a stroke patient. Marie has a high physical level but her balance and vision on the right side and her cognition has been reduced due to her illness. The purpose of this training session is to improve Marie's balance, her cognition and her field of vision. The tiles are according to Mette obvious to use in this case because this way Marie can train more than one of the three areas at the same time.

In the table below we have listed the different exercises in Marie's training program for this session (see Fig. 3).

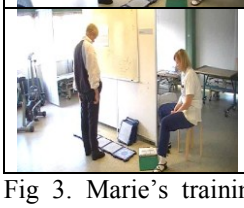
	**Exercise 1** *Game:* Colorrace - 2 minute. *Arrangement:* 8 tiles & formed as a "U". *Times:* 3 times. *Other items:* None.
	**Exercise 2** *Game:* Colorrace - 1 min. *Arrangement:* 9 tiles & formed as a "U". *Times:* 5 times. *Other items:* The blackboard.
	**Exercise 3** *Game:* Simon Says. *Arrangement:* 5 tiles & formed as a line. *Times:* 5 times. *Other items:* None.

Fig 3. Marie's training session with different physical arrangements of the modular tiles and different exercises.

In exercise 1, the 8 tiles have been organized as a "U" and the game "Colorrace - 1 minute" has been inserted. "Colorrace" is a game where the player has to step on the tiles that light up. Mette has chosen this exercise because it gives Marie the opportunity to work with both her balance

and her field of vision to the sides. First of all, by playing the game "Colorrace" Marie is forced to move her feet in a high tempo and when she is stepping on the tiles with her one foot she is balancing on the opposite leg. Secondly, because the tiles are arranged as a "U" Marie is forced to pay attention to the sides and not only in front of her.

The second exercise is based on Mette's evaluation of Marie's performance of exercise 1. During exercise 1, Mette observe how Marie's balance and field of vision has improved. Marie is e.g. not overlooking the lightning tiles to the sides as she did at the last training session. The result of the evaluation is that Marie needs to be challenged more. In exercise 2 the tiles are being adjusted to the improvement of Marie's physical development. Mette adjusts the tiles by adding one more tile to the arrangement. The expansion of the tiles forces Marie to work with her balance in a different way because she has to take more steps or have her legs more apart from each other than in exercise 1. To challenge Marie further, Mette introduces the element of counting. At first Mette is the one counting how many tiles Marie manage to step on for one minute and writing the result on the black board. But after a while, this task is put on Marie's shoulder. Adding counting to the exercise is a way of making Marie speed up the tempo because she wants to do better. This is also a way of training Marie's endurance and shared attention because she has to look at the tiles and step on them while she at the same time is counting. According to Mette, Marie is managing the tasks well.

The purpose of exercise 3, which is the last one in this session, is to slow the tempo down and let Marie train her memory. Mette adjusted the tiles to this goal by reducing the 9 tiles to 5 tiles and by exchanging the game "Colorrace" with the memory game "Simon Says". With the game "Simon Says" Marie is forced to slow her tempo down because she has to pay attention to the lightning pattern on the tiles and memorize where the lightning tiles are placed.

Here we have presented a case where we have described how the tiles became part of a training session because the physiotherapist could adjust them to her patient's individual needs. The way the tiles take part in different training session is through a specific adjustment to the patient's individual needs. During our investigation we have found many different combinations of exercises on the tiles.

In three tables, we document the different exercises with the tiles used by the therapists for stroke patients, cardiac patients and COLD patients (Fig. 4-6). For completeness, we include also the exercises from the home-rehabilitation project to make a more completely overview of the different exercises with the tiles (Fig. 7). The results are found by the therapists, and expressed in the interviews.

Game	Arrangement	Treatment Area	Time	Participants	Result
Colorrace Floor (2 min.)		Balance & field of vision	Two times (4 min.)	One patient	Obtained more awareness to the left and the right side.
Colorrace Floor (1 min.)		Divided attention & field of vision	Five times (5 min.)	One patient	Improved the patient's capability to focus on more elements at one time.
Colorrace Floor (1 min.)		Balance	Five times (5 min.)	One patient	Improved the patient's balance on the right leg.
Colorrace Floor (1 min.)		Balance	Five times (5 min.)	One patient	Improved the patient's balance on the left leg.
Colorrace Floor (1 min.)		Balance & endurance	Five times (5 min.)	One patient	Improved the patient's balance and endurance.
Colorrace Floor (1 min.)		Balance & cognition	Five times (5 min.)	One patient	Improved the patient's ability to act on and understand instructions.
Colorrace Floor (1 min.)		Balance, cognition, endurance & divided attention	Three times (3 min.)	One patient & the therapist	Improved the patients speed and endurance.
Colorrace Floor (1 min.)		Balance & cognition	Six times (6 min.)	One patient	Improved the patient's mobility.

Fig. 4. Exercises for patients recovering from thrombosis.

Game	Arrangement	Treatment Area	Time	Participants	Result
Stepper (1 min.)		Fitness & endurance	5 times (5 min.)	One patient	Improved the patient's mobility and condition.
Lunge (½ min.)		Balance, coordination & concentration	6 times (3 min.)	One patient	Improved the patient's reaction.
Colorrace Floor (2 min.)		Fitness, endurance & concentration	3 times (6 min.)	One patient	Improved the patient's physical level.
Colorrace Wall (1 min.)		Concentration, balance & coordination	4 times (4 min.)	One patient	Improved the patient's competences to balance when the body weight is placed differently.

Fig. 5. Exercises for patients recovering from cardiac attack.

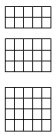
Game	Arrangement	Treatment Area	Time	Participants	Result
Colorrace Floor (2 min.)		Fitness, Condition, tempo & divided attention	From one to ten times. (2-20 min.)	Two or more patients. Or a combination of patients, relatives and the therapist.	Improved the patient's physical and mental condition because the patients are being physical active while they are having fun. This combination can make the patient forget about their fear for exercising due to their illness.

Fig. 6. Exercises for patients with chronic obstructive pulmonary disease (COLD).

Game	Arrangement	Treatment Area	Time	Participants	Result
Colorrace Floor (2 min.)		Endurance & balance	3 times (6 min.)	One patient	Improve the patient's balance and physical level in their own environment.
Colorrace Floor (1 min.)		Cognition & endurance	5 times (5 min.)	One patient	Improve the patient's mobility.

Fig. 7. Home-exercises for discharged patients.

Figure 8 shows an example of how the therapists used the tiles in training sessions where exercises on the tiles have been included in order for the patients and the therapist to reach their goal. As an exercise-equipment, the modular tiles are used by the therapists in training sessions in a combination with other exercises and equipment.

Game	Arrangement	Treatment Area	Time	Participants	Result
Colorrace Floor (1 min.)		Balance, cognition, endurance & divided attention	Five times (5 min.)	A patient who has a high physical level but damages on the cognition and balance due to a stroke.	Improved the patient's ability to act on and understand instructions. Speed and endurance
Colorrace Floor (2 min.)			Three times (6 min.)		
Step (1½ min.)		Fitness & balance	One time (1½ min.)		
Table tennis		Cognition	One time (5 min.)		
Walk the stairs (Down & Up)		Fitness	One time (6 min.)		

Fig. 8. A training session with focus on the patient's fitness, cognition and balance.

The list of exercises shows that the tiles are being adjusted to the patients' need when they are part of the rehabilitation praxis. The different parameters such as: the amount of tiles, the arrangement of the tiles, the games and the amount of time are parameters which the physiotherapist can fine-tune and thereby make them to some useful tools for their patients.

In interviews with the therapists, they also expressed the need for rearrangement and adjustment of exercise equipment to the individual stroke patients:

- "It is not more complicated to work with the tiles compared to other exercise-tools we use. We are used to re-arrange the set up all the time because we have to vary the exercises."
- "It is possible to adjust the tiles to the specific patient by re-arranging and shaping the tiles in different ways. This possibly is a necessity for the exercise-tool to be part of the equipment in the physiotherapy."
- "It is possible to work on more components, such as e.g. endurance, balance, view, memory and concentration, at the same time."
- "It is possible to evaluate the improvement on the patients' physical and mental level while they are interacting with the tiles."

Also, the interviews along with previous studies [18] suggest that most patients find exercising on the modular tiles motivational, since it is fun to compete against yourself and others.

5. Related Work and Discussion

There are many challenges to prevention and rehabilitation of elderly. For instance, fall incidence rates currently pose a serious health problem for older adults. Among those who are 65 or older, it has been estimated that 35 percent to 45 percent of otherwise healthy, community-dwelling adults fall at least once a year [19]. According to Dalleck, decreased balance is attributable to an age-related decline in multiple physiological systems that contributes to decreased muscle flexibility and strength, reduced central processing of sensory information, and slowed motor responses (American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopedic Surgeon Panel on Falls Prevention, 2001) [19]. In addition to an increased risk of falls, diminished balance and mobility may limit activities of daily living or participation in leisure-time activities. Accordingly, it is essential that balance exercises be incorporated into the physical activity programs of older adults.

Shigematsu, Okura et al. [20] made important findings with the square stepping exercises. Square stepping exercise is performed on a thin mat (100*250 cm) that is partitioned into 40 squares (25 cm each, compared to the 30cm of the tiles). Patients perform different walking exercises of gradually higher difficulty level on the squares, including corrective steps in certain directions, as indicated by the instructor/therapist. Indeed, there is a whole scheme of step patterns going from elementary levels over intermediate levels to advanced levels. In all cases, the instructor/therapist needs to instruct the patient(s) on how to perform these step patterns on the thin mat.

Shigematsu, Okura et al. made numerous larger studies with control groups to investigate the effect of such square stepping exercises. In one study, they had a group of elderly to perform the square stepping exercises and a control group of elderly to perform normal walking. The statistical tests showed that the functional fitness of the lower extremities (one of the most common risk factors for falls) was improved to a greater extent in the square stepping exercise group than in the walking group. Furthermore, the perceived health status was improved in the square stepping exercise group. Hence, they conclude that the study "provides new evidence that square stepping exercise is a more useful exercise program than regular walking for older adults; thus, it may serve as a new form of exercise to prevent falls" [20, p. 80-81].

This supports the therapeutic findings with the modular interactive tiles. As an important addition to the square stepping exercises, the tiles are by themselves lighting up in the pattern needed to be performed by the patient, and the tiles are providing immediate feedback to the patient on the correct/incorrect performance. Hence, the tiles are automatically instructing the patient and automatically giving feedback on the performance. This quality of the tiles is labour saving, it ensures correct movements, and it motivates patients. Further, the features of the modular interactive tiles allow for a combination of physical and cognitive training of elderly.

6. Conclusion

The observations of therapeutic practices with the modular interactive tiles for a variety of patient groups (cardiac patients, stroke patients and COLD patients) suggest that therapists do indeed take advantage of the flexibility that the modular system provides, as was the hypothesized reason for utilizing inspiration from modern artificial intelligence and modular robotics in the design of the system. The therapists create the activities for the patients modulating exercises and levels by changing the physical set-ups with the modular tiles system. This is indeed important in the daily therapeutic practice, which is characterized by the treatment of patients with many different, individual needs. A system should therefore provide flexibility to adjust to treatment area, activity, patient level, and patient fatigue. The observations of therapeutic use in this paper suggest that the modularity gained from the inspiration from modular robotics is one solution to provide such flexibility. At the same time, the modularity provides an ease of use, possibility of use anywhere, and robustness through distributed processing.

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