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Modular Robotic Tiles – Experiments for Children with Autism

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Abstract

We developed a modular robotic tile and a system composed of a number of these modular robotic tiles. A system composed of the modular robotic tiles engage the user in physical activities, e.g. in physiotherapy, sports, fitness, entertainment. The modular robotic tiles motivate to perform physical activities by providing immediate feedback based upon physical interaction with the system. With the modular robotic tiles, the user is able to make new physical set-ups within less than a minute. The tiles are applicable for different forms of physical activities (e.g. therapeutic rehabilitation) and at the same time give unique possibilities for documentation of the physical activity (e.g. therapeutic treatment). This kind of playware is highly motivating due to immediate feedback and fun, interesting games. The pilot study included here indicates that the modular robotic tiles may also be used by children with autism, and that the tiles can automatically recognise the children behaviours with very high accuracy by using an artificial neural network.

Introduction

Processing in electronic artifacts is traditionally based on central control. This is the case in VCRs, televisions, mobile phones, industrial robots, toy robots, etc. In such cases, the device is controlled by an electronic system with a central control. If just a small part of the central control breaks down, the whole system/device may break down. The modular robotic tiles challenge the traditional central control, and allow processing to be distributed among a number of processing units that can connect together to form a larger, collective system. The individual unit is self-contained, including processing capabilities, communication capabilities and batteries. The system comprising a number of such units allows the end-user to define the physical shape and the functionality of the artifact and to interact with the artifact.

By enumeration of neighbors, the individual unit is able to communicate with other specified units in the system. The detection of neighbors and the overall structure can be done automatically by the system itself at run-time, which facilitates easy modification of the physical form by any user.

User interaction and capabilities of constructing electronic artifacts are enhanced by particular processing methods. The modular robotic tiles allow construction of both the physical shape and functionality through the physical construction with no necessary need for a personal computer or similar, external programming station or monitor.

We can make the tiles into *playware*[5] by making games to run as software on the system composed of modular robotic tiles. Games can adjust themselves to fit any physical configuration made by the user. Each game can be adjusted to fit particular user groups and levels, such as individual therapeutic patients, fitness trainees, etc.

The modular robotic tiles differ from other interactive surfaces and game surfaces in the modularity, the possibility for users to modify the physical shape, the easy setup, the possibility of exclusion of external host computer, the self-contained energy source, the wireless communication (local and global), and the individual games.

Figure 1. One of the children with autism playing with the modular robotic tiles.

For instance, we have used the modular robotic tiles for rehabilitation of cardiac patients (at the hospital Sygehus Fyn Svendborg and at Rehabilitation Centre Odense). For cardiac patients, the games on the tiles may motivate a

rise in pulse to appropriate levels. Physiotherapist Tonny Jaeger Pedersen, Sygehus Fyn Svendborg hospital says: "the individual training, which the intelligent tiles allow for, is really an advantage. Motivation and competition is the fuel which make us do the most – regardless of whether being healthy or a patient." [1, 2]. Other games may be used: for instance, for knee operated exercises that demand the correct movement of the knee and the correct force exerted to play the game, for elderly play and games that support balance training, etc.
However, here we will look at how the modular robotic tiles may be used for cognitive rehabilitation. We may imagine that cognitive tasks may be implemented on the modular robotic tiles and feedback (light & sound) given to the user based upon the user performance on the cognitive tasks. Games of different levels may challenge users with different cognitive capabilities, and the games may be easily adjustable to the different capabilities. This may, e.g., be exemplified by imitation games on the system of modular robotic tiles for autistic children. In order to introduce the modular robotic tiles in this field, we will start with a simple example of implementation.

Modular robotic tiles

The system is composed of a number of modular robotic tiles which can attach to each other to form the overall system. Each tile has a quadratic shape measuring 300mm*300mm*33mm – see Fig. 1 and Fig. 2. It is molded 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 blocks). 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.

Figure 2. The modular robotic tiles from Entertainment Robotics.

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 block. 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 themselves 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 blocks on the floor and a group of blocks on the wall, demanding the user to interact physically with both the floor and the wall.

Related work

Previously, we developed the robotic building block concept, e.g. exemplified with the I-BLOCKS for play in hospitals and developing countries [3, 4], and interactive playware playgrounds [5]. The robotic building block concept for the playware playgrounds came from a longer design process started in 2001 and for the I-BLOCKS from the late 1990'ies. As an example, the neural I-BLOCKS [6] can be viewed as a modular entertainment system that allows anyone to create neural networks by physically building with the modular robotic building blocks, I-BLOCKS. This use of modular robotics for entertainment and learning with the I-BLOCKS is used in Africa for allowing non-expert users to become developers of novel intelligent robotics in schools, hospitals, orphanages and science parks.

The modular robotic approach was further elaborated in the playware playgrounds [5]. The intelligent playgrounds are developed as a set of modular robotic tiles that allows implementation of physical computer games on the playgrounds, which are now installed in numerous schools, kindergartens, and youth clubs in the city of Odense in Denmark. Some work shows how implementations with neural networks may allow the playground to recognize the children's behaviour on the playground and adapt the games at run-time to the individual child.

The modular robotic approach for entertainment is used here in this paper to allow the development of novel robotic therapy tiles not only for rehabilitation of cardiac patients, but also for autistic children in an entertaining way.

In general, the modular robotic approach to entertainment robots is investigating how the public can understand and use robotics by introducing robotics as entertainment and play in the daily life and environment of the people. This happens through the combination of modern artificial intelligence, modular robotics and entertainment to provide novel opportunities in play, rehabilitation, sport, music, teaching, third World development, etc. – it is believed that the approach may provide non-expert users easy access to the technology in a playful and motivating way.

Not many other systems for large scale physical manipulation are truly modular and distributed. An exception is the floating tiles prototypes by P. Marti's group [7]. Most other systems are either small in scale (e.g. hands-on constructionist robot building kits such as Topobo [8], System Blocks [9] and few other similar systems), not for end-user physical reconfiguration (e.g. z-tiles [10], smart-floor), or not truly modular with distributed processing.

Modular robotic tiles for children with autism

In general children with autism may have problems with social/emotional relationships, problems with communication, problems in surroundings consciousness, motor problems and they can have cognitive problems. Moreover many of the children also have other diagnoses such as ADHD (attention-deficit hyperactivity disorder). One of the aspects of these handicaps is that the children have serious problems with being creative and that they have problems playing on their own without guidance on how to play. However, our first pilot tests with the children showed a very interesting behaviour from the children. The observations done by the therapist from the autism home Bihuset told us that the children's behaviour with the tiles was very comparable to their normal behaviour in everyday life. Since the children's behaviour seems very much connected to their diagnosis, this gave us an indication of the possibility to use the tiles as a supplementary tool to support the therapists in diagnosing the children. So the research question becomes: can data collected from experiments with the modular robotic tiles be used to recognize specific behaviours or to categorize users? If so (i.e. if it is possible to recognize what problems the individual child has), it could even become possible to adapt the application to fit the child and thereby making the play more interesting.

Game implementation

For this experiment, we used a set of 15 tiles and the game called *colour-mix*. The basic idea is to mix colours in different ways, dependent on how the tiles are assembled. 3 tiles are predefined as source tiles respectively with the colors red, green and blue. The other 12 tiles are normal tiles, with the property that they can change their colours accordingly to their local neighbourhood. If a normal tile is connected to a red source tile, the normal tile will become red just as its neighbour but with a lower intensity. The source tiles never change their colour. If a blue source tile also is connected to the normal tile at the same time as a red source tile, the normal tile will blend the two colours to become a purple tile. A normal tile should always light up with a lower intensity than its neighbours colour intensity, which makes the colour spreading from a source tile decrease when the distance to a source tile increases.

For the colour-mix game, we used a distributed control approach, which is fairly straight-forward since every tile is equipped with both communication and computation capabilities. The tiles can be moved around and connected to each other in any configuration. In this distributed environment it is very easy to make local changes based on the local environment. A tile can easily read neighbouring tiles states, and thereby change its own state accordingly to some local rules. By not having a central server to administer the data flow between tiles, the stability of the application will not depend on the reachability of a master-tile. Simple rules based on the local environment are easily implemented and the software on the individual tile can be kept simple. Other advantages are that there is no need for instructions to the users on how to use/control a master-tile, and the possibility to extend the application by adding simple new rules to one or more of the tiles. Also, the distributed control facilitates the emergence of new behaviours, when different rules are influencing each other. It is not always possible to predict what can emerge from such a system. This could be a drawback to an application if it was critical to the behaviour of the whole system that the user always get what she expects. In a performance application emergence is actually an advantage, because it would create unexpected results from the users point of view, and thereby teasing her curiosity to continue using the application. A major drawback with this kind of distributed control is that there is no easy option to log events in the system. Hence, we added radio modules to the tiles to allow them to send logged data to a host computer, which was used exclusively for data collection.

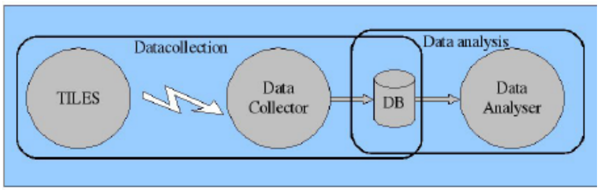

Figure 3. The data collection and data analysis scheme.

Experimental protocol

The experiments were performed at the institution 'Bihuset'. Bihuset is both a residential home for children with autism, and a home for relieving parents with children with autism, for a single day or two. The two different functions are placed at two different addresses. (Jørgen Haubroe Andreasen is the head therapist at the residential home, and Inga is the head therapist at the relieving center.) The first experiments were conducted at the residential home with two children named Nik and Ole. These two children performed very different with the tiles and it was very interesting, accordingly to the therapist Jørgen, that both of the children's normal behaviours was reflected directly in their use of the tiles. The rest of the experiments were carried out in the institution's relief centre. The main reason for this was the need for children who were suitable and present for the experiments. The children at the residential home are much more handicapped than the ones coming at the relieving centre, and therefore the children from the relieving center seemed more suitable for the initial experiments. Due to vacation among both the children and the staff, there were some difficulties in following the original experiment plan. The plan was adjusted, and we tried to make as many experiments as possible. Unfortunately it was not possible to make experiments with enough children to create statistical reliable results. Table 1 shows the test subjects (the name of each child has been changed to make them anonymous.)

Table 1. Children, diagnoses and number of tests performed.

Name	Diagnosis	Tests
Nik	Infantile	5
Anne	Infantile	3
Dan	Infantile	2
Zofus	Atypical	3
Josef	Atypical	2
Ole	Asperger Syndrome	3
Marck	Other development disorder	2

The following plan was carried out in each of the experiments.

- Duration of each experiment is 10 minutes.
- Each experiment is documented on video.
- A computer collects data from each experiment.
- When more than one experiment is performed with the same child, the environment must not change significantly.
- The children are very briefly presented to the tiles, and told to play with them for 10 minutes. They are told to do whatever they feel like.
- When the time has started the children can not get any help from the adults.
- The adults may only interfere with the experiment, if the child has lost the interest for the tiles completely. The only thing that is allowed for the adult is to ask the children to use the tiles again.
- When the 10 minutes has gone, the adult stops the child from playing and stops the video and the computer logging.

Data analysis

After all of the experiments were finished, the automatically collected data was analyzed offline. First a list of different criteria was found by watching the recorded videos. These criteria were created in such a way that each child would get a score for each criterion when analyzing the collected data. These analyses could then be used to differentiate the individual users from each other, by looking at the result from each criteria analysis. In the following only individuals will be examined, and not groups of individuals. If the number of users had been higher it also would have been possible to see if there was any data that could differentiate groups from each other. The children could have been grouped by cognitive level or other categories involving their handicap. The categories were:

1. Number of tiles used during the experiment
2. The number of clusters created by the user. A cluster is defined as 2 or more tiles assembled.
3. Number of pressed tiles.
4. Removing a tile and placing it at the exact same position immediately after.
5. Removing a tile and placing it at a new position immediately after.
6. The average cluster size.
7. After a complete assembly of all tiles in one cluster, the cluster is destroyed again. A cluster is only considered destroyed if 2 or more tiles are removed from it.
8. The cluster shapes in the clusters created by the users (line, rectangle, quadratic, advanced).
9. The speed by which the user assembles the tiles.
10. Average intensity of red, green and blue LEDs on tiles moved.
11. Average number of source tiles pr. cluster.

Some of the categories can be expanded, so that category number 2 becomes two categories (average and max number), number 8 becomes three categories (rectangle, quadratic, other) and number 10 becomes three categories (one for each colour), so there will be a total of 16 categories.
For each experiment, the score in these categories can be collected *automatically* during the play with the modular robotic tiles. The score for each category can be normalised and fed into a simple, feed-forward neural network (C1 … C16 in figure 4).

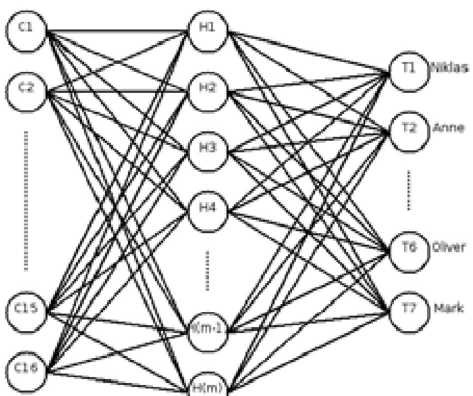

Figure 4. The neural network

We feed the data into the feedforward neural network in order to understand whether possible differences in the criteria scores can be used to recognize any specific behaviour pattern – by trying to recognize the individual child. By recognizing an individual during play it may become possible to adjust the activity on the tiles accordingly to this individual's needs.
Each experiment was divided into 4 phases to create more examples. The first phase from each experiment was removed from the examples as they are very different from the rest of the experiments phases. This gave a total of 3 examples per experiment and with a total of 20 experiments this is 60 examples in total.
The training set contained 3 experiments with Nik, 2 with Anne, 1 with Dan, 2 with Zofus, 1 with Josef, 2 with Ole and 1 experiment with Mark. This is a total of 36 examples, but only 35 where used since one of them contained nothing but 0 scores. The test set contained 2 experiments with Nik and 1 experiment with the rest of the children. This is a total of 24 examples, but only 23 where used for the same reason as above. Each example includes all 16 criteria scores as input and 7 output neurons to indicate each of the individuals. The neural network can be seen in figure 4.
The number of hidden neurons was selected to 9, since fewer showed a tendency to make the network converge to fast, and with more hidden neurons the network had problems converging.

Table 2. The neural network output (in bold) for each experiment.

Name	T1	T2	T3	T4	T5	T6	T7
Nik	**1,000**	0,000	0,000	0,000	0,001	0,000	0,000
Nik	0,006	0,000	0,001	0,001	0,000	**0,880**	0,000
Nik	**1,000**	0,000	0,001	0,000	0,002	0,000	0,000
Nik	**0,449**	0,000	0,025	0,000	0,000	0,017	0,000
Nik	**0,878**	0,000	0,476	0,000	0,000	0,025	0,000
Nik	**0,961**	0,000	0,132	0,000	0,000	0,002	0,000
Anne	0,000	**0,989**	0,003	0,000	0,004	0,000	0,235
Anne	0,004	**0,999**	0,010	0,000	0,002	0,000	0,000
Anne	**0,999**	0,000	0,000	0,000	0,005	0,000	0,000
Dan	0,001	0,002	**0,989**	0,000	0,006	0,000	0,000
Dan	0,001	0,002	**0,989**	0,000	0,006	0,000	0,000
Zofus	0,000	0,000	0,000	**0,997**	0,000	0,000	0,000
Zofus	0,000	0,000	0,000	**0,995**	0,000	0,000	0,000
Zofus	0,000	0,000	0,000	**0,991**	0,000	0,000	0,000
Josef	0,000	0,042	0,000	0,000	**0,495**	0,000	0,330
Josef	0,026	0,000	0,002	0,000	**0,947**	0,000	0,000
Josef	0,001	0,333	0,000	0,000	**0,689**	0,000	0,006
Ole	0,002	**0,873**	0,001	0,000	0,000	0,000	0,016
Ole	0,176	0,000	0,000	0,001	0,000	**0,431**	0,000
Ole	0,002	0,000	0,000	0,008	0,000	**0,999**	0,000
Marck	0,000	0,004	0,001	0,001	0,000	0,003	**1,000**
Marck	0,000	0,023	0,002	0,000	0,007	0,002	**0,985**
Marck	0,001	0,000	0,011	0,000	0,000	**0,651**	0,122

The results can be seen in table 2 which shows the value for each target neuron with the test set. The max value for each result is in bold. The expected result for Nik would be that the first output neuron should be the highest, for Anne it should be the second, for Dan the third etc. If all the classifications where correct we should see a diagonal of bold numbers.

It can be seen that the network makes a correct classification on 19 of 23 examples. This is 88% correct classification of the children. The examples that do not get correctly classified are all one example out of three from the same experiment, and the two remaining examples from that same experiment are correctly classified. So a post-processing into one result for each experiment would then give a 100% correct classification. It remains to question these results because of the very limited number of examples available. To create a statistical reliable result there should be many more examples in the test set.

Discussion and Conclusion

It is important to take these experiments for what they are and nothing more. We were able to perform a technological development and an initial pilot study. It was not possible for us, at this moment, to perform a complete scientific study with the autistic children as the user group, which means that we can make no statistical tests to verify the indications given above. It is important be aware of this fact. We were not able to perform large scale tests due to material constraints (we only produced one hundred tiles), time constraint and limited access to the user group.

Nevertheless, we find the *indications* interesting and worth further discussion, development and tests. The indications with the small test group are that whereas the children with autism may not make creative performances with the modular robotic tiles, they will however build and interact with the tiles in very individual, stereotypic manners. This may come as no surprise, but the interesting indication is that the novel technology may be able to *automatically* recognise this individual behaviour. Indeed, with post-processing, the artificial neural network used in this study was able to make a 100% correct classification of the 7 children with autism from the pilot study (and 88% correct without post-processing).

It will be very interesting to use these indications to investigate whether such modular robotic tiles or similar playware can be used as a supplementary tool in the diagnosis process for the children with autism. Typically, there are many tools used for the diagnosis, and the one presented here should be viewed only as a supplement to these other tools. However, if automatic recognition of the individual behaviour (the individual diagnosis) is possible also for larger test groups, then it may become an interesting tool to support and supplement the other diagnosis tools.

The pilot study also gives indication that this particular user group is able to interact with the modular robotic tiles. Therefore, we are initiating collaboration with J. Nadel's group at the hospital Hôpital de la Salpêtrière in Paris to study how to promote emotionally positive social interaction through physical action, specifically in imitative scenarios for children with autistic spectrum disorder, with large user groups and test groups.

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