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Modular playware as a playful diagnosis tool for autistic children

Henrik Hautop Lund

Abstract— **Based upon user-configurable modular robotics and design principles for modular playware, we developed modular robotic tiles to be used as playful, interactive tools for children with autism. The modular playware can make automatic documentation of the construction play activities by the autistic children. Using artificial neural networks for automatic classification of the individual construction practices, we may compare this classification with the diagnosis of the children, and possible obtain a supplementary diagnosis tool which is based on the autistic children's free play with the modular robotic tiles. Preliminary experiments with 7 autistic children show that the automatic neural network classification with post-processing can be done with a 100% accuracy for this small sample set, and thereby give some preliminary indications of the potential of the approach.**

I. Introduction

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). There is a wide spectrum of disorders, and making precise diagnoses of children with autism is a major, difficult task for both therapists and hospital staff. One of the aspects of the 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.

Nevertheless, we believe that under some circumstances with the right kind of interactive play tools in the form of playware, children with autism may actually be able to practice and enjoy construction play. As outside observers, we may view their constructive play activity as stereotypic, but at the same time it is evident that there are clear individual differences in the way the children confront and perform the construction play with playware. Playware is intelligent hardware and software that creates play and playful experiences amongst users of all ages [1]. A number of design principles have been outlined to create modular playware [2], amongst these the development of inclusive games, and it is our belief that we may create playful modular playware for children with autism following these design principles.

By allowing children with autism to engage in free play with playware, it may be possible to learn something about the children, for instance by observing how the individual child is constructing and interacting with modular playware. Indeed, we may envision that the intelligent hardware and software of playware may automatically register the individual modes of interaction, and automatically make classification of the individual modes of interaction.

In this paper, we will investigate such design, development and use of modular robotic tiles to allow for such an automatic classification (by using artificial neural networks) of the autistic children's play modes, and show that there may be a correspondence between the automatically documented play modes and the individual diagnosis, indicating that there may be room for development of supplementary diagnosis tools based upon autistic children's play.

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II. Related work

For some years, researchers have tried to develop different robotic systems for children with autism. For instance, Billard developed the Robota doll for imitating gestures by children [3], and Robins et al. tested this and other humanoid doll robots with autistic children [4]. Nadel et al. tested robotic systems at Hospetal de la Salpetriere, Paris in extensive use by autistic children for positive emotional responses, e.g. in imitation, synchrony and turn-taking interactions [5], Kozima developed the Keepon robot for the study of autistic children's rhythmic imitation and response to simple, stereotypic expressions [6], Brezeal and Picard's groups are developing a mobile robot for social interaction with autistic children [7], and Shibata developed the Paro robot [8], which was used also for children with autism. Marti et al. [9, 10] made an interesting study of the use and adoption of a modular robotic system as a tool for autistic children's entertainment and therapy. Scassellati speculated and provided preliminary data also on the use of social robots in diagnosis [11].

In most of the cases mentioned above, the robots were instantiations of either mobile robotic "cars" or anthropomorphic robots in the shape of dolls or teddy bears (e.g. baby seal robot), i.e. toys that are normally used in pretend play.

In the same way as one may naturally question why pretend play should be especially adapt for autistic children, one may naturally question the possibility for autistic children to engage in construction play, for instance with robotic systems. In the same way as the above-mentioned work present indications of the autistic children's interaction with systems that are usually intended for pretend play, we may speculate that other kinds of play may be facilitated with intelligent "playware". To the best of our knowledge, there is little existing research on autistic children's possibilities for engaging in construction play with modern playware (e.g. playful robotic systems), the only exception being the work from Marti's research group on active surfaces for aquatherapy [9, 10], and some of our general work on construction play with modular robotic devices for children with different abilities [12].

Nevertheless, the regardless of the playful value that the children may attribute to the activity, it remains an interesting factor whether such playful interaction with robotic systems in a novel way may be the basis for an automatic diagnosis tool.

I. Modular Robotic Tiles

The design principles for modular playware build upon the development of modular robotics to create a kind of playware, which is flexible in both set-up and activity building for the end-user to allow easy creation of games. Key features of this design approach are modularity, flexibility, and construction, immediate feedback to stimulate engagement, activity design by end-users, and creative exploration of play activities. It has been argued that these features permit the use of such modular playware by a vast array of users, including disabled children who often could be prevented from using and taking benefits from modern technologies [2].

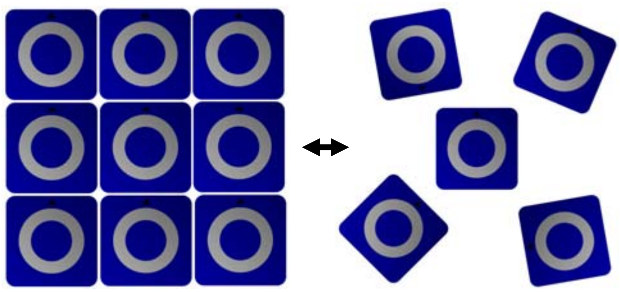

Fig. 1. According to the design principles for modular playware, the modular robotic tiles are made to be easy for any user to assemble and disassemble.

Therefore, according to these design principles, we developed a system composed of a number of modular robotic tiles which can attach to each other to form the overall system. Each modular robotic tile has a quadratic shape measuring 300mm*300mm*33mm – see Fig. 1 and Fig. 2. 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 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.

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 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 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.

II. Play Design

As a result of the design, many different motivating play activities may easily be set up for children (and adult) e.g. for sensorimotor play such as colour race, stepper games, reaching games, dancing games, and more cognitive sensorimotor games such as Memory and Simon says.

Therefore, the design approach also allowed us to quickly design the modular robotic tiles to be used for playful cognitive construction games (see fig. 1, right). We used a set of 15 tiles and the construction 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 colours 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.

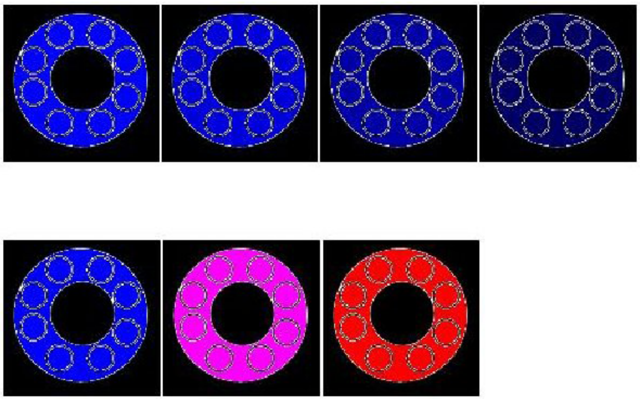

Fig. Xx. The colour mix application where colours are flooding from source tiles to normal tiles, dependent on how the children put the tiles together.

For the colour-mix construction game, we used a distributed control approach, which is fairly straight-forward since every modular robotic 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 e.g. a master-tile or a host computer. 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 e.g. 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, and this is in the hands of the end-users construction.

III. EXPERIMENTAL SETUP

We performed a set of experiments with the modular robotic tiles colour mix play at the institution 'Bihuset' in Denmark. Bihuset is both a residential home for children with autism, and a home for relieving parents with children with autism. 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

Fig. 2. One of the autistic children playing with the modular robotic tiles.

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.

IV. Data analysis

The automatically collected data from the experiments can be fed into a simple, feedforward neural network. The input takes the form of 16 input nodes where each node represents an automatically collected normalised value of categories:

1. Number of tiles used during the experiment
2. Average number of clusters (2 or more tiles assembled) created by the user.
3. Maximum number of clusters (2 or more tiles assembled) created by the user.
4. Number of pressed tiles.
5. Removing a tile and placing it at the exact same position immediately after.
6. Removing a tile and placing it at a new position immediately after.
7. The average cluster size.
8. 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.
9. The cluster shapes in the clusters created by the users: rectangle
10. The cluster shapes in the clusters created by the users: quadratic
11. The cluster shapes in the clusters created by the users: advanced
12. The speed by which the user assembles the tiles.
13. Average intensity of red LEDs on tiles moved.
14. Average intensity of green LEDs on tiles moved.
15. Average intensity of blue LEDs on tiles moved.
16. Average number of source tiles pr. cluster.

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 Fig. 3).

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. (In future, 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 Fig. 3.

The number of hidden neurons was selected to 9, since fewer showed a tendency to make the network converge too fast, and with more hidden neurons the network had problems converging.

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.

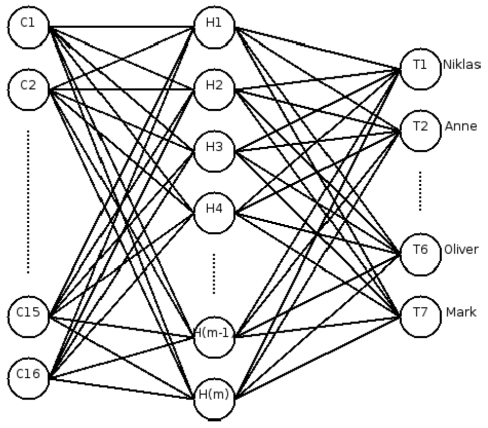

Fig. 3. The neural network

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 gives a 100% correct classification. It remains, however, 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.

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

V. Discussion and Conclusion

The design of modular playware in the form of the modular robotic tiles with the colour mix play application allowed the autistic children to participate in construction play. In the limited test sample, it was clear that the autistic children performed their individual, stereotypic construction play in a manner which was recognizable by a simple, feedforward neural network implemented in the playware tool. Anecdotally, it was found that the cases which were most difficult for the neural network to classify corresponded to the cases, in which the therapist used the longest time (years) to make the correct, precise diagnosis. In general, the therapists viewed the modular robotic tiles as a potential supplementary tool for diagnosis. Indeed, in evaluating the experiments, the head therapist Jørgen Haubroe Andreasen states that "apparently, autistic children "play" or use the robotic tiles in a specific way dependent on the degree of handicap and diagnosis. This is indeed remarkable, and it will rightfully call for further investigations" [13]. Still, it is important to keep in mind that the data presented here are only from a very limited test set, and therefore does not provide a full scale statistical significance test.

Nevertheless, the indications provided in this paper open up for an interesting novel research direction investigating playware and robotics as playful tools for cognitive challenged children by both given the children a playful experience and automatically investigating the playful interactions to provide insight (and possibly diagnosis).

For instance, we may also speculate that it is possible to use the modular robotic playware to obtain knowledge about the children's social capabilities. We could imagine that some kind of playware would allow to recognize:

- Does user A imitate user B
- Does user A hand over tiles to user B
- Does user A and user B use the same tiles
- Does user A remove tiles just placed by user B

For instance, with the tiles, it may be possible to create such measures using an RFID reader in the tiles, and then have the children use a bracelet with a build in RFID chip. When the child picks up a tile or presses a tile, the RFID reader could read which chip is closest and add that information to the logging. But it may be possible to design many different kinds of playware that allow for such play and automatic classification, and future research and development will hopefully show examples of this.

Further, we believe that there are numerous possibilities for investigating the motor capabilities of the children utilizing a modular robotic playware tool, e.g. as the tiles presented in this paper, but also in other user-configurable modular robot designs. We observed that when using the tiles, some of the autistic children placed them in a upright position, front toward the floor, or built a tunnel with the tiles leaned against each other in a 45 degrees angle on the floor. Some children throwed the tiles to the ground and other placed them on the floor with caution. It would be possible to create a large set of criteria if it was possible to measure how a tile is positioned in space, and how it is handled. The following list shows some ideas for such criteria:

- Is the tile thrown
- How is the tiles position in space
- How fast is a tile moved
- When two tiles are assembled: which of the tiles was moved toward the other.

From a technical point of view this can be done with an accelerometer sensor build into the tiles, but as mentioned, it may also be investigated with other kinds of playware tools.

It is our hope that other researchers will appreciate and possibly take up these challenges based upon the initial indications provided here, in order to investigate and develop playful diagnosis practices.

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