Modular Robotic System as Multisensory Room in Children's Hospital

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Abstract

We developed a system composed of different modular robotic devices, which can be used e.g. as a multi-sensory room in hospital settings. The system composed of the modular robotic devices engage the user in physical activities, and should motivate to perform physical activities by providing immediate feedback based upon physical interaction with the system. The modularity, ease of use and the functionality of the devices such as modular robotic tiles and cubic I-BLOCKS suit well into these kinds of scenarios, because they can provide feedback in terms of light, vibration, sound and possibly many other ways, since the devices are fairly generic, which means that they can be augmented with other sensors or actuators. It is therefore possible to create applications with different stimuli and to dynamically change parameters to provide immediate feedback to the users. A main finding of the tests conducted here at a children's hospital, is that it was found to be very important to create feedback that was easily recognised by the users, and it was found that the interaction was boring if the feedback was too implicit (subtle) and not well understood by the user. Instead, users appreciated *explicit immediate feedback* very much because it was obvious and understandable, and did not require any a priori knowledge of the application.

Introduction

In recent developments, some research has focussed on the development of modular robotic devices that act as playware. We define *playware* as the use of technology to create the kind of leisure activities we normally label play, i.e. intelligent hardware and software that aims at producing play and playful experiences among users and of which e.g. computer games are a sub-genre [1].

The aim of the research is to combine robotic systems, artificial intelligence and play culture to produce new products that can be used in play, sports, health, rehabilitation, music, architecture, art and learning. The collaboration strongly combines the forces of both technical and human art research to focus on how new products can be designed, and to gain further knowledge on areas such as play culture and how this is evolving as our life becomes digital.

Fig. 1. The playground tiles used in a city square.

An outcome of earlier research in playware is electronic tiles (see playground tiles on fig. 1), which were developed as a new product that could stimulate the youth to engage in more physical active games to fight obesity and other life-style related diseases [2]. The tiles consist of a microprocessor, LED lights, force-sensitive sensor and means of communicating with 4 other devices. The tiles can be put together in large playgrounds, with wires providing for power and communication, and are controlled by a central computer. 6 of these playgrounds have been installed at 6 institutions (kindergartens, elementary schools and youth clubs) in Odense. In [3] research was conducted, to find out if it was possible to dynamically adapt the games for the users, while they were using the playground. The idea was to even out the difference among the users, to create an equally challenging experience with no regards to speed or other factors that would be beneficial to win a game. For instance, if speed is a key, the game would require a faster response from fast children than it would from slower children. This would be determined dynamically by classifying each individual and then adapt the game accordingly.

Further, we developed the modular robotic tiles, which are more suitable for applications, where it should be

easy to change the topology. The initial generation of these flexible tiles are interconnected by magnets, and they communicate by using IR diodes. 8 LED's are placed in a ring surrounding the FSR sensor, and thus, it is more intuitive, where the user should press the tile to activate it [4].
Whereas the playground tiles were mostly used for playgrounds, the modular robotic tiles have been used in various therapeutic setups. At the Rehabilitation Central in Odense, physiotherapists are using the tiles to create exercise games that are costumed for each individual patient by changing the topology and various application parameters (such as time, speed and FSR activation level). They have a wide range of patients, but most of them are recovering from surgery, and needs to regain strength and manoeuvrability. Because of the diversity of the patients, they need to facilitate many different tools and machines, so that every need can be satisfied. It is investigated if the modular robotic tiles can be used in various setups to help the training process of the patients. The applications on the tiles were originally developed for Sygehus Fyn (a hospital in Svendborg), which works with recovering heart patients [5].

Fig. 2. Modular robotic tiles for cardiac rehabilitation at the hospital Sygehus Fyn Svendborg.

Further, at Hôpital de la Salpetriere in Paris, Jacqueline Nadel is using the tiles to stimulate and motivate children with autism spectrum disorder (ASD). Due to ASD, the children have social impairments, and do not explore their environment for novel artefacts or events. By using the tiles, they hope to generate a feeling of self-efficiency in the children, by encouraging the children to push the tiles. When they do so, the lights will change from blue to red (and vice-versa), which is an immediate effect and hopefully the child will recognise this event as being his/hers responsibility. Finally, at the Robots at Play festival [6] we have demonstrated, how the tiles can be used in music and sport applications.

Fig. 3. The modular robotic tiles used as an interactive goal for soccer training and entertainment.

Research in modular robotics has also spawned projects such as ATRON, Odin and the cubic I-BLOCKS. The cubic IBLOCKS are interesting as playware, since they are used in education and entertainment areas. The first prototype consisted of LEGO Duplo bricks, which were equipped with a microprocessor and various sensors. By assembling the bricks, different applications could be built. The newest prototype (see figure 6) is developed and maintained by Jacob Nielsen, and is currently used in the RoboMusicKidz project [7]. The hardware is very similar to the hardware in the modular robotic tiles, so basically it is only the physical form that differs and the extension possibilities.

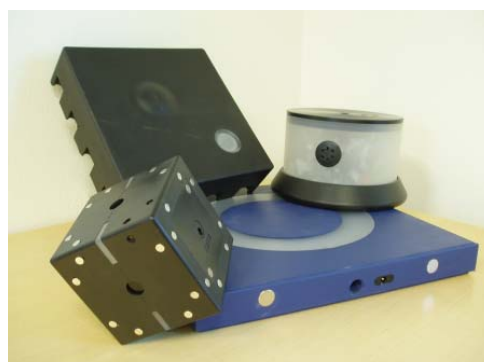

Fig. 4. Examples of modular robotic devices that should use the same protocol for easy integration and flexible configuration.

The modular robotic tiles and the cubic I-BLOCKS can be used in very flexible applications, since it is very easy to arrange them differently on run-time. Changing the topology can be done very easily, since they attach to each other using magnets, and there are no wires or mechanical connections, that would make it more difficult to rearrange the individual devices.
Changing the topology of a setup can be one way of interacting with the application. Also, it allows the user

to customize the setup before use, and it makes it easy to adapt the application to whatever need the user has.

For instance, there seems to be numerous opportunities for investigating the use of modular robotic playware devices as part of multi-sensory environments, which are used at hospitals and other institutions to stimulate patients and to provoke different reactions due to the stimulation. The range of patients is wide and different kinds of tools and remedies are available to provide the stimulating experiences. The most common tools are providing visual stimuli in terms of light, auditory stimuli in terms of sound effects or soothing music or physical stimuli, which can be a vibrating or massaging device.

Producing the sensations can also be done by using the actuators of the robotic modules. All the modules have built-in light capabilities, and by embedding other types of actuators, it is possible to provide sound and physical stimuli. From this point of view, there should be no trouble in using the robotic modules in a multisensory environment. Furthermore, by utilising the computing power and the sensors, it is possible to provide feedback to the user that is determined from combining the sensory input with some knowledge about the use. In other words, it is possible to interact with the user in an intelligent way, which might help to provide even better stimulation.

The development of multisensory room with modular robotic devices was studied for a different user group, namely elderly dementia patients in a hospital in Italy [8, 9] and modular robotic devices have been developed for children with different abilities [10]. Also, the MEDIATE project studied the development of an electronic multisensory room [11, 12]. In that case, there was no use of modular robotics, and hence the set-up seemed fixed with less flexibility than what is investigated here. Also, in general, most other interactive walls or floors are all quite static set-ups that do not allow for the user to perform physical reconfigurations at run-time (e.g. products such as t-Wall and LightSpace).

In order to allow for flexible use of the different modular robotic devices in the multi-sensory environment, Anders Henningsen and Rasmus Nielsen developed a generic and versatile communication protocol and framework for the modular robotic devices described below.

Modular robotic devices

Modular Robotic Tiles

The modular robotic tiles are created to be mobile, even when the application is running so that the topology can be changed by any user, even at run-time. The modular robotic tile consists of a square tile, in PUR, with a circular cover. The cover is made of a transparent satiniced plate and a centre made of PUR, such that the light from the 8 RGB LEDs, used for output on the printed circuit board (PCB), are uniformly distributed and the FSR in the center of a tile could easily be activated. Two tiles are connected via the two magnets on each side of the tiles, and they could be mounted on a magnetic surface like a metal wall or a radiator, because 4 magnets are built into the back of the tile.

The hardware on the modular robotic tile is based on the ATmega1280, which internally has 4 USARTs that is used for the IR transceivers where the tile is communicating with its neighbours through. These tiles are also prepared for communication through a XBee module, which make them able to communicate wirelessly across multiple platforms. The modular robotic tile also has a 2-axis accelerometer, which senses the inclination compared to gravity.

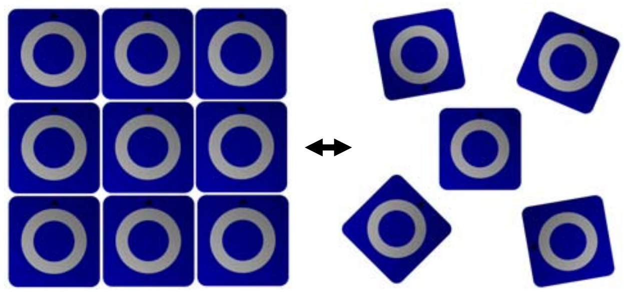

Fig. 5. The modular robotic tiles can be physically reconfigured by any user at run-time.

This new generation of tiles is much more distributed than the former playground tiles. It is not only the battery power supply in each tile that makes this tile suitable for distributed applications, but also the way they are coupled together and communicating with each other. Last but not least, these tiles are not preprogrammed, like the Playground tile, to start in a bootloader, where they are waiting for a given message to start the application.

Summary of the modular robotic tiles:

- Based on the ATmega1280
- 4 communication channels (IR light)
- Opportunity for wireless communication (XBee)
- 8 RGB LEDs, placed under the circular cover
- 1 FSR sensor
- a 2-axis accelerometer

I-BLOCKS

Similarly to the modular robotic tiles, we have developed modular building blocks such as I-BLOCKS and the new Cubic I-BLOCKS. Their hardware are by intention much alike the hardware in the modular robotic tiles, they are also based on the ATmega1280 and are communicating via IR light, with their neighbours. They have a 3-axis accelerometer and 4 RGB LEDs are used for output. The

hardware of the cubic I-BLOCKS is created so that it can be expanded with an extra internal PCB, which can be used for different sensors or actuators. There already exist different expansion boards with e.g. display, ultrasonic sound, USB connector and a XBee module.
Summary of the cubic I-BLOCKS:

- Based on the ATmega1280
- 4 communication channels (IR light)
- Opportunity for expansion, e.g. display, XBee or USB
- 4 RGB LEDs
- a 3-axis accelerometer

MidiBox
The MidiBox is created as a tool for receiving or transmitting MIDI commands, through the internal XBee module. The MidiBox is then interfaced to another MIDI device, a PC, MIDI keyboard etc., which could send notes or generate the given sounds. The MidiBoxes have been used in different applications. Recently they are being used in the RoboMusicKidz project by Jacob Nielsen and was used in the interactive concert with Funkstar De Luxe [13].

Fig. 6. Children creating music with the cubic I-BLOCKS.

In general, the devices are very alike with regard to the hardware and the choice of the sensors and actuators. They are created such that distributed applications are suitable. The XBee module is chosen as a link for three of the mentioned devices, which make them perfect in applications where they all are used at the same time.

Application environments

We have tested the modular robotic tiles in a number of applications environments. We describe briefly these environments below.

Odense Rehabilitation Central
At the Rehabilitation Central in Odense, physiotherapists are working with patients that are recovering from surgery and needs to regain strength and manoeuvrability. They receive a wide range of patients with different needs, and need to facilitate many kinds of machines and exercise equipments, and are using many different kinds of exercises to help their patients. It is very important, that they can supervise the patients, so that they do not overstrain themselves, which could possibly be dangerous after a comprehensive surgery. The therapists have been using the modular robotic tiles, which they have incorporated in some of their training programs. The applications on the tiles, was originally developed to Sygehus Fyn, who works with heart patients. They have a permanent setup of tiles on the wall, and a bunch of tiles, that they can set up on the floor in any configuration, that they desire (see Fig. 2).
There are several possibilities for developing applications for this target group. On one hand, they need exercises that increase the pulse of the patient in a controllable way, and on the other hand, they need exercises where the patients are supposed to move a specific limb in a specific way. Both classes of exercises must be configurable, so that they are suited for each individual patient.

Nadel Group, Paris
Jacqueline Nadel from CNRS is working with children who suffer from ASD, which causes impairments in their social skills. One of their methods for therapy, uses familiar objects (such as sunglasses, cowboy hats, umbrellas and so on) and arrange these in a setting with the child. All items are duplicated, so the therapist can use one object, while the child uses an object of the same type. Some of the children do not explore their environment, and do not initiate interaction with these objects, so the therapist has to initiate, and try to encourage the child to imitate his behaviour. By using the modular robotic tiles, they will try to show the children, that a physical interaction with these tiles can result in feedback such as light and sounds, which then hopefully will generate a feeling of self-efficiency in the child, because the child was responsible for the feedback. The first simple application in test, simply changes the light from blue to red (or vice versa), when the tile is pushed.
The best setups for these therapists are simple applications – possibly run on different types of modules – that they use with the children. It should be easy to use, and no comprehensive control of the application is necessary. Again, there is lots of possibilities for using multiple types of modules, since there are no restrictions on how the children physically interact with the modules.

Handicapafsnittet Odense
At Handicapafsnittet (a center for treatment of handicapped children in Odense), the physiotherapists are

dealing with children with both physical and mental handicaps. Some of the diagnoses are:

- ASD
- Physical handicaps
- Development problems
- Different kinds of syndromes

They have tested the modular robotic tiles with the same applications that are in use at the rehabilitation center in Odense. However, it seems that those particular (rehab) games are not motivating for these children, and some refinement will be necessary for this group of users. Some of the therapist requests are:

- Games that will enforce cooperation among the children.
- Application control should be entirely in the hands of the therapists.
- Educational games (spelling, math)
- Games that resembles common children plays (jigsaw puzzles, twister)
- The ability to change the appearance of the module

Fig. 7. A child with autism playing with the modular robotic tiles [4].

H. C. Andersen Children's Hospital

The H. C. Andersen Children's Hospital was official inaugurated April 2nd 2008 in Odense by HRH Prince Joachim. The responsibility of the hospital is to treat children and infants. It is mostly patients, who cannot get treated in the county hospitals and children with urgent needs or rare and complex conditions. The hospital also works as an educational institution as a part of the University of Southern Denmark. The hospital contains a multi-sensory environment, which are used for many different kinds of patients and for various purposes. The room provides different tools and means for stimulation, and is often visited by children and their family, when staying at the hospital for a longer period of time.

There are many possibilities in using this target group, and the robotic devices will be very easy to use in the room. The therapists have shown great interest in the devices, and are very open for a test setup, that is more dynamic than the current equipment in the room.

General Protocol

In order to obtain a versatile system, we developed a protocol which

- Is device independent
- Supports for multiple platforms
- Supports for both centralised and distributed applications
- Can utilise of the modular devices in a dynamic environment
- Is easy to integrate and use

The framework has to be device independent. The meaning of this requirement is that different devices could be used in the same application, without changing the code in the application or protocol. The framework has to be implemented, and designed, in a way such that the protocol and the application is working no matter what communication lines and drivers, that are used.

The devices that we use are modular devices, which are created so that they can be used without other devices. When a single device is used, the applications are limited, but a single device could be seen as a platform in a larger perspective. E.g. instead of creating a field of devices (e.g. tiles) which always are rectangular or another shape where all devices are connected locally, it should be possible to spread out the devices without changing the application. The devices will in these applications have to communicate through a wireless link, which specifies new requirements for the communication in the protocol.

In some cases, all the devices may need to know the full exact topology. This specifies not only large requirements about the design of the new framework, but also about the memory available. A full knowledge about the total topology could take up a large amount of the memory. One of the biggest problems is to maintain the topology in every device in a dynamic environment.

Since a lot of the devices are modular, and easy to connect and disconnect, the framework has to handle changes in the topology, since this could give opportunities, for new interesting applications, where the devices need to be moved around to interact with the system.

The last requirement for the protocol is that it has to be easy to integrate, not only in a new application, but also on a new device related to the other devices. If the protocol can be compiled into a new project, it has to be easy to use, which means that the initialisation and the methods in the protocol are simple and understandable. Compiling the applications and protocol is also relevant, when it has to be easy to integrate, this require an understandable structure of the files, code, makefiles etc. that are used in the project, and a simple toolchain. An easy way of programming the devices is also preferable.

Mechanisms in the Protocol

Different mechanisms have to be implemented to fulfil the requirements. The design of the most important issues is described in this section.

Using Alive Signals to Spot Topology Changes

Alive signals is one of the most important mechanisms when modular devices like these have to be used like it was intended, namely in applications where the changes in the topology is an interaction with the system. Without alive signals or a similar mechanism, it would not be possible to spot these topology changes, know which devices that are active in the system, how these are reached and keep all the routing tables up to date. A lot of these information depend on the alive signals and the parameters regarding this.

The actual alive signal is quite simple. When a given interval has elapsed, the device then transmits an alive packet on the concerned channel, every channel has its own counter. When another device, a neighbour, receives this packet it reacts compared to whether this device was known or unknown. If the device has not been seen before, it updates its routing table and transmits a new broadcast packet, describing the new device, and how they are connected.

If the alive signal was received on a local channel, the device which receives the packet resets its own alive interval on this channel to the half of the original interval.

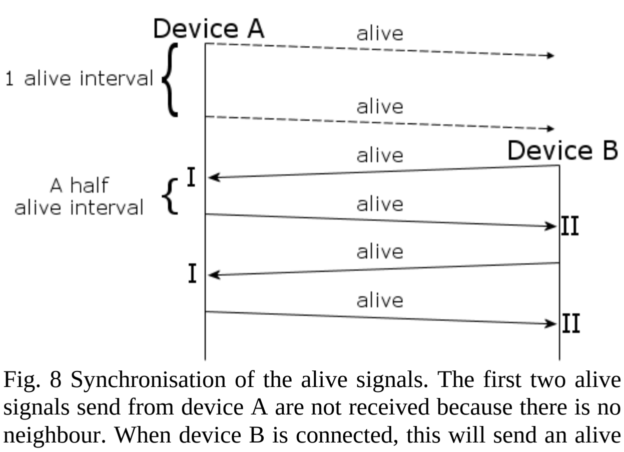

Fig. 8 Synchronisation of the alive signals. The first two alive signals send from device A are not received because there is no neighbour. When device B is connected, this will send an alive signal, which synchronises the timer of device A. Device A is synchronised on I while device B is on II.

This way the alive signals will be synchronized, and they will take turn to send alive signals to each other. Remote channels will never be synchronized, because the alive signals are transmitted as broadcasts, and every device that receives the alive signal would then be synchronized the same way, which would result that they all would send their alive signals almost at the same time.

The alive signals also contain a checksum of the routing table on the current device. This way two neighbour devices could verify whether they have identical tables or not, and react on this, e.g. by exchanging their tables. The routing tables have to be the same on the whole platform, so it is possible to reach all the devices, and the shortest paths in the system can be found. If a packet is received, with an unknown receiver address, the packet will be discarded, and never reach the intended device. Maintaining the routing tables is an important task on the network layer in the protocol.

Routing Tables

Routing tables are used in the protocol to store all the devices that are active in the system. An entry in the routing table consists of the address of the represented device, the channel needed for the shortest path, the address of the next device on the path and the total cost, which is the length of the path to the device. The cost is created such that it is possible to weight the different channels, e.g. by having a cost of 5 on a wireless channel and a cost of 1 on a local channel. The system will then choose to send a packet through 4 local channels than 1 wireless.

Every device will have its own routing table, and will have the responsibility to maintain it, by updating it when the device receives new alive signals, they disappear or special messages are received regarding changes in the topology.

History for Loop Detection

Loops in the communication paths could be a problem when working with these devices, because of the position of the communication channels. To ensure that packets not will loop forever, a circular history is used in every device, which remembers which packets that have been seen before. If a packet is received twice, the packet is then deleted and not processed or forwarded. A history could only work if all packets are unique, this is done by saving the address of the sending device, which already is unique, and allocating a frame number to every new packet. These two values, which will be a part of every packet, will create unique frames and they will be stored in the history. A single byte is used for frame numbers in the packets, and when this increasing number reaches it maximum, which is 2541, it will start all over again from 0, packets could then be similar to earlier transmitted packets, but an aging system of the entries in the history, ensures that these entries are expired when this happens, if the entries not already have been overwritten by newer entries.

Bootloaders
Bootloaders are implemented for the therapy tiles and cubic I-BLOCKS, to ease the transmission of the program code to the devices. Instead of programming all the devices one at a time with the JTAG, it is now possible to transmit the program code to a device through one of its communication channels, local or remote. When this device is programmed, it will distribute the code to all its local neighbours, which do the same until all the devices on the given platform are programmed.

Experimental Setup at HCA Children's Hospital

The purpose of the enhanced multisensory room is to use the devices as tools for various stimuli, and to create dynamic applications, that can adapt to the users by processing the information from the interaction of the devices. By examining the behaviour of the users, it might be possible to provide a more directed stimulus, which is tailored to each individual or to a group of users. We used the modular robotic tiles and the cubic I-BLOCKS, because they are very flexible and easy to handle. The Playground Tiles was disregarded, because they take up too much space, and are not very easy to move around, which is a general requirement for artifacts in the room due to cleaning conditions. The modular robotic tiles and the cubic I-BLOCKS can be used for different kinds of stimuli, and we will consider how to utilise this in our application proposal.
It should be noted, that during the test period by Anders Henningsen and Rasmus Nielsen, the nurses and other groups of therapist announced their strike action at the same time as the collaboration with the hospital was started. The impact was that only high-priority patients were available at the hospital and the majority was not able to test our equipment in the sensory room, due to their condition. For this reason it was very difficult to make larger tests of the application to collect a lot of data for analysis. It also affected the types of patients, who were available. The sensory room are normally used by children with disabilities, who have preference of the room, because they do not have the same opportunities as healthy children in terms of playgrounds and ways of being activated. But during the strike action, only children that do not suffer from any physical disabilities and do not have any development problems, were available at the hospital.

Application
We created an application that allowed for:

- immediate feedback to the user when an action has been taken.
- various types of stimuli that can be controlled by the system.
- simple application that is susceptible to quick updates and adjustments.
- autonomous application which exhibit behaviours without the intervention of the user.

We decided to use the modular robotic tiles as components in an interactive light-wall. By placing 16 tiles in a 4 by 4 square on the wall, we were able to provide a very powerful light stimulus, by showing various patterns in different colours. The light-wall is also sensitive to pressure, and provides one way of interacting with the wall. The tangible cubic I-BLOCKS are used for interaction with the system, and are themselves able to provide direct feedback in terms of light and vibration. The cubic I-BLOCKS make use of a 3D accelerometer to detect the orientation with respect to gravity, and it is also possible to detect if the user is shaking the cube. They communicate locally through IR channels, and by using our protocol stack, topology changes can easily and quickly be detected. All of these behaviours can be integrated into the software as a way of interacting with the system.

Fig. 9. Easy Storage (lower left) and set-up for sound (upper left) in the multisensory room of HCA Children's hospital.

We developed a light wave application which is completely distributed, and the purpose is to create so-called lightwaves on the tiles. A random tile will light up in a random colour, and then propagate this colour to its direct neighbours and eventually fade its own colour out. The same behaviour applies for the neighbours, who all also will light up, propagate the colour to their neighbours, fade out, and so on (see fig. 10).

The design of the lightwave application is based very much on visual stimuli, and it is the hope that it can draw some attention, because of the moving colours. If the room is dark, the lightwaves may be very clear and eye-catching.

The cubic I-BLOCKS can be used for controlling the lightwaves in different ways and by turning, shaking or assembling/disassembling the cubes, different events can be generated, that will have an immediate observable effect. Suggestions for variable parameters are:

- the propagation speed of the lightwaves.
- the trail of the lightwave (e.g. how long each tile is showing the color, before fading out.)
- the intensity of the lightwaves.
- the amount of lightwaves.
- the color of the lightwaves.

The computer can be used for logging the events, and for controlling sound effects and background music. Together with musician Kasper Falkenberg, we made some soothing background music, and for each lightwave, there would be sound effect, e.g. a note from some instrument.

The final setup consists of the following equipment (also see Fig. 9):

- 16 modular robotic tiles (at least one with a XBee RF module).
- 1 Whiteboard for holding the Therapy Tiles.
- 3 cubic I-BLOCKS with XBee RF modules inside.
- A charger with room for 15 devices.
- A small computer with a XBee2USB dongle.
- 2 satellite speakers with 1 subwoofer.

In the corner of the multi-sensory environment, they have collected all control-related equipment, so that the therapists have easy access to control the various tools. We have placed the computer and the loudspeakers in this corner, and the only thing, the therapists have to do, is to push 2 buttons to turn on the computer and the speaker system.

Lightwave Parameters

The modular robotic tiles are able to receive several commands that affect the parameters for the lightwaves. These commands are:

Duration Time: the duration time is a time value in milliseconds, and can in the time of writing be a value between 200 and 1500 ms. It affects how long each tile should be lid up, before fading out. The longer the duration time is, the longer trails will be drawn from the lightwaves.

Forward Time: the forward time is a time value in milliseconds, and can in the time of writing be a value between 200 and 1500 ms. It controls the propagation speed, and how fast it should spread from tile to tile.

Start Interval: the start interval controls how often a lightwave should occur. The values can be between 5000 and 1500 ms. For instance, if the start interval is 5000 ms, the lightwaves will occur randomly with a maximum of 5 seconds between each lightwave.

The above three commands are controlled by three cubic I-BLOCKS. Using the 6 orientations of a cubic I-BLOCK, we can provide 6 levels for each parameter. The LEDs on the cubic I-BLOCKS are used for both indicating the purpose of the cubic I-BLOCK and the current level for the specific parameter.

For a later implementation, we changed the parameter START_INTERVAL to be a FORWARD_WAVE instead. This allowed the users to create lightwaves themselves in their own colours.

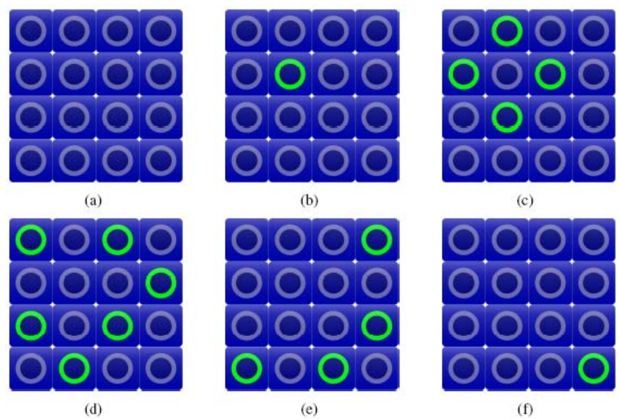

Fig. 10. The propagation of a lightwave starting from square (2,2) in the upper left. The start position could e.g. be random or based on a hand pressure on the tile.

HCA Controller

The HCA Controller is the software, that is running on the computer. It runs on top of the protocol framework and provides logging capabilities into a persistent data storage, and it also provides means of controlling music and sound effects. The controller is using the ProtocolStack from the protocol framework, and it is implementing the ProtocolListener interface, so that it will receive any incoming data that is destined for the application. The AudioCenter provide means of playing different notes with three different instruments. It can also create a WAVPlayer, which can read any wav files and it is possible to control the volume of the music.

The controller uses the HSQLDB relational database engine, which are based entirely on Java. It provides a fast and easy-to-use database, which can be integrated into the HCA Controller and log all the incoming events for further analysis. The DataContainer class is a wrapper for the data that is contained in a single event. When the system is started, the controller will create a new database and provide it with a timestamp. A table for the events are also created, and it contains 7 fields: id, command, 3 columns for integer arguments, 1 column for a string-type argument, the address of the sending device and finally a timestamp. The argument columns are used to store the values, that are changed when an event occurs.

Tests

The multisensory room with the modular robotic devices was developed and tested over three iterations as described below.

Fig. 11. A child and her father in the multi-sensory room.

First Iteration test

The first iteration covers the first application that was developed and deployed at the hospital. The first feedback that we received was that the tiles and cubes were very easy to use, and they had no trouble in starting and shutting down the system. However, they requested some kind of user guide, so that the children and their parent could use the system on their own.

The lightwall was very much appreciated and the colours and lightwaves were attracting the attention of both the personnel and the children and their parents. The sound of bubbles was also working well, and the children found it amusing. However, they did not understand the purpose of the cubic I-BLOCKS, and was not able to see the effects on the lightwall, when changing from one level to a subsequent level. It was possible to convince them of the effect, when changing from the highest level to the lowest level with a given cube, because this impacts on the parameter the most, but all the intermediate levels were not observable, or at least not as obvious. Of course, this was not our intention.

The use of cubic I-BLOCKS was also appreciated and they had made some interesting observations regarding the physical structure and use of the cubes. The children had fun turning the cubic I-BLOCKS around, so that the colour would change, and for some children it was almost a challenge to disconnect them due to the strong forces of the magnets, that hold the cubic I-BLOCKS together. The hospital staff observed that the use of the modular devices stimulated physical movement, which could be used for some groups of children. Children with bowel problems are encouraged to move around, and it was found, that the cubic I-BLOCKS could be a tool for stimulating physical movement. This could be done, by placing the cubic I-BLOCKS around the child with enough space between each of them, so that the child would have to move the body to reach the cubes. Another child had been through a rough period of time due to cancer, but was recovering again. She was physical weak after the exhausting period, and she had trouble in disconnecting the cubic I-BLOCKS. But the therapists observed that she expressed self-confidence and happiness, when she finally disconnected the two cubic I-BLOCKS.

Second Iteration Test

In the second iteration, we changed the number of levels for each parameter, so that (hopefully) it was easier to see the effects on the lightwall, when orientating a cubic I-BLOCK. From 6 levels, we went down to 3 and made the span between the lowest and highest level wider, so each level would be significantly different from the other levels. Since the cubic I-BLOCKS have 6 sides, each level was represented by two different sides.

To encourage further use of the cubic I-BLOCKS, we provided the therapists with new cubic I-BLOCKS with vibrators, which were supposed to replace the old cubes. By turning the cubic I-BLOCK, it would then provide visual stimuli (changing colour of the LEDs) and it would vibrate for half a second. We also added the possibility for the users to shake the cubic I-BLOCKS, which would change the volume of either the bobble sound effect, or the volume of the background music, which also was added in this iteration. The background music was composed by Kasper Falkenberg and is a very relaxing and calm piece of music.

After creating user guides for the personnel and changing the number of levels for the parameters, the staff and children were able to observe the immediate feedback from turning the cubic I-BLOCKS. The vibrating stimulus was found very amusing, and it further encouraged the use of the cubic I-BLOCKS.

We also received positive feedback regarding the background music. The children quickly realised, that by shaking the cubic I-BLOCKS, it was possible to alter the volume of either the bubble sound effect or the music.

The hospital staff noticed that some children were searching for specific colours. For instance, one girl only liked the purple colour, so she would turn the cubic I-BLOCKS in various ways to get the purple lightwaves. This indicates two things: she has not understood the purpose of the cubic I-BLOCKS, since they do not control the colour of the lightwaves, and it indicates, that we should provide the possibility for letting the user controlling the colours as well. From the feedback, it was clear, that the children have a favourite colour, and that this could be integrated in the system.

Third Iteration Test

For this iteration, we changed the function of cubic I-BLOCK, because changing the start interval parameter did not seem very obvious to the users. Instead, there was a bigger interest in better control for the lightwaves and the colours, which the user had no control of in the former iterations. Cubic I-BLOCK now functions as a wave generator, and each side of the cube controls a unique colour for the lightwave, which yields 6 possible colours. We did not change any of the sound effects or the background music, because it seemed to work fine at this point.

The change of I-BLOCK was very much appreciated, because it provided the users with (a more obvious) immediate feedback, and it was now possible to create lightwaves in a desired colour. However, in some cases problems regarding the wireless communication ruined the feeling of immediate feedback from using the cubic I-BLOCKS, since the commands were not properly received by the lightwall. This was quickly fixed, but initially this was a demotivating factor for the users, because of the lack of feedback from the system. But in general, the *explicit immediate feedback* provided a clear change in the user behaviour.

Data collection and evaluation

Each time the computer is turned on, a new database is created and associated with a timestamp. We did not provide any means for the therapists, to enter any information about the user (such as an ID), because it was very important to keep the equipment simple and easy to start. It was reckoned, that by including a screen and a keyboard, the therapists would be less motivated for using the system in the sensory room. Also, due to the striking action, it has been hard for the therapists to schedule appointments in the sensory room with the patients, so a majority of the data represents spontaneous and short sessions of therapy in the room.

The consequences of this, is that most of the gathered data has no direct association with the individual users, and it is not possible to determine if two sets of data have been gathered from the same user. The data is still of use, since it can be used for detecting patterns or certain behaviours, but it is not possible to recognize individual users and associate datasets with users, since any matches can not be confirmed.

A standard test protocol has been defined for the controlled tests, to ensure uniform datasets that can be compared: For the tests that we conducted, we defined the following protocol:

- A minimum of 3 tests should be conducted with the same individual.
- Each test must be of approximately 4 minutes.
- For the first test, the user will get an introduction of how to interact with the system, but will not receive an explanation of the feedback from each action taken on the system.
- Between the first and second test, the user is interviewed and asked questions about the system, to find out if the user had discovered the connection between a certain action and the feedback of the system.
- Before the second test, the user gets an explanation of the connection between the actions and the feedback.
- The third test should be conducted at a later time if possible (e.g. the next day), so that the user enters the room and uses the system with a fresh mind.

In general, the lightwall was popular, because of the very strong and eye-catching lightwaves that emerged in many different colours. When the curtains were pulled and the light turned off, the lightwall had a strong effect.

The use of the cubic I-BLOCKS was also well received, but initially the function of each cube was not as obvious as we wanted it to be. They did impact on the lightwaves, but the feedback from the first two iterations of the project clearly showed us, that the functionality was too *implicit*. The children (and staff) were very focused on the cubic I-BLOCKS when interacting with them, and missed the feedback on the lightwall, which should have indicated to the user, that they just changed something in the system. Also, the definition of turning a cubic I-BLOCK was misinterpreted a couple of times. It was necessary to turn the cubic I-BLOCK 90 degrees to either direction, before it would activate, but some of the users were rotating in smaller angles, which meant that there was no feedback and this lead to a demotivation of the user for using the cubic I-BLOCKS.

The parameters (DURATION_TIME, FORWARD_ TIME, START_INTERVAL) that were changed, were *too subtle* and we should have chosen more powerful effects instead. This was also indicated when we switched the START_INTERVAL parameter with the FORWARD_WAVE, as it was more obvious, what happened when turning the cubic IBLOCK. A similar switch to more *explicit feedback* should be done and investigated with the remaining two cubic I-BLOCKS.

One suggestion of how the functionality of the cubic IBLOCKS should have been implemented instead of the chosen solution would be letting each cubic I-BLOCK represent a colour (red, green or blue). If a cubic I-BLOCK was turned, it would create a lightwave in that particular colour on the lightwall. If two cubic I-BLOCKS were to be connected, this would mix the colours, e.g. red and blue would create purple, and by turning these cubic I-BLOCKS, it would also create a lightwave on the lightwall and in that composite colour (e.g. purple). This scenario reminds a bit of the colour mix setup that we used when working with autistic children and the therapy tiles [4]. That work used three colour tiles (red, green and blue), that were emitting colour packets to their neighbours when connected, and the colours would blend.

We could still use the old parameters (such as propagation speed and time on each tile for each colour) to create an adaptive application. For instance, measurements such as how often the cubic I-BLOCKS are turned or the actual speed of the rotation, can be used to adjust the lightwaves on the lightwall. From the feedback we have received, we estimate that this would have been a better solution and more attractive for the children at the hospital.

The use of sound and music could have been more extensively, but there was not time to test this further. The current setup plays simple tones for each lightwave, it plays a sound of bubbles and it provides soothing background music. When the user shakes one of the cubic I-BLOCKS, it will turn up the volume for the bubbles or the music. It was discussed, if there should have been an attempt to create multiple sound universes, e.g. music with different atmospheres and tempi. Then it would have been possible to associate the activity and aggression of the user with a suitable sound universe. Imagine, that it is detected that the user is highly active (even too active) and the system tries to calm the user by playing some relaxing and down-tempo music. The ways of combining the activity of the user with universes is many, and various effects could be obtained.

Conclusion

Compared to the equipment, which is normally found in a sensory room, it is argued that the robotic devices can provide much of the same stimuli to the users. The modularity, ease of use and the functionality of the devices suits perfectly into these kinds of scenarios, because they can provide light, vibration, sound and there are many other possibilities. These devices are fairly generic, which means that they can be augmented with other sensors or actuators. However, it can be argued that the physical form factor of the cubic I-BLOCKS is not perfectly suited for the little children, who barely can grasp them, and the strong magnetic force that is used for connecting the cubic I-BLOCKS may be too much compared to the strength of some visitors of the room. This has not been a main issue for the project, but the staff has made comments about it and we have observed a little boy, who was struggling with the cubic I-BLOCKS, because he was only able to use one hand.

The lightwave application provided powerful light stimuli, and the possibility of dynamically changing parameters to provide immediate feedback to the users. In the tests conducted here, it was found to be very important to create feedback that was recognised by the users, and it was found that the interaction was boring if the feedback was too implicit (subtle) and not well understood by the user. When we changed the behaviour of one of the cubic I-BLOCKS to allow the users to create lightwaves, the users suddenly appreciated this *explicit immediate feedback* because it was much more obvious and understandable, and did not require any a priori knowledge of the dynamics of a lightwave.

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