Tangible Music Composer for Children

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ABSTRACT

Music education should start from an early age. Theories of child development and learning emphasize the importance of manipulating physical objects. Music learning and teaching has traditionally been carried out mainly by visual and auditory activities. With this in mind, we combine music learning with tangible interfaces to stimulate senses toward music in children over six years old. We present a token+constraint tangible interface for children to learn musical skills such as musical notes, rhythm and the sound of different instruments. The work describes a low-cost tangible interface addressed to children that allows learning music in an intuitive, incremental and collaborative manner. The system recognizes in real-time pre-established patterns and associates them with musical notes and instruments to allow composing music. The system was designed to be usable and to benefit from the advantages that tangible interfaces can provide to children. Furthermore, it was implemented with low cost and easy to get tools and resources, such as wooden boards and a standard webcam.

Keywords: tangible interface, music, low-cost, incremental learning, collaborative work, intuitive performance, human computer interaction

1. INTRODUCTION

Humans have an innate ability to act in physical space and to interact with physical objects [1]. The exploration and manipulation of physical objects are a key issue in children's learning, and children can sometimes solve problems with concrete physical objects that are more difficult for them using abstract representations [2]. Furthermore, a drawback of using digital technology to teach is the difficulties in exploring and manipulating abstract 2D representations on a monitor and the lack of fine motor skills and hand-eye coordination that children present in order to use a mouse or other standard input devices [3]. However, integrating interactivity in physical objects supports traditional exploratory play with physical objects that can be extended and enhanced by the interactive power of digital technology [4]. This solution is approached by Tangible User Interfaces (TUIs). TUIs use physical forms that fit into the user's physical environment to enable them to serve as representation and control for its digital counter parts, that is, they aim to blend the physical and digital worlds [5, 6]. Users do not interact directly with a Graphical User Interface (GUI) by means of a pointing device, but use physical components to communicate with the computer. The basic working paradigm is as follows: a user uses their hands or other body parts to manipulate some physical object(s) via physical gestures; a computer system detects this, alters its state, and gives feedback accordingly [7]. The mapping between the physical input device and the resulting output is relatively direct. In this sense, Montessori [8] observed that children easily engaged in play and they concentrated while playing with physical objects. One kind of TUIs is the token+constraint interface. This class of tangible interfaces is built upon relationships between systems of physical tokens and constraints. In this context, on the one hand, tokens are discrete, spatially reconfigurable physical objects that typically represent digital information. On the other hand, constraints are confining regions within which tokens can be placed. These regions are generally mapped to digital operations, which are applied to tokens located within the constraint's perimeter [9]. The advantages of TUIs for children when learning are that it requires little time for them to use the interface because it is natural and intuitive and can leverage users' prior knowledge from the real world [2], it supports more than one user and children collaborate among them [10, 11], it engages children in participating [12, 13], it promotes sensory engagement [14], it supports trial and error activity and it offers an alternative way of interaction and control of the computing environment [14]. Moreover, physical movement and gestures can enhance thinking and learning [15, 17, 18]. Motivated by Erikson's theory, which states that children older than six years develop the ability to learn basic skills and work with others [19], we focus our work in teaching music skills to children from age six and upon, aiming at stimulating their senses and introducing them into music in an intuitive, playable, collaborative and easy manner. There is a lot of research works focused on teaching different music aspects, but as [20] comment, most systems lack in giving the opportunity for individual musical expression and in their experiments they observed that users generally preferred the ability to explicitly specify the notes they produced. In this paper, we present a token+constraint tangible interface for children to learn musical skills such as musical notes, rhythm and the sound of different instruments. The system is a low-cost vision based interface that uses a webcam and easy-to-find and economical components, which allows users to learn music by composing. The system is addressed to users with no technical skills, and supports active involvement, group learning and incremental learning. Children can combine and modify the position of the tokens to create musical compositions in real-time, learning in an incremental manner and adding complexity when gaining experience. The paper is organized as follows: Section 2. describes the state of the art on music learning through TUIs. Section 3. and 4. report on how our music composer was developed by describing its functioning, and how it was designed and implemented. Section 5. reports on experiments conducted to assess the fault tolerance of the hardware and software used in our music composer. The last section concludes the paper by summarizing the original aspects of our work and discussing future avenues of it.

2. LITERATURE REVIEW

Music learning and teaching has traditionally been carried out mainly by visual and auditory activities, and arm gestures to beat time. When learners are children, clapping, tapping and other body gestures are included. Nowadays, research in music learning and teaching by means of tangible interfaces in interactive musical environments is being explored. The aim is to engage children in an entertaining, playful and constructive learning and teaching process. In this section, we review research works that involve tangible objects to approach different aspects of music: creation of musical compositions or musical patterns and other properties of music such as tempo, volume or pitch. BodyBeats [13] is a suite of three electronic instruments for children to create musical sound patterns and experience with manipulating beats and rhythms. Two of these instruments are based on touching an external device. The first one is the MixMatrix, where one or more users press and hold one or more push-pads that generate a unique pre-selected (or recorded) sound thus creating musical patterns. The second one is TrampleBeats, a small trampoline augmented with electronics capable of transforming the sound of jumping into the sound of a beating drum. The Marble Track Audio Manipulator (MTAM) is an augmented marble tower construction kit where marbles represent sound clips and tracks represent different sound effects [21]. The system is built with an I-PAC controller which it is used to trigger events by receiving the marble position in the tower of tracks. Two ends of a circuit attached to the sides of each track are closed when the metal marble enters. To create musical compositions, children collaboratively build a marble tower with components that represent different musical effects and then play their compositions by dropping marbles into the tower. MoSo Tangibles are a set of interactive, physical artefacts with which children manipulate the pitch, volume and tempo of ongoing tones, in order to structure their understanding of these abstract sound concepts in terms of multiple different concrete body-based concepts [22]. These artefacts (to squeeze, wave, rotate, shake, etc.) contain basic sensors that measure the movements that the artifacts were intended to evoke [23]. They evaluated their system with children and all children were able to successfully interact with the tangibles when reproducing examples sounds, but not all were able to verbally express their understanding of the musical abstract concept. AudioCubes is designed for sound exploration and users interact with a set of cubes and their positions [24]. Each audioCube is a plastic cube with a digital signal processor (DSP) with optical sensors and emitters (infrared, red, green, and blue LEDs). The sensors and emitters receive and send audio signals which are generated or processed by the signal processor in the cube and by interacting with different cubes, a signal processing network can be created. Users of different ages tried the system with different objectives: understanding its use, playing or generating a music pattern. One Man Band provides users with 3D gestural interfaces to control both the timing and sound of the music played, with both single and collaborative player modes by means of the Wii MoteTM and nunchuks. They compared their system to the game Wii Music, and they observed that users generally preferred the ability to explicitly specify the notes they produced [20]. Block Jam is a TUI that controls a dynamic polyrhythmic sequencer using 26 physical blocks. The blocks are square-shape and count with a 3-color LED matrix to display images on the block and have two input mechanism, a button for toggling the state/function, and a dialing gesture for choosing sound. They tested their system in participatory demonstrations eliciting a positive experience and provoking a collaborative response in users [25]. Focusing on tangible interfaces on tabletops to create music, we can find projects such as the ReacTable [26], which is a table surface, where users place different objects and the system tracks, using computer vision techniques and two cameras, the nature, position and orientation of these objects to work as a sound modular synthesizer. AudioPad is a similar work, but instead of using computer vision, it uses a radio frequency tracking system to track the objects on the table that resonate at a unique frequency, and the output is looped sounds [27].

3. DESIGN OF THE TUI FOR COMPOSING MUSIC

Based on the benefits of TUIs and the works reviewed in the literature, we set out with the development of a low-cost tangible interface that allows the creation of music in an intuitive, incremental and collaborative manner. Our goal was to create a music composer for children older than six years, to introduce them to the music world in a fun, creative, educative and intuitive way. In our approach, we emphasize the use of low cost resources and open source software; therefore we developed a low cost vision based interface that uses a webcam and easy-to-find and economical components. Children guided by a music teacher will learn in an incremental way, gaining knowledge and acquiring skills, individually or in groups, by starting with simple and basic tunes of one instrument before advancing to more complex compositions with more instruments. We use a token+constraint approach for the design of the interface: with a matrix board as the constraint region to place the tokens that identify musical instruments and also sounds. The interaction with the system is carried out by placing instrument tokens in the first column and sound tokens in the associated row. Then, the tokens configuration arranged by the user on the board will be played to reproduce music in real time and in a continuous loop.

Instruments and Sounds

In order to allow children to experiment with different sounds and to create a virtual band, we included diverse instruments. Four instruments were chosen initially: the electric guitar, the bass, the piano and the drums. We chose these ones because they are the most popular ones in western cultures. Depending on the instrument the output sounds of the system come in the form of musical notes, chords or percussion sounds. Musical notes were used for the bass, whereas for the piano and guitar we used chords. For the drums, the tokens represent different parts of the drum set.

Board and Tokens

Figure 1: Musical instrument used in the application. The shapes were chosen ad-hoc.

Figure 2: These seven tokens represent chords, notes and parts of the drums. Their meaning depends on the instrument being used.

Four different tokens with different shapes chosen ad-hoc represent each of the musical instruments (Figure 1): a circle for the piano, a triangle for the electric guitar, a star for the bass and finally a square for the drums. Another seven tokens are used for the chords, notes and drums parts (Figure 2). For the bass, guitar and the piano, the tokens represent the seven musical notes and chords (DO, RE, MI, FA, SOL, LA and SI) in American notation, that is, C, D, E, F, G, A, B. For the drums, each token is a sound from a different part of it. C stands for the Hi-Hat cymbals, D is the middle Tom-Tom, E is the crash cymbal, both F and G are the floor and high Tom-Tom, A is the kick or bass drum and B is the snare drum.

The board is the confining region where the tokens are placed and it is a matrix with six rows and nine columns. The first column is used only to indicate the instrument (musical instrument tokens), whereas the remaining ones are used for sounds. Each column represents an instant in time, in a continuous loop. In our case we used a four seconds loop, divided into eight equal instants of time. This means that each column represents half a second in the loop. The board was built using a $30x60cm$ piece of wood to make it robust. Holes in the wood were done using a laser system in order to make room to place the tokens and the tokens are the remaining wood pieces after the cuts. In order to improve the system's usability, as it can be seen in Figure 3 (a), the holes in the first column have a different shape from the rest. This is done to clearly differentiate the instruments from the sounds to avoid mistakes and to restrict the type of token (Figure 3 (b)) that is located at each hole. An instrument token cannot be place in a sound hole and vice versa. The small tab on top of each hole is to allow the tokens to be easily placed and removed (Figure 4). Figure 5 shows a possible combination of tokens.

Hardware and Software Requirements

Once the tokens are placed on the board the next step is to play the music associated with such configuration. This led us to define the running cycle of our

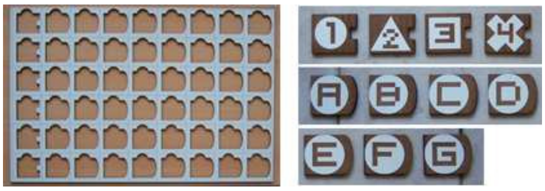

Figure 3: (a) The board and (b) instrument and sound tokens made of wood.

Figure 4: The small tab on top of each hole is to allow the tokens to be easily placed and removed.

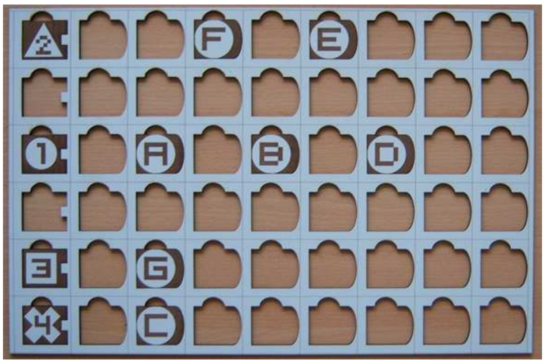

Figure 5: A possible combination of tokens. The first column is used only for instrumental token, the rest of the columns are used for sound tokens.

system, which was divided into four stages (Figure 6):

Stage 1 Capture an image of the board with the tokens.

Stage 2 Identify all the tokens and translate this information into a manageable data structure.

Stage 3 Play the music based on the data structure.

Stage 4 Update a Graphical User Interface (GUI) to virtually represent the information on the board

Stage 1 requires a camera with enough resolution to enable image recognition. A standard low cost webcam should fulfill this requirement. Another important aspect to take into account is the camera position. The clearest view of the board can be achieved by placing the camera on top of the board. Stage 2 requires image processing to recognize the tokens. Several libraries are available for this goal, like OpenCV [28] or ITK [29]. We believe that this stage must be solved using an open source library, with a free license to enable a low-cost system. Stage 3 plays the music taking into account that there are eight quarters of a second in the board. In this stage it is necessary to have a precise control over the tempo of the music, i.e. we need to emulate a metronome, that is, a device that produces a regular repeated sound like a clock that helps musicians play music at a particular speed. Stage 4 can be implemented with any GUI library. We accomplish Stage 1 by using a standard webcam, a Genius iSlim 1320 webcam, which has a 1.3 Megapixels resolution lens. We tested a VGA camera, with a 0.3 Megapixel lens but the image quality was not sufficient for further processing. To achieve the best view angle, we used a tripod with a wooden extension to place the camera on top of the board. For the development of the composer we chose the object-oriented paradigm, using C# as the programming language. This allowed for a more natural, reusable and intuitive software design. A key aspect in this work was the image recognition, carried out in Stage 2. We used OpenCV because of its large support community, its ease of use and its free open license. A wrapper was needed to use OpenCV in C#, in our case we selected EmguCV[1]. Additionally, we used the "C# MIDI Toolkit"[2] for the metronome emulation and the DirectX library for sound output. In order to evaluate the computer vision techniques of the system, we developed a diagnostic tool to monitor the image recognition (Stage 4). This stage was solved using the standard C# GUI library. However, users interact with the system by just concentrating in the board and tokens without looking at the computer screen.

4. THE IMPLEMENTED TECHNOLOGY

The core of this project is the image based recognition, which is done in real time. Tokens within the board region are recognized by the software, through a webcam, and translated to an internal data structure (DS). This DS is then used to play the music. Image recognition is made by comparison. There are two sets of token images already loaded in the system: one set is for the musical instrument tokens and the other one is for the sound tokens. The images captured by the camera are compared with the loaded ones. The result of each comparison is a number between 0 and 1, where 0 means that both images are nothing alike and 1 means that both images are perfectly equal. The main algorithm behind this process is as follows: first an image is grabbed from the webcam and transformed into grayscale to improve performance. As the distance from the webcam to the board and its size are known information, the image is cropped so that only the board is visible. A region of interest (ROI) is then set with the size of the tokens within the board image. This ROI will work as a sliding window within the board and it will always be focused on a token. Once the ROI is set on a token position, the image inside the ROI is compared with the set of loaded images, if the result is higher than a threshold then the images are considered equals and the DS is updated. This process is done for the mu-

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[1] http://www.emgu.com

[2] http://www.codeproject.com/Articles/6228/C-MIDI-Toolkit

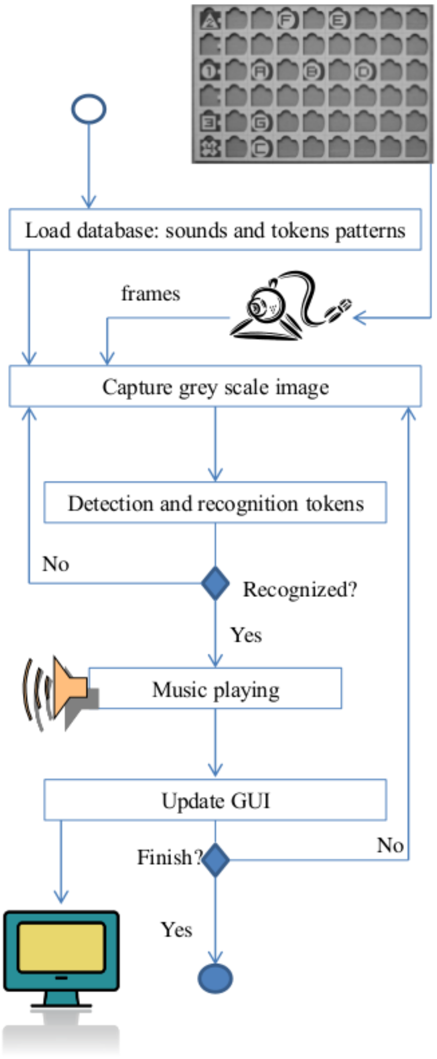

Figure 6: System's functioning.

Table 1: Lux values for different scenarios. The first column is the amount of light measured, and the second one is the type of light been measured

Luminance	Surface illuminated by:
1 lux	Full moon overhead
50 lux	Family living room lights
80 lux	Office building lights
100 lux	Very dark overcast day
320-500 lux	Office lighting
400 lux	Sunrise or sunset on clear day
1000 lux	Overcast day. TV studio lighting

sical instruments and for sounds separately. All comparisons are made using a template matching method, a technique that aims at detecting areas in the source image that coincide with a sample or template image. In order to identify the matching area, the technique compares the template image with each part of the source image, by sliding it pixel by pixel on the source image. In each location, an indicator is calculated that represents the coincidence in that place, that is, how similar is the template image with that particular area of the source image. This is called the match metric. For each location of the template image (T) over the source image (I), the match metric is stored in a result matrix (R). The comparison metric is calculated using the following equation:

$$R(x,y) = \frac{\sum_{x',y'}(T(x',y')\cdot I'(x+x',y+y'))}{\sqrt{\sum_{x',y'} T(x',y')^2\cdot\sum_{x',y'} I(x+x',y+y')^2}}$$

Finally, the last module in the system is the GUI, the virtual representation that displays the status of the board in real-time. This interface also allows the user to start and stop the system. A hand-shape icon on top of the board indicates the column being played and at the bottom of the GUI there are the play and stop buttons. Figure 7 shows a user interacting with the composer. The source code of this project is available at CodePlex[3] under "GNU General Public License version 2 (GPLv2)".

5. SYSTEM'S FAULT TOLERANCE

We measured the system tolerance to environment conditions and hardware placement. As our system uses image recognition based on a webcam, ambient light is a crucial factor. Using a light meter, we measured the amount of light needed to successfully recognize the image patterns. The lower light measured that allows a correct recognition of the token was of 27.70 lux and the highest light value was 976.80 lux. Below 27.70 lux and over 976.80 lux the system was not able to recognize the tokens successfully. Table 1 describes some references values for light measures in lux for different contexts.

The hardware placement is also very important. The recommended distance between the camera and

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[3] http://musicatangible.codeplex.com/

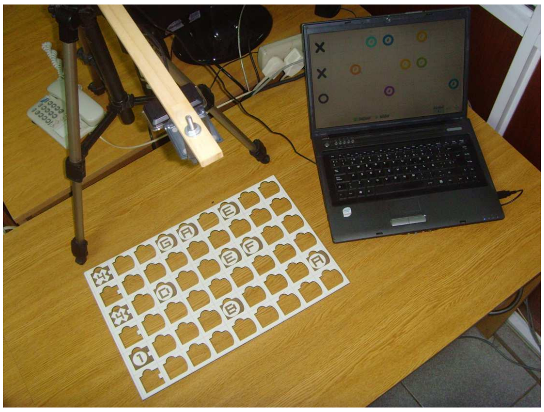

Figure 7: The tangible composer being used.

the board is of 62 cm. and the board should be perpendicular to the camera. We tested the tolerance of the system on these two characteristics. All tokens' spaces where filled for these tests. When the board is totally perpendicular regarding the camera, the recognition is achieved successfully. Two degrees rotation from the center of the board, both clockwise and counter clockwise, does not affect the system. On three degrees rotations, on both directions, one of the tokens was not detected. On four degrees rotations the same token was not recognized. On five degrees rotations, five tokens were lost. Finally, on seven degrees rotations between nineteen and twenty tokens were lost. At this point the system is no longer usable. As stated earlier, the preferred distance between the camera and the board is of 62 cm. There is a 1.5 cm tolerance, both up and down; but beyond these points some tokens may begin to be unrecognized. The webcam is currently working at 30 FPS. We tested lower values of FPS but did not affect the recognition system. However, it took longer to update the image captured by the webcam and therefore it took longer to update the GUI and the internal data structure. The webcam used is a 1.3 mega pixel camera, but we also tried with a 0.3 mega pixel camera which image resolution was not good enough for the system to recognize the tokens.

6. CONCLUSIONS AND FUTURE WORK

In this paper we presented an interface to learn and compose music by means of a tangible interface. The system is addressed to children over six years old and its requirements are based on the learning theories that highlight the importance on manipulating and exploring physical objects to learn. Users can learn and compose music individually or collaborating with other users in an incremental manner: starting with simple tunes to learn the sounds of a particular instrument and then making them more complex by adding other instruments and taking into account the tempo. The system is a portable and robust constraint+token tangible user interface. Users place instrument and sound tokens over a board and by means of computer vision techniques the computer detects the tokens' configuration and plays the composed music. The system's fault tolerance was analyzed to comprise the environments requirements, and our tests showed that the system can work in normal lighting conditions. Furthermore, the interface is a low cost system as it works with a standard webcam. Usability issues were taken into account when designing the board and the tokens as they were cut in wood for robustness and the components' shapes were designed for users to work in a comfortable and error-free way when placing the tokens. As future work we are interested in the application of this system in a real life learning environment. We have already contacted the local music school and they are extremely interested in participating in this project. A user evaluation of this interactive system among the students in the target age group will be conducted and the results will be published. Through the practical use in the class, we will validate the effectiveness of our proposed music composer based on the feedback from teachers and learners, as well as improving our system.

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