MUSED TECHNOLOGIES INC
School of Engineering Science – Burnaby, BC – V5A 1S6
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February 8, 2010

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Functional Specification for a Musical Carpet

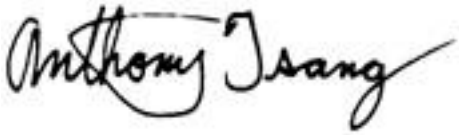
Dear Dr. Rawicz:

The enclose document, *Functional Specification for a Musical Carpet*, describes the functional requirements for the educational device we are developing. The musical carpet will replicate two octaves of a piano embedded into a carpet and will contain additional features that will act as educational aids. This device allows the user to grasp the fundamentals of music in an entertaining fashion.

This functional specification is used to simplify the design process by creating a comprehensive set of requirements, which can be followed throughout the design process. This also contains high-level user test plans that not only help in understanding what we wish to achieve but will save us time late in the development cycle when we are integrating and testing our device.

MusEd Technologies is a team of four driven and skilled individuals: Anthony Tsang, Anton Ayzikovsky, Danny Jiang and Payam Norouzi. If you would like to contact us with questions or comments, please contact Anton Ayzikovsky via e-mail at aaa75@sfu.ca.

Sincerely,



Anthony Tsang
MusEd Technologies Inc.

Enclosure: Functional Specification for a Musical Carpet

FUNCTIONAL SPECIFICATION FOR A MUSICAL CARPET

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Submitted to: Dr. Andrew Rawicz – ENSC 440
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EXECUTIVE SUMMARY

Many studies have been performed linking the healthy development of children and music. There has been some controversy over the legitimacy of these studies. But even if those studies are in question, anecdotal evidence suggests that music is beneficial regardless of whether it can make your child smarter or not. Music is often a highly influential factor in people's lives and we hope to be able to continue this in future generations.

Development has been divided into two teams. One team will program the microcontroller on a development board. The second team will work on the controls and system outputs, testing their functionality separately. As soon as the parts allow for integration, we will begin integrating the separate components so that testing can be performed. Within each team, different features have been prioritized as core features, less core features and additional features.

We have provided detailed requirements that can be used to streamline development. This can also be use the promote uniformity between separate modules and will be critical to streamlining integration. The document also contains our system test plans, whose function is two-fold. Firstly, the test plans can be implemented for testing when development is well underway or nearing completion. Secondly, the system test plan helps paint a picture of desired functionality which complements the requirements listed in this document.

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Glossary

ADC	Analog-to-Digital Converter
DAC	Digital-to-Analog Converter
DIP	Dual In-Line Package
EEPROM	Electrically Erasable Programmable Read-Only Memory
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FCC	Federal Communication Commission
I2C	Inter-Integrated Circuit
LED	Light-Emitting Diode
MCU	Micro-Controller Unit
PCB	Printed Circuit Board
SRAM	Static Random Access Memory
SPI	Serial Peripheral Interface
TWI	Two Wire Interface
USART	Universal Asynchronous Receiver/Transmitter

1. INTRODUCTION

The musical carpet is an educational device aimed at younger children. The goal is to create a product that can both teach and entertain. The device consists of two octaves of piano keys that can be played intuitively, though the device will also be able to synthesize other instruments. This product also includes a play and sing mode, which will indicate whether the singer's voice is in tune with the note played.

1.1 SCOPE

The scope of this document covers both the proof-of-concept and production versions of the musical carpet that MusEd Technologies Inc. is intending to produce. The requirements laid out in the document must be met for the final product to be a success and can be used as a basis for further improvements made to the product.

1.2 INTENDED AUDIENCE

The functional specification document is intended for internal use within MusEd Technologies Inc. as well as for external reviewers. The project manager will use this document to set milestones and ensure that development is progressing as planned. The design engineers will refer to this document to guarantee product compliance while the test engineers will use the test plans to conduct unit tests throughout the development process.

1.3 CLASSIFICATION

Functional requirements are denoted by the following method:

[Rx-y] The functional requirement is listed here.

The R denotes a requirement and is present for every entry. The x is a variable that denotes the requirement number, not in order of priority. Finally, the y is a variable replaced with one of the following three roman numerals.

I. The requirement applies to the proof-of-concept system only.

II. The requirement applies to both the proof-of-concept system and the final production system.

III. The requirement applies the final production system only.

2. SYSTEM OVERVIEW

Figure 2-1 describes the high-level block diagram for the musical carpet. It includes a sensor module, main control unit, audio processing unit, display module, speaker and microphone.

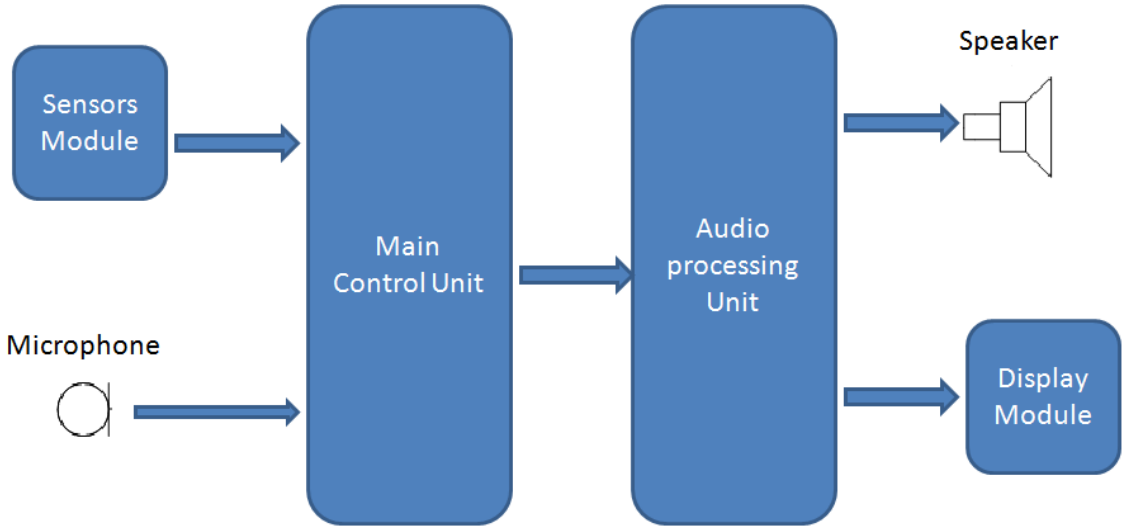

Figure 2-1. High Level Design Block Diagram

The musical carpet has two modes of operation; the basic mode and the voice training mode. These modes are described in Figure 2-2.

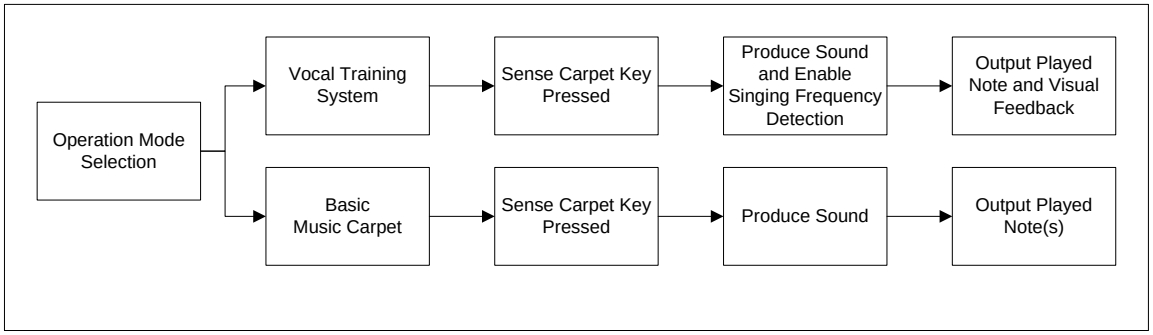

Figure 2-2. Operational Block Diagram

The system consists of a set of step-operated pushbuttons embedded into a carpet, which are connected to the main control unit. The processor sends pre-recorded sound samples of the corresponding frequency out to the speaker system. Consequently, the voice recognition system is enabled. The system filters out the sound of the device itself and compares the user's voice frequency with the frequency of the note being played. The LED indicator shows if the user sings too low, too high or in perfect pitch, providing a perfect voice-training assistant. The system design is shown in Figure 2-3.

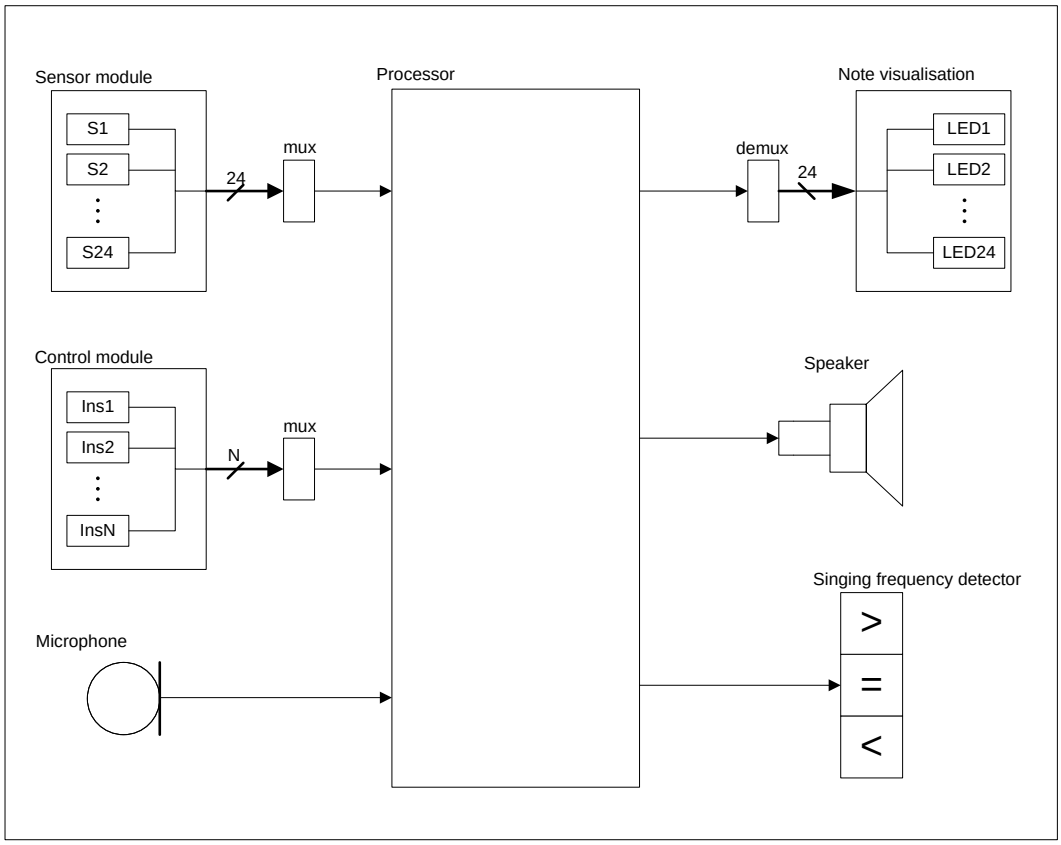

Figure 2-3. System Schematic diagram

The above diagram shows the main features of the product. The twenty-four sensors and corresponding twenty-four LEDs represent the two octaves of notes – white (Do Re Mi Fa So La Ti) and black keys on the piano. The control module is a set of pushbuttons located on the control board and used for selection of the instrument sound desired by the user. The microphone (when enabled) is used to sense the user's voice, which is compared to the note played and the result is the output from the singing frequency detection module. Power to the system is supplied through a regular AC outlet to avoid battery changing/recharging.

3. SYSTEM REQUIREMENTS

3.1 OVERALL SYSTEM REQUIREMENTS

3.1.1 GENERAL REQUIREMENTS

[R1-II] The musical carpet should be able to generate tones from different musical instruments.

[R2-III] The retail price of the musical carpet must be under 100 Canadian dollars.

[R3-II] The musical carpet must be both educational and entertaining. Users can sing the note that was played and the musical carpet will indicate whether the pitch is too high or too low. The display unit should be constructed in the form of an art installation.

[R4-II] The musical carpet should have recording and playback features. Users are able to record the music patterns and play it back later.

3.1.2 PHYSICAL REQUIREMENTS

[R5-II] The carpet should not be too big or too small. A reasonable size would be $1.5m^2$.

[R6-III] The entire system should not weigh more than 600g.

[R7-II] The carpet should be easily folded or rolled without damaging the sensors and other components.

[R8-III] Analog circuit, MCU, speaker, microphone and audio processing unit should be assembled on a single circuit board.

[R9-II] The electronic components should be organized in a logical way for easy circuit debugging.

[R10-III] The user interface should be able to disconnect from the carpet for easy storage and transportation.

3.1.3 ELECTRICAL REQUIREMENTS

[R11-III] The musical carpet can be powered by either four 1.5V batteries or an AC adaptor.

[R12-III] The AC adaptor should accept both 120V and 240V input at 60Hz.

[R13-II] The power supplies must be regulated.

[R14-II] A single power adaptor would provide all the components in the musical carpet.

[R15-III] The power cord should not be too long or too short. A reasonable length would be one metre.

[R16-I] All key nodes should be easily accessible for measurement.

3.1.4 MECHANICAL REQUIREMENTS

[R17-III] The PCB must have 5mm clearance from the case to avoid electrostatic discharge (ESD).

3.1.5 ENVIROMENTAL REQUIREMENTS

[R18-II] The musical carpet is intended for indoor use only.

[R19-II] The musical carpet must function properly under typical room temperatures (10 - 40 degrees Celsius).

[R20-II] The musical carpet should not generate any other noises beside the intended sounds through the speakers.

3.1.6 RELIABILITY AND DURABILITY

[R21-III] A button for resetting the software to factory defaults should be provided along with a software-resetting algorithm in case of any software failure.

[R22-II] The exterior of the case should not be electrically conductive.

[R23-III] The musical carpet must not be break by reasonable amounts of vibration or by falling from less than a two metre height.

[R24-III] The case containing the control unit and display module should be waterproof.

[R25-III] Over-voltage circuitry should be introduced at the input from adaptor in case the wrong adaptor is plugged into our device.

[R26-III] To avoid ESD damage to the printed circuit board (PCB), decoupling capacitors should be installed near power rails and MCU inputs.

3.1.7 SAFETY REQUIREMENTS

[R27-III] The AC adaptor should have an over-current protection circuit, so it won't easily be burnt.

[R28-III] All the electronic components should be lead-free (RoHS compliant).

[R29-II] All the electronic components should be properly installed to prevent electrical shocks.

[R30-III] Each separate part in our device should not be large enough to avoid choking hazards.

3.1.8 STANDARDS

[R31-III] The musical carpet should pass all the requirements for Toy Safety listed by Health Canada [6].

[R32-III] The product must pass the Electromagnetic Compatibility (EMC) test and meet the Federal Communication Commission (FCC) requirements before it is released to the market [7].

3.2 MAIN CONTROL UNIT REQUIREMENTS

The main control unit's primary responsibility is to sample sensors and microphone input and deliver control signals to the audio processing unit so that it plays the corresponding sound. The audio operations will be discussed in Section 3.3. This controlling unit consists primarily of a microcontroller (MCU) with internal analog to digital convertors (ADC).

3.2.1 GENERAL REQUIREMENTS

[R33-II] The MCU must have enough inputs and outputs (I/O) for sensors and LEDs.

[R34-III] The MCU should be as simple as possible while supporting all required features.

[R35-II] The MCU must have at least one ADC for the microphone and the resolution of the ADC must be at least eight bits.

[R36-III] The MCU should have a sleep mode feature for saving power.

[R37-II] The MCU should have at least two pins reserved for external hardware interrupts.

[R38-II] The MCU must have at least 2KB electrically erasable programmable read-only memory (EEPROM) for storing recorded music.

3.2.2 ELECTRICAL REQUIREMENTS

[R39-II] The MCU should operate near 5V.

[R40-II] The power consumption for the MCU should be less than 100mW.

3.2.3 PHYSICAL REQUIREMENTS

[R41-I] In the prototype, the MCU should be in a dual in-line package (DIP). Therefore, it can easily be mounted on a breadboard.

[R42-II] The MCU must be small. A reasonable size would be a 5cm length and a 1cm width.

[R43-I] The MCU should have a rectangular shape.

3.2.4 COMMUNICATION INTERFACES

[R44-I] The MCU should have a Serial Peripheral Interface (SPI) for communicating with devices such as EEPROM or a digital potentiometer.

[R45-I] Communication protocols should consist of two wire interface (TWI), also known as inter-integrated circuit (I^2C).

[R46-II] The MCU must include a programmable, serial universal asynchronous receiver/transmitter (UART) for communicating with a computer. We will also create a graphical user interface (GUI) and the user will be able to control the musical carpet through the GUI.

3.2.5 USABILITY REQUIREMENTS

[R47-I] The MCU should support C compliers.

[R48-I] The MCU should have a Joint Test Action Group (JTAG) interface for easy debugging.

3.3 AUDIO PROCESSING UNIT REQUIREMENTS

The main function of the Audio Processing Unit (APU) is to receive the signals provided by the main control unit and to play the corresponding sound. The Audio Processing Unit will primarily consist of a microcontroller with an external digital to analog convertor (DAC), external SD card, current-voltage amplifier and digital potentiometer.

3.3.1 GENERAL REQUIRMENTS

[R49-II] An 8-bit DAC will convert sound samples into an analog signal and has to be fast enough to output samples at 22KHz.

[R50-II] The APU should be able to produce multiple sounds at the time.

[R51-II] The APU gain should be user adjustable.

[R52-II] The APU should have a digital potentiometer for controlling the output gain.

[R53-II] The APU should have two tactile buttons or a volume knob for controlling the gain

[R54-II] The APU should have a basic current-voltage operational amplifier.

[R55-II] The microcontroller for the APU should be capable of running at a 1MHz clock speed.

[R56-II] The APU's microcontroller should have a timer with a separate pre-scaler.

3.3.2 MEMORY REQUIRMENTS

[R57-II] The APU must be capable of storing sound samples with a combined length of 10 minutes at an 8KHz sampling rate and an 8-bit depth. Most microcontrollers do not have that much internal memory, therefore an external SD card can be used for this propose.

[R58-II] The APU's microcontroller must have at least 1KB EEPROM for storing the user recorded music.

[R59-II] The APU's microcontroller should have at least 2KB static random access memory (SRAM) for buffering.

3.4 USER INTERFACE REQUIREMENTS

The user interface consists of a set of buttons for changing musical instruments and adjusting gain. It also includes LEDs as display elements. The output should be driven by the main control unit or the audio processing unit.

3.4.1 GENERAL REQUIREMENTS

[R60-II] The user interface should be available at all times.

[R61-II] Response to user input should be through an LED output.

[R62-II] The user interface should notify the user when their voice is out of tune.

[R63-II] The user interface should allow the user to select different musical instruments.

[R64-II] The user interface should allow the user to select different modes of operations.

3.4.2 USABILITY REQUIREMENTS

[R65-II] The user interface must be simple to use.

3.5 SENSOR REQUIREMENTS

Carpet-embedded sensors are a crucial part of our system. The sensors are responsible for detecting user inputs, in the form of a footstep, and transmitting the information to the main controller unit. A capacitive sensor method is used in our design, employing metal sheets and a soft, compressible material as the dielectric.

3.5.1 GENERAL REQUIRMENTS

[R66-II] The sensor surface area should be at a comfortable size for both adults and children to operate.

[R67-II] The tactile force required to engage the sensor should be low enough for a toddler to make the contact, but should avoid false positives.

[R68-II] The sensor should be able to withstand substantial force, like that of a heavy adult, without malfunctioning.

[R69-III] The sensor should be able to pass a cycle-test of at least 100,000 cycles.

[R70-III] The sensor's active area should be evenly distributed over the entire piano key surface. Meaning that pressing the middle of the key or the edge should produce the same effect.

[R71-III] The sensor's response time should be less than 100 ms.

3.5.2 SAFETY REQUIREMENTS

[R72-II] The parts of the sensor that carry current should not be exposed under normal operation.

[R73-II] The sensor's contacts should be within a safe voltage and current so that it does not cause bodily harm to humans or pets even if exposed.

3.6 SPEAKER/MICROPHONE REQUIREMENTS

The microphone and speaker are one of the main user-device interaction modules. However, requirements are flexible for these two units, since any basic speaker and microphone combination with standard audio plugs can be used.

3.6.1 GENERAL REQUIRMENTS

[R74-II] The speakers should be able to output 15 Watts at the frequency range of 100 Hz – 10 KHz.

[R75-I] The speakers should be able to interface with the control units via a standard 3.5 mm stereo jack.

[R76-II] The microphone's frequency response should be in the range of 100 Hz – 10 kHz.

[R77-I] The microphone should be able to interface with the control units via a standard 3.5 mm stereo jack.

4. USER DOCUMENTATION

[R78-III] The user documentation should consist of a user manual as well as a setup guide.

[R79-III] The user documentation should be written for consumers with minimal technical expertise.

[R80-III] A non-technical writer should edit the user documentation prior to finalization, to ensure an appropriate reading level.

[R81-III] The user documentation should be written in English, French and Spanish for the North American market. The document can be translated for other languages if sales are expanded to an international market.

5. SYSTEM TEST PLAN

To ensure the musical carpet is fully functional, we will thoroughly test each component, as well as the whole system with all the parts integrated. The component testing consists mainly of testing for the sensors, the main control unit and the audio processing unit.

5.1 SENSORS TESTING

The output of the sensors should simply be an on or off signal. We will first test the sensor under normal usage conditions. That is, the sensor will generate high/low signals when it is under a normal or compressed condition. Next, we will ensure the sensor is able to withstand the substantial force of a heavy adult without malfunctioning. After we run the same test for every sensor, we will combine all the sensors and perform similar tests as well as measure the power dissipation of the sensors.

5.2 MAIN CONTROL UNIT TESTING

The main control unit is to sample sensors inputs and deliver signals to the audio processing unit. The control unit acts as the interface module between the sensor module and the audio processing unit. Before the main control unit is connected to the sensor module or the audio processing unit, we will simulate sensor inputs using several pushbuttons and the control signals sent to the audio processing unit will be monitored using LEDs. For the microphone input, we will be feeding in a sinusoidal signal from the function generator. The microcontroller should be able to covert the signal to digital samples based on the magnitudes of the input signal. Then it will analyze the signal to provide user feedback.

5.3 AUDIO PROCESSING UNIT TESTING

The audio processing unit is the most challenging part of our system. The audio processing unit should be able to generate multiple sounds at the same time instead of simply playing one sound. Comprehensive combinations of sensor activations will be tested to ensure proper playback. Having accomplished this successfully, we will then need to process the voice of a singer and compare it with our sample within a pre-determined threshold. The result will be compared and shown, using the user interface.

5.4 INTEGRATED SYSTEM TESTING

Once everything is put together, it is time to test the final product. First, we will test the integrated product within our team. Then the final test would be done in public. We will let people come and play with our instrument so that we can spot any device malfunctions that we could not discover thus far.

6. CONCLUSION

The functional specifications listed in this document provide a set of comprehensive requirements for the musical carpet. Development of the proof-of-concept has begun and is planned in accordance with the requirements listed with I or II. The proof-of-concept is expected to be complete and available for evaluation by April 3, 2010.

6. SOURCES AND REFERENCES

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