Design of a tactile audio gallery for visually impaired students

Ajay Ramesh, Nithin Raj, T K Srikanth, and Madhav Rao

***Abstract*—Technological advances towards improving teaching tools to aid better learning experience for visually impaired students is continuously driven. The challenge from the engineering design perspective is to develop systems that can provide comprehensive information, as imparted to visually aided students in a classroom. Braille for text is highly useful, but does not provide adequate information for pictorial representations. Hence, learning from diagrams or graphs is challenging for visually impaired students. An alternate method is needed to deliver content and provide an enhanced learning experience. A tactile audio gallery tool was developed to offer consolidated guided information in a view to improve learning experience for visually impaired students. The novel educational tactile audio graphics platform consists of a board with embossed pictorial diagram, designed with embedded array of parallel plate capacitors that are interfaced to the microcontroller with inbuilt speakers to deliver the content. The content in the form of text is preloaded in the memory, which is accessed by the microcontroller and rendered to the speaker, on tactile response.**

Keywords*—*tactile, diagrams, visually impaired.

I. Introduction

Braille, a standard mass scale technology adopted to perceive text through touch, and audio translations of written text have made books accessible to the blind population. However, the technology employed for text perception is not suitable in rendering complete cognitive information about pictures or graphics [1], [2]. Diagrams are considered to provide consolidated information, leading to a better learning and understanding of the topic. However, for visually impaired students, the inability to perceive rich information in the form of diagrams, graphs, and maps is an inevitable loss. Hence, a much needed learning tool that can offer similar cognitive learning capability is highly recommended. An alternative in the form of tactile based raised points has been explored [3], [4], [5], but the consolidated information delivery is sequential in nature, with raised braille based text description about the diagram given in a separate document. The visually impaired students need to go back and forth on the raised diagrams and braille text to retrieve comprehensive information, which makes the learning process tedious and time consuming. The other challenge is to standardize perceivable dimensions with variations for the diagrams and maps in the physically raised structures, often limiting the scope to add consolidated information. A tactile graphic system in the form of a touch panel has been implemented [3], [6], but at high manufacturing and design costs. Few other works utilize image data from kinect and web camera. However, the overall system remains non-portable and fixed to the workstation [3]. Few commercial systems such as Baker's system and Iveo Hands-on learning system [7] use dedicated software and are not easily accessible due to high cost, non-portability, and prerequisite computer literacy [8], [9]. Hence, the best solution was to simultaneously provide information through an audio channel while the diagrams are tactile sensed, resulting in two dimensional (2D) comprehensive information, which is a step closer to guided information provided to visually aided students. An audio guidance device in the form of a digital button was also experimented with [8]. The digital button was designed to repeat the information for the learners, but the bottleneck was to find optimum position of the button in a densely informative space and making the design process scalable. Various forms of tactile educational methods [10], [11], [12] have been developed, which deliver information related to graphics or maps alone, yet additional information was not made available at the same time. Tactile audio graphic system using smartphone based touch panel, that is continuously monitored by Kinect is developed and tested, as described in [8], however the integrated system with touch panel and an independent kinect system is considered economically unviable. Tactile graphics with Quick Response (QR) code driven voice data has also been investigated [10], but the size of an individual QR code limits the design space. An audio guidance system is integrated with the developed tactile sensing module to deliver content which enhances the perception of comprehensive information by the visually impaired students. The paper discusses a scalable solution in the form of tactile audio gallery system for visually impaired students.

II. Design

The tactile audio graphic system is designed as two independent modules in the form of a reader and a card. The tactile audio reader (TAR) subsystem is designed to identify the tactile sensed regions and initiate the delivery of audio content. The tactile diagram card (TDC) subsystem consists of tactile graphics printed on a plastic substrate, which is then fixed to a plastic board with underlying sensory system. The two subsystems are electrically wired to provide comprehensive information to visually impaired users based on the touch on the diagram. The underlying sensors in the TDC unit support in identifying spatial location of the touch. The TAR unit includes an audio content delivery module which is initiated based on the tactile sensing in the TDC unit. The TAR unit is designed with an Arduino Mega microcontroller which interfaces with all the TDC wires via two multiplexer units, and drives the speaker for delivering audio content. Arduino Mega offers SRAM size of 8KB, which is apt for parsing a program to select and play the audio file. An Secure Digital (SD) memory card and Radio Frequency Identity (RFID) reader are wired to the microcontroller via Serial Peripheral Interface (SPI) protocol in the TAR block to pre-store the audio contents, and identify a diagram in the TDC unit respectively. An array of capacitive touch sensors in

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the TDC unit forms the tactile component of the design. The tactile sensory system is designed in the form of capacitive sensors where the plastic based embossed diagrams form the dielectric. The copper patch on one side forms one plate, user touch forms the other plate, and completes the capacitance, thereby the change in charged peak voltage due to the variable capacitance is detected by the microcontroller. A schematic of a single capacitive sensor formed on the embossed plastic diagram with copper patch forming one side of the plate and user touch forming the other side of the plate is shown in the Figure 1. The variable capacitance adjusted due to the user touch demonstrates a higher charging time constant, as compared to a smaller capacitance obtained before the user tap. The array of copper patch is connected to an MPR121 multiplexer and further extended to Arduino Mega controller via I2C lines. The MPR121 multiplexer is a popular industry standard designed general purpose capacitive measurement 10-bit output device [13]. On user tap, the total capacitance measured on sensing channel is the combination of finger touch induced capacitance to ground (C_X), and the constant stray capacitance (C_{STRAY}), as shown in the Figure 1. The MPR121 applies a constant DC current source to measure the peak voltage reached, during fixed charging and discharging time. The peak voltage measured is inversely proportional to the total capacitance formed at the sensing output. A 10 bit analog to digital converter (ADC) integrated in the MPR121 offers a detection resolution of 0.01 pF.

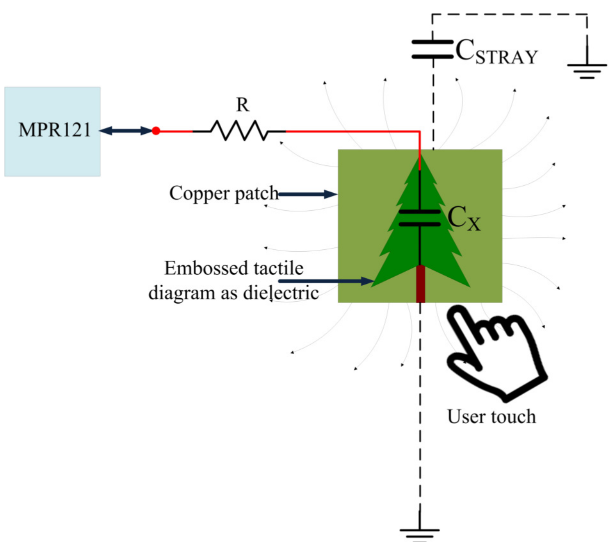
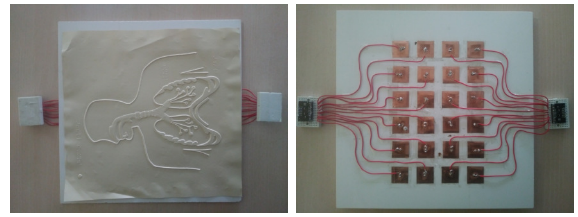


Fig. 1: Schematic of the copper patch based capacitive tactile sensor.

The sensory system is currently designed as an array of copper patches with individual patch size of 1×1 $inch^2$, and a gap of 0.5 $inch$, on the rear side of the planar plastic board, as shown in the Figure 2. This forms the tactile diagram card module in which each sensor in the array maps to particular information in the embossed diagram, printed in the card. Currently, 6×4 capacitive sensors are designed as a rectangular grid to position the diagram effectively. The audio content, delivering localized information in the TAR are mapped to sensors, designed in the tactile card. The system expects the CAD designers to print the diagram in proportion to grid space covering the sensors.



(a) (b)

Fig. 2: Photograph of (a) tactile diagram placed on the front side, and (b) the grid of copper patches designed on the rear side of the board.

The embossed tactile diagram printed on a flexible paper is borrowed from AssisTech at IIT Delhi which is the Center of Excellence in Tactile Graphics [2]. The affordable tactile diagram is fabricated using 3D printed and thermoformed mold, invented by AssisTech. The tactile diagram is glued to the planar plastic board of $3mm$ thickness. The sensory system is designed on the other side of the plastic board. The overall tactile audio graphic system design is shown in the Figure 3.

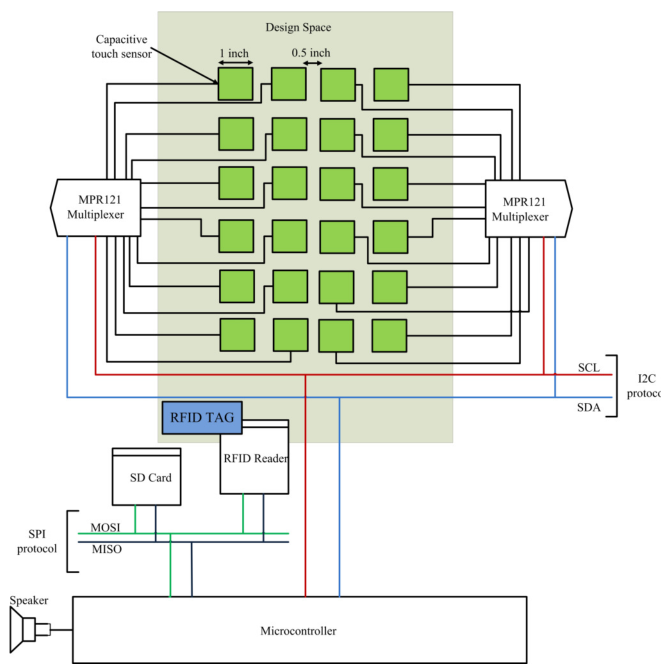


Fig. 3: Schematic diagram of a tactile audio graphic system.

The content related to the printed tactile diagram is loaded in the external SD memory card, which is interfaced to the microcontroller. An Arduino Mega is considered for this prototype design, to accommodate for higher SRAM size of 8 KB, store mappings and playing audio files. The Arduino Mega board is also used to interface multiplexers, external memory, and RFID reader. An RFID reader is included in the TAR design to identify a TDC unit from a batch, designed for a curriculum, and deliver specific content related to the TDC block.

III. Experimental Results

The tactile sensor designed in the form of capacitive touch sensor was experimentally tested to determine the change in capacitance. A pulse signal with an ON time of 5 ms, and off time of 5 ms was provided to a copper patch forming the first plate of the capacitive sensor. The other conducting plate is formed by user touch, hence a touch sensitive variable capacitance is offered by the sensor. Intuitively, with no touch, low capacitance is offered by the patch, and on user touch, the capacitance increases. The voltage difference measured across the copper patch and user index finger when away and tapped near the design cell is shown in the Figure 4. The change in the charging time constant due to user tap indicates an increase in the capacitance on user tap. The low time constant difference as indicated in the Figure 4 is sensed by the high resolution MPR121 multiplexer which is connected to the Arduino Mega controller via the I2C bus. Figure 4 shows the zoomed version presenting the difference in charging profile during user touch and otherwise.

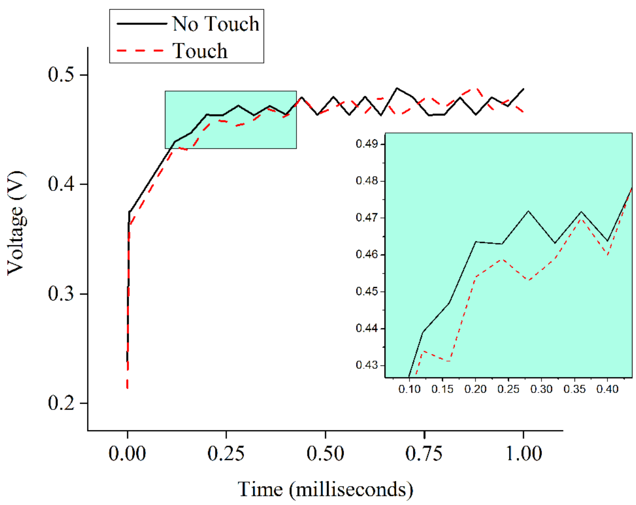
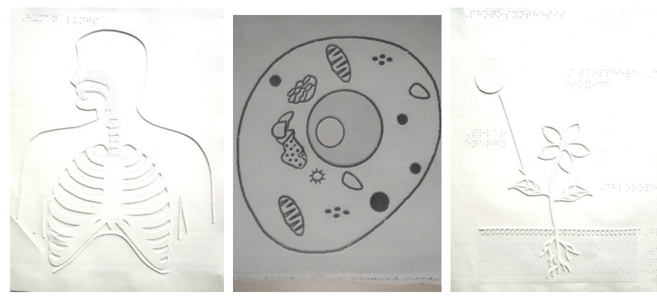


Fig. 4: Charging profile of touch enabled capacitive sensor.

The developed tactile sensing and audio feedback was tested on three popular diagrams, as suggested by the blind schools and shown in the Figure 5. These diagrams are generally part of biology, and physics curriculum, and were evaluated for the proposed system design. The localized content for each TDC modules were preloaded in the TAR block consisting of speakers, micrcontrollers, and RFID reader. Each of the TDC modules was given to a group of visually impaired students. The touch on the embossed diagrams initiated necessary specific audio information related to the touched region, in addition to the tactile sensing perceived by the students. The minimum resolution was set to twice the general size of an index finger, which is set to slightly above $2 \times 2\ cm^2$. Tactile perception with index finger was recommended for the students evaluating the TDC unit. The diagram was placed on a grid consisting of an array of sensory system and regional information was successfully invoked on tactile sensing of that particular region. A different tactile diagram with already stored content requires minimum setup time to replace a diagram board in the designed system. The plug and play mode of diagrams with a single tactile audio graphics reader system makes the overall system feasible and economically viable. Each of the tactile cards is configured with a tag to identify the diagrams in the overall pre-stored audio lessons in the external memory. Any new addition of TDC with the breakout wires connecting the array of copper patch made capacitive sensors, are required along with the audio content of the diagram. The labelling in the audio content are mapped to the underlying sensors designed in the TDC block.



(a) (b) (c)

Fig. 5: Different tactile design cards showing (a) human respiratory system, (b) animal cell, and (c) photosynthesis, which were used to evaluate the proposed system.

IV. Conclusions

The proposed tactile educational audio gallery system in the form of TAR and TDC were designed and developed in a view to offer comprehensive audio guided information and easy usage for the visually impaired students. The reader system accepts multiple diagram cards, each labelled with a unique RFID tag to identify and deliver relevant audio content. The TDC with a grid of copper patch based capacitive touch sensors, was designed to map the diagrams accurately. The tactile sensing of various parts in the diagram and audio delivery of the contents was found to be feasible with different users. The independent card and reader subsystem design also ensured that the sensory system and its dimensions are standardized and the diagram printing is scaled accordingly with no changes in the tactile reader module. The robust tactile reader module design allows the flexibility to use multiple tactile diagrams and provide a single reading solution for graphics based information to visually impaired students, which otherwise does not exist.

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