An Effective Design and Construction of Robotic musical instrument Using PIC Microcontrollers

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Abstract— *an automated musical instrument is a device which generates sounds using mechanical actuators, electronics and control process rather than conventional human involvement. The main problem in developing such a device can be listed as the initial cost required for the relevant music instrument and actuators, undesired damages caused to the instrument during designing process, the size of the device and the mechanism adapted to store data and codes of long programs which represents a song or a music. This paper investigates the concept of design and construction of an effective robotic musical instrument whose operations are governed by PIC microcontrollers to overcome the above mentioned problems. The construction is implemented over an electric guitar using a set of unique actuators along with analogue electronics. The actuators used to pick the strings and hold the chords are designed using discarded transformers and metal strips obtained from construction toys. The actuators are controlled with appropriate timing via the microcontroller to generate the pre-programmed music. Besides, the entire device was portable in the original guitar cover itself. What's more, the power supplied to the device is 20 V DC. Moreover, the performance of the device in generating good music was remarkable.*

Keywords—PIC microcontrollers, automated musical instruments

I. INTRODUCTION

Robotic music instruments are known as devices those generate sound via electric motors, solenoids, gear systems with the combination of electronics and control process. The idea is to generate music without conventional human involvement. Robotic music instruments are more useful for Computer music societies those are being formed in some developed countries such as Korea, Japan, Spain, Turkey etc. (Center, 2016). Robotic musical instruments is a field which exists since many decades. The ICMA (International Computer Music Association) had been conducting several conference since 1974 (Association, 2016). There are several categories of robotic musical instruments. The main categories those can be listed are Piano robots, Percussion robots, String robots and Wind robots. Despite the above mentioned categories of robotic musical instruments, what's the purpose of evolving a robot that could play music instruments? In other wards what is the purpose of automating a musical instrument which is secluded from human involvement regarding music generation? There are specific reasons for this.

a. Conflicts between musicians in a music band.

b. Interference in music playing between musicians due to Drugs, Ego etc.
c. Specific Allergies of Musicians for the material that the instrument is made of.

The main root cause for dissolutions of many music bands around the world were in-between conflicts, usages of drugs and ego between members of the band. There are several cases which lead ego towards repercussions like murders (Hurston, 2013). But this didn't end the music journey of some members of the dissolved bands. They adapted robotic musical instruments to their bands in order to evade conflicts, drug addicts and ego (Times, 2001). In the history of brass music instruments, allergy was an unfortunate instance for many musicians. Many musicians receded from playing those instruments to which they were allergic (USA, c2012). Most of these musicians who were basically engineers, proposed various methods to operate those instruments via mechanical and computer controlling. In many countries around the world, musical groups have adapted robotic musical instruments (Wikipedia, 2015). As years Kept passing many associations were formed to encourage this newly emerging field. For instance, ICMA etc. And in many universities such departments were established. For instance, The Electronic Music Department etc.

II. METHODOLOGY AND EXPERIMENTAL DESIGN

A. Methodology

Though, playing of musical instruments by human seems to be an easy task, playing musical instruments using robots is a very difficult task. However, robotic musical instruments are built by paying huge prices to the above mentioned fact. So what are the prices payed?

1. Usage of highly expensive actuators and control units for the task.
2. Deforming or damaging the musical instrument in order to couple those actuators.
3. Increment of size and weight of the musical instruments.
4. Disabling the portability of the device due to increased size and weight.

This thesis is based on the concept of design and construction of an effective robotic musical instrument whose operations are governed by PIC microcontrollers to overcome the above mentioned drawbacks in conventional robotic musical instruments.

1) Reduction of initial cost of the device: in order to reduce the cost of the project, no music instruments are newly bought. Therefore the music instruments used for the task is a domestic electric guitar. Solenoids are desirable mechanical devices which could be implemented on the guitar to actuate it very easily. But the drawback in solenoids are the force-to-size and force-to-cost ratio. The force exerted by a low cost or low size solenoid is comparative low (GEEPLUS, 2010). Therefore, discarded 12V transformers are used along with metal strips which are obtained from construction toys in order to evolve a unique actuator which is replaced with solenoids. The reason for using a transformers is that, a transformer is fundamentally an electromagnet which can be easily scrounged from discarded devices such as poewepacks, chargers etc. Moreover, PIC microcontrollers are used since they are very low in cost compared to other embedded devices.

2) Refraining from damaging the music instrument: in most of the automated musical instruments the original music instrument is deformed to hold the actuator permanently and firmly either by cutting or drilling holes. This eventually affects the quality of music generated by the automated musical instrument due to cracks formatted with time (Forster, 2016). Since the main goal of the project is not to damage the musical instrument and create good quality music, actuators those are designed via transformers are coupled to the neck of the guitar by clamping it rather than permanently fastening them. Also original holes drilled by the manufacture on the guitar are used to fasten some of the actuators avoiding the need to drill additional holes. These methods ensures that no damages are caused to the musical instruments and good quality music is generated.

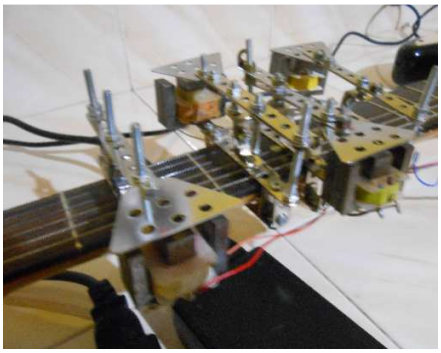

Figure1. Actuators clamped to the neck of the guitar

3) Reducing the size and weight of the device: In many of the automated musical instruments the size and the weight is normally high. The reason for this is the usage of bulky actuators, multiple control units etc. The size of the proposed device is compact due to the compactness of the actuators and PIC microcontroller used. A PIC microcontroller is several times smaller than many other development boards which could be used for the task such as Arduino, Arm boards etc. The weights of the actuators are limited since the transformers used for the task are very small in size.

4) Enabling the device to be portable: many of the automated musical instruments are not portable due to their increased size and mechanism used to generate music. For instance consider a String robotic musical instrument. Portability becomes impossible since most of these devices are fixed permanently to an enormous support which bears all the actuators. In the case of the proposed device, all the actuators are coupled to the guitar itself in a confined area. This enables the entire device to be portable in the original guitar cover itself.

B. Experimental Design

The functionalities of the proposed device in music generation is based on the program which is downloaded to the microcontroller. The program downloaded to the microcontroller is a set of instruction codes which represents a particular song or a music. The proposed robotic musical instrument is a combination of three major components. They are the electric guitar, the PCB (Printed circuit board) which bears all the electronics and

microcontroller containing the software and the actuators to pick the strings and hold the chords.

Figure2. The proposed robotic musical instruments

1) The PIC microcontroller: Consider how a guitar is played by a human. It's a synchronized task of holding chords and picking the strings according to the commands given by the brain with accurate timing. Similarly, the back bone of this project is to govern the operations of the mechanical actuators with appropriate timing through computer algorithms to generate music. Whereas the actuators on the guitar plays the role of a human's finger while the PIC microcontroller plays the role of a human's brain. The PIC microcontroller used for the task is a 16F84A chip. As the encoded song is downloaded to the microcontroller, it functions as a human brain commanding the appropriate actuator with appropriate timing. The microcontroller can't be directly used to energize the actuator since the output voltage of the microcontroller is insufficient to energize the 12V transformer coils in the actuators. For this reason, the 5V outputs of the microcontroller is sent to an amplification circuit consisting of MOSFETs (Metal-Oxide Semiconductor Field-Effect Transistor) and OP-amps (Operational Amplifiers). The out puts of the OP-amp for 5V inputs are set to be 20V. This output is used to excite a MOSFET to drive a large current to energize the actuators. All this tasks are executed within a fraction of a second. Energizing and de-energizing various actuators with appropriate timing via the microcontroller enables the guitar to automatically generate the exact music that was downloaded to the microcontroller.

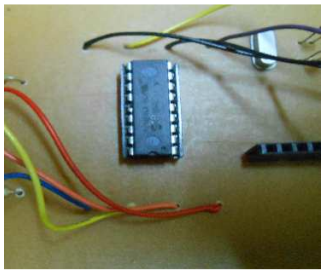

Figure3. The 16F84A PIC microcontroller

2) Actuators used: There are eight similar actuators fixed to the guitar in order to get the desired task done. Four actuators are coupled to the neck of the guitar to hold different chords while others are fixed at the picking area to pick the relevant guitar strings. The main recipes of the actuators are discarded 12V transformers and metal strips obtained from construction toys. Small transformers are made by stacking E and I plates in a specific pattern to form a core. The transformers are given a modification by re-arranging the pattern of their usual stacking. All the I plates are avoided while all the E plates are stacked back to gather in the same direction. This eventually creates a poly electromagnet which has one N-pole and two S-poles to enhance the magnetic force imposed by it *(INDUSTRIAL MAGNETICS, c2007-2016)*, *(Fecht, 2014)*. The metal strips are used to form a cantilever. One end of the cantilever is rigidly fastened to a vertical screw. Besides the screw is fastened to one end of the base strip while the other end of the base strip is fixed with the modified transformer. The other end of the cantilever is fixed with a flat metal plate having a clearance of around 1 mm with the transformer. A plunger right above the frets on the guitar neck of the appropriate chord/note is fixed to the middle of the cantilever to hold chords and music notes by pressurizing the strings while the cantilever is pulled by the strong electromagnet. In the meanwhile, at the other end of the guitar the same mechanism is used to hammer the appropriate strings instead of picking. Four actuators are used to hold specific chords and notes on the guitar frets while three actuators are used to strike individual strings when playing music notes and one actuator to strike three strings together when playing chords.

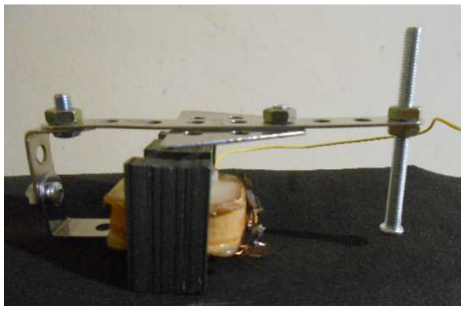

Figure4. The actuator used to hammer the strings

3) Force calculations: Normally the force required to pressurize a string in order to fret a clean note is around 5N (500 grams). Therefore the electromagnets should exert a force at least around 5 N on the strings. The force exerted by an electromagnetic is given by the following equation.

Force = ((N x I)^2 x k x A) / (2 x s^2)

where N is number of turns of a coil,
I is the current passing through the coil,
A is cross-sectional area of the solenoid,
s is distance between solenoid and external object,
k is permeability constant (4 x PI x 10^-7)

Figure5. The equation for the force exerted by an electro magnet

The maximum current measured through the coil was 470 mA. The cross-section area of the solenoid core is 1.5 cm^2. The approximated distance between the cantilever and the transformer is 1 mm. The number of turns of the transformer coil is 600.

$$F = \frac{([600*470*10^{-3}]^2*[4*\pi*10^{-7}]*[1.5*10^{-4}])}{(2*[1*10^{-3}]^2)}$$

$$= 7.4949 \text{ N}$$

$$\approx 7.5 \text{ N}$$

This result ensures that the force exerted by the electromagnet is sufficient enough to pressurize the string to hold a clean note/chord. Recall the fact that the modified transformer is a poly electromagnet. For this reason the actual force exerted by the actuator will be higher than the theoretical value obtained above.

4) PCB and circuit components used: The entire circuitry is printed on a copper clad board to obtain a PCB layout having a size of 8x3 $inch^2$. The reason for this is to avoid complexity, size increment and stray capacitance due to increased wires. Since the actuators are energized and de-energized repeatedly at considerably short intervals the circuitry of the project can barely be considered as a high frequency circuit. For this reason, using jumper wires may create undesirable impedance those may lead the circuit to malfunction. This impedance can affect the stability of the OP-Amp (Carter, c2009), (Ardizzoni, 2005) causing the actuators to be under energized. Therefore a PCB layout is used to avoid increased wire resistance, external wires and stray capacitance.

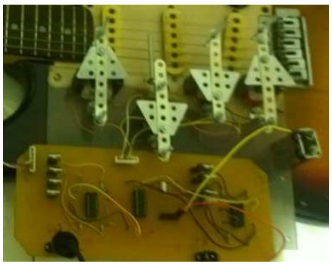

Figure6. The PCB used for the task

5) Encoding of music/songs: Consider the proposed robotic musical instrument prior to the download of software/program to the microcontroller. The device can be compared to the body of a human who is in coma. Though the device is powered up there will be no music generated since the microcontroller provides no signals to the actuators. Therefore, the encoded song /music should be downloaded to the microcontroller in order for the device to function. The encoding of song is a process of converting a song that could be listened by ears into instruction codes those could be executed by microcontrollers. For instance consider a song being played by a human on a guitar with the following chords progressions. A _ $C^{\#}$ _ D _ D^{b} _ E and so on with a delay of 500 ms (milliseconds) in between two chords. Encoding the above chord progression is done by writing a program to instruct the microcontroller's I/O ports (input and output) in the correct order with a delay of 500 ms to signal the actuators those are relevant to holding those chords. Similarly, any songs or music can be encoded using the method mentioned above. As the encoded song is downloaded to the microcontroller the reverse process is done by executing those encoded instruction to generate the exact music via the guitar.

III. RESULTS

The cost of the proposed robotic musical instrument was limited to 600 rupees since many of the materials and components used were obtained from discarded items.

What's more, no damages were caused to the guitar that was used. The entire device was able to be packed without any damages in the original guitar cover itself. However, the proposed robotic musical instrument's performance in generating good music while fulfilling all the objectives discussed above was remarkable.

IV. DICCUSSION AND CONCLUSION

A. Discussion

Encoding a particular song/music is the critical task in this project. There are two parameters which should be known in order to encode a song.

1. The exact music notes and chord progressions of the song.
2. The actual time gaps between music notes of the songs that's to be encoded.

The task of encoding may be easy for a person who has some knowledge in music. As the music is listened by ears, the music notes and the chord progressions may be recognized easily. Therefore, programming the microcontroller in order to signal the actuators relevant for holding those music notes and chord progressions won't be a difficult task. Despite the fact of identifying the music notes and chord progressions, identifying the timings of a song is a tedious task even for anyone who has good music knowledge. Therefore, an interval timer is used to calculate the timings between music notes and chord progressions. The timer is manually clicked each and every time when the music notes are changed while listening to the song. The timer displays the consecutive timings between two clicks. These timings are used to encode the music/song. The average of five time measurements are taken in order to increase the accuracy of the timings and avoid human errors.

The memory capacity of the PIC microcontroller should be considered when encoding a song. If the coding exceeds the memory capacity of the microcontroller due to increased lines of codes, the encoded program can't be downloaded. Therefore, longer programs are written using functions. For instance consider a program having around five hundred lines, due to repeating set of codes. The repetitions of these codes would acquire huge storage capacity. If the repeating part is written under a function, the program of five hundred lines may be limited to around hundred lines. This may save a huge storage space in the memory for additional songs which could be downloaded.

Unlike any other instruments, an electric guitar enables the player to incorporate the following effects while playing it.

1) Bending: Bending is a process of bending a string with the finger across the fret while holding a music note in order to vary the tension of that string. This changes the pitch gradually adding colourful effects (creativeguitarstudio, 2009).

2) Squealing: Is a technique used to make the guitar whistle. The strings are picked with the edge of the pick (CrashCourseMuso, 2010).

3) Harmonics: The strings are given a light touch in specific places on the fret board to reach extremely high pitch notes (rockongoodpeople, 2007).

4) Pick-Sliding: It's a technique used to get the jet effect by sliding the pick along the strings (Channel, 2009).

5) Palm muting: The vibrations of the strings are decayed much faster than usual by partially resting the palm on the strings (iVideosongs, 2008).

Likewise, There are many techniques such as tapping hammer-nos, pull-offs, sweep pickings etc. What's more, all these innovative effects are manually generated by a keen guitar player depending on his feelings and circumstance. To facilitate these effects to the Robotic musical instrument, a different type of mechanism can be implemented no the actuators. For instance a feasible mechanism to bend the string, to slide the pick along the string etc. Also, introducing a neural network into the main system, can introduce a new method to encode the songs automatically, when the original music is listened by this intelligent system.

B. Conclusion

This thesis is based on the concept of design and construction of an effective robotic musical instrument to overcome the drawbacks of conventional robotic musical instruments using PIC microcontrollers. These drawbacks were discussed in this thesis. Also the mechanics, electronics and software aspects of the device were analysed. An electric guitar was used with several scrap materials, electronic components and a 16 series microcontroller to achieve the objectives of this project. Automating a guitar is totally different from automating any other music instruments. A guitar is an instrument which is totally feel based as well as a very human instrument when comparing with other musical instruments. However, the performance of the developed robotic musical instrument in generating good music while overcoming all the drawbacks in conventionally automated music instruments discussed in this thesis was excellent

and successful. Moreover, this may be considered as a new field to create automated musical instruments to express innovative music ideas.

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