Electronic Guitar MIDI Controller for Various Musical Instruments Using Charlieplexing Method

Robinson Devasia, Aman Gupta, Sapna Sharma, Saurav Singh and Neeru Rathee

Abstract Music is nowadays, a way to learn for kids, passion for youth, and a mode of meditation for adults. The urge to be able to use different varieties of sounds for a creative composition of music is the biggest challenge for musicians, which is quite complicated as well as time-consuming task. To resolve this issue, this paper presents an approach to generate sounds of various musical instruments corresponding to the particular notes of a guitar. The fundamental principle behind the proposed work is that, though all the musical instruments play the same notes but have different timbre characteristics. The electronic guitar is designed in such a way that it enables a guitarist to play all kinds of instruments without physically learning them. The guitar is connected to a computer through a microcontroller. It has multiple input ports, a part of which acts as frets and remaining as strings. The number of input pins is far less than the actual number of frets and strings. The technique called Charlieplexing achieves it. The instrument to be played can be selected from the instruments listed in the software. After selecting a particular instrument, a guitarist can play it just like a conventional guitar. Computer connectivity also allows the guitarist to practice music with earphones making it a soundless device for others.

R. Devasia (✉) · S. Sharma
Indraprastha Institute of Information Technology Delhi, Okhla Industrial Estate, Phase III, Near Govind Puri Metro Station, New Delhi 110020, Delhi, India
e-mail: robinson18173@iiitd.ac.in

S. Sharma
e-mail: sapna18222@iiitd.ac.in

A. Gupta
Continental Pvt. Ltd., Bengaluru, Karnataka, India
e-mail: amanguptamsit@gmail.com

S. Singh
Rochester Institute of Technology, New York 14623, USA
e-mail: ss3337@rit.edu

N. Rathee
Maharaja Surajmal Institute of Technology, Janakpuri, New Delhi 110058, India
e-mail: neeru1rathee@gmail.com

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1 Introduction

Music is a tool, which connects souls and this is the reason it has been used in various therapies [1], control, and guidance. Creating music is an art. The notes, rhythm, pitch, and texture have to be in perfect proportion otherwise it would be nothing more than noise. Music is also a part of our culture, which we have seen evolving from traditional folk music to rock bands [2]. It has become a way to express oneself, and the passion is increasing day by day.

The world has witnessed musicians like Bob Marley, The Beatles, Tansen, Hari Prasad Chaurasia, Zakir Hussain, Ravi Shankar, and many more. Each of them was/is an expert in their field. The Beatles is known for their rock music. Zakir Hussain is known for his tabla playing art, Ravi Shankar for Sitar, Hari Prasad Chaurasia for flute, and Raghu Dixit for Guitar.

Musicians play different musical instruments to generate a different type of music, but the theory behind each instrument is the same and share the same literature of notes and chords. Despite this fact, one has to put efforts to learn to play different instruments. An expert musician of one instrument will not be an expert of another instrument if he/she has not mastered it, for e.g., an expert Sitar player may not be able to play Guitar or an expert Guitar player may not be able to play flute without learning. To learn all the instruments is very time-consuming, tedious, and challenging task in the music industry. To address the above issue, researchers have put their best efforts to synthesize musical sound artificially, and they achieved great success in this field.

Many researchers have worked in this field and come up with solutions like Orb Composer-A music composing software using artificial intelligence, OrchExtra-A sound enhancement system run from one's laptop, etc. Digital music refers to an art of music that is described, created, spread, and stored via digital technology by using the computer and the Internet, and where sound streams are processed in other processing modes. It is a product of the electronic and computer age [3, 4]. The success achieved in synthesizing various musical instruments is remarkable and appreciable.

All the work done to date toward music synthesis or control is dedicated to a single instrument. The work toward multiple instrument control using a single instrument guitar as a MIDI controller is missing. In the presented work, an attempt has been made to control numerous instruments using a single instrument MIDI controller. The basics behind the proposed work are based on the fact that the music literature of every instrument is same and hence can be used to play all kinds of the instrument through single design (Table 1).

Table 1 MIDI signal instruction

Value (Decimal)	Value (HEX)	Command	Data types
128–143	80–8F	Note off	2 (note, velocity)
144–159	90–9F	Note on	2 (note, velocity)
160–175	A0–AF	Key pressure	2 (note, key pressure)
176–191	B0–BF	Control change	2 (controller no., value)
192–207	C0–CF	Program change	1 (program no.)
208–223	D0–DF	Channel pressure	1 (pressure)
224–239	E0–EF	Pitch bend	2 (least significant byte, most significant byte)

Electronic Guitar is a MIDI Controller that replaces the existing controllers with a cheap and efficient controller, which can be played just like existing guitars. This MIDI controller looks and can be performed exactly like a guitar. However, it does not directly produce sound; it generates MIDI signals, which are sent to the computer to do all the processing for the production of the sound. This input/output system eliminates the use of expensive guitars and MIDI interface as it acts as both at the same time. The conventional strings are not used in this guitar. Hence, it eliminates the handedness of the instrument and the effects on tensed strings due to changes in temperature. This provides some advantage over existing guitars.

The organization of the presented paper is as follows. Section 2 describes the conventional guitar basics; Sect. 3 gives a brief of MIDI controller. In Sect. 4, the Serial peripheral interface is explained in detail. Sections 5 and 6 focus on Sequence generator and Guitar circuit, respectively. The algorithm of the proposed work is explained in Sect. 7. Finally, the conclusion is presented in Sect. 8.

2 Conventional Guitar

2.1 Working Principle

The fundamental principle behind the conventional guitar is resonance. Resonance here refers to the amplification of vibration by a particular design/structure. Any vibrating string generates sound. The frequency of vibration is inversely proportional to the length of the string and its thickness, thus shorter string results in higher vibration frequency. In acoustic guitars, "all of the sound energy that is produced by the body originally comes from energy put into the string by the guitarist's finger."

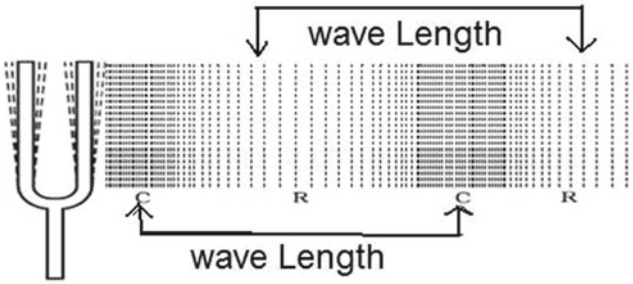

Fig. 1 Wavelength

In the electric guitar, the sound box is not as useful as in an acoustic guitar though the strings vibrate on the same frequencies as an acoustic guitar. The sound pickups of electric guitar act as a transducer for converting the change in air pressure to electrical energy that is then sent to an amplifier (Fig. 1).

2.2 Parts of Conventional Guitar

2.2.1 Strings

Strings of varying lengths and diameters are used in different instruments. The materials used for guitar strings are Nylon, Nickel, Bronze, Silver, etc.

2.2.2 Pickups

Pickups are transducers that may be piezo, magnetic, single coil or of any other type. It converts the string vibrations into electrical signals. These signals are fed directly to amplifiers or devices adding features like distortion etc. to these signals.

3 MIDI Controller

MIDI is a technical standard that describes a protocol, digital interface, and connectors, which allows a variety of device to connect and communicate with each other [5] (Fig. 2).

Fig. 2 MIDI

MIDI carries mainly three components in a message namely notation, pitch, and velocity. The MIDI interface operates at 31.25 k Baud rate using an asynchronous serial data byte comprising 1 Start bit, 8 Data bits (0–7), and 1 stop bit. This makes a total of 10 bits per serial byte with a period of 320 μs [6].

MIDI bytes are divided into two types command bytes and data bytes. Status byte is in range 0x80 to 0xFF. The data byte is in the range 0x00 to 0x7F in hex [6]. Commands include things such as note on, note off, pitch bend, and so forth. Data bytes include things like the pitch of the note to play, the velocity, or loudness of the note, amount of pitch bend and so forth [6, 7]. MIDI messages comprise a STATUS byte (bit 7 = 1) followed by DATA bytes (Bit 7 = 0). Messages are divided into two main categories: Channel and System. Channel messages contain a four-bit channel number encoded into the Status byte, which addresses the message specifically to 1 of the 16 channels. System messages are not encoded with channel numbers and are divided into three main types: System common, system real-time, and system exclusive [6–8].

A. *Abbreviations and Acronyms*
MIDI: Musical Instrument Digital Interface
B. *Units*
Baud Rate: It is a unit for symbol rate or modulation rate in symbols per second. *Unit symbol* **Bd**.

4 SPI

The **Serial Peripheral Interface (SPI)** buses are asynchronous serial communication interface that are used for communication between an integrated circuit such as a microcontroller and a set of relatively slow peripherals. The interface was developed by Motorola in mid-1980s and has become a de facto standard [9].

The SPI module allows a duplex, synchronous, serial communication between the MCU and peripheral devices.

During an SPI transmission, data is transmitted (shifted out serially) and received (shifted in serially) simultaneously. The serial clock (SCK) synchronizes shifting and sampling of the information on the two serial data lines. A slave select line allows selection of an individual slave SPI device, slave devices that are not selected do not interfere with SPI bus activities. Optionally, on a master SPI device, the slave select line can be used to indicate multiple master bus contention as described in SPI Block Guide V03.06 released by Motorola Inc. (2003, February).

5 Sequence Generator

24-bit output driven with a single output pin is implemented with the help of SPI protocol which sends 8 bits of data all together serially to the three shift registers connected in the series to each other. The data, which is to be sent to the third register, will be transmitted to the first so that it can be latched to the end. A common clock is given to all these three registers so that when the pulse is provided by the SPI for next 8 bits, the data in register automatically moves to the next register, so the separate clock is not needed for sending the data to the next register.

Once the data is latched on the shift registers the data is then sent to the storage register by sending a clock to the storage register by this method the data will reflect at the output altogether without delay.

As given in Fig. 3 U3 shift register acts like the strings of the guitar. U2 and U4 act as the frets of the guitar. The sequence is generated so that a fret is checked for each string of the guitar, whether it is pressed or not. The LEDs are named D18, D19, etc.

6 Guitar Circuit

In this guitar, the concept of plucking and pressing the fret string is peculiar because the strings for fret and the plucking are entirely independent. In the circuit, J1 and J2 are the fret of the guitar, which is completed, with the help of the conducting wound wire tied over the fret. If the particular fret is pressed, a 5 V signal reaches the collector of a specific transistor through J3, depending on which string of the fret is pressed, J4 acts as the string of the guitar (Fig. 4).

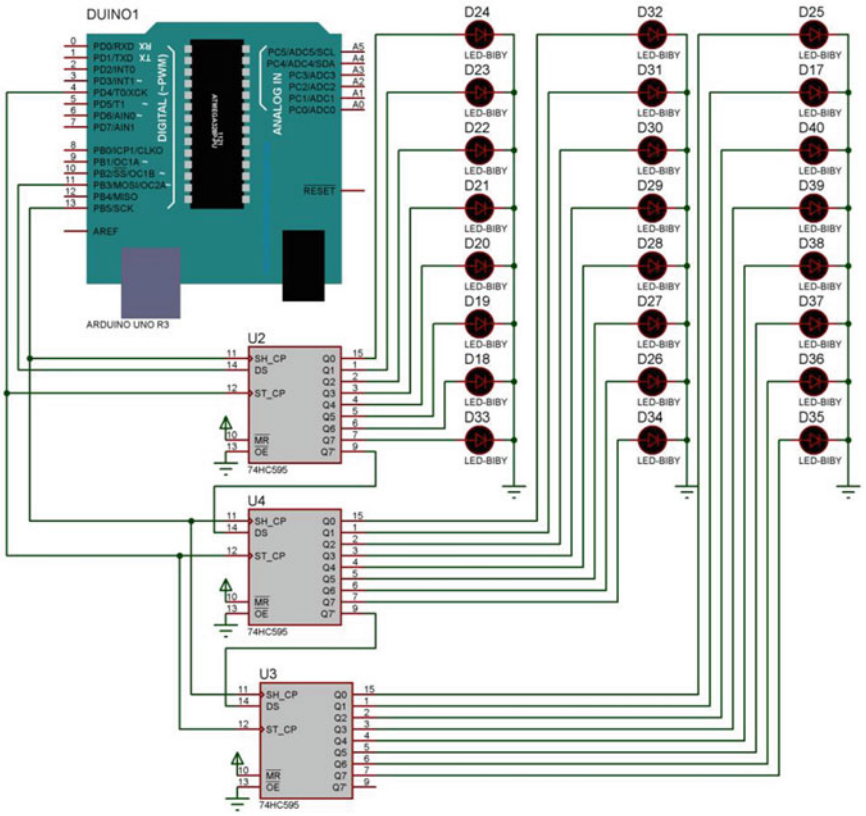

Fig. 3 Sequence generator circuit

The five V signal will remain at collector until a particular string is plucked, i.e., emitter side is plucked with the help of a plectrum. Plectrum is attached to the digital pin of the controller that will detect the voltage at the collector of the particular transistor.

The sequence running in the shift register is very fast compared to the human response it seems that every pin has the voltage at the same time, but every time the sequence inside the shift registers is different. As soon as a voltage is detected at the digital pin, the algorithm looks in the table for the particular sequence, which is inside the shift register at that specific instant. For every sequence, a note is assigned which is sent to the computer as soon as it is detected in the form of the MIDI signal.

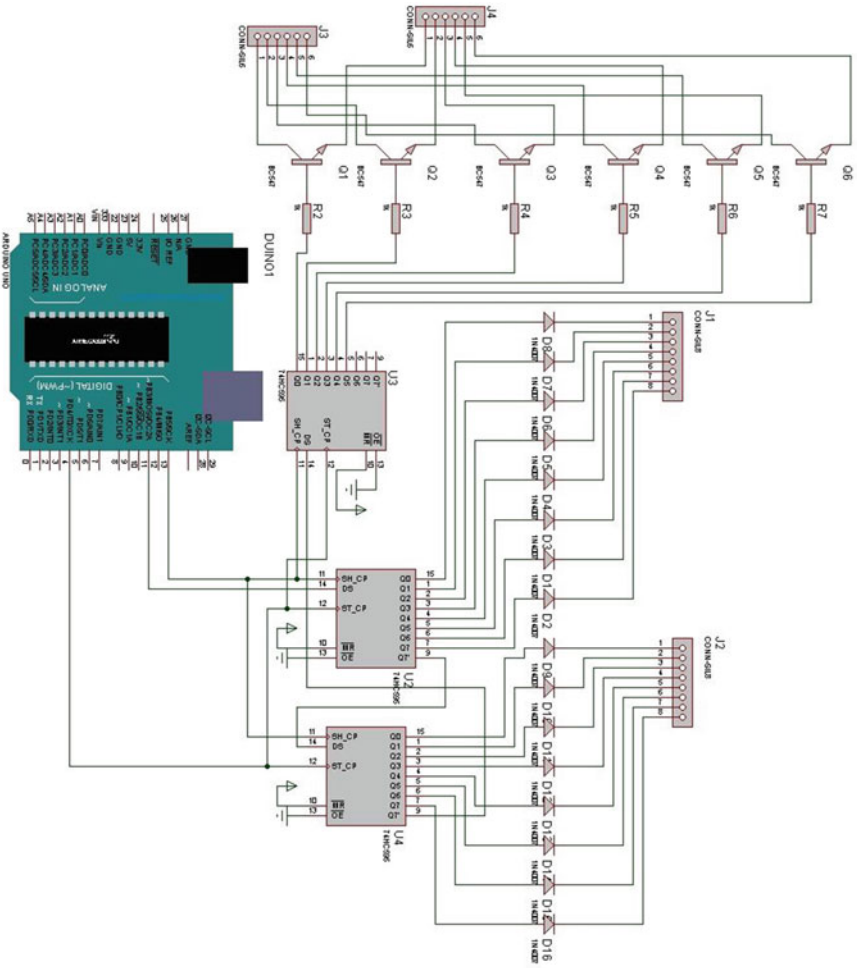

Fig. 4 Guitar circuit

6.1 Components

6.1.1 The Processing Unit (*Arduino*)

The processing unit used here, for converting Input Digital Signals into corresponding MIDI Signals, is Arduino. Arduino is an open-source electronics platform based on easy-to-use hardware and software working at the 16 MHz clock frequency. SPI can

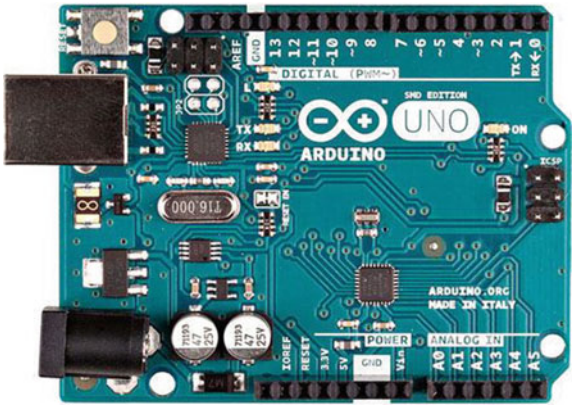

Fig. 5 Arduino UNO

generate and transfer a sequence of 8 bits at 8 MHz frequency, which is fast enough for human perception. The Arduino board used in electronic guitar is Arduino UNO [10] (Fig. 5).

6.1.2 Shift Registers (*74HC595*)

As per the data sheet released by Texas Instruments Incorporated Dallas, Texas 75265, (March 17, 2017), the 74HC595 device contains an 8-bit serial-in, a parallel-out shift register that feeds an 8-bit D-type storage register. The storage register has parallel 3-state outputs. Separate clocks are provided for both the shift and storage register. The shift register has a direct overriding clear (SRCLR) input, serial (SER) input, and serial outputs for cascading. When the output-enable (OE) input is high, the outputs are in the high impedance state. Both the shift register clock (SRCLK) and storage register clock (RCLK) is positive-edge-triggered. If both clocks are connected, the shift register is always one clock pulse ahead of the storage register.

6.1.3 Transistor

It is a semiconductor device, which can be used as an amplifier or a switch. In this system, NPN transistors are used for better switching application. It is used as a switch so it is operated in cutoff and forward saturation region.

7 Algorithm

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MIDI_message:-protocol to send MIDI signal which consists
of three parameters which are the command, note, and
velocity.
SPI:- Serial Peripheral Interface Bus is a protocol to
send 8 bits of data from a single bus.
1. Loop: 24-bit Sequence is generated.
2. SPI.transfer after breaking it into three parts
3. Latch the sequence data to the output register through
the clock
4. If(digitalRead(input_pin))
    {
     MIDI_message to the computer
    }
   Else
    {
     GOTO Loop;
    }
5. Computer receives the signal and process it.
6. The intermediate software sends the data to the sound
   processing software.
7. Sound processing software assigns different sounds to
   the received signal.
8. The sound is played through the loudspeaker.
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8 Results and Conclusion

Electronic Guitar is a single remedy for all the problems of the guitar world. It is an embedded system that eliminates the dependency of sound on the acoustics of the guitar or the pickups used. Instead, the sound is generated using the Digital audio software. Hence, the same instrument can sound like a Nylon string guitar, an electric guitar, piano, or even a drum set without compromising with the sound quality. Since the produced sound does not depend on the timber, size of the instrument, type, and quality of strings, etc., thus the electronic guitar is very cost efficient and portable.

Its conventional design preserves the feel of real guitars with steel strings, but it is independent of the tension in the strings. Being a digital device, it excludes the need to tune the guitar, and it eradicates the problems of tensed strings like bending of guitar, breaking of strings, degradation of strings, etc. This functionality of the guitar also makes it “Soundless”. Signals are fed directly to a computer and can be heard on headphones.

Through further research, the latency of the sound produced can be further reduced. Further improvements can be made by eliminating the requirement of audio software and thus making the guitar self-sufficient. Added functionality on the guitar can include programmable buttons, thus providing the functionality of pedals, loopers, etc.

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