Development of a Drummer Robot

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ABSTRACT

This work addresses the development of a MIDI compatible robotic system that is capable of mechanically operating drum and percussion instruments. The system is composed of a custom designed hardware controller capable of reading MIDI data and mechanical actuators capable of striking percussion pads. The objective of the project is to create a conceptual product aimed at the entertainment industry; more specifically, the animatronic industry which employs the use of robotics and technology to create new possibilities in the realm of audio visual entertainment.

INTRODUCTION

With the proliferation of robotic advancements, robots are currently being designed and utilized in many new fields including entertainment. The primary motivation for this project was to explore new ways in which robots can be used to entertain more specifically in the field of performing arts. The primary objective of the project was to design a product that helped bridge the gap between the field of robotics and existing music technology. The result was the proposed development of a MIDI compatible robotic drummer.

Musical Instrument Digital Interface or MIDI is a widely used music communication protocol used in the music industry. It was introduced in 1983 to create a standard communication language for digital musical instruments, interfaces, and related equipment [1]. The protocol is still currently used in industry and new ways to employ it are being developed. Although the protocol has been implemented in numerous commercial products including stage lighting and special effects products, at the time this article was written, no name brand music or robotic equipment manufacturer offers a commercial robotic manipulator compatible with MIDI.

The system specific goals of the project were to develop a MIDI compatible hardware controller capable of decoding and processing MIDI information and a mechanical actuator driven by the mentioned controller capable of striking a wide range of percussion instruments and pads. The device's compatibility with the protocol allows users to control it by means of any of the vast number of commercially available MIDI compatible sequencers, synthesizers, drum machines and other MIDI capable equipment available in the market. The manipulator is capable of mechanically triggering acoustic and electronic drum pads as well as other percussion instruments.

PREVIOUS WORK

Current work in this primitive field is limited to a variety of experimental one of a kind robotic drummer designs including Fredy Fantastico from the Swiss robot band RozzoBianca as shown in Figure 1 [2], and the Dr Rhythm 55, among others. Many of these designs utilize either pneumatic actuators or servos to generate actuator motion.

Figure 1. RozzoBianca's Fredy Fantastico [2]

Although publications on robot implementations in performing arts are not very common, there is substantial work in the field of robotics that can be used as a basis for design. For example information obtained from work in feedback controls, actuator design and control, and robot sensor systems, is required for the successful development of the proposed device.

BACKGROUND ON MIDI DEVICES

MIDI devices are equipped to receive MIDI messages on one or more of 16 selectable MIDI channel numbers. A device's particular voice (or patch, program, timbre) will respond to messages sent on the channel it is tuned to and ignore all other channel messages, analogous to a television set receiving only the station it is tuned to and rejecting the others. The exception to this is OMNI mode. An instrument set to receive in OMNI mode will accept and respond to all channel messages [1].

Depending on the status byte, a number of different byte patterns will follow. The Note On status byte tells the MIDI device to begin sounding a note. Two additional bytes are required, a pitch byte, which tells the MIDI device which note to play, and a velocity byte, which tells the device how loud to play the note. Even though not all the MIDI devices recognize the velocity byte, it is still required to complete the Note On transmission. The command to stop playing a note is not part of the Note On command; instead there is a separate Note Off command. This command also requires two additional bytes as the same function as the Note On byte. Many instruments transmit and respond to key velocity, the speed at which a key is depressed. Some even respond to the speed at which a key is released. Most simply allow dynamic range to be controlled, while others have the capability to alter timbre or spatial location through velocity. Recent instruments often have the capacity to cross fade or switch between two different sounds, based upon the speed of a keystroke. Figure 2 below illustrates the typical Note on messages that the controller is designed to interpret [1].

	Note On Header				Channel Number			
Byte 1	1	0	0	1	X	X	X	X
	Note Value							
Byte 2	0	X	X	X	X	X	X	X
	Velocity Value							
Byte 3	0	X	X	X	X	X	X	X

Figure 2. Note ON MIDI Message

	Note On Header				Channel Number			
Byte 1	1	0	0	0	X	X	X	X
	Note Value							
Byte 2	0	X	X	X	X	X	X	X
	Velocity Value							
Byte 3	0	X	X	X	X	X	X	X

Figure 3. Note OFF MIDI Message

SYSTEM DESCRIPTION

Figure 4 below illustrates a diagram of the system developed followed by a photograph of the finished prototype in Figure 5. As mentioned previously, the overall system is composed of an external user selected software sequencer that is used to generate MIDI information. A Hardware controller accepts the MIDI data and decodes the supplied information. Lastly, an array of mechanical actuators operated by the controller is used to strike the user selected drum set or percussion arrangement.

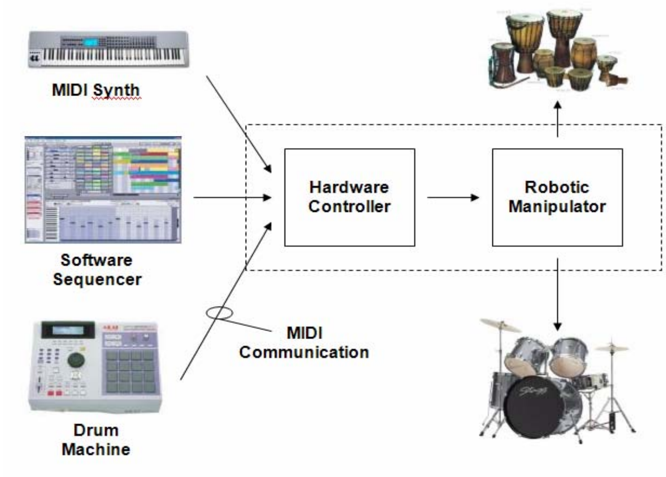

Figure 4. System Diagram

Figure 5. Drummer Robot Prototype

MIDI INTERFACE

In order to supply MIDI data to the controller a commercially available MIDI interface was utilized. The purpose of the interface is simply to convert the signal connector from the computer's USB port to the standard 5 pin DIN MIDI connector required by the MIDI protocol. Since these are extremely basic and standardized circuits, it was not designed nor built from scratch. Instead, an M-Audio Uno MIDI interface was purchased to be used with the system. The device is depicted in Figure 6 below.

Figure 6. M-Audio MIDI Interface

The M-Audio Uno MIDI interface features are described in Table 1 [3].

Table 1. Interface Specifications

• 1-in/1-out MIDI via USB connection (16 x 16 MIDI channels)
• Class-compliant* installation under Windows XP and Mac OS X (no drivers required)
• Full-speed connection to either a PC or Apple computer equipped with a USB port
• MIDI input and output LED indicators
• Bus-powered—requires no external power supply
• Compact and lightweight design for easy transport

CONTROLLER SPECIFICATIONS

By far the most critical and intricate part of this robotic system is the controller. Prior to its design commercially available PIC controllers were evaluated for possible implementation. It was eventually determined that the specifications from a typical PIC based controller would not be sufficient in achieving the controller design goals. For this reason, it was determined that a custom built controller would perform better. The developed controller is depicted in Figure 7.

In addition to the above-mentioned specifications, the overall prototype system constructed features a total of nine independent MIDI channels. The number was based on the number of pieces of the selected drum set to be used, an Alesis DM5-Pro Kit, but it can easily be extended to as many as needed. Each channel can be mapped so that it may be triggered by a specific note on a specific channel. Note and channel mapping can be performed in real time and from the controller itself.

Figure 7. Custom MIDI Controller

The comparison between a typical based PIC controller and the custom device developed are presented in Table 2. As can be seen from the overview of features the developed controller provided a more optimized control and handling of the MIDI information for this specific application.

Table 2. Controller Features & Comparison

Features	Typical PIC Controller	Developed System
Bytes processed at a time	1	3
Parallel Channel Processing	No	Yes
Dynamically Stackable Channels	No	Yes
MIDI Robust Overflow Protection	No	Yes
Note Mapping	Must Re-compile code & Download	Onboard, Real Time Control
Channel Mapping	Must Re-compile code & Download	Onboard, Real Time Control
Max Channels	PIC dependent (8-16 typical I/O)	No Max
Power Switching	Requires External Hardware Driver	AC and DC Switching Capable
MIDI Optimized Hardware	No	Yes

The controller's data processing algorithm consists of six steps as described below.

1. Synchronization. The controller synchronizes to accept the continuous MIDI stream operating at 31.25Kbits / sec.

2. MIDI Stream Interception. The MIDI information is received from the sequencer and the MIDI message is broken up into its respective bytes.

3. Signal Conditioning. The signal is prepared and condition prior to processing.

4. Serial to Parallel conversion. The signal is converted from serial to parallel prior to processing.

5. Message Extraction. The data within the message is decoded and processed.

6. Output Signal Routing. Based on the message processed a signal is sent to the required actuator for triggering.

POWER SYSTEM

The controller's power requirements as well as the actuator array required the implementation of a robust power system. The prototype controller is composed of a few hundred integrated circuits and components which draw a fair amount of current. A 300 Watt power supply supplying a steady filtered source of 5V was utilized to power the controller logic circuit.

The power system also incorporates four Condor GPFM115-24 supplies shown in Figure 8. These supplies provide 24 volts to the actuators with a capacity for delivering up to 4.8 Amps each [4]. These power supplies were required since each actuator can extract up to 1.5 Amps of current when activated. The power system was designed in a modular way so as to be able to increase the number of supplies without major adjustments in case the usage of more actuators is desired.

Figure 8. Condor GPFM115-24 Power Supply

DESIGN OF THE ACTUATOR

To create the motion required to allow a drum stick to strike a given drum, a drumming actuator was developed. The first generation actuator is illustrated in Figure 9. The actuator is composed of an electric solenoid, a drum stick mounted on a pivot point, and a custom built casing. The drumsticks selected are groove percussion 5b drum sticks. The first generation actuator requires only a small hole to be drilled in the stick to fix it to the actuator casing.

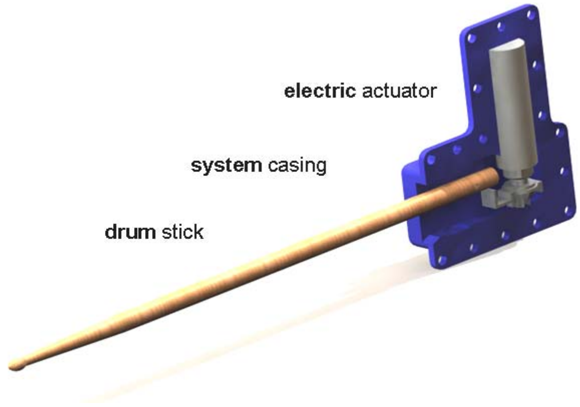

Figure 9. Internal View of the Actuator

Several of the other experimental drumming robot manipulators that have been design by others in the field utilize servo motors and or pneumatic actuators to drive the drum sticks. In this project solenoids were utilized to perform this function. Solenoids can be electromechanical, hydraulic, pneumatic, but are all used for the same effect which are to create a linear motion by a spring-loaded force. When given energy, the actuators will produce a force ideal to hitting drums. When an electric current is sent through the solenoid, which is more specifically a motor wire coiled, a magnetic field is created and applies force to the plunger. The plunger, as shown in Figure 10, is similar to the armature in a dc motor in the fact that effect is caused by the magnetic field. The only difference is that the solenoid only produces linear motion, as opposed to rotational.

The initial solenoids, illustrated in Figure 10, used were pull type solenoids having a stroke of 0.5 in. Although these first solenoids proved to be inexpensive and quick, more powerful solenoids were later selected.

Figure 10. Solenoids in First-Generation Actuator

The solenoids currently in use in the second generation actuator are 24V solenoids capable of exerting 130oz of force at 1/8 inch of stroke. They have an overall stroke of close to 1 inch and are of the push type. They consume approximately 1.2 Amps when activated.

To switch the power each actuator solid state relays were used. By the use of the solid state relays a fully discrete system is produce to reduce the feedback current produced by the actuators, which could cause spikes and noises levels on the for the controller systems. Specially while having low latency switching capabilities that does not jeopardize the precision of the controller, and have an accurate drum strike.

FABRICATION OF THE ACTUATOR

Figure 11 depicts the implemented array of actuators in the prototype drummer assembly.

Figure 11. Implemented Array of Drummer Actuators

The design requirements of the actuators developed called for the ability to be implemented on any kind of drumming instrument. In order to achieve this, a simple two part casing was design that could be easily reproduced. The final prototype of the actuator design was developed using SolidWorks to properly adjust the critical dimensions of the assembly. Copies of the casing model where then reproduced on a rapid prototyping machine. The resulting models were then hardened using resin to produce a hard case.

ANALYSIS OF THE MECHANISM

Mechanically, the manipulator is composed of a solenoid, a pivot point, and compensating spring loads in two locations. As can be seen from the Figure 12, the solenoid is represented by a spring and damper load, which is the driving force of the mechanism. Since the center of gravity is concentrated more to the right of the pivot point it needs a compensated force to move the stick back to its horizontal position preparing the stick for the next beat.

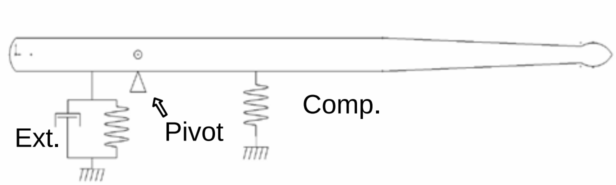

Figure 12. System Diagram

Figure 13 represents the free body diagram of the system. In this diagram the forces being applied to drum stick can be seen. The pivot point creates a leverage mechanism where forces create angular momentum with respect to the axis. $\mathbf{F_s}$ is the solenoid force been applied; $\mathbf{F_k}$ is the force of the recoiled spring; $\mathbf{F_g}$ is the force of gravity and finally $\mathbf{F_i}$ is the force of the impact created by the drum pad and the stick.

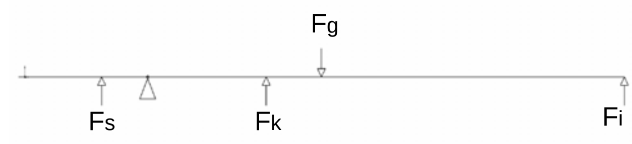

Figure 13. Free Body Diagram

The sealed linear solenoid used for its fabrication produced a 1 inch stroke of travel at 130 oz of force. Sufficient for the application it is needed to accomplish. Keeping in mind the force that a drum needs to be stroked to create the sound, a calculation of distribution of forces needed to be solved to determine the location of the axis of rotation of the drum stick. The dimension of a standard drum stick is approximately 16 inches long by 5/16 inches in diameter (at its far end and throughout the majority length of the stick) with an average weight of 1.76 ounces. With this information the standard location for the pivot point was established. The assumption was made that the stick would impact the drum pads with enough force to create the sound. Since the actuators are height adjustable, this procedure would rely on the installer and would be a user preference setting.

Through various calculations it was concluded the best location for the pivot point is 2 inches from the end of the stick and having a striking point of the solenoid of .75 inches from the pivot point at a maximum distance of travel of about 1/4. Creating a force at the end of the stick calculated to be 6.9 ounces at the moment of impact and have a final travel distance of 4.6 inches. The resulting force was determined to be enough to engage the drum pads with a good momentum strike.

A finite element study of the system was performed using COSMOSWorks. The study was able to estimate stress levels at the impact location of the drum stick as shown in Figure 14 and Table 3. The result of these tests assures that the stick will not fail upon strike.

Table 3. Stress Analysis Results

Von Mises Stress	
Minimum	8.03 N/m^2
Location	16.25 in., 4.09x10^{-16} in.
Maximum	6.80x10^6 N/m^2
Location	1.93 in., 3.54x10$^{-0.06}$ in.

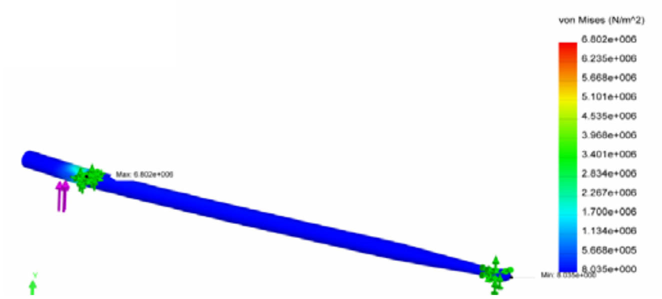

Figure 14. Stress Analysis

LIGHTING AND SPECIAL EFFECTS

In addition to driving the robotic manipulators, the controller can also be used to control stage lighting and effects. This feature was added for maximum visual effect of the robotic drumming system. The controller's output's that drive the drumming actuators can also be couple with custom designed load control units as seen in Figure 15.

The load control units can drive A/C loads such as lighting units and effects such as lasers and spot lights. Figure 16 illustrates the sample lighting rig utilized in this project.

Figure 15. A/C Load Control Unit

Figure 16. Drummer Robot Prototype Lighting Rig

TESTING

The finished robotic assembly was installed on an Alesis DM5 Pro Drum Kit. An electronic drum set was selected over a conventional set to allow more versatility in the types of songs the robot can play. The DM5 drum module offers over 500 drum sounds allowing the robot to play MIDI files from most types of music [5]. In addition, the drum rig provided by the Alesis kit allows the set to be customized and expanded with ease [6]. The system was then connected to the Cakewalk Home Studio sequencing software and a variety of MIDI files were then mapped to play through the robot and lighting rig. The performance was then evaluated visually and aurally.

CONCLUSION

As stated previously, the purpose of this study was to bridge the gap between robotics technology and music entertainment by exploring how aspects of the two can be fused to produce new alternatives in the field of entertainment. The completed device, when tested, performed as designed. The system is capable of playing drum patterns and lines from standard MIDI files. It was noted that the response of the system was adequate and the system can play reasonable quick beats. Initial testing showed promising results for the further development of such controllers. Overall, the project was successful at meeting all of the design requirements set and all the obstacles encountered were overcome.

FUTURE WORK

The initial device to be developed is capable of driving nine independent manipulators with a possibility of future expansion. Velocity information supplied by MIDI master controllers will initially not be processed by the hardware controller. This will allow the system to strike a percussion pad with only one pre-set speed translating to only one pre-set volume; however, a second generation proposed controller after completion of the initial prototype will process MIDI velocity information allowing for the robotic manipulator to perform with a more human feel.

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