Electric traditional Chinese musical instrument - Xun

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1 Introduction

1.1 Objective

Xun[1], invented 7000 years ago, is one of the oldest musical instruments in China. It used to be made out of clay or bones and now ceramic. However, Xun is now faced with two problems. First, unlike other musical instruments, it lacks an electronic version with which one can practice without making loud sounds and disturbing neighbors. Second, since the population that play Xun is very small, few teachers are available and new players may find it hard to play Xun without an efficient learning method.

To get more people familiar with Xun, we aim to make an electronic instrument using sensors and a microcontroller. Sensors take inputs from player, consisting of pressure sensors and airflow sensors. Pressure sensors will take player's gesture as input to determine which note the instrument should play. Airflow sensors will examine the strength of the blow to determine how loud the instrument should play. Microcontroller make decisions based on input and output the sound of Xun in digital form. The recorded sound of Xun is stored in microcontroller ahead of time and goes to audio jack after passing a DAC module and an amplifier.

One can play the sound of the instrument through headphones, so our instrument will not disturb people by making loud sound. Also, as more people are interested in electronic Xun, it will be easier for people to learn this instrument in general.

1.2 Background

There are already electronic wind instruments on the market that can function as a lot of instruments, such as Saxophone and flute. However, those instruments are very expensive and cannot function as Xun. Our device will be necessary for 3 reasons. First, there are not electronic musical instruments capable of making sound quality of a ceramic or clay wind instrument. Second, the EWI wind controller on the market cannot provide a mode of Xun for its unique shape. Third, our device will be much cheaper than the EWI wind controller, which costs 700 dollars. Moreover, we may develop an LED system that provides instructional signals to guide players during performance if time allows.

1.3 High-level requirement list

- Instrument must be able to produce musical sound of typical quality of Xun.
- Instrument must be able to produce the correct note based on player's hand gesture.
- Instrument must be able to change its sound magnitude based on player's blow strength.

2 Design

Electronic Xun requires four sections for successful operation: a power system, a sensor system, a microcontroller, and an output system. The power section will deliver power at desired voltage level to the rest of the circuit. The sensor system consists of a pressure sensor and an air flow sensor. They will detect players' control and provide information to the microcontroller in digital form. Microcontroller then determines the specific sound corresponding to the player's input and output the music signal to the output system. Output system takes the digital signal produced by the microcontroller, converts it to analog signal and amplifies it to a desired magnitude.

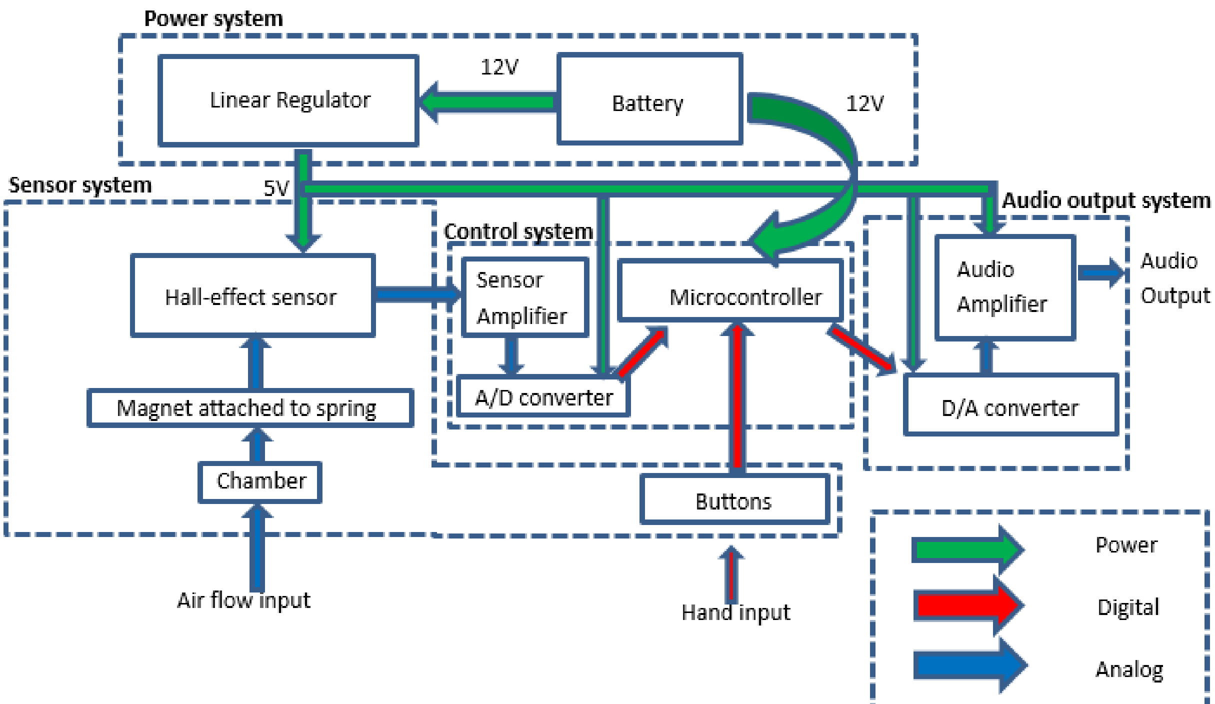

Figure 1. Block Diagram

2.1Power Supply

Power supply will deliver power to the rest of the circuit. It consists of a 12V DC lithium -ion battery and a linear regulator.

2.1.1 Li-ion battery

The lithium-ion battery must be able to provide power steadily to the circuit before it runs out of energy. Linear regulator and microcontroller will be directly connect to this 12V DC power supply.

Requirement 1: Must be able to hold 1000 mAh in order to power the circuit for at least 60 mins.
Requirement 2: Must be able to provide at least 35 mA peak current.

2.1.2 Linear regulator

Linear regulator is chosen to be AP1150. It takes power from the battery and convert it to 5.0V level output that is required by specific components. Hall-effect sensor, sensor amplifier, A/D converter, audio amplifier and D/A converter are connected directly to linear regulator.

Requirement 1: The linear regulator must provide 5.0V +/- 10% from a 11.0-12.5V source.
Requirement 2: Must be able to provide at least 25 mA peak current.

2.2 Sensor system

Sensor system will get all necessary input from the player, namely the tone-hole combination and the blowing pressure. Buttons, a set of passive sensors, will respond to the player's tone-hole combination and send input signals to the microcontroller for the purpose of pitch determination. Air flow sensor, an active sensor, will be used to reflect the blowing strength of the player and send voltage signals to ADC module to determine the loudness of audio output.

2.2.1 Buttons

We will use ALPS Tactile Switches. The buttons, when pressed, will generate an electrical signal that can be detected by the microcontroller. There are 6 buttons in the sensor system, corresponding to the 6 holes on the actual instrument. User will feel a click when the button is fully pressed. Microcontroller will get the status of the 6 buttons at the same time.

Requirement: Must generate an electric signal of 3.0V +/- 10% when they are effectively pressed. The electric signal will persist until 1ms +/- 10% after the player releases the button.

2.2.2 Hall-effect sensor

"A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field [2]." Hall-effect sensor is chosen to be AK8771 and it will output a voltage according to the magnitude of the nearby magnetic field. It is used to sense the magnetic field given by the magnet attached to spring. The output voltage goes to A/D converter. With the spring swinging back and forth, hall-effect sensor gets magnetic field of different magnitudes, and generates voltages of different magnitude accordingly.

Requirement 1: Must be sensible enough to give a 0.5V +/- 10% voltage when a 500 Gauss magnetic field is located 1-2 cm away from the sensor.
Requirement 2: Must give out 0.2V +/- 5% output difference per 200 Gauss input change.

2.2.3 Magnet attached to spring

Magnet attached to spring is placed near the hall-effect sensor. It will directly receive the air flow from player's breath. The breath will push the spring to a steady location closer to hall-effect sensor. The harder the player blows, the closer the magnet and sensor are, and the larger magnetic field the sensor feels.

Requirement 1: Magnet must give at least 500 Gauss at a distance of 8 cm +/- 5%.
Requirement 2: Magnet must have a diameter less than 1.2 cm in order to be fit into the chamber.
Requirement 3: Spring must be able to contract 2.5 cm +/- 10% at 300 L/min +/- 10% air flow.

2.2.4 Chamber

Chamber is used to contain the air flow from player's breath. Player blow from one end of the chamber, and the other end is covered with magnet attached to spring. Using a chamber prevents air leak.

Requirement: Must have at least 0.8 cm diameter and 2.5 cm length to hold magnet and spring.

2.3 Control system

The control system takes all input signals from the sensor system. After processing the input signals, it will output digital sound signals stored previously in the microcontroller to the audio output system.

2.3.1 Sensor Amplifier

We will use AK2920 amplifier. The sensor amplifier takes voltage signals from the air flow sensor and amplifies the signal to a range of 0 to 5V so that the A/D converter will be able to process the voltage signals.

Requirement: Must be able to detect as low input offset voltage as 0.2V +/- 5%.

2.3.2 A/D converter

We will use AK5355 for A/D converter. Analog voltage signals generated by the hall-effect sensor and amplified by the sensor amplifier will be converted to digital forms for the use of microcontroller. A resolution of 16 bits will be used to represent the airflow strength.

Requirement: Must be able to generate a sample per 0.1ms +/- 5%.

2.3.3 Microcontroller

It is chosen to be SparkFun RedBoard. Based on the signal input from the sensor system, the microcontroller will generate the corresponding sound stored previously in the memory. Six buttons will generate a total of 64 kinds of pitches.

Requirement 1: Must be able to give output signal within 0.1ms +/- 5% after the microcontroller receives the sensor input generated every 0.1ms +/- 5%.
Requirement 2: When the player is not blowing, microcontroller should not give any output. When the player is giving a blow less than 100 L/min, microcontroller should give output at 1V +/- 10% voltage level. When the player is giving a blow more than 100 L/min, microcontroller should give output at 2.5V +/- 10% voltage level.

2.4 Audio output system

Digital signals from the microcontroller will be processed by a D/A converter and amplified to an audio output jack.

2.4.1 D/A converter

We will use AK4331, a 32 bits DAC. The digital to analog converter will be used to take the digital signals from the microcontroller and convert the signals to analog signals to be processed by the audio amplifier for the purpose of audio output.

Requirement: Must be able to support sampling rate frequency of 44.1 kHz +/- 0.1%

2.4.2 Audio Amplifier

We will use AK2920. Analog audio signals sent from the DAC module will be amplified by the audio amplifier to a range of 0-5V so that it can be output to the audio jack.

Requirement: Must be able to support analog volume level +4dB to -10 dB, with 2dB Step +/- 5%.

2.5 Risk Analysis

The airflow sensor is of the most significance and the highest risk to the completion of the project. Whether the airflow sensor will be able to successfully detect the airflow from the player's mouth and output a reasonable voltage signal or not is essential. Two major essential components, a spring, and a magnet, must both be embedded inside a chamber to avoid air leak. The third component, the hall-effect sensor, should be placed outside the chamber but close enough to detect the changes in the strength of magnetic field. We will need to determine the threshold of a voltage signal to tell the difference between a state where spring is steady and a state where the spring is actually bent by the airflow generated by a player. Moreover, the spring is supposed to quickly swing back to its original steady position as soon as the air flow is stopped, and it should easily swing so that the player do not have to blow too much air to generate a sound. All the requirements mentioned above are difficult to meet because it requires perfect manufacture of the device and a large amount of signal testing and parameters adjustment.

Further, the sound qualities of Xun might not be as real as that generated by the actual musical instrument. Due to the quality of recordings and the data transmissions back and forth, the sound quality may need further adjustment after the implementation of the system.

Last but not the least, every module must be real-time for the nature of the project. ADC and DAC module might need some time to process the signals, but we need to process signals of a wide range of frequencies and amplitudes in real time. Microcontroller need to process the input signals, load the previously stored sounds, and determine which pitch and loudness should be output to the audio system in real time. These requirements can be hard to meet but we can only allow a maximum delay of 0.5 second.

3 Safety and Ethics

There are several potential safety issues with our project. Li-ion batteries can get very hot when it's overloaded and can even explode under this kind of situations [3]. To handle this, we will make careful choices of batteries and electronics. In addition, we will go through all data sheets and make sure that the overall load of circuits won't exceed the limit of the battery.

Another potential safety hazard comes from players' blowing. As people blow air into the instrument, which has actually a small semi-closed space, it's unavoidable for the moisture in the breath to get liquefied. As a result, there can be some water inside the carrier, which may cause short circuits in our systems. To resolve this issue, we plan to use some packets to seal the electronic systems so that they won't be in direct contact with the moisture.

Now that we're trying to imitate the instrument Xun, it's possible that our sound qualities will have some differences from the original. As a result, when evaluating and making conclusions about our project, we'll obey the IEEE code ethics, #3:"To be honest and realistic in stating claims or estimates based on available data" [4].

We are responsible for the impact of our designs and aim to comply with the IEEE code ethics, #5:"To improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems" [4]. We hope to bring more people to this amazing historical instrument and facilitate educations in this area.

We'll also stick to the IEEE code ethics, #7:"To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others [4]”. On the one hand, we will thoroughly record and report all the external sources we use. On the other hand, we’ll also take comments and suggestions from other people, including peers, TAs and professors, seriously to improve our design.

References

[1] Wikipedia, ‘Xun (instrument)’, 2018. [Online]. Available: https://en.wikipedia.org/wiki/Xun_(instrument). [Accessed: 19-Sep-2018].

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[4] IEEE.org, "IEEE IEEE Code of Ethics". [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 19-Sept-2018].