Position Control Using Pitch Feedback
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Abstract

A position control system utilizing pitch feedback is being developed. The system will be demonstrated on a robot playing a musical instrument called the theremin. Unlike previous research involving computationally intensive pitch sensors, we would like to explore the possibility of a control system using a pitch sensor with a low computation overhead. The robot is being improved upon to make its arms more effective in playing the theremin. One pitch sensor was developed, evaluated, and deemed to be lacking. An improved pitch sensor has been developed and is being evaluated. The revised pitch sensor will be generally applicable to student robot projects that involve music or other tonal feedback.

1 Introduction

One of the primary aims of STEM (Science, Technology, Math, and Engineering) education activities is to inspire young students to pursue careers in engineering and technology. Robot-related activities can be a very strong source of inspiration for a wide range of age groups. On the other hand, music is an excellent tool for attracting the interest of an audience in general. Adding music to robots can hence raise the potential to inspire. In this context, music playing robots can make a strong contribution to enhance the effects of STEM activities.

Pitch feedback is used in autonomous as well as human operated systems. Several detection systems, such as metal detectors and Geiger counters, emit audible frequencies to provide information to human operators. A surgical robot system developed at the University of Pennsylvania provides feedback by converting the tool tip contact accelerations to audible pitch to aid in tool manipulation [5]. An earlier system attempted to provide 3D position information of a surgical tool by converting it to audible pitch [9]. Autonomous robots have been used to play musical instruments by controlling arm positions while using pitch feedback [6], [1]. A humanoid robotic mouth makes use of pitch feedback to generate a controlled imitation of human speech [7].

Typically with pitch feedback systems, the parameter being directly controlled is not the pitch. So it is an interesting control problem. Frequently, this parameter has no direct relation to the pitch. This applies to a theremin playing robot, where the relation between hand position and pitch generated is very non-linear. A theremin is a musical instrument with a pitch control and a volume control antenna. These antennae act as capacitors for two LC oscillator circuits [2]. Placing a foreign object within range of these antennae, e.g. a hand, alters their capacitances. This change in capacitances changes the frequencies of the oscillator circuits. These frequencies are in turn used to control the frequency and volume of the sound generated. As the pitch and volume antennae are approached, the pitch and the volume increase and decrease respectively. There is a large number of different materials, sizes, shapes, and even environmental conditions which may modify the electrostatic fields around the antennae, and hence the capacitances of the oscillators. Therefore, it is almost impossible to develop a generalized model of the theremin.

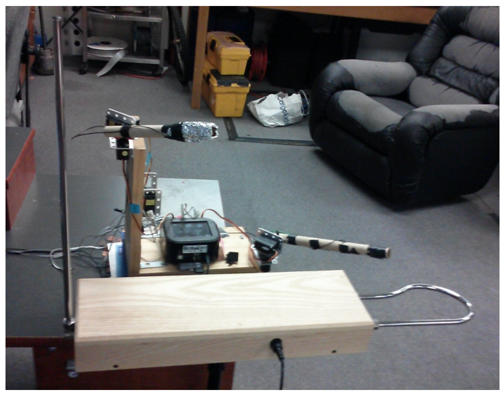

Figure 1: *Theremin and robot. The pitch antenna (left) and volume antenna (right) are visible. The robot features 2 DOF arms for each of the antennas.*

The primary objective of this research is to develop a low cost, easy to use, pitch feedback control system. This will be demonstrated by using a robot to play a theremin (see Fig. 1).

2 System Overview

Fig. 2 illustrates our pitch feedback position control system. The theremin has already been discussed. The following subsections elaborate upon the rest of the system.

2.1 Hardware

The current hardware configuration comprises a pair of arms with two degrees of freedom each. In the current configuration, only one degree of freedom is used for each arm. The actuators used are low cost hobby servos. These are controlled by the CBC v2, which is a robot controller based on a 350 MHz ARM9 processor. It has 4 servo control ports, 4 motor control ports, 8 digital input, 8 analog input ports, 2 USB ports, and a serial port [4].

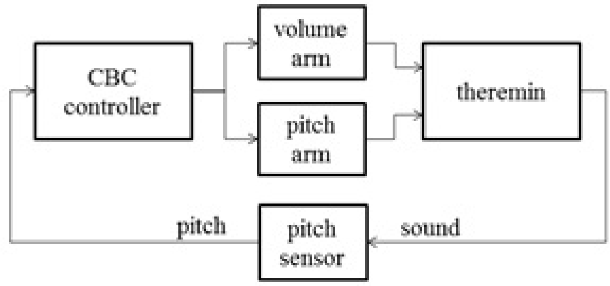

Figure 2: *Overview of the position control system using pitch feedback.*

2.2 Software

Open source KIPR Instructional Software System C environment [3] has been used to program the robot. Currently, the robot has been programmed to perform two functions; calibration and feedforward playing. During the calibration phase, the relevant playing positions of the volume and pitch control arms are determined. The volume control antenna is located using a contact sensor on the volume arm and the low volume position is determined. A reasonably distant position is selected as the high volume position. Calibration for the pitch control arm involves sweeping the arm around the pitch antenna, sensing the pitch at each position, and recording the arm positions for the first available complete octave, i.e. 12 pitch values belonging to the same octave. The resultant position-pitch pairs are recorded in a lookup table.

The feedforward playing sequence is as follows. Information on the musical note to be played is retrieved from memory. This includes the pitch, its playing duration, and the pause that follows. The corresponding position of the pitch control arm is retrieved from the calibration lookup table. The pitch control arm is then moved to that position and the volume control arm is moved to the high position so as to make the note audible. After the playing duration time has passed, the volume arm is moved to the low volume position and no sound is audible. After the pause time is over, the above sequence is repeated for the next musical note.

3 Sensors

Two sensors have been used for the robot. A contact sensor is used to locate the volume antenna of the Theremin. This is polled using a digital input port on the CBC. A pitch sensor is used to determine the pitch being played.

Initially, a pitch sensor was made by hacking into a commercially available guitar tuner. This was polled using 2 analog ports. It did not provide any information on the octave being played. It was unreliable; it provided valid frequency information for only about 50% of the instances at which it was polled. It was slow to respond. To avoid all these undesirable features, a second pitch sensor was developed.

The second pitch sensor design is based on a counting principle. The time taken for a sound wave is measured by counting the number of high frequency clock pulses which occur within one cycle of that wave [8]. Fig. 3 illustrates the counting principle. Knowing the frequency of the counting pulses, the frequency of the sound waves can be determined. A 500 KHz clock frequency was selected so as to give a maximum of 2% frequency error at 5 KHz. This error depends upon the smallest time interval which can be measured. It is equal to the period of a single clock pulse. The maximum frequency of sound generated by the Theremin was found to be below 5 KHz. For lower frequencies, the error would be less. This sensor is designed to be polled through the serial port.

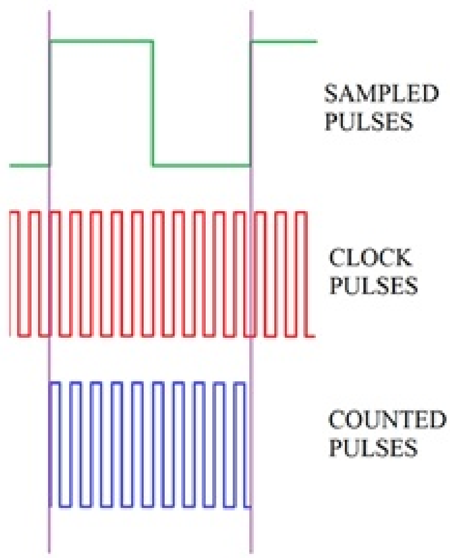

Figure 3: *Counting principle used to measure frequency. The number of high frequency clock pulses which occur within one time period of a sampled pulse is counted.*

Fig. 4 illustrates how the new pitch sensor works. A filter converts the approximately sinusoidal sound wave into a square wave of the same frequency. Next, the counter counts the number of clock pulses between two rising edges of the filtered sound wave. Every time a new rising edge is detected, the count is restarted. Knowing the count n and the clock frequency f_{clock}, the sample frequency f_{sample} can then be determined by division. For example, for a 500 Hz sample, and a 500 KHz clock, the sensor should give a count of 1000, which can be then used to determine the frequency. Preliminary results indicated that the error computed frequency was about 1%. This can be explained as follows. The count may vary by 1, since only complete pulses are counted. The count can also vary as the frequency of the clock may fluctuate slightly. Finally, some precision is lost during division.

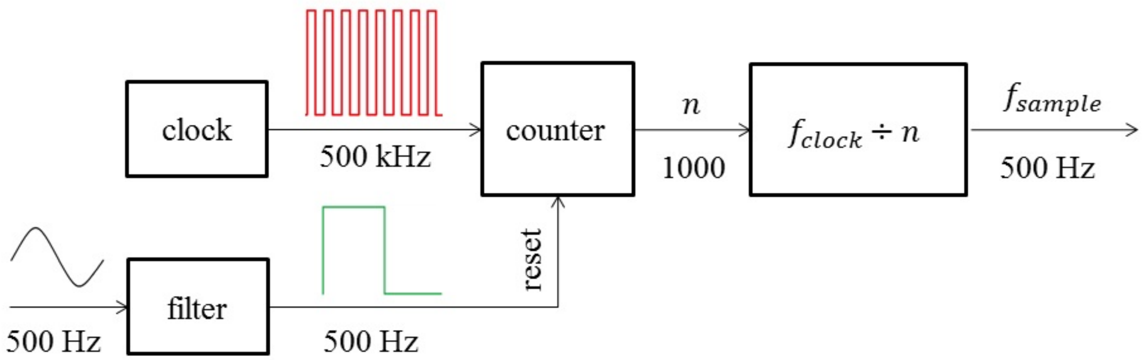

Figure 4: *Example illustrating the workings of the second pitch sensor for a 500 Hz sound wave.*

4 Current Work

Current work involves evaluation of the second pitch sensor through feedforward playing. This sensor is expected to be faster and much more reliable. The design helps achieve a faster response by determining the frequency of each sound wave within the time period of that wave. The reliability is maximized by storing the last data set in a memory buffer. This way, a valid data set is available each time the sensor is polled.

So far, the robot has only been able to play music pieces which use a single octave. These include nursery rhymes like Twinkle Twinkle Little Star and Old Macdonald Had a Farm. This was due to the lack of octave information in the old pitch sensor. By the time we present at the conference, we hope to be able to play musical pieces spanning more than one octave.

5 Conclusions & Future Work

A robot has been developed to play a theremin. A pitch sensor was developed and found to be inadequate for realtime feedback. A second pitch sensor was developed with features designed to overcome the limitations of the previous sensor.

Future work involves development of a pitch feedback control algorithm. In parallel, necessary changes will be made in the hardware design to improve theremin playing performance. The above robot platform will aid as a development testbed.

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