Virtual Grand Piano

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1. Introduction

1.1. Objective

Digital pianos currently available in the market are expensive, heavy and non-portable devices that require meticulous maintenance and large amounts of power. A piano player may require a portable instrument at short notice to practice or test musical pieces without wanting to travel all the way to a studio. We plan to explore a possible solution to this problem by designing a virtual instrument that contains no moving parts, is extremely portable and contains all the functionality and sound design of a digital keyboard.

We are proposing to implement this virtual keyboard by isolating the movements of the player in 3D space using camera modules and identifying each individual key press and relaying it to a control unit. We will capture information about which key on the piano was struck by the player, the speed with which the key was struck as well as any sustain or touch pedal inputs held by the user. We are planning to do this by having the player wear a glove with pressure sensors, reflective materials on the fingertips and a wireless transmitter on each hand. The player can then virtually play the piano on any flat surface that would be marked with stickers calibrated with the camera modules.

1.2. Background

The digital keyboard is an extremely versatile instrument for any musical artist. It can be used as a MIDI controller for a custom synthesizer or as a digital piano that authentically reflects the sounds of a traditional piano. It is often the case that an artist may want to test out a melody on the fly or practice a piece without having access to a physical keyboard. With the increasing sophistication of image processing techniques and fast processing times provided by hardware components we are planning to overcome this problem completely virtually. The only inputs required by the instrument for emulating a digital keyboard are the movements of the player's fingers. While a flat interface may not provide the feel of a traditional piano it could be immensely useful as a portable solution and may be set-up in compact spaces that may not accommodate a full piano. It is especially suitable as a MIDI controller which has become an essential part of the modern music production process[1]. The player's inputs would be wirelessly transmitted to a central control unit that would process the note and velocity of the player's movements and feed it into an audio synthesizer.

We haven't come across a similar system that implements a digital keyboard using the location of the player's fingers as it is difficult to accurately locate position in 3D space using conventional techniques. In addition the system would need to have high processing capabilities due to the real-time multi-sensor processing requirements of the system. We plan to overcome these challenges by utilizing an FPGA module that would be able to process inputs from multiple camera and pressure sensors in real-time and relay them to an audio synthesizer.

1.3. High-Level Requirements

- The system must recognize and trigger the correct note played by the user with the appropriate sensitivity reading.
- The system must be portable and may be deployed on any flat surface if calibrated appropriately.
- The system must reflect the configuration of a traditional piano including both black and white keys and be able to accurately resolve each.
- The system must be reasonably fast, processing the sensor inputs and triggering the appropriate key with minimal delay.

2. Design

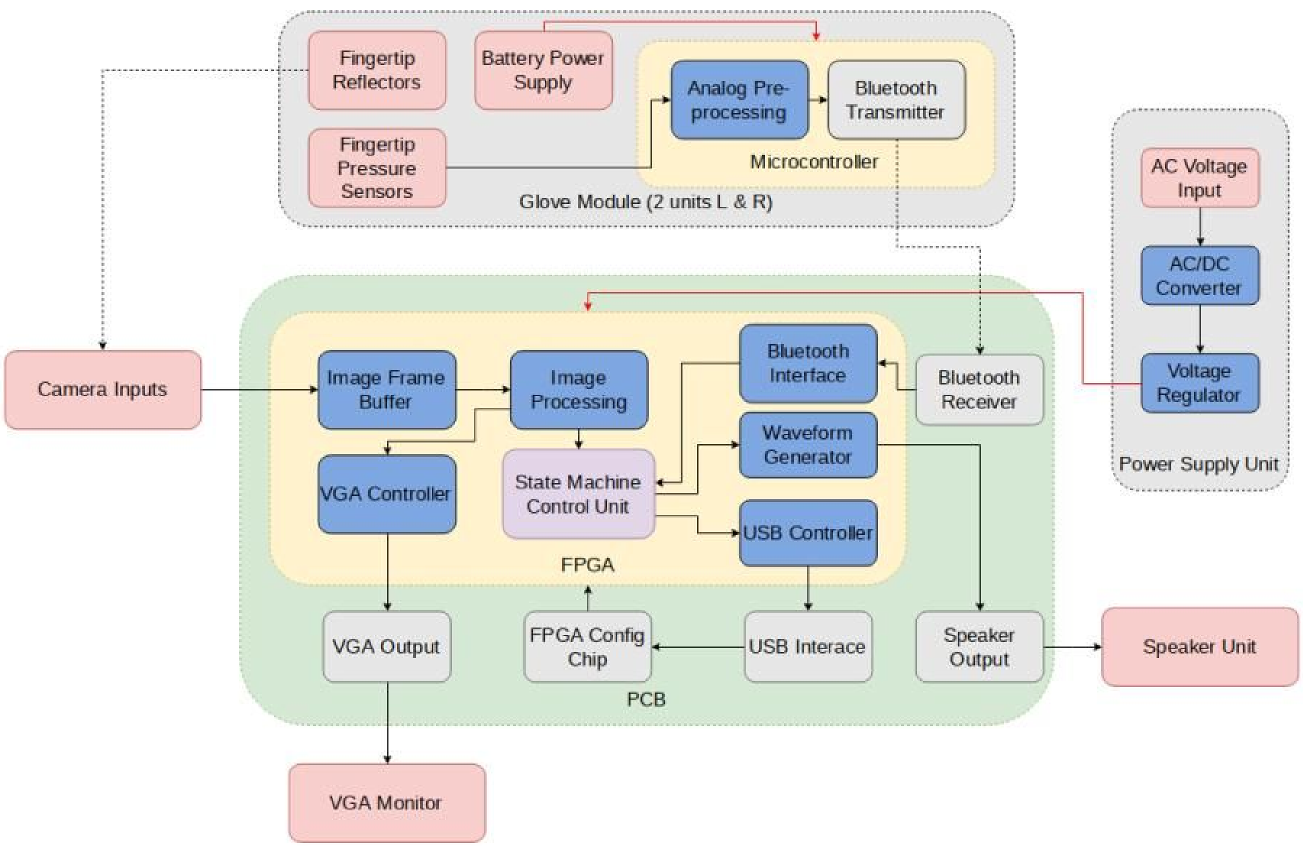
Our core design requires the implementation of three distinct modules.

The movements of the player are recorded through two glove modules equipped on the player's left and right hands. This glove module consists of reflective material on each of the five fingertips that can be isolated by the camera module. The pressure of a key press is recorded by five pressure sensors on each of the fingertips and relayed to a microcontroller unit located on a bracelet-like device on the player's hand. This microcontroller is powered by an onboard battery and relays the recorded inputs in real time via a bluetooth device to the main control unit.

The power to the main control unit is supplied by a power supply module that converts the AC mains voltage to DC voltage usable by the FPGA module using a voltage regulator.

The central control unit is responsible for receiving inputs from the various sensors, processing these inputs to identify the key triggered and the key velocity and relaying this information to a waveform generator implemented as an FPGA module. The waveform generator outputs the sound to an available speaker unit. We are planning to use two camera modules to track the left and right hand of the player and process these inputs simultaneously to trigger the musical notes as required by the player. We are also planning to display the captured image on a VGA monitor so that we can view the images in real time to provide the user with feedback about their finger positions and the key boundaries.

Virtual Grand Piano - Block Diagram



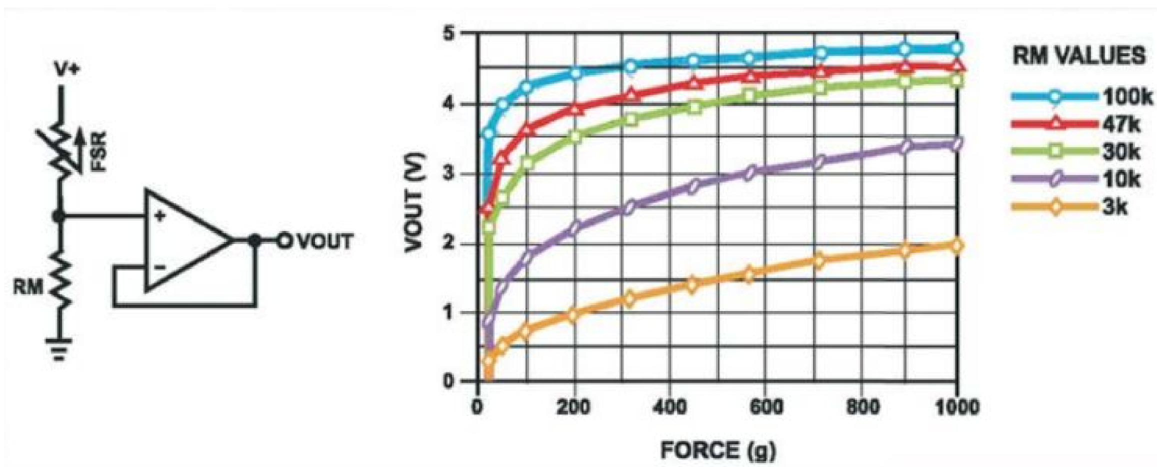
2.1. Camera Sensor

We are going to be using the CMOS OV7670 camera modules to capture the images of the user's fingers from the top view. This will provide us with information about the location of each of the user's fingers on a virtual piano grid. This data will be processed by the image processing unit on the FPGA to isolate which keys are being triggered by the user.

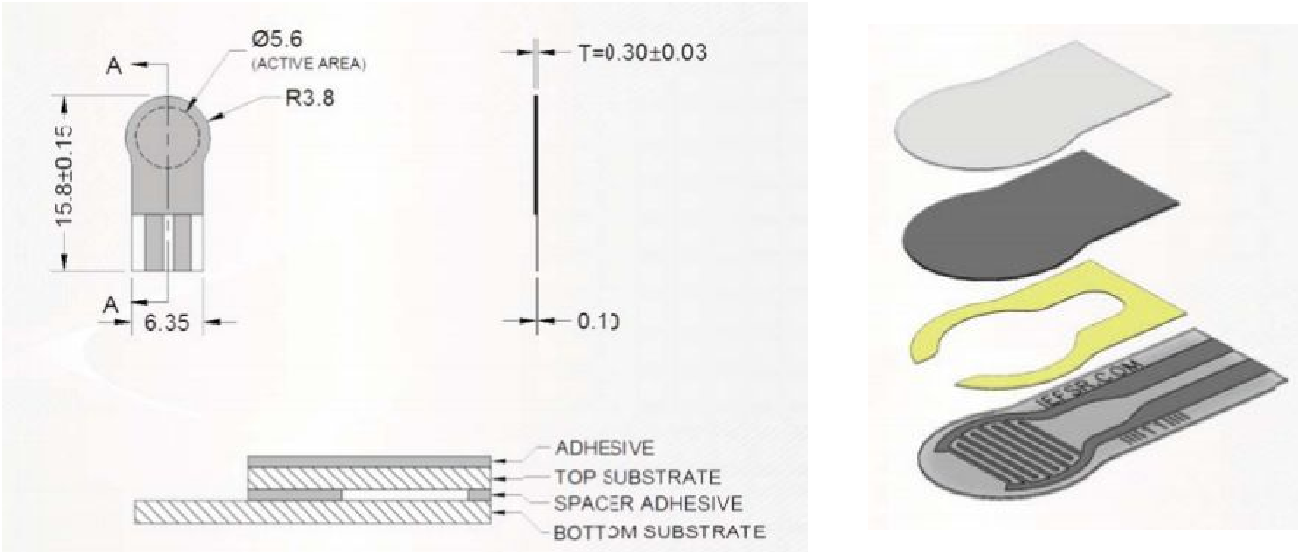
Requirement: The camera sensors should be able to isolate the position of each of the user's fingers to provide information about which key was triggered.

2.2. Pressure Sensor

We are planning to use the FSR 400 series force sensitive resistors by Interlink Electronics to record pressure input data from the user's fingertips. We have chosen these sensors due to their low cost and small size factor. This will grant the player mobility while playing the instrument. The following are the circuit integration and characteristic details of the pressure sensor:



The following are the mechanical details of each of the pressure sensors:



Mechanical characteristics of FSR 400 series pressure sensor (Readings in mm)

Requirement: The pressure sensor should be able to capture information about whether a key was triggered by the user and the key hit velocity to provide information about the note tonal properties such as amplitude and frequency.

2.3. Bluetooth Module

We will be using the provided Bluetooth module[2] for transmitting the data captured in the glove module pressure sensors to the processing module.

Requirement: The module should be able to transmit pressure readings from the microcontroller unit in real-time to the central FPGA package with reasonable accuracy.

2.4. FPGA Package

We are currently planning to use the Altera Cyclone IV EP4CE series FPGA packages in our project due to our familiarity in previous projects with the device and the accompanying software. The FPGA provides the required processing speed for fast processing of image data in real-time and can be used to interface with our peripherals on the PCB.

Requirement: The FPGA package should be able to process the input data from the image sensors in real time and provide the output to the waveform generator with minimal latency.

Risk Analysis: The FPGA package has a Ball Grid Array (BGA) pin connection with on the order of 300 pins which could pose a problem to isolate pins while soldering. For this reason we are also considering implementing our design on smaller scale FPGAs with similar processing power.

2.5. Microcontroller Unit

We are planning to use an AtMega microcontroller from the AVR family for our project due to the low cost and ease of integration with our specific peripherals. Since the microcontroller is situated on each hand, it has to be lightweight and mobile.

Requirement: The MCU should be able to process the pressure sensor inputs and relay it to the bluetooth module in real time for transmission to the central control unit for interpretation.

2.5. Central Unit Power Supply

This integrated circuit supplies the required power to the FPGA at the voltage level required in the specific operating conditions of our project.

Requirement 1: The voltage regulator must provide required voltage for the FPGA +/- 5% from a 3.7-4.2V source.

Requirement 2: Must maintain thermal stability below 125°C at a peak current draw of 250mA.

3. Ethics and Safety

The following are the potential safety hazards with our project:

- *Battery and Power Supply Unit:* We will be using batteries in our project, and li-ion batteries are known to become highly volatile at extreme temperatures or if overcharged. For this reason, we will be closely monitoring the battery temperature and charge throughout the project where batteries are used. We will also be making use of the mains load voltage to power our central logic board. We will take the recommended precautions into account to safely access the power supply.
- *Glove Module:* Our glove module may pose hazard as well in terms of the power from battery, which may cause overcharge at extreme temperature. Our FSR may cause extra hazard that results from unexpected resistance value. In order to avoid any possible hazard we have to understand the expected range of the resistance that the FSR can vary and try to avoid any voltage output that can cause danger.
- Our glove module might conflict with IEEE Code of Ethics #1, "to strive to comply with...sustainable development practices"[3]. Our glove module can make use of any glove in the market. However, in order to make the development practice sustainable, our glove module will make use of gloves that are made out of sustainable method.

4. Risk Analysis

The mains power supply unit poses the highest risk to the safety of each of the components in our design and needs to be implemented carefully to both the safety of the team members as well as of the designed circuits. We also think that the integration of the FPGA chip onto the PCB by soldering could pose a risk to the correct operation of the circuit. This is due to the size and complexity of the pin configuration in the FPGA packages. Additionally, as we will be using multiple camera sensors we will need to consider options of positioning and safeguarding the camera fixtures to protect them from accidental wear.

5. References

1. "Why MIDI Matters." The MIDI Association. Accessed February 07, 2018. https://www.midi.org/articles/why-midi-matters.
2. RN41 Bluetooth Module Datasheet. http://ww1.microchip.com/downloads/en/DeviceDoc/rn-41-ds-v3.42r.pdf
3. Institute of Electrical and Electronics Engineers, Inc.. (2006). Code of Ethics IEEE, http://www.ieee.org/. Retrieved at Feb 8, 2018, from the website temoa : Open Educational Resources (OER) Portal at http://www.temoa.info/node/23284