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DIGITAL PLAYER PIANO

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ABSTRACT

Playing the vast majority of piano pieces without the use of both hands is impossible and retrofitting a piano to be a digital player piano is an expensive endeavor. This project was started to design and build a replicable system that modifies an existing acoustic piano to be played by an automated system with the option of accompanying a pianist to play a duet or overcome a physical barrier the player is experiencing.

The applications of this project include giving amputees the ability to play piano pieces, providing a digital player piano that utilizes a mechanical keyboard, and providing a practice tool in general through the modification of tempo and the ability to focus on certain parts of songs. The expected result was a partial-keyboard prototype with these features that can be installed in a modern piano more efficiently than current market options for primary customer Ron Dufort, from Xerox.

At the conclusion of the project a working prototype cable of playing two octaves of the piano was delivered to the customer. The piano is able to be given a song through a user interface which is sent wirelessly to the electrical components which actuate the mechanical striking mechanism. The integration of these three subsystems was achieved through the design process detailed in this paper.

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NOMENCLATURE (INCOMPLETE)

Nomenclature	Other Names	Definition
MSP430	“Metronome”	
MSP432	“Note Controller”	
Plunger		
PWM	“pulses”	
Raspberry Pi	“main controller”	
Solenoid		
Time Step		

INTRODUCTION

Current digital player piano market options are severely expensive ranging from $3000-$15000 dollars through benchmarking conducted at the end of 2016 [REFERENCE HERE]. The objective of the project was to create a digital player piano with a variety of accessibility features from a budget of $500 with the multidisciplinary team introduced above. The project was conducted at the Rochester Institute of Technology where the primary customer was Ron Dufort, from Xerox, who has a passion for pianos and is determined to help handicapped individuals return to piano playing. A previous team made an attempt at completion of the project in the last year but was unsuccessful at playing a single note which created a daunting challenge for this year’s team.

That challenge, however, was approached through a detailed design process with assistance from faculty guides including Russell Phelps, Elizabeth DeBartolo, and Louis Beato. The team first analyzed the customer requirements and trimmed them in order to be able to achieve success in the one academic year time period followed by generating the relevant engineering requirements for the project. Through scheduling, various calculations, and intense

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analysis of financial factors, a detailed design was generated and various parts from the bill of materials ordered in preparation of assembly in the Spring of 2017. Many problems were faced in creating functioning electrical, mechanical, and software subsystems which became more extreme when the integration process began with the goal of achieving a cohesive system.

Through the use of a detailed problem tracker, faculty guidance, and the multidisciplinary team, efforts were focused on the most critical problems in order to meet the various design reviews, demos, and customer deadlines. The design process was crucial to the success of the project through generating various live documents used in benchmarking, scheduling, and ensuring the requirements of the project were met. The work group also conducted various team building exercises and peer evaluations in order to improve efficiency and collaboration among the members. Through successful interdisciplinary function and proper design process, the team delivered a working prototype that satisfied the customer's needs on time to be used by the next team in order to expand the replicable design to the rest of the piano and additional features which were planned for but not able to be achieved due to time constraints.

PROCESS

The process for building the piano was mainly segregated into circles of overlapping concern in order to maximize efficiency and knowledge specialization in the corresponding sections. The main separations included generally electrical subsystems & computer science, system mounting/striking proposals, and electrical power system designs for the solenoids. All of the sections had to cohesively meld together in order for the project to actually work, but for the first half of development, a mainly independent working style was possible.

The first thing to do was develop the customer requirements followed by the engineering requirements that correspond to the previous. After laying out the requirements the design process began through various brainstorming sessions and utilization of the pugh chart technique in order to choose the best options. Extensive inter-disciplinary collaboration was required to ensure each sub-system would eventually integrate with the others. The process for each subsystem will be discussed individually and the integration process discussed after.

PROCESS: ELECTRICAL

The electrical system design began once the piano drive system was determined. Once solenoids were determined as the actuation mechanism, the next step involved designing a solenoid drive system. The first iteration involved a simple BJT controlled via a PWM value from the uController. Due to power consumption and heating issues, the BJTs were later replaced with more efficient power MOSFETs. Further experimentation found a need for fly-back diodes, in order to prevent backfeed current into the MOSFETs' drain, thus increasing the lifecycle of each MOSFET. The last iteration of the solenoid drive circuit was to include pull-down resistors on the gate of each transistor. This prevents the gate from floating during the startup sequence of the uControllers. The final power system consists of a transistor, pull-down resistor, flyback diode, and the solenoid itself in the following configuration:

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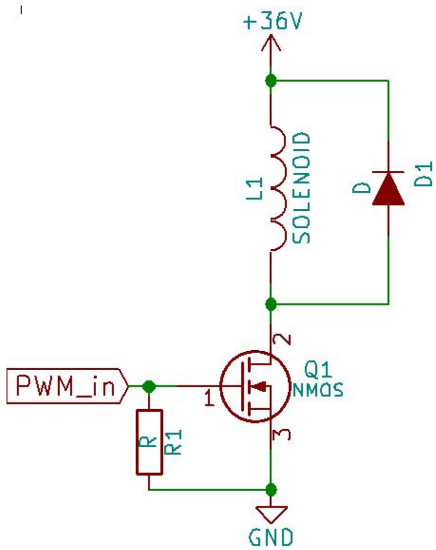

This allows for the microcontroller's 3.3 volt logic levels to be translated into a dynamic range of up to 36 volts to control the intensity of the solenoids and thus the volume of triggered notes. MOSFET gate devices have been selected to control the solenoids as they require no input current at the gate and can switch rapidly without overheating with the current draw measured during testing.

The PWM microcontroller is a Texas Instruments MSP432. This is what controls the output signal to the power electronics, as shown previously. As the title PWM microcontroller implied, the MSP432 utilizes PWM to emulate an analog output. Through the use of timer registers internal to the MSP432 these PWM outputs can be automated so that once they are set the microcontroller is freed to do other tasks. Among these tasks is the interpreting of the song, as stored internally. Each note of the song is stored with four pieces of information. The solenoid number to be played, the timestamp at which it is to be played, the intensity at which the PWM value is to be, and the duration for which the note will be held. This information is sent to the MSP432 via a Raspberry pi, which is handling the user interface and stores all songs not currently being played. The MSP432 parses signals that dictate the structure of notes that will be played. The MSP432 was configured to "understand" notes built in the following protocol:

TABLE OR DIAGRAM OR SOMETHING TO GO OVER PROTOCOL

In addition to the MSP432s a MSP430 is utilized as a metronome. An interrupt configured by the main controller on the 430 communicates with the MSP432s in the system to update them regarding the song's current time step which was set to 10 ms. The MSP432s check every 10ms based on a pulse from the MSP430 in order to determine if a note is to be started or ended. The 10ms time step was selected because no song would require a smaller time step in order to be played accurately.

PROCESS: SOFTWARE

The protocol is able to give all of the precise distinctions of each of the notes. GO INTO DETAIL ABOUT SIZES, etc OF THE DIFFERENT PARTS AND WHY. THIS GOES INTO THE PI AND THEN THE SOFTWARE PART.

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The note packets are each sent in to the MSP432 from a raspberry pi microprocessor unit. The raspberry pi microprocessor is configured to interpret songs in a standardized format and pipe them down to the MSP on a note by note basis after converting them individually to the protocol format.

The song format that is interpreted and stored by the raspberry pi is the .MIDI file format. MIDI files are widely used in many different industries to store song and other data relevant to timing based executions. MIDI files are structured in a fashion……..

PROCESS: MECHANICAL

The goal of the mechanical subsystem was to give mechanical advantage to actuators tn order to consistently strike the correct keys while abiding by the customer and engineering requirements. Due to budget constraints, the design relied heavily on 3D printed parts in order to rapidly prototype each iteration of the design. Communication with the electrical side was also important to ensure the design would integrate nicely later down the line.

The process began with brainstorming sessions in order to develop various concepts on how the keys would be stuck. The most important customer requirements were to retain the piano's original functionality, not mutilate the piano, and attach our mechanism as close to the actual key as possible in order to not affect the natural mechanisms of the piano and the distinct tone that arises from that technology. Space constraints also drove the design process with regard to the mounting technique. Pugh charts and benchmarking were utilized in order to decide on the best approach to striking the keys.

Solenoids mounted to a board and attached to steel cable sent over a dowel rod connecting to the key was the consensus on how to strike the keys. [INSERT CROSS SECTION FIGURE DEPICTING MECHANICAL ELEMENTS] This design adheres to the customer requirements and is compliant with the budget limitations. The solenoids would be fixed in a two level array on the board, as the keys of the piano are very closely aligned, and the solenoid body was wider than the space in between each key. Keeping the space constraints in mind, the board would be held vertical so as to take up as little space as possible in the piano case. In order to actuate the keys, a series of parts were needed to attach the solenoid to the piano actuation mechanism. A cap for each solenoid was 3D printed and secured by a screw to the end of the solenoid plunger. Thin nylon wire was used to run from the plunger cap, over the metal rod, and down to the hammer striking mechanism of the piano. To ensure easy gliding of the wire over the rod, simple wheels were 3D printed and ran along the rod for each respective wire to be held. One of the concerns faced during the design process was how to easily attach, detach and tension the wires so the keys could be played. To achieve this, a connection piece with an ergonomic thumb handle hooked around the pin on the bottom of the piano striking mechanism was designed where the wire was permanently tied. This allows the connector to be removed from the piano without anything permanently tied to the piano itself. In order to tension each wire properly the wire ran through the plunger cap on the design board and was pulled until taught and then secured utilizing a thumb screw.

[POSSIBLY ADD MORE ABOUT SYSTEM INSTALL AND MAINTENANCE FEATURES]

PROCESS: INTEGRATION

Integration of the various subsystems was challenging. The first step was integrating the electrical and mechanical systems. This was done through generating code that would strike each individual key to confirm that the systems worked in conjunction with each other. This required several iterations in order to ensure each solenoid was receiving the right amount of

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current. Once the mechanical and electrical systems were integrated the software side was added.

With various people writing code this process was the most challenging to achieve. The engineers began by utilizing one display in order to read the serial ports from the pi and MSP432 to know what was actually being sent between the two. After quickly realizing a second display was needed in order to be more efficient the sets of code were more quickly debugged in order to generate a functioning system.

[ADD MORE OF THE CRITICAL PROBLEMS FACED?]

Results and discussion

The final prototype consists of a scaled down version of the originally requested model while still encompassing the majority of the intended functionality. Utilizing 2 octaves instead of a fully piano in order to demonstrate feasibility and remain within budget, the constructed prototype is able to deliver a user based input file from the interface to the individual octave controllers which allows the specified solenoid to play the appropriate note. Though the intended functionality was met for the project, some key requirements were not obtainable due to various constraints.

Handicap user accessibility is still limited for the final prototype as separating the user's MIDI input file to accommodate for a specific handicap was found to be out of reach due to software engineering setbacks. Fortunately, many piano specific MIDI files that are easily found through open source applications were created using separate "tracks" for each individual hand allowing for some handicap accessibility .

Loudness volume range has been limited due to inconsistencies among individual solenoids from manufacturing defects in the winding wire thickness. Originally, solenoids were tested using a handheld decibel meter with the PWM control input adjusted to compensate for volume. Due to some solenoids responding poorly at low PWM (Volume) levels, the current prototype piano will have to function at higher volumes to compensate for inconsistent solenoids.

Several goals were deemed unachievable due to monetary and time constraints. The active tempo adjustment system was foregone but could easily be implemented in software if the input feedback system was affordable. The same can be said for the pedal control system which accounts for users who are handicapped in that regard. Had a larger budget been allocated and less problems experienced, these systems could be easily integrated into the current prototype which is unfortunately left for future teams.

Unfortunately, some requirements were not met due to initial engineering designs that had unintended consequences later on. Install time is approximately 90-120 minutes, slightly longer than the goal for 30 minutes. The ability to scan sheet music and convert to MIDI format was also not achieved and deemed out of reach for the current prototype due to time constraints.

Conclusions and recommendations

In conclusion, the piano was completed as a low budget proof of concept. Though it does not have any note playing feedback system to allow the piano to follow along with the pianist, it took a new design idea from the most basic form into something that successfully plays the piano. At the beginning of this project the team was given a goal of getting the device to play a song, and the team met that goal. With the teams low budget, cheaper alternatives had to be used, but with this design in place, a scaled up version that can play all the notes is now within reach for another team. With the robust design used for 24 keys, a following iteration of this project would be to refine and build upon the progress already made. Overall this project was

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successful on its main goal of playing a song.

One of the main ideas behind this project's conception was as a tool for people with physical limitations to be able to play the piano with the assistance of the device. This is a feature that is not fully implemented in this design. Specifically, the device does not know when the user plays the piano so it can not follow along with someone playing with one hand. The system can only remove individual notes the person can play from the automated playing.. Through the utilization of a ffeedbacks ystem the piano would know which key and at what time notes were played by the user, which opens up many more possibilities for this device including some of the long term goals of the customer.

The team faced limitations financially while building the system. The solenoids were the largest expense of the total budget which meant relatively cheap solenoids were purchased to save room for all of the other necessary parts required. These solenoids, although appropriate for the requirements of the system, do not offer much of a sound range for dynamics in playback. If higher quality actuators were used more force could be applied to strike the key, and a greater scope of dynamics could be exploited.

The mechanical system could be improved to encompass a more modular design. The system could utilize a rigid connecting rod to a rotating crank pulley on the dowel rod with dimensions that would give a mechanical advantage to the solenoid. This would allow the cheap solenoids to produce more of a dynamic range. Unfortunately, due to tolerance an individual tuning mechanism should still be included in order to modify the tension for each key. The mounting system could also incorporate a way to keep the cables in place during removal in order to escape re-tuning the system after each removal process. Three-dimensional printing is still ideal for future teams as the number of parts is fairly small and the required strength of the parts is low.

Another big design improvement would be to move all control for the solenoid playing to one compact, low profile circuit board. The current design uses 2 MSP432s and 1 MSP430 evaluation boards, for just 2 octaves which are bulky and would not be used in a commercial product. A much smaller control system could move this project towards a more complete and professional design. It may also behoove future teams to look at ways to drive all 88 keys on the piano without using multiple microcontrollers, as the current design uses 1 controller for every 12 keys. Future iterations could build upon the breakout board used to drive the solenoids designed for this device through replacing the connections to the evaluation board with an actual chip. On this board the circuitry power to the solenoid could be improved to a totem pole drive circuit which could be used to improve solenoid actuation along with a snubber circuit to reduce the chance of electrical failure.

References (Not Complete)

Within the text, references should be cited in numerical order, by order of appearance. The numbered reference should be enclosed in brackets. For example: “It was shown by Prusa [1] that the width of the plume decreases under these conditions.” In the case of two citations, the numbers should be separated by a comma [1,2]. In the case of more than two references, the numbers should be separated by a dash [5-7].

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Example References:

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[1]

Acknowledgments – use style "acknowledgments clause title"

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