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THE ACTUATED GUITAR: A PLATFORM ENABLING ALTERNATIVE INTERACTION METHODS

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ABSTRACT

Playing a guitar is normally only for people with fully functional hands. In this work we investigate alternative interaction concepts to enable or re-enable people with non-functional right hands or arms to play a guitar via actuated strumming. The functionality and complexity of right hand interaction with the guitar is immense. We therefore divided the right hand techniques into three main areas: Strumming, string picking / skipping, and string muting. This paper explores the first stage, strumming. We have developed an exploratory platform called the Actuated Guitar that utilizes a normal electrical guitar, sensors to capture the rhythmic motion of alternative fully functioning limbs, such as a foot, knee or the head, and a motorized fader moving a pick back and forth across the strings. A microcontroller is utilized for processing sensor data, which allows flexible mapping of user input to the actuation of the motorized fader. Our approach employs the flexibility of a programmable digital system, allowing us to scale and map different ranges of data from various sensors to the motion of the actuator – thereby making it easier adapt to individual users.

Author Keywords: Interactive performance systems; Interfaces for sound and music; Music and robotics; Social interaction in sound and music computing; Actuated instruments; Actuated guitar; Musical instruments for the disabled.

1. INTRODUCTION

Playing a musical instrument can be an interesting and worthwhile pursuit, but in many cases is impossible for someone with a disability. Those of us living without disabilities can just pick and choose an instrument of our liking. We may prefer the sound of a certain instrument, wish to follow in the footsteps of an idol, or learn to play specific songs from the radio. Some people succeed and actually learn to play an instrument, but many give up along the way when they realize what it takes in time and effort to learn to play an instrument well.

What about people with disabilities that wish to play musical instruments? In this work, we begin to address the question via the development of alternative interaction methods for playing the guitar. Disabilities can either be congenital, or caused by illness or accidents in any stage of life. If an arm or hand amputee, or anyone having a medical problem such as cerebral palsy wishes to play a traditional instrument, it is likely that they will be unable to reach the instrument's full potential (or possibly not be able to play an instrument at all). The obstacles while learning to play an instrument designed for those without disabilities can be too large to overcome.

We focus here on the use of technology to enable alternative methods of playing the guitar, specifically for those who have limited or no use of one hand or arm. The use of actuators, feedback systems, and flexible interaction design techniques present a novel design optimized for easy customization. Furthermore, playing music can be a good activity for "Forced Hand Use" training [1]. This method encourages those with cerebral palsy or stroke patients, for example, to use their affected arm, with the aim that they will begin using that arm more in daily life or regain control with the arm or hand.

2. RELATED WORK

Related work has included a wide range of approaches to either customizing existing instruments, or designing entirely new music interfaces. These have ranged from simple mechanical aids [2] (sold by companies such as A Day's Work, LLC[1]), to advanced bioelectric controllers allowing users to produce computer-generated music [3]. An example of a simple tap-pad interface developed for disabled users is the TouchTone [4]. However, we have chosen here to focus on string instruments – specifically the guitar – rather than percussion, wind, or other families of musical instruments.

Most traditional instruments require more than one limb to be used while playing. As there are millions of disabled who lack the use of one or more of their limbs in the world today, these people are excluded from many types of music making. While quite a number of efforts have been undertaken in the past to modify existing instruments for use by the disabled, there have not been many specifically targeting the guitar as an instrument for disabled users.

Our work involves creating a semi-robotic musical instrument. A historical view of robotic musical instru-

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[1] http://www.adaysworkmusiceducation.com/

ments is included in [5]. Robotic instruments focused on the guitar include the League of Electronic Musical Urban Robots (LEMUR's) GuitarBot [6], among others. While the GuitarBot is much more capable of completely automating the motions needed to play a guitar than our current work, it discards any affordances of direct human playing skills, due to a design that places each string on a separate 'neck'. We purposefully aim our development at more traditional guitar bodies, thus enabling users to develops skills that are as close to the normal techniques as possible. It follows in some of the author's related work with actuated instruments [8].

3. INTERACTION METHODS

Playing a guitar traditionally requires the use of both hands. The right hand does the strumming and or picking of the strings, and fingers of the left hand are used for fretting the strings. As stated in the introduction, the scope for this research is to enable or re-enable people who are not able (or lost the ability), to play the guitar. Our first approach focuses on the right hand, and how it interacts with the guitar. The common interactions of the right hand have been identified and divided into three stages:

Stage 1: Strumming
Stage 2: String picking and string skipping
Stage 3: String muting

The research is thus divided into the three stages, based on the dexterous complexity of each type of interaction. This paper elucidates only the first stage, strumming. Strumming is the most basic right hand interaction technique, making it a good place to start, as well as a prerequisite for the following stages to build upon (see **Figure 1**). Next we describe and discuss our approaches to strumming a guitar when the user does not have full control of the right hand.

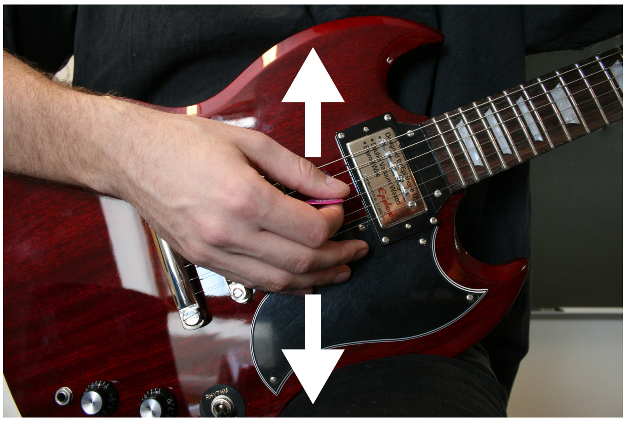


Figure 1. Strumming a guitar is the most basic right interaction possible with a guitar. Strumming is a near-perpendicular rhythmic motion across the strings.

3.1 Candidates for Rhythmic Movement

As the left hand is occupied fretting the strings, possible candidates for control of our motorized strumming actuator include various portions of the legs, the head, or possibly the remaining part an amputated arm, see **Figure 2**. Without mechanical aids, these parts of the body do not offer any realistic means of physically strumming across the strings in a normal playing position. However, the remaining part of an arm, the head or part of a leg (even a foot or toe) do offer the possibility to move in a rhythmic pattern.

Moving the arm or legs in a continuous rhythmic pattern are likely the best options, as humans are accustomed to naturally moving these body parts in rhythmic patters for long periods of time (for example when walking or running). For people with no control of their legs nor right arm, the head can also be used to move in a rhythmic pattern, albeit the muscles in the neck are not normally used for repeated rhythmic movements (and may quickly fatigue). Nevertheless, over shorter periods of time this would still give such individuals the ability to strum the actuated guitar.

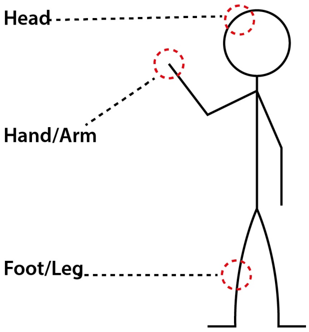


Figure 2. The different body parts that can be used instead of a paralyzed limb to interact with the instrument.

3.2 Gesture Capture and Motion Tracking

Because the rhythmic movement of these alternative parts of the body are not able to physically strum the strings in a normal fashion, our system needs to capture the motions and translate them into control signals for the actuator on the guitar. This can be done through the use of various sensors. The sensors can be mounted several different places on the body in order to optimize the experience for each individual.

Our initial experiments have made use of a simple accelerometer sensor that might be ideal for a person with an amputated right hand. It is fitted with a velcro armband and strapped onto various parts of the body. Many other types of sensors can also work as input for the actuated guitar, such as gyroscope sensors, which capture rotational movements. An individual that can only rotate their head, for example, could use this type of sensor, with the rotational input translated to the actuator's linear output – robotic strumming of the strings via a motorized fader.

The authors have considered many other options as well, such as a full Inertial Measurement Unit (IMU) that combines data from an accelerometer, gyroscope and magnetometer to provide a more precise estimation of orientation and motion, or even commercial options such as the

Leap Motion device[2], which could be mounted in various locations to capture player inputs. In the next phase of this research we plan to incorporate a single-chip IMU, the MPU-9150 released by Invense, Inc. It is a 9-axis motion tracking solution with built-in sensor fusion algorithms combining data from a 3-axis gyroscope, a 3-axis accelerometer, and a 3-axis magnetometer.

3.3 Mapping Sensor Input to Actuation

When customizing the actuated guitar for people with various disabilities, our digital approach attempts to make it easy to perform the necessary mapping of data from various input sensors (simple filtering, scaling and offset operations) to control of the strumming actuator. This is especially true when compared to the wide variety of mechanical approaches that would be needed for different scenarios and users. At the moment, these changes are managed in the firmware of the microcontroller that our system uses, but these parameters could also be changed graphically via a visual programming environment such as MaxMSP[3] or PureData[4]. This approach, based on the FireFader system [8] would likely be preferable for individuals who wish to modify the system themselves.

One example would be a user with a partly paralyzed leg, but who can still stomp their foot. Mounting our sensor on the foot will translate that motion into input for a microcontroller, which can then map the input to fit the actuator's full range of motion. This gives us the possibility of amplifying small motions to move the output actuators an entire strum-length, translate rotation motions into linear motions (if using a gyroscope sensor), etc. Doing this by purely mechanical means will be a highly complex construction and difficult to quickly modify to fit different users with different needs.

4. LIMITATIONS

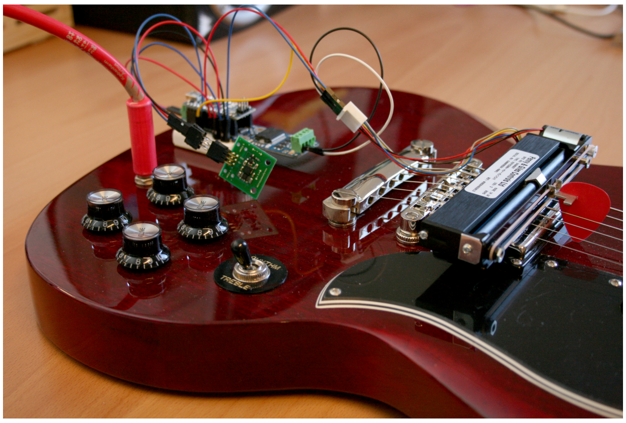
The fine motor control exhibited by a normal human arm, hand and fingers will be difficult if not impossible to replicate via low-cost robotic actuation. A human hand can move in almost a hemispherical fashion at the end of the wrist. Fingers can stretch, bend and move sideways. In addition to the physical movements, we also receive sensory feedback from our hands and fingers. Although we are in the initial stages of this research (focused only on strumming to date), it is already clear that custom actuators would need to be designed, if attempting to truly approach this kind of control and feedback. Therefore, we have so far only researched the types of movements that are the most crucial to maintain, in order to design a substitution for the hand strumming a guitar.

It is worth noting that we are working with an electrical guitar for this prototype, and that the actuator we are using (a small motorized fader) can cause electrical noise to bleed from the motor's electromagnetic field into the guitar's pickups. This occurs due to the proximity of the electrical guitar pickup, be it single coil or humbucker design, near the plucking location on the strings (a position required to best capture the sound). This electromagnetic noise problem can be substantially circumvented by running the pulse-width modulation (PWM) signal that controls the motorized fader at a frequency higher than normal human hearing (more than 20kHz). While an acoustic guitar would not have this problem, the more fragile body makes it somewhat difficult to mount actuators on the guitar's body without damaging or compromising its ability to produce a good acoustic sound.

5. EXPLORATORY PLATFORM

To help us explore the possibilities offered by this research, a proof-of-concept guitar was created as described below (see **Figur 3**). The device consists of an Epiphone SG Standard electrical guitar, Arduino Nano V.3 board with an ATmega328 microcontroller, a "2motor" controller board from Gravitech with an L298 dual H-Bridge driver, an Analog Devices ADXL322 accelerometer, and a Penny+Giles PGFM3200 motorized fader.

The Arduino Nano sits on top of the 2motor board, both of which are plugged into a breadboard that is adhered to the guitar's body. The accelerometer is connected to the microcontroller's analog input ports for processing. A USB cable powers the Arduino, motor board and the motorized slider, and allows for quick data access and easy upload of software to the Arduino during our development process. The system can also be battery powered.



Figur 3. Implementation of the proof-of-concept guitar, which consists of an accelerometer, guitar, microcontroller, motor controller, motorized fader, and a pick.

The data flow throughout the system is shown in **Figure 4**. A user interacts with the accelerometer, which sends a signal to the Arduino. The ADXL322 is capable of sensing two independent axes, but as seen on **Figure 1** the type of movement we are most interested in when approximating traditional playing technique is just a single axis of motion. We therefore omit one axis entirely. The axis in use is averaged over 30 samples, as the sensor produces somewhat noisy data, and we are primarily interested in lower frequency information. The microcon-

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[2] Leap Motion, http://www.leapmotion.com/

[3] MaxMSP, http://cycling74.com/

[4] PureData, http://puredata.info/

troller also reads the current position from the fader's potentiometer.

The feedback from the fader position in combination with the target value from the low-pass filtered accelerometer data determines what control data to send to the motor controller, for example in which direction and how fast to move. To avoid jitter while the fader is idle, the microcontroller only commands it to move when a sufficient G-force threshold is applied to the accelerometer in a given direction. The motor controller then turns on the motor in the given direction, and the fader strums the guitar. This is similar to the 'Real-Time Feed-Forward Control paradigm' outlined in [9].

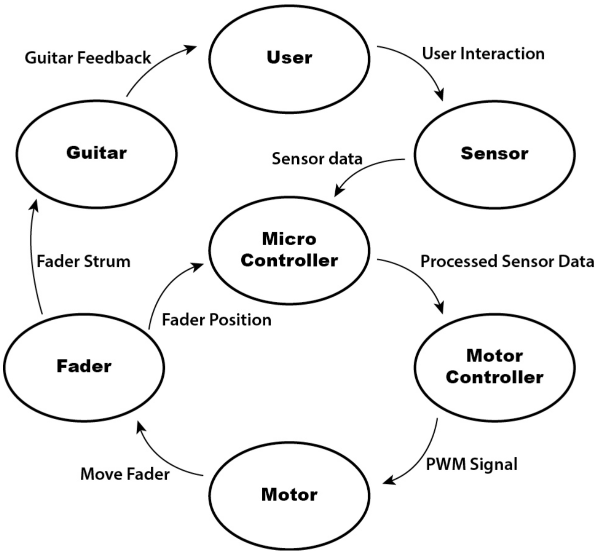

Figure 4. The data flow throughout the system. The user interacts with the sensor, which allows them to 'remote control' the position of the actuator – via internal feedback in the microcontroller that steers the system's output – thereby producing sound perceived by the user, completing the outer (interaction) feedback loop.

6. FUTURE WORK

There are many avenues of future work that would be interesting to pursue. For example, the initial studies shows that using a single accelerometer brings limitations. The constant pull of gravity of 1G is impossible to remove from such a sensor's output, making it difficult to get the same reading when strumming up and down (lateral motions are therefore preferable). The IMU mentioned in section 3.2 will help to resolve this issue, by allowing us to remove gravity effects through a calculation of the residual accelerations after subtracting the gravity vector. It should also enable us to explore much more detailed interaction due to the greater number of sensor types.

Trying completely different types of sensors, as mentioned in section 3.2, is also something we plan to pursue. Standard 'sip and puff' or simple force-sensitive resistor types of sensors would facilitate entirely different types of input, and could be interesting helps for more severely disabled people to strum the guitar.

7. CONCLUSIONS

We have shown that it is possible to enable or re-enable people to strum a guitar using an accelerometer as input controlling an actuated guitar using different body parts. Drawing on a range of inspiration we have shown that disabilities does not need to stop people to explore and experience normal instruments made for people without disabilities.

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