# Music Therapy: High Level Design

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# 1. Introduction

Parkinson’s Disease, Multiple Sclerosis, and Huntington’s Disease are a few of the debilitating conditions that have a devastating effect on motor function. These diseases can only be treated, not cured. By developing effective treatment plans, the progression of damage can be better managed and increase quality of life. Looking at small-scale solutions, simple and accessible treatments have yielded promising results that act as a supplement to major and invasive surgeries.

Our idea is to create a wearable device that can track the gait of a Parkinson's patient to assess progression of the disease and additionally be a therapy tool to improve motor function. Gait analysis is a method in diagnostics for motor disorders such as Parkinson’s or Huntington's Disease and can track the degradation or improvement of a patient’s motor function. Music-based interventions have shown great benefits in the treatment of motor impairment that translates to cognitive, speech, and language rehabilitation through entrainment, the temporal locking process in which one system’s motion or signal frequency entrains the frequency of another system. In this case, the motor system locks with the rhythm of music. Rather than the established use of music therapy alone, utilize a wearable that will alter the speed/rhythm of the music played to develop a feedback system with positive reinforcement.

# 2. Problem Description and Proposed Solution

A number of neurological and degenerative diseases cause motor function impairment that can greatly decrease the quality of life, independence, and health and safety of patients. This degeneration can be rapid, and in cases where the source of motor impairment is incurable, the recovery process can be lengthy, difficult, and yield minor improvements if any. Since the causes are so vast, there are many medications, therapies, and rehabilitation treatments that vary in effectiveness, carry risks, and have high costs or low accessibility. The goal is to find a treatment method that is non-invasive, low-risk, low-cost, and accessible as well as proven by extensive research and widely applicable to the range of people affected by motor dysfunction.

Music therapy is growing in popularity and recognition as a treatment for motor dysfunction. This approach will be applicable for rehabilitation after stroke, Parkinson's Disease (PD), Multiple Sclerosis (MS), Epilepsy, traumatic brain injury, and more. Specifically, in PD, the timing and size of repetitive sequences of internally generated automatic movements are particularly affected. The most evident consequence of this deficit is the alteration of gait patterns, including loss of rhythm, shorter steps, slower gait, and trunk instability. Music-based interventions can positively affect functions such as motor performance, speech, or cognition in these patient groups. The psychological effects and neurobiological mechanisms underlying the effects of music interventions are likely to share common neural systems for reward, arousal, affect regulation, learning, and activity-driven plasticity.

Entrainment is at the root of the principles of music therapy. It is defined as a temporal locking process in which one system's motion or signal frequency matches or persuades the frequency of another system to adjust to its own. The stronger signal entrains the weaker signal with one adjusting the other, or if the two are equal, they both adjust to meet in the middle. In our case, the rhythmic signal causes the temporal-motor system to adjust and match its frequency. Studies using fMRI and magnetoencephalography observe the brain’s response to rhythmic input and locate where in the brain activity is occurring. It was found that even when the conscious mind did not recognize a rhythm change, the brain activity reflected recognition of the shift, and motor functions such as tapping were affected. Therefore, the auditory system is clearly interlocked to the motor system by multiple pathways and sensitivity to changes in input. In summary, auditory rhythm acts as a forcing function to optimize motor control across all facets and the rhythm input influences movement timing as well as modulates muscle group activation patterns and the control of spatial movement.

With the extensive research compiled to support the success of these therapies and the exploration of neural pathways in the brain, the plan is to take an organized and technical approach to how rhythmic auditory stimulation in conjunction with structured movement and timed tasks can improve motor functions such as gait velocity, cadence, stride time symmetry, stride length, weight-bearing time, stride variability, and balanced muscular activation pattern.

## Solution:

Our proposed solution is a wearable device that tracks the patient’s gait, performs software processing of the gait metrics to determine corrective response by the device, uses this information to alter the tempo of the selected music, and physically transmits this music (wired) to the patient via an audio device.

Our device will be designed to be conveniently wearable and comfortable to use. This modular device (including all hardware components) will be worn by the patient at the hip, via a belt clip or similar hardware. It will be capable of holding and supporting the weight of the gait tracker, associated electronics including the battery, and the output of our chosen wired audio device. This will all need to be contained in a physical “box” to hold our finished modular product.

One of the main functions of our product will be the accelerometer, used to track the patient’s gait. A motion sensor (accelerometer) will be configured to track hip displacement across space, indicating the frequency, length, and time of the patient’s steps. These are all key metrics that will determine how the patient’s motor skills are functioning, and what modifications to the music therapy are most beneficial in real-time. This will be done with a microcontroller, wired with associated electronic passives and a rechargeable battery. The collected information will be sent via SPI or I2C to the software processing stage.

With the physical gait metrics collected, code will be written to analyze the information and compare it to pre-set standards. The user will choose music based on desired gait characteristics, focusing on equating pace to beats per minute. The measured gait metrics will take variation from pre-set (adjustable) gait frequencies, lengths, etc. and alter the music accordingly. This processing will include physical metrics from current research on music therapy’s effect on Parkinson’s and Huntington’s patients, and use this research to determine the pre-set standards and most applicable musical responses.

The musical recommendations from the software processing function will then be used to modify the music being fed to the audio device. This will be done to pre-loaded music with known characteristics. The music will physically be transmitted to the patient via wired headphones, with an audio jack feeding from the wearable device itself. This choice of interface also allows for the use of a speaker if desired.

## 3. System Requirements

3.1. Requirement 1: Embedded Intelligence Capabilities

3.1.1. Needs to have a capable enough chip, memory, and peripherals to support constant, real-time signal processing of inputted gait data from the accelerometer.

3.1.2. Can store, edit, and output audio files to an external audio jack and audio device.

3.1.2.1. Editing of the audio file will include speeding up and slowing down the pace of the music, without changing the pitch of the music. This will require detailed signal processing, and enough embedded intelligence and memory to handle the software operations.

3.2. Requirement 2: Rechargeable Battery Power

3.2.1. Our wearable device should be able to run continuously for several hours at a time, without running out of power. We will choose a rechargeable battery pack that means both the specified power requirements and voltage requirements (when we have a better idea of what both of those are).

3.3. Requirement 3: User Interface

3.3.1. Our user interface will be attached to the wearable device such that the user can preprogram what kind of music they would like to hear during their movement session, as well as their desired pace of gait.

3.3.2. The interface will consist of an OLED display (most likely 3 or 4 inches for visibility) and pushbuttons for the user to easily input their selections.

3.3.2.1. There will be pre-programmed songs (audio files stored in the devices memory) such that a wireless interface is not necessary.

3.4. Requirement 4: System Details

3.4.1. The system will include one centralized printed circuit board. It will be connected to a number of peripheral devices. These include our OLED display, a rechargeable battery pack, a headphone jack, a pedometer/accelerometer, and push buttons (that are both located on the PCB and accessible from the exterior of the product so that users can press them).

3.4.1.1. The PCB and peripherals will be self-contained in a modular, sturdy “box” that can be solidly clipped/connected to the user’s hip.

3.5. Requirement 5: Inclusive wearability

3.5.1. We must keep in mind the target audience of our idea: those with impaired mobility and motor function. Thus the device must be easily put on, soundly attached to avoid the need to bend down and pick it up, and relatively comfortable as to not impede motion.

3.5.1.1. We intend for the device to be attached at the waist, a location that is typically reached without strain.

3.5.1.2. The mechanism must be investigated more, but our preliminary inclination is a clip that can slide on to one’s waistband or belt. The hip is a location we believe will not influence one’s movement, and clipping from above will reduce the likelihood of the device falling.

3.6. Requirement 6: Dangerous Voltage or Current protection

3.6.1. We do not anticipate our device producing voltage or currents that would be dangerous to the human user, since all our electrical components (aside from the audio system) will be enclosed in our wearable.

3.6.1.1. The only exposed components would be the pushbuttons that the user manipulates to input their desired walking pace and music selection. We will take care to make sure these pushbuttons are installed securely, and that no wiring is exposed.

3.7. Requirement 7: Mechanical Requirements

3.7.1. Our most important mechanical requirement is that our device is compact and lightweight enough that it does not impede either the user’s walking motion, or the device’s functionality.

3.7.1.1. Initially, we are aiming to limit our modular, enclosed device to a size no greater than 5” by 3”, and weighing no more than 1 pound.

## 4. System Block Diagram

4.1. Subsystem 1: Gait Tracking

4.1.1. Needs to accurately detect motion via our onboard accelerometer. Accelerometer will record when a “movement” has occurred, and (pending further research) our gait analysis will translate these movements into steps. The movements will be quantified, and interfaced to the gait analysis subsystem.

4.1.2. Rugged enough to withstand sudden, quick, and sustained motions up to running speed. Accelerometer should not break down with sudden or accelerated movements. Its physical placement and attachment are factors to consider here.

4.2. Subsystem 2: Gait Analysis

4.2.1. Needs to process the incoming data from the accelerometer into walking steps and specify how much time occurs in between each step. Software uploaded to our microcontroller.

4.2.2. Translate this raw step data into a walking pace, and compare this pace with the user’s pre-inputted walking pace.

4.2.2.1. Initial software description: Hold a buffer of “5 steps” worth of data. When a new step is taken, the oldest of the 5 steps in the buffer is replaced with the new step. The average pace is calculated from this 5 step buffer, and when the average pace of the buffer data changes by +/- 10% the music processing software will be told to take action and change the music tempo.

4.2.3. Based on the pace comparison, music tempo recommendations will be sent to the music processing subsystem (whose software is also uploaded to the microcontroller) whenever it is determined that a drastic enough change in pace has occurred that a tempo change is necessary.

4.2.4. The gait analysis should be resilient to any button presses (adjusting volume, for example) while walking

4.3. Subsystem 3: User Interface

4.3.1. Interface focuses on user input, as output is purely audio.

4.3.2. Needs to be simple and intuitive - many of our desired user base are older with limited technology experience. Needs to accurately display music options, and update as selections are made.

4.3.2.1. At this point, pushbuttons seem to be the best option - they can be labeled intuitively and limit the complexity of movements a user can attempt to make when interacting with the interface.

4.4. Subsystem 4: Music Storage

4.4.1. External memory that can store the data needed to present multiple options of music, preferably enough to provide a range of bpm to coincide with desired paces.

4.5. Subsystem 5: Music Processing

4.5.1. Access music and tempo data from the storage location. The music will be stored either in an external flash memory device on the PCB.

4.5.2. Access live gait analysis data (tempo recommendations based on the weighted average of the user's walking pace). The music tempo will be updated to reflect these recommendations when a drastic enough (controllable metric) change in pace has occurred.

4.5.3. Ensure the music is still pleasant to listen to: cannot alter the pitch when altering the tempo. This will require significant real-time signal processing to avoid noticeable pitch changes.

4.6. Subsystem 6: Music Output

4.6.1. Must use a standard jack to connect to headphones or to a loudspeaker

4.6.2. Adjustable volume with push buttons instead of a knob for easier control

4.7. Subsystem 7: Power and Regulation

4.7.1. A rechargeable battery that is not too bulky or heavy to the extent that it makes wearing the device uncomfortable.

4.7.2. Needs to be able to power the whole system for the designated time period. Since this device is not directly connected to the user, worries about power regulation according to other medical devices that interface directly with the body (ex. an electrode) are not relevant.

### *4.8. Future Enhancement Requirements*

4.8.1. Phone connectivity for a more convenient and familiar interface
4.8.2. Option to connect to bluetooth headphones
4.8.3. Connect to Spotify/Apple Music/YouTube Music etc.

## 5. High Level Design Decisions

5.1. Subsystem 1: Gait Tracking

5.1.1. Which specific accelerometer we will be using to most accurately measure clear and distinct steps.

5.1.2. How we will make our accelerometer “step recognition” resistant to accidental steps from motions such as adjusting volume via a pushbutton on the device.

5.2. Subsystem 2: Gait Analysis

5.2.1. How drastic of a change in pace, and/or minimum time at a new pace, is required to necessitate a recommended change in music tempo.

5.2.2. The coding structure of the software itself will need to be determined, including libraries, inputs, and outputs.

5.3. Subsystem 3: User Interface

3D printed case for the electronics. There will be two push buttons for volume, one increases and one decreases. Two more push buttons for up and down to navigate through the menu that will be on the screen with different options for desired pace (each with an equivalent song) and a select button. On the back of the case will be a power switch.

5.4. Subsystem 4: Music Storage

5.4.1. A 1 GB SD Card will be used to store the downloaded music.

5.4.2. We can include an SD card socket that is wired to the main controller.

5.5. Subsystem 5: Music Processing

5.5.1. How the microcontroller will access the selected song from Music Storage.

5.5.2. What libraries, inputs, and outputs will be needed in the software to update the music tempo and control the pitch. How the software will process the music signal in a way that pitch is preserved despite changes (potentially drastic) in frequency.

5.6. Subsystem 6: Music Output

5.6.1. How the volume will be controlled: buttons.

5.6.2. There will be 10 volume settings, the push buttons will be used to navigate up and down between these discrete levels.

5.7. Subsystem 7: Power and Regulation

5.7.1. We will use a rechargeable 5V battery, which can then be further regulated to 3.3V on our PCB. The battery will be recharged by USB-C.

## 6. Open Questions

6.1. Do we need an external device/memory chip to hold the downloaded music? If so, what type and how do we interface it with our main controller?

6.2. How do we make an easy-to-use interface? Push buttons? Other?

6.3. What physical casing works best?

6.4. How do we alter the tempo of the music without distortion of the music to a reasonable degree?

6.5. How do we fine tune the gait analysis piece - particularly how do we approach accurate analysis with enough data versus quick real time tempo updating based on that data?

## 7. Major Component Costs

| Part Type | Part No. & Link | Description | Cost |
|---|---|---|---|
| Motion Sensor | ICM-42670-P | 3-axis accelerometer with I2C/SPI Interface | $4.80 |
| Microcontroller | ESP32-S3-WROOM-1 Module | Microcontroller | $3.20 |
| Audio Codec Chip | ES8311 | Contains DAC, pre-amplifer, headphone driver, digital sound effects, analog mixing, and gain functions | $0.47 |
| Audio Amplifier | NS4150 | Amplify audio signal for headphone/speaker output | $1.17 |
| Audio Jack | TRS Audio Jack | Used to connect headphone/speaker | $0.75 |
| USB-to-UART Bridge Chip | CP2102N | Connect microcontroller to PC to program/debug | $4.44 |
| USB-to-UART port | UJ31-CH-G2-SMT-TR | Self-explanatory | $2.50 |
| Buttons | In stock | Buttons for user interface | <$1.00 |
| Micro SD Card | SanDisk 1GB MicroSD | Memory for storing audio files | $15.89 |
| Micro SD Socket | Micro SD Socket | Insert Micro SD | $1.95 |
| OLED Screen | 1.3" 128x64 | Used for interfacing with | $19.95 |

| | | | |
|---|---|---|---|
| | graphic display | user and selecting settings | |

**Total Cost: $56.12**

## 8. Conclusions

Music therapy is a significant tool growing in popularity as a treatment for motor dysfunction. Our design utilizes the recognized principles of music therapy and expands on its common application. The goal is to realize a new research concept of music therapy with tempo-matching to gait speed; this idea utilizes the base benefits of music therapy while adding positive reinforcement, feedback, and therapy personalization. This approach will be applicable for rehabilitation after stroke, Parkinson’s Disease, Multiple Sclerosis, Epilepsy, traumatic brain injury, and more. Our high level design addresses the necessities for engineering that this concept entails.

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