SwingBeats: An IoT Haptic Feedback Ankle Bracelet (HFAB) for Dance Education

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Abstract. Dance choreography is often synchronized with music. Thus, a major challenge for learning choreography is moving the correct body part to a signified rhythm in the music surrounding the beat. However, the rhythm is often more complex than a metronome. SwingBeats is a real time, haptic feedback system under research and development with the goal of helping learners of any dance style to a) focus on learning the various dance moves, steps, patterns, and dynamics without the need to keep constant track of the music's beat pattern, and b) to condition any choreography for the dance through custom built Internet of Things (IoT) wearables.

This paper is to report on the development and preliminary success of custom Haptic Feedback Ankle Bracelets (HFABs) for the SwingBeats system. HFABs enable learning the footwork for any dance through conditioning the learner to move their feet in accordance to the choreography which follows the beat of the music. Thus HFABs condition muscle memory in the same way learning to play the piano conditions the musician's finger muscles to anticipate each move ahead of time and play the notes in perfect harmony. Thus far, the custom HFABs have been tested with Tap dancing because this style of dancing is predominantly focused on footwork and includes a relatively small degree of freedom in the directions each foot can travel during dancing. The results are thus easily generalizable to any footwork with the addition of more haptic actuators as needed per degrees of freedom.

Keywords: Haptic feedback · Internet of Everything (IoE) · Internet of Things (IoT) · Rhythmic metronome · Tap dance education · Wearable technology

1 Introduction

Dancing is a form of human expression consisting of purposefully selected sequences of bodily movement, each with aesthetic or symbolic values, most

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often synchronized with music. Since dancers must land specific movements on specific beats, it is crucial to maintain a constant awareness of beat and rhythm while dancing. However, many have issues remembering the order of steps and rhythm of choreography. They may forget what step comes next or what part of the music that step occurs on. Since proper steps and timing are key for properly performing a dance, they are currently conditioned into muscle memory by endless practice in leading up to a performance for instance. This is similar to how practicing playing the piano conditions the musician's finger muscles to anticipate each move ahead of time and to play the notes in perfect harmony on the night of the performance. For the case of pianists, research has shown promise in being able to enhance their practicing experience as well as to shorten the time needed for practicing by using Passive Haptic Learning (PHL) gloves as seen in [6]. Thus, it stands to reason that haptic feedback assistance can be provided for conditioning muscle memory for other tasks such as dancing.

To address this issue for dancing, the SwingBeats project has developed IoT Haptic Feedback Ankle Bracelets (HFABs) to signal learners when and how to move their feet to the beat of the music. This can provide the learner with immediate feedback, thus improving the learning experience. Tap dance was chosen as the first dance style to test the HFABs. Tap dance is a style of dance focused on rhythmic footwork which is characterized by the sounds of the metal taps affixed under the toes and heels of the dance shoes striking the floor. Tap dance is the perfect style of dance for this phase of the system's development as this style focuses on the feet rather than the whole body. This paper will discuss the usage of HFABs for tap dance education only, but HFABs are usable for any style of dance without loss of generality. Future work will include further development and testing of HFABs for additional dance styles.

Section 2 will provide a background overview as well as the motivation for the development of HFABs and Sect. 3 will explore existing products. Section 4 will detail the design and development of SwingBeats' HFABs and Sect. 5 will detail the testing methodology, logistics, and results for the system with Alpha testers. The, Sects. 6 and 7 will delineate the currently under development features and future targets for the development of HFABs respectively. And lastly, Sect. 8 will offer some concluding remarks.

2 Background

At the time of this writing, the SwingBeats system has been under research and development for two years.

2.1 History

As was reported in HAVE 2019, the SwingBeats system began as an iOS metronome application that acquires a song's beat pattern from Spotify's API [10] and vibrates an iPhone and/or a smart watch to the beat of the music [7].

While the mobile app works great as a metronome, it does not teach learners how to dance or to follow a specific choreography. With the addition of HFABs, the SwingBeats app can now wirelessly transmit a set of instructions to an HFAB in order to actuate the correct vibrators at the correct times. This guides dancers' footwork by communicating the exact part of the foot they are supposed to move at that exact point in the choreography.

2.2 Motivation

Dancers usually learn choreography in a dance studio with an instructor that can observe their movements from all angles and give them feedback on how they are doing as well as how they could improve. With tap dance for instance, this feedback usually pertains to their rhythm and whether they are using the correct part of the correct foot at the correct time to produce that rhythm.

Remembering a dance involves a lot of practice which frequently takes place at home without an instructor. However, if a student does not remember the dance choreography from class, missed a rehearsal, or is unable to attend a weekly dance class due to cost, availability, or other factors such as a pandemic, they will not be able to practice effectively. Furthermore, at the time of this writing, due to the COVID-19 pandemic most dance studios are closed and students are taking dance classes via video conferencing applications, which does not offer the same learning experience as the instruction and feedback they would have received in person from a dance instructor. Video conferencing does not allow for watching instructors from multiple angles nor is it suitable for receiving feedback from instructors as they are unable to observe the learners from all angles.

Closing this learning gap is one of SwingBeats' main motivations which is achieved by allowing learners to transmit the choreography they need to practice from their SwingBeats mobile phone app to their SwingBeats HFABs. The HFABs vibrate the correct actuators located on the correct part of each foot at the correct times and thus help condition the learners' muscle memory - in effect helping learners practice and learn the choreography.

3 Existing Products

As reported in [7] not many products for assisting in dance education exist.

3.1 Metronomes

Most existing metronome applications such as WatchHapticMetronome [4], and "Pulse - Metronome & Tap Tempo" [5] and hardware metronomes such as Soundbrenner Pulse [9] and Core [8] are simple metronomes meant for helping musicians stay in sync with the beat. As such, they do not have any real application in dance education beyond helping dancers stay in sync with the beat of the music. This however, is not enough as learning how to dance requires awareness and conditioning of complex choreography.

3.2 Haptic Socks

As part of Georgia Tech's 2018 "Get a Move On" hackathon, a team of graduate students prototyped a pair of haptic socks with three sample elementary tap routines [2]. The socks sent vibrations to individual legs in order to instruct the dancer which foot to move when. However to the best of the author's knowledge, this product was never followed upon nor commercialized.

4 SwingBeats Haptic Feedback Ankle Bracelets (HFABs)

Haptic Feedback Ankle Bracelets (HFABs) depicted in Fig. 1 are custom IoT addons for the SwingBeats system [7] designed and built to assist in the learning of the footwork for any dance. This is done by triggering the movement of the feet in accordance with the programmed choreography which is in sync with the beat of the music. The main two use cases for HFABs are to 1) help condition the learner's muscle memory to remember choreography during learning and practice and 2) to allow a dancer to dance to any choreography on the spot even without having learned or practiced a choreography in the past.

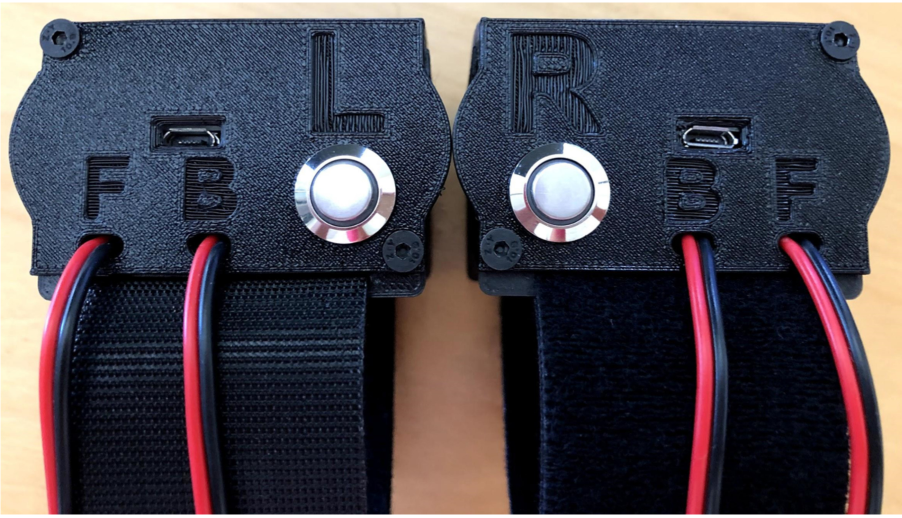


Fig. 1. SwingBeats Haptic Feedback Ankle Bracelets (HFABs)

4.1 Hardware

The HFAB circuitry depicted in Fig. 2 centers around the ESP32 series of System on a Chip (SoC) development boards and includes vibration motors, a rechargeable battery and charging apparatus, and an on/off push button.

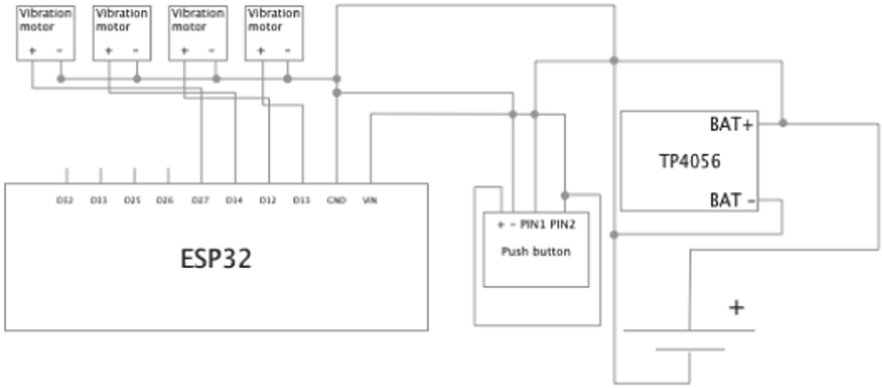
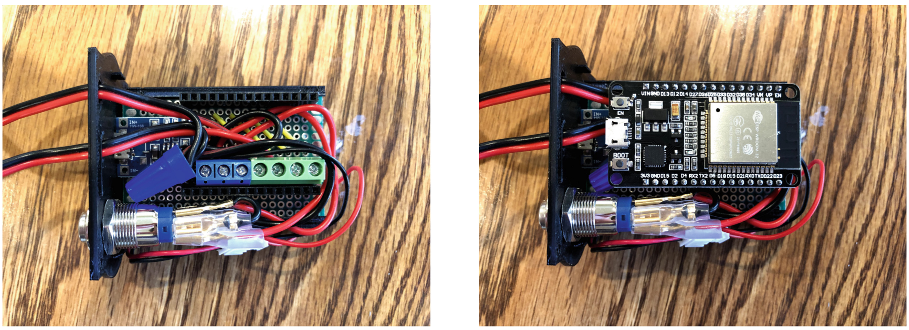


Fig. 2. HFAB schematic

All of the HFAB's circuitry is mounted and interconnected on a soldered Printed Circuit Board (PCB) that as depicted in Fig. 3 sits in a 3D printed drawer that slides in and out of a 3D printed casing for easy access.



(a) Without the ESP32 in position (b) With the ESP32 in position

Fig. 3. Internals of an HFAB

Communication: SwingBeats' HFABs communicate with a mobile phone via Bluetooth Low Energy (BLE) to acquire the music beats and choreography queues. There are no wires between the two HFABs nor between the devices and the phone, as a truly wireless setup is essential to maximize mobility and degrees of freedom when dancing.

For the first prototype, the number of BLE connections to the phone are limited. The HFAB mounted on the left ankle (referred to as the primary device) establishes a connection with the iPhone via BLE to receive instructions. It then forwards the instructions to the one mounted on the right ankle (referred to as the secondary device) via WiFi. The secondary device only listens to the primary device and never the iOS application.

Actuation in the Form of Vibration: As dancing shoes are quite tight, it could be a problem if the vibration motors used are too thick. As a result the micro (10 mm diameter $\times$ 3 mm thickness) flat coin vibration motors depicted in Fig. 4 were used which have a DC voltage rating of 3 V and an operation speed of 12,000 RPMs.

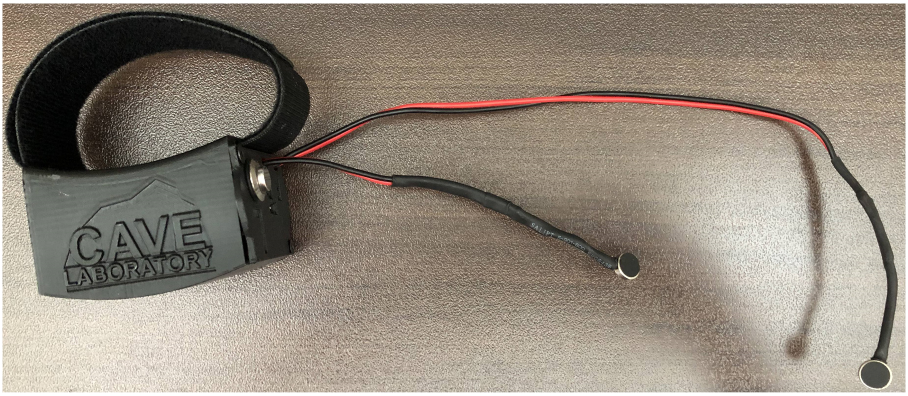


Fig. 4. HFAB with micro, flat coin vibration motors

Two different levels of vibrations for the toes and a single level of vibration for the heal actuators were incorporated in order to help learners distinguish between certain steps. A lighter vibration on the toes indicates when the learner is supposed to strike their toes on the ground but not transfer any of their body's weight onto that foot (a.k.a. not step onto that foot). A stronger vibration on the toes indicates when the learner is supposed to step onto that foot.

Tap dancers stand on the balls of their feet which means their heels are off the ground. This is so they are able to drop their heels to make a tap sound instead of having to first lift their heel off the ground and then drop it to get the same sound. The importance of this increases as the rhythms being created with the tap sounds get faster and faster. It would thus be impossible to produce such fast rhythms otherwise. Therefore for now, only one vibration level has been programmed for the heel actuators which indicates when the dancer needs to drop their heel to the ground. Different heel vibration levels will be programmed in the future to incorporate more advanced tap moves.

Since beginner tap dancers struggle with remembering to stand on the ball of their feet, if the dancer is meant to step (meaning lift their foot and drop it to the ground), as aforementioned only the toe actuators will vibrate so they do not drop their heal when they take the step and thus remain on the balls of their feet. There are however times during tapping that the dancer needs to use their entire foot such as when the dancer strikes the floor with their entire foot for a louder sound but does not step onto that foot, jumps to the other foot, or hops (jumps and lands on the same foot). To indicate these instances, both the front and back actuators vibrate. When the dancer is to strike their foot, but not step onto it, a lighter vibration occurs; and when the dancer is to jump or hop, a stronger vibration occurs. Both feet will vibrate if the dancer is meant to jump with both feet.

The vibrations, regardless of level, occur for 200 ms which is long enough for the dancer to feel and recognize them, but not long enough that they would continue into the next step. One of the biggest decisions when programming the HFABs was deciding if the vibration should start right on the beat or slightly before the beat. If before the beat, the HFABs can not vibrate too far ahead of the beat so the dancer can still distinguish when they are meant to strike the ground. After testing out both methods, it was decided to have the device vibrate 100 ms before the beat. This is so the dancer's brain has time to react to what part of the foot vibrated and perform the correct footwork. Therefore the HFAB will vibrate 100 ms before the beat starts and finish vibrating 100 ms after the beat occurs. Meaning the HFAB vibrates through the beat so dancers have enough time to react to the vibration and step on the beat.

Modularity: The HFABs have been designed and built to ensure that every internal component can be swapped out without the need to desolder or resolder anything. This allows for speed and ease in repairing and upgrading each and every one of the components. Furthermore, the modular approach to SwingBeats' hardware design is especially important for future applications, as different dance styles will require slightly different set ups. For example, while tap dance only requires a vibration motor on the front and back of each foot, other styles will require four vibration motors on each foot's front, back, left, and right. To this end, terminal block connectors were used to connect the vibration motors to the ESP32 development board, and two extra connectors were included to enable easy expansion.

Power: HFABs are powered by a LiPO 3.7 V 1500 mAh battery. A McIgIcM TP4056 battery charger is used to enable usb charging of the battery.

Cost: Table 1 details the cost of each hardware component. Due to economies of scale however, all of these components can be purchased for a fraction of the prices listed here when purchased in bulk from overseas vendors. It should be noted that the total coast does not include the extra wires, heat shrink tubing, and solder used in each HFAB. Since it is extremely difficult to truly ascertain these components' cost due to their bulk availability in the lab. Hence, to roughly incorporate their cost, the total cost of an HFAB's circuitry is rounded to $14 USD.

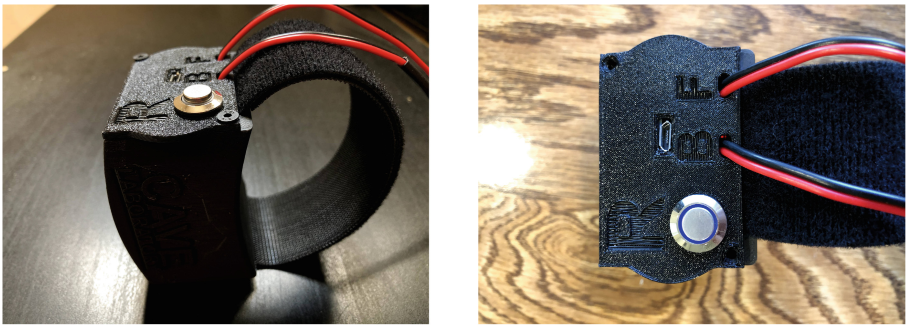
Table 1. Cost of items

Components for a single HFAB	Count	Cost
MELIFE ESP32	1	\$5.07
YDL 3.7 V 1500 mAh 603959 Lipo battery	1	\$4.50
McIgIcM TP4056 battery charger	1	\$0.59
Linkstyle 12–24 V 12 mm ON/OFF Latching Push Button Switch	1	\$2.00
YXQ 1030 Flat Vibration Motor Coin	2	\$0.63
Blank PCB	1	\$0.40
Total		\$13.82

4.2 3D Printing

The HFAB's circuitry is encapsulated by a 3D printed case consisting of a main body and a slide in drawer as seen in Figs. 5, 6 and 7. The case is 3D printed using Polyethylene Terephthalate Glycol (PETG) filament to provide a high level of durability without making the case brittle [3]. At a 0.2 mm layer height, making a complete set of two cases (one for each of the left and right ankles) takes 11 h and 22 min, uses 103 g of filament, and costs roughly \$3.8 USD to produce. This brings the hardware cost of producing a single HFAB to \$14 (for circuitry) + \$3.8/2 (for 3D-Printing) = \$15.9 which is rounded to \$16 USD once the cost of the Velcro is assumed to be \$0.10 due to its availability in bulk at the lab.

The casing dimensions are 55 mm × 45 mm × 70 mm (L × W × H) in order to maintain a low profile on the user's leg. As can be seen in Figs. 5a and 6b, the main body of the capsule is curved to comfortably fit around the dancer's leg right above the ankle joint. An opening on the ankle side of the case holds a Velcro strap used for securing the HFAB to the dancer's leg. This opening has a tight tolerance in order to provide resistance so that the device does not freely shift on the strap, while still enabling easy user adjustments.



(a) Side profile of switched Off HFAB

(b) Switched on HFAB

Fig. 5. Assembled HFAB in custom 3D-printed case with heal and toe actuators

The use of Velcro also enables the mounting of the HFABs at almost any distance above the ankles based on the dancer's preference. The length of the actuator cables can be adjustable and custom built but for this first prototype have been kept to a minimum length to reduce tangling. In order to ensure that the heal actuators have the shortest cables as possible, the HFABs are designed to be mounted with their actuator cable holes facing backwards. To this end, the left and right ankle HFAB cases have small variations in order to help easily distinguish them from each other: when mounted around the ankle, the power toggle switch and actuator cables on each need to be facing backwards as seen in Fig. 6a and the Creative, Augmented, and Virtual Environments (CAVE) Laboratory's logo on each case faces upward as can be seen in Fig. 6b.

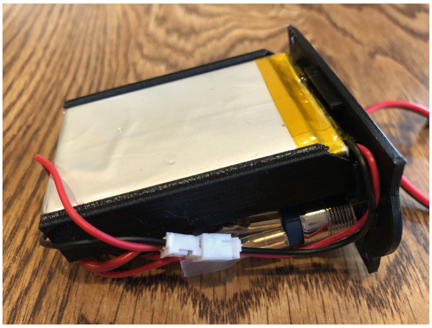
(a) Front view: Power switch and cable holes face backwards

(b) Side View: Creative, Augmented, and Virtual Environments (CAVE) laboratory logo faces upward

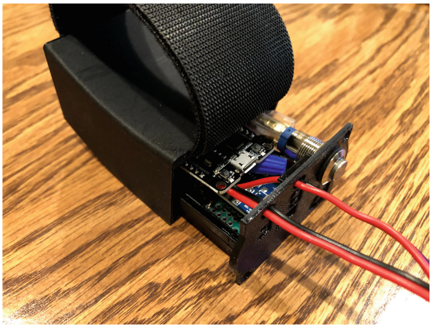
Fig. 6. HFABs mounted above dancer's ankles

If that fact is forgotten, the case also has an "L" or "R" carved out right above the power switch in order to further indicate whether the HFAB is for the left or right ankle, which can be seen back in Fig. 1. The letters "B" and "F" are placed above cable holes for the actuators to indicate whether the actuator should be placed on the back (heel) or front (above the toes) of the foot. The front also contains a hole for the micro-USB charging port. An incline around the charging port provides room for charging cables of various housing dimensions to be accommodated. The interior of the capsule has a tight tolerance so that the PCB is right against the interior wall, preventing movement of the PCB when pushing in the charging cable. Two mounting holes diagonal from one another secure the slide in drawer to the main body using M3 $\times$ 6 mm screws.

Inside the capsule, the removable drawer has a two sided tray. On the side facing the user's leg, the tray has small ridges on its two edges that act as a slide mechanism allowing the PCB and its hardware to be slid into position and secured due to their tight tolerance. This mechanism can be partially seen back in Fig. 3. The other side of the tray has another similar slide in mechanism for the battery, as can be easily seen in Fig. 7a. The use of these slide in mechanisms ensures that the device's hardware is secured and does not rattle in the case when in use. In addition, the tray acts as a barrier between the PCB hardware and the battery, ensuring no damaging interactions occur between the two. This tray also makes assembly and disassembly significantly easier, as all the HFAB's hardware is directly mounted on the slide-in tray and can be easily inserted or removed from the casing as is conveyed in Fig. 7b.



(a) Battery compartment under slid-in tray of HFAB along with connector for easy replacement of battery.



(b) Hardware compartment tray partially slid out of HFAB case in order to expose circuitry.

Fig. 7. HFAB slide-in tray mechanism

4.3 Software

The software necessary to make everything work is divided into two locations: the SwingBeats (currently iOS only) mobile application and the ESP32 microcontroller.

iOS: The basic flow of the application which can be seen in Fig. 8 is as follows: First, the user taps a button on the screen to establish a connection between the SwingBeats application and the Spotify application. SwingBeats checks if the Spotify application is installed and if the user has a Spotify premium subscription. This step is required as Spotify iOS SDK requires the user to have a Spotify premium account for remote playback. Next, the user turns on the HFABs by pressing the toggle button on the device. A ring light around the button will illuminate when the device is powered on as depicted in Fig. 5b. Once the HFAB is on, the user can scan for the device in the SwingBeats phone application and connect it via BLE. Connection between the left and right device is automatic assuming both devices are turned on. Once a connection is established between the iPhone and the device, the user can choose between four choreographed dances. Each dance is labeled by the song used when performing. When the song is selected by the user, the application runs an algorithm that converts the dance moves into compressed instruction sets for the HFABs. Finally, the user can tap the start button when he/she is ready to begin. The start button sends the instructions to the HFABs to start the vibration in sync with the song playing on Spotify.

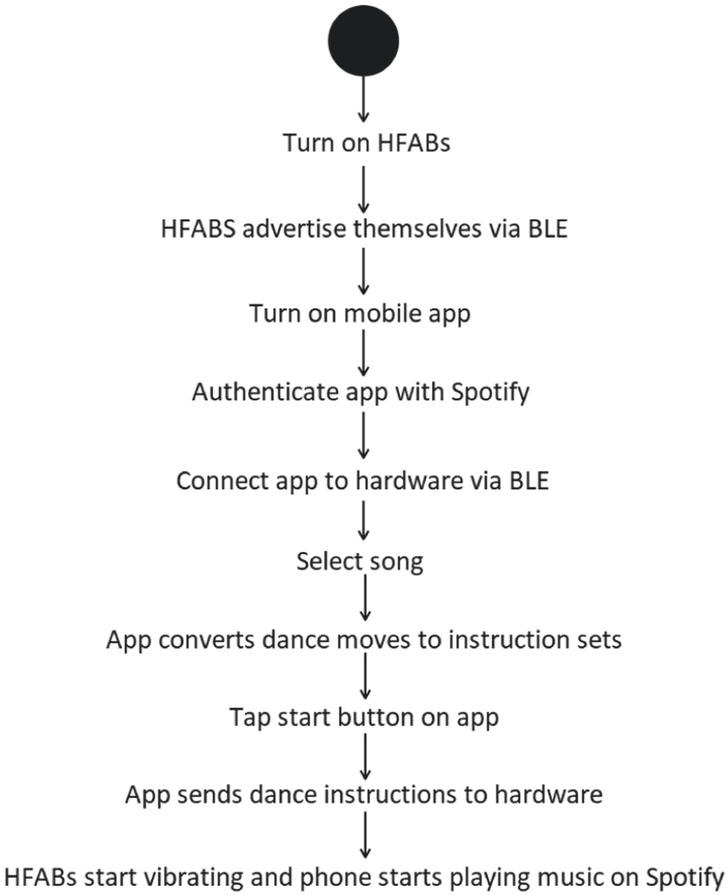


Fig. 8. SwingBeats HFAB connection and utilization sequence diagram

ESP32: One priority of the HFABs' design is for them to be as small and light as possible in order to prevent disruption of any of the dance moves when being worn. This makes the ESP32 series of SoC perfect for HFABs due to their small size and wireless communication features. Furthermore, ESP32 microcontrollers come with a dual core processor which enables the parallel processing of the vibration instructions and the timings of the beats without the need for multi threading and context switching between the two processes.

The software on the primary HFAB is in one of two modes: waiting or dancing. In waiting mode, the primary HFAB listens for instructions from the phone.

The moment it receives dance instructions, it processes and forwards that message to the secondary HFAB. In dancing mode, the HFAB's ESP32 uses core 0 to read timings and adjust the amount of time to delay until the next vibration, and uses core 1 to manage turning the vibrations on and off. Each vibration is turned on for 200 ms.

5 User Testing

For the initial round of testing, advanced tap dancers with 8–20 years of experience were recruited. While this may not be the eventual key demographic that will take advantage of SwingBeats' HFABs, feedback from people with a lot of tap experience is crucial for successful product development. These individuals know what is most important when learning to tap dance, thus will be able to provide the most useful feedback on how the HFABs are helpful and what can be done to improve them as they have past learning experiences to compare this experience to. Given the pandemic, however, many were not available to test the HFABs or did not have the resources such as tap shoes and a suitable floor to dance on in order to participate. Thus, only 7 testers were recruited for this round of testing. However, even given this small number, the feedback provided was invaluable for how the HFABs performed and how they could be improved. Once the COVID-19 pandemic subsides, the upgraded HFABs will be tested with larger numbers of participants from the introductory tap dancing class on campus.

5.1 Methodology

Each participant took part in 4 rounds of testing where each round consisted of a different tap dance choreography. Every dance was 14 eight-counts long (112 beats) and consisted of beginner basic tap moves. Each dance incorporated the same steps in different orders and the songs were approximately the same beats per minute (bpm) thus all dances were at the same level of difficulty. The dances incorporated portions with slower and portions with faster rhythm. The four tests involved learning the dance, practicing the dance with the music while watching the instructor, and filming themselves perform the dance. The participants were on a video conference call with the instructor while they filmed themselves performing the dance to ensure that they recorded the video immediately after learning the choreography. In one round, participants practiced and recorded with the HFABs. In another round, they practiced with HFABS but recorded without using them. In a third round they practiced without the HFABS but recorded with their assistance. And finally in the last round they practiced and recorded without using the HFABs. Each group did each of these rounds in a different order with different choreography in order to ensure that no environmental bias enters the results from any of those factors.

All the testing except for one participant occurred over video conferencing with one of the authors who has years of experience tap dancing and teaching tap dancing. Each round took 30 min including learning, practicing, and performing the dance. Teaching participants how to use the system and app for the first time also took about 30 min. Participants learned the dance without the music. They were allowed to ask any questions they had on the dance at any time. Then, they were able to practice the dance with music and feedback from the instructor 4 times before filming themselves perform the choreography without the instructor guiding them. With beginner tap dancers it is expected that testing will take much longer. However, since the choreography for these tests were basic and the participants were advanced, they did not need much time to learn the choreography prior to recording.

5.2 Results

Everyone in the testing had a different skill level. Thus their videos were compared and judged solely against their own videos from their various rounds of testing. When analyzing the videos, the main criteria for judging were correct timing, performing the correct step, and whether they started and stopped the dance move at the correct time. Then, their dances were ranked from the one they performed most accurately to the one they performed least accurately considering those criteria. In order to rank the testing setup, 4 points were given for performing the best, 3 for second best, 2 for third best, and finally 1 point for worst. If the dancer did the same on two dances, each dance was given the same amount of points. There were multiple cases where it was too hard to distinguish between someone's second best and third best performance. When adding up the points, as can be seen in Table 2 practicing and performing with HFABs was the most effective. No HFAB usage was second in effectiveness. Only practicing with HFABs but not performing with them was third effective. And finally only performing with HFABs was least effective.

Table 2. Testing results: HFAB usage vs. performance

HFAB usage/performance	Best	Second	Third	Worst
HFAB used during both practice and performing	3	3	1	0
HFAB only used during practice	0	5	0	2
HFAB only used during performing	1	2	3	1
HFABs not used for practice nor performing	3	1	1	2

Based on the feedback elicited via a survey from the participants, testers found practicing and recording with the HFABs helpful as they were able to get used to the vibrations of the dance and thus allow it to guide them in performing. However, many felt that as experienced dancers used to learning without HFABs, they were more comfortable learning and performing as they normally would without HFABs in comparison to using HFABs for only the practice or recording portions but not both. Future testing with less experienced dancers will provide a better perspective for seeing how prior dance expertise affects the results.

5.3 Feedback

After testing was completed, each participant was asked to fill a survey on the strengths, weaknesses, and ways to improve the HFABs. Some of their most important overall thoughts are summarised here.

On Vibration Initialization Time: About 71% of participants thought the system should vibrate a little ahead of the beat (as programmed) in order to have time to react. 15% thought it should vibrate on the beat, and 15% could see benefits in both ways. Given that 86% are happy with the current design, no future modification is planned for this feature.

On Vibration Strength: Every tester noted that the vibrations needed to be stronger in order to be more useful. They also noted that because of the low intensity of the vibrations they were unable to differentiate between the softer and stronger vibrations. 57% of participants thought the device helped them get back on track if they lost their place, know what foot to use, keep track of when the choreography got slower or faster, know when the dance started and stopped, and learn the musicality and timing. The other 43% of participants thought that the vibrations need to be stronger for the HFABs to be as helpful as intended in helping them learn and remember the dance choreography. This issue has already been resolved as will be discussed in the Work in Progress section below.

On Usage Purpose: 43% of participants found using the device for both practicing and performing most helpful. 23% found just practicing with the device most helpful. And the remaining 23% found just performing with the device most helpful. All participants thought the system would be beneficial for beginning tap dancers especially to be used for them to practice between classes. Further testing with beginners will provide more clarity on the most effective use of the HFABs.

6 Work in Progress

6.1 Increasing Vibration Intensity

The current version of SwingBeats is capable of producing stronger and weaker vibrations by controlling the speed of the vibration motors. This is done by using Pulse Width Modulation (PWM) on output pins of the ESP32, and simulating more or less voltage for the vibration motors. However, participant's commented that because the vibrations were not strong enough, they could not distinguish them from one another as easily as they should or at times not at all. Since the ESP32 output pins are not capable of producing voltage higher than 3.3 v the circuitry is being redesigned using transistors to have the output pins act as on/off switches that connect/disconnect the vibration motors to/from the battery directly which can supply higher voltages up to 3.7 v. Initial testing in the lab has proven significant increase in the vibration intensity of the actuators.

6.2 Addition of a Second Dimension of Vibration

Another improvement to the actuation is to add a variation in length of vibration depending on the speed of the choreography. For example assume a dance has steps 500 ms apart in some parts and 250 ms apart in other parts. The actuators would have to vibrate for longer to signify that the rhythm is slower and shorter to signify the rhythm is faster. And since as aforementioned the actuators vibrate through the step, in this way, the HFABs will be able to communicate more than only which part of which foot to move and when but also how fast to perform that movement.

6.3 SwingBeats Phone Application UI Improvements

Currently, little effort has been put into the design of the mobile app beyond what was reported on in this paper and in [7]. The application needs to include individualized features that allow for users to create and add their own choreographies and to get valuable diagnostics data such as battery life, etc. as well as sensor date (more on this later) from each of the HFABS.

6.4 Direct BLE Connection Between Phone and both Left and Right HFABs

The current version of HFABs designates the left leg's HFAB as the primary and the one for the right leg as the secondary. Only the primary HFAB communicates with the phone and relays the instructions for the right HFAB through a WiFi connection between the two. This is inefficient as it causes unnecessary communication which drains battery life and pollutes the airwaves, but more impotently prevents the usage of the right HFAB by itself. This is being rectified by revamping the mobile application to establish two concurrent BLE connections and disseminating the choreography for the left and right HFABs separately.

6.5 Programming Warm Ups

A common feedback received from many testers was that they did not have enough time to get used to the system. They didn't have time to get used to how different steps felt with the vibration. Thus, while learning the dance it was hard to rely on the vibrations to guide them. One way to fix this problem is to program warm up dances into the system. A warm up consists of repetitive steps to help beginners learn certain steps and get advanced dancers ready for more advanced combinations of those steps. Every dance class begins with a warm up. Thus it makes sense for SwingBeats to incorporate them. For example, an instructor may begin all of the tap classes she teaches with a shuffle warm up. This warm up occurs in most tap classes as a shuffle is a fundamental tap step used in most dances. The warm up includes doing the step 8 times on one leg then 8 times on the other. The dancer then repeats this multiple times at different speeds. Using SwingBeats' HFABs during this warm up for instance would allow dancers to get used to the vibrations indicating a shuffle. That way when they felt that vibration during a dance they would know exactly what step to perform. And similarly for all other moves that show up in warm us. Furthermore, by adding a body temperature sensor, the HFABs will be able to sense when the dancer's body has warmed up and is ready for transitioning to the actual dance. This can be one of the data points which is sent back to the mobile/watch app in order to signal to the dancer that they have warmed up and are ready for transitioning from the warm ups into their dance routine.

6.6 Dance Intensity Measurement

Through the addition of a Pulse Oximeter and Oxygen Saturation (SPO_2) sensor, the HFABs will be able to monitor the heart rate and oxygen levels of the dancer throughout a dance. Not only does this allow the graphing and maintenance of the workout intensity experienced by the dancer, but also the ranking of dances by their level of intensity and thus difficulty. This can further help determine what warm ups are needed before attempting a certain choreography or even what level of dance proficiency may be needed to attempt a certain choreography. Furthermore, this can help determine when the blood oxygen level of the dancer has reached its needed level during warm up which would be due to the muscles having reached their ready (warmed up) state so that the dancer can move on to the dance.

7 Future Work

7.1 Recording Dances

The current prototype relies on hand transcribed choreography. This is a manageable solution at the moment but impossible to scale. Therefore, gyroscopes and accelerometers are being worked into the HFABs' design in order to enable the recording of dances when performed by a professional or instructor. This addition is very important as it would massively increase the size of SwingBeats' repository of dances and enable the addition of dance choreography by users without any programming or even knowledge of the inner workings of the system. Some other implications of this include being able to compare different dances, visually represent some dances using only the motion data, and to measure dance expertise levels needed to perform a certain dance or choreography. Furthermore, with quantified dances, the dance performance can be recorded as has been shown to be possible in ballet dancing [11].

7.2 Real Time Instruction

Enabling the real-time transmission of the choreography from an instructor to a learner will enable a whole new world of possibilities. Instructors could in real-time lead individual or groups of learners in their class regardless of whether the class is conducted in person in a dance studio, or over video conferencing anywhere on earth.

The ability to transmit general dance movements through a tactile language has been demonstrated in work done by a team of researchers at Universidad de las Américas Puebla where they developed a rudimentary tactile language prototype consisting of 9 tactile vocabulary for assisting in the transfer of motor skills [1]. Participants in their study had a 90% recognition rate for the haptic signals, highlighting the viability of haptic feedback in dance instruction.

The goal with SwingBeats' HFABs would however be to transmit nuanced bodily movements from the instructor to the learner in order to not only convey the movement but also help teach the movement. The communications channel between the instructor and learner's systems should also be full-duplex in order for the learner to also be able to transmit their movements to the instructor so the instructors can provide even more feedback based on how the movements feel rather than only how they look or sound (in the case of Tap dance). This is important because even though a dance move can look correct, it may not be of the correct intensity for instance and thus for example fail to lead a follower correctly in a partnered dance.

7.3 Enabling Group Choreography

Currently, each set of HFABs are controlled by a single instance of the SwingBeats phone application. It stands to reason that the SwingBeats app can control many more sets of HFABs simultaneously. This can be done in two modes: all HFAB sets being in sync or each having their distinct instructions. These modes are explored more below:

Staying in Sync: As of this writing, the HFABs used by an individual are not in sync with anyone else's. If the HFABs were capable of being in sync, this could help groups of dancers make sure they are all in sync with one another. This is extremely important in tap dance because of the sound of the steps. It is very obvious when someone is off from the rest of the group, which diminishes the performance significantly. This becomes especially important during A Capella group dancing, when a group tap dances with no music, as they are creating the music with the sound of their taps striking the floor. In this application, it is even more important that dancers are in rhythm as there is no music to cover up when someone is off. During A Capella it is extremely difficult for groups to stay in sync because without the music keeping a consistent beat that all can hear and synchronize with, many may begin to count the beats incorrectly in their head. However, Swingbeats' metronome [7] and HFABs would fill the gap created by a lack of music and vibrate to the beat for all dancers to follow. This will ensure they all stay in sync.

Puppeteering Group Performances: Using the SwingBeats application to puppeteer every dance move of every dancer in a performance has the ability to revolutionize the performing arts industry. A choreographer will be able to record each individual dancer's movements using SwingBeats' recording feature and then bring them all together under a single harmonized performance where the moves of each individual need not be similar. The dancers would all use SwingBeats for warm ups and once practice of the performance begins, each will receive the haptic feedback specific to their moves from their HFABs. This will reduce the time needed to individually train each dancer and to harmonize each with the group. Without such puppeteering capabilities, this process can take months depending on the complexity of the choreography and number of dancers involved.

Furthermore, the choreographer can easily change the tempo for all dancers at once without having to retrain each individual dancer. The faster or slower vibrations will convey that to the dancers as they practice. Even more beneficial, the choreographer can easily modify or even drastically change or add movements to each dancer's choreography without having to retrain the dancer with the new moves and then reharmonize them with the group. SwingBeats will thus in essence enable the puppeteering of any dance performance with ease, speed, and precision.

7.4 Real Time Choreography Puppeteering

The use of HFABs can allow a whole new performing art or sport: Real-Time Dance Puppeteering. Imagine the ability of choreographers to create/change choreographies on the spot during a live performance where they can build off of the mood of the audience and/or the abilities of the dancers. Or a dance or athletic instructor/coach puppeteering a group of dancers or attendees who simply show up with their HFABs and after warm ups are sent choreography or exercises moves. Or even dance-offs where two coreographers and two sets of dancers show up and compete with one another to the cheering of the audience.

7.5 Case Improvements

Reducing 3D-printing Time: 3D Printing at the 0.2 mm layer height provides quick print times for the device's casing but at the expense of printing resolution and thus aesthetics. Future iterations of the device will have their cases printed at a variable layer height. This would mean thick fast to print layers around the case, with thin slow to print layers around the connector ports, the drawer's sliding mechanism for the circuitry and battery, and the CAVE Laboratory's logo. As a result, the case will print faster than it normally would at a high resolution while maintaining a high level of detail where it matters most.

Incorporating Connectors for Actuators into the Drawer: Currently, the drawer includes two holes for the actuator cables to enter. This does not allow for the on-the-spot customization of the cable lengths, colors, etc. by the user nor allows the upgrading of the actuators without opening the case should new or different type of actuators become available. Furthermore, the ability to disconnect actuators will enhance the packaging and carrying ability of the HFABs without the worry that the cables could get bent or damaged in the process. And it enables dancers to use only the actuators they want. For instance if a dancer is trying to use an HFAB to cue a certain move she keeps forgetting or which she does not have time to condition into muscle memory through a long practice period, then she could remove all the other actuators which do not engage in that particular movement or sequence without having to change the vibration choreography in the mobile SwingBeats application.

7.6 Custom PCB

By using a custom Printed Circuit Board (PCB) for mounting and interconnecting the HFABs' electronics, the length and height of the casing can be shrunk. As a result, the HFABs will be smaller and lighter which will make long-term wearing of the device much more comfortable for the user. Furthermore, this will significantly reduce the assembly time for each HFAB's circuitry and thus enable their mass production with more precision and efficiency.

8 Conclusion

The SwingBeats HFABs provide an effective way to learn Tap dance footwork as the results indicate. Without any loss of generality, it can be argued that such haptic devices can not only easily be used to teach/learn other dance styles' footwork but also athletic footwork such as for soccer, physical therapeutic guidance, or even walking assistance for patients suffering from cerebral palsy or recovering from a stroke. However, much more development and testing are needed for the tuning of the system to these other domains.

Furthermore, as the proliferation of haptics continues, and the size, energy usage, and cost of readily available haptic components continue to shrink, it becomes more realistic and aesthetic to produce such devices for not only the ankles but also for all other parts of the body.

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