ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Dancing Scoring Robot

Team #29

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1 Introduction

1.1 Problem and solution overview

The problem that the dancing scoring robot addresses is that people who engage in dance for personal entertainment and exercise often lack access to expert feedback on their technique and performance quality. In traditional dance settings, such as dance studios or fitness classes, instructors may not have the time or resources to provide individualized feedback to every participant. This can lead to frustration and a lack of motivation to continue dancing.

The dancing scoring robot provides a solution to this problem by offering personalized evaluations of the user's dance performance, including feedback on elements such as rhythm, timing, and posture. By using the machine, dancers can receive immediate feedback on their performance, allowing them to make adjustments and improve their skills in real-time. Additionally, the machine's scoring system can provide a fun and engaging way for users to track their progress and challenge themselves to improve their scores. The dancing scoring robot thus provides an accessible and effective means for people to improve their dance skills and achieve their fitness goals.

Although there are existing products with similar goals, these products evaluate users based on simple and, in most cases, mono criteria. For example, Just Dance using X-box[1] evaluates users' performance based merely on their pose matches, neglecting the continuity and fluency of their motions. Our team aims to resolve these limitations by devising a solution that achieves more objective dance scoring by implementing three distinct evaluation methods. We will utilize hardware components such as a camera, smart bracelet, processor, storage, and display to create a robot capable of scoring the dancers' performance. The robot will have good human-computer interaction to enhance user experience.

To ensure a comprehensive evaluation of the dancers' performance, we will adopt three different methods for evaluation. Firstly, we will evaluate whether the dancer's movements are based on both pose matches and motion continuity. Secondly, we will assess how well the dancer's movements match the dance music. Lastly, we will evaluate the dancer's body condition in real-time, analyze the intensity of their movements, and record the dancer's hand movements in greater detail. By integrating these three evaluation methods, we can create a robust and comprehensive evaluation of the dancer's performance, which will be displayed on the screen. This solution will enable judges to make more objective decisions and provide dancers with valuable feedback to improve their performance.

[1]https://www.xbox.com/en-US/games/store/just-dance-2022/9N04KQK2LBZL

1.2 Visual Aid

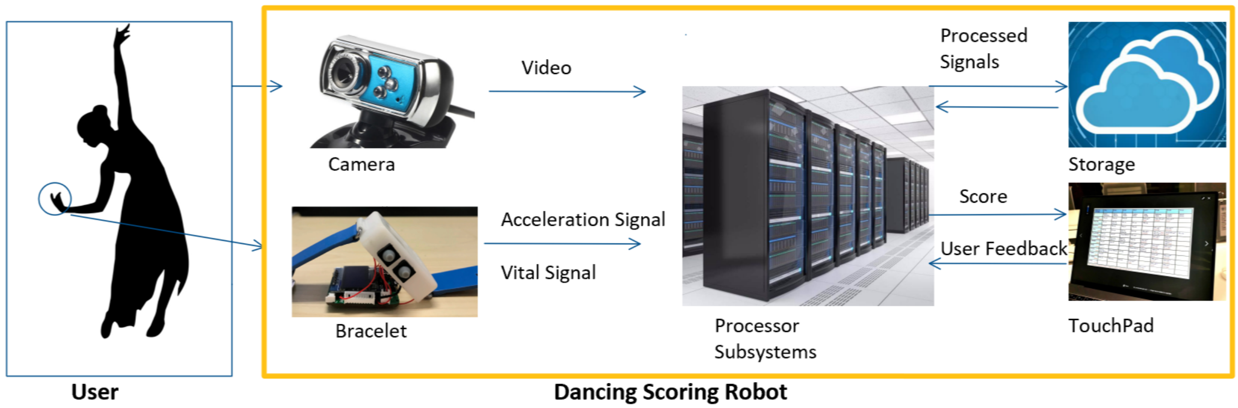

Figure 1: Visual Aid for Dancing Scoring Robot - Internal System

Figure 2: Visual Aid for Dancing Scoring Robot - External Look (Conceptual)

1.3 High-Level Requirement List

- The evaluation result should be able to check the precision of a series of poses in a certain order. Check the evaluation system through setting 2 different poses with a 5s interval. Conduct the experiment several times, one time with precise poses, one time with wrong pose and another with wrong order. If the evaluation system could give 3 different scores with only the correct one highest, then the pose identification precision of the system could be verified.

- The evaluation result should be able to check the time precision of a series of poses. Check the evaluation system through setting 2 different poses with a 5s interval. Conduct the experiment several times, one time with precise time interval, one time with 3s interval and another with 7s interval. If the evaluation system could give 3 different scores with only the correct one highest, then the time precision of the system could be verified.
- The evaluation result should reflect the exercise effect for different users. Try a 3mins' dance with the whole system working with 5 different users. Record the heart pulse rate before and after the dance. Compare the heart pulse rate with the exercise effect evaluation output score, if they match, then the precision of the exercise effect evaluation could be verified.

2 Design

2.1 Block Diagram

The block diagram is shown in Figure 3.

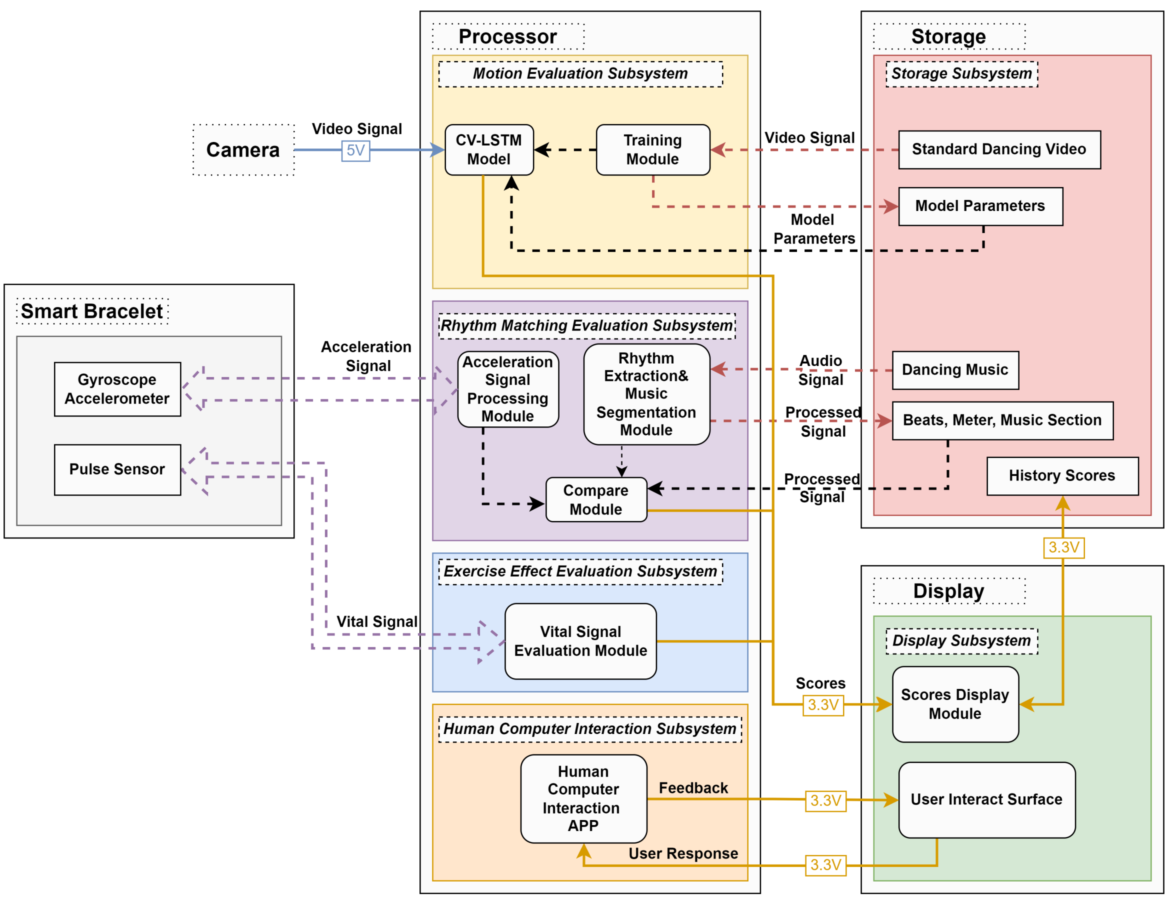

Figure 3: Block Diagram

2.2 Physical Design

Our physical design lies primarily in the bracelet. In order to get the physical dimension of the whole bracelet, firstly we list out the electronic modules' dimensions as shown in the Table 1 below. Then we decide the relative layout of total modules. Based on the sensor working environment, the pulse sensor must on the side facing the skin. From the aspect of human-machine interaction, in order to keep the heat transfer rate as large as possibile, the battery is placed on the top. The total layout is shown in Figure 4. Thus, we could get the minimum dimensions inside the bracelet shell: 62*35.7*17, with unit of millimeter. As we decide to 3D print the bracelet shell with PLA, the dimensions of the outer shell would be around 65*40*20. As the soldering and wires would influence the physical dimensions, the detailed shell design is postponed until finishing the electronic assembly.

Modules	Length (mm)	Width (mm)	Height (mm)
STM32	22.86	53.34	2.00
CC2541	35.70	15.20	2.00
MPU6050	20.26	15.56	2.00
MAX30100	Diameter = 16.00		2.00
TPS63020	24.00	34.00	4.50
Battery	62.00	62.00	8.50

Table 1: The electronic modules' dimensions of smart bracelet.

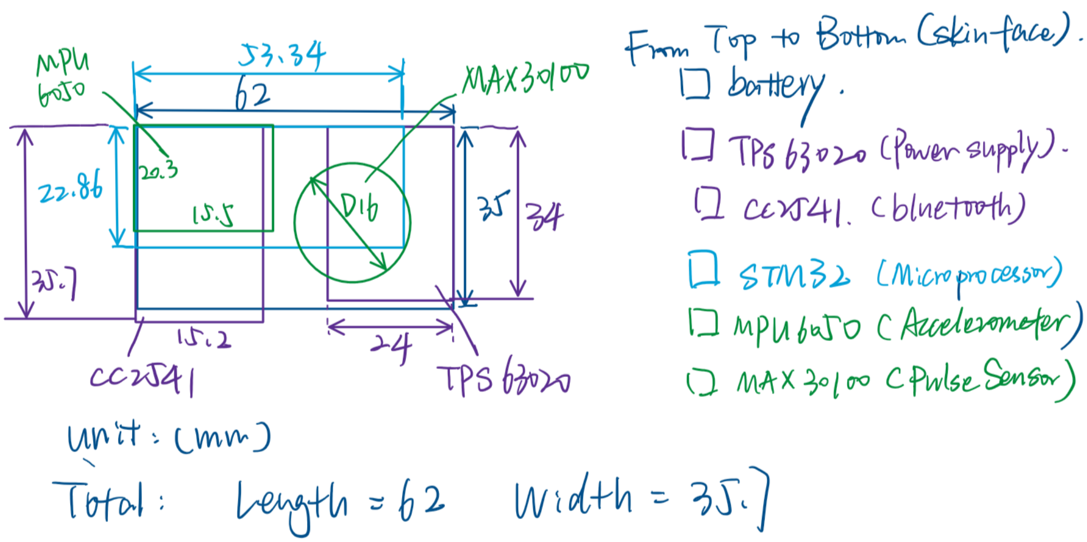

Figure 4: Physical Design of the Bracelet

2.3 Subsystem Overview

Our dancing scoring robot consists of **evaluation subsystems**, a **human-computer interaction subsystem**, a **storage subsystem**, a **display subsystem**, and **external devices**. Detailed descriptions are as follows.

2.3.1 External Devices

We are utilizing two major external devices.

Bracelet.

The bracelet contributes to the dancing scoring system by collecting the vital signal and the kinematics signals in the instant-time manner. In order to meet the functional requirements, the bracelet mainly consists of 1 microprocessor, 2 sensors and 1 communication module. The Accelerometer contributes the kinematics signals and the Pulse sensor contributes the vital signal. The wire connection diagram is shown in Figure 5 below. In Figure 5, only the core chips are presented with some pins unconnected. All those pins are well soldered in the modules in the real components. Above the connection line in the Figure 5, the port communication types are clearly stated.

The requirements of the bracelet consists of 2 part. First, the bracelet should meet the function of collecting the kinematics signals which are clearly enough for motion evaluation analysis. Second, the bracelet should be human friendly, without any potential harm to the users. The detailed requirements and verifications are listed below.

Requirements	Verifications
1. The kinematic sensors should record the acceleration signals that could reflect certain body movements with peaks. 2. The working temperature of the bracelet should not hurt the user. Test the whole system while dancing for longer than 5 minutes.	1. It could be verified by checking the real-time signal output directly from the output of the bracelet when conducting large body movements. 2. Measure the temperature of the bracelet's back face. If it is smaller than 45 Celsius, the safety of human-machine interaction could be verified.

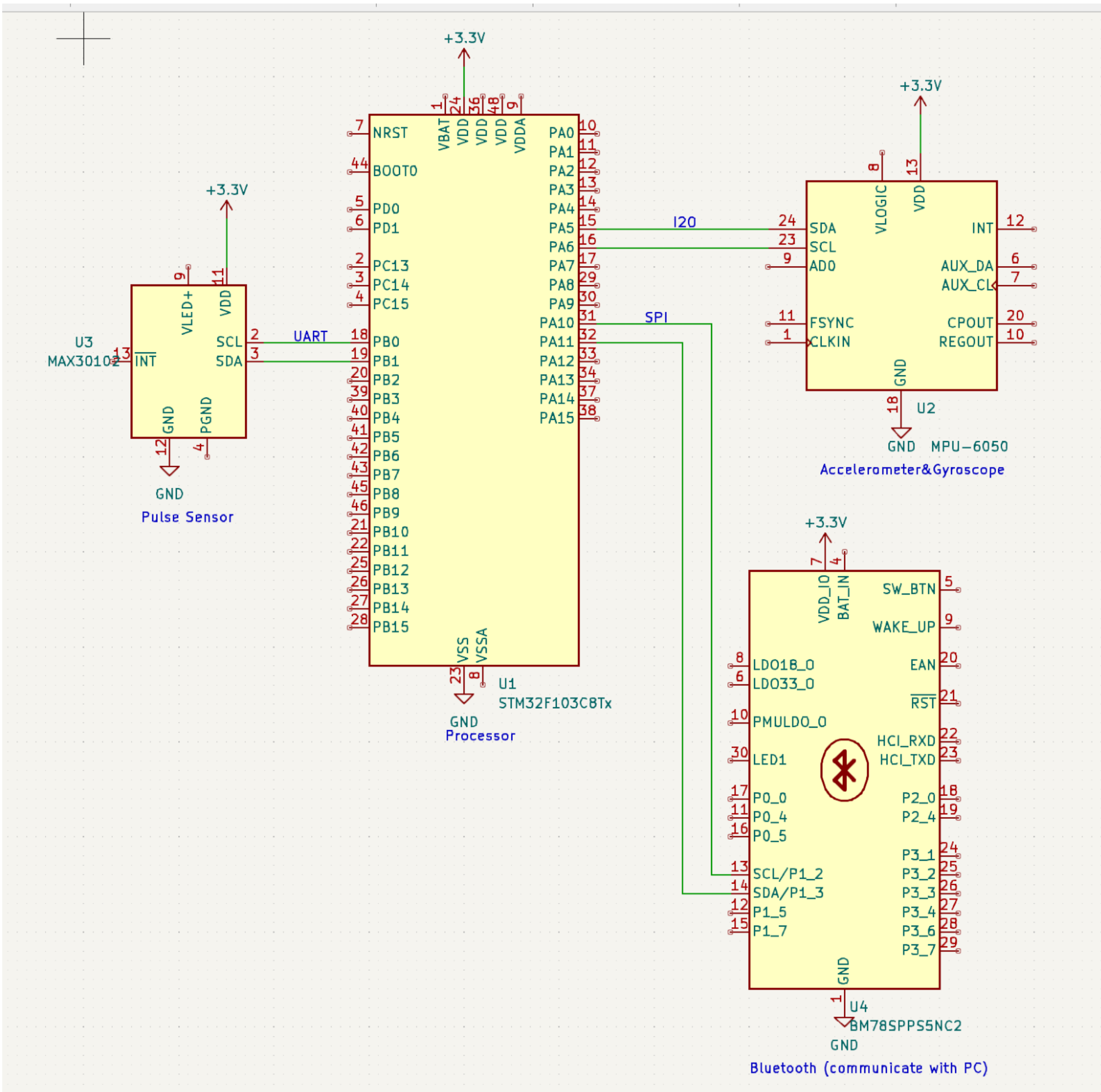

Figure 5: Wire Connection Diagram

Camera.

The camera plays a crucial role in the evaluation of the dance performance by capturing the intricate movements of the dancer. The subsystem comprises a high-quality camera that is capable of recording the actions of the dancer with utmost precision. The camera is equipped with advanced features such as high-resolution imaging, low-light sensitivity, and fast autofocus, to ensure that every movement is captured with unparalleled clarity.

To facilitate the smooth transmission of video signals from the camera to the evaluation system, we have included a state-of-the-art wire that ensures minimal interference and signal loss. This wire is specifically designed to transmit high-quality video signals without any degradation in quality.

Moreover, to enable the robot to capture the motion of the dancer from multiple angles, we have incorporated a rotatable base. This base allows the camera to move around flexibly, capturing the dance performance from different perspectives. This comprehensive evaluation helps in identifying any flaws or inaccuracies in the performance, which can be rectified to improve the overall quality.

The camera is a vital component of the dance evaluation system that ensures accurate and detailed assessment of the dancer's movements. The advanced camera, high-quality wire, and rotatable base work together seamlessly to deliver the most comprehensive evaluation of the dance performance.

Requirements	Verifications
1. The camera should be capable of recording at least 1080p resolution video to ensure high-quality video capture. 2. The camera should be able to focus quickly and accurately on the dancer's movements. 3. The wire used to transmit video signals from the camera to the evaluation system should ensure minimal interference and signal loss. 4. The camera should be able to move around flexibly on a rotatable base to capture the dance performance from different perspectives.	1. This can be verified by examining the recorded video footage and checking the resolution settings in the camera's specifications. 2. This can be verified by testing the camera's autofocus capabilities and observing the speed and accuracy of the focus adjustments. 3. This can be verified by testing the video signal quality during transmission and observing any degradation in signal quality. 4. This can be verified by testing the camera's movement capabilities and observing the range and flexibility of the base.

2.3.2 Evaluation Subsystems

We are evaluating dancers' performance from multiple aspects to guarantee a comprehensive assessment.

Motion Evaluation Subsystem.

In this module, we propose the integration of Mask R-CNN [1] for pose recognition, together with Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM [2] for sequence captures, to develop a comprehensive system for dance analysis. Mask R-CNN is a deep learning model that employs an instance segmentation approach to identify the location and shape of objects in an image. In our system, it will be used to recognize and track the poses of dancers in a video sequence. Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM are advanced models for sequence capture and analysis, which are capable of capturing long-term dependencies and contextual information. These models will be used to capture and analyze the dance sequence and provide insights into the movements and patterns of the dancer.

To train the integrated model, a large database of dance videos and their corresponding expert ratings will be utilized. The model parameters will be adjusted to ensure optimal performance and accuracy.

Once the users' dance videos are collected through external devices and transmitted via the wire connections, the model instance will generate users' motion scores. These scores, which will be passed to the display subsystem, provide a detailed analysis of users' dance performance and insights into the overall quality of their performance.

Requirements	Verifications
1. The system must achieve an accuracy rate of at least 90% on existing dance videos and expert ratings. 2. The system should be able to evaluate the continuity and fluency of dancers' motion. 3. The system should be able to extract and compare poses from 3D views.	1. It could be verified by dividing the large database of videos and ratings into 80% of training set and 20% of testing set. Before inviting users, we should first test on the 20% to verify that (a) the error rate between system-generated scores and the expert ratings should be ≤ 0.1, and (b) the correlation coefficient between the system-generated scores and the expert ratings must achieve at least 0.9 on this subset of dance videos. 2. It can be verified by comparing its evaluation results with those of a human expert in a controlled experiment. The evaluation results should have a high degree of agreement with the expert's evaluation (e.g., Cohen's kappa coefficient ≥ 0.8). 3. It can be verified by conducting multiple pose comparisons of the same pose from different 3D views and comparing the results. The pose comparisons should show a high degree of consistency between different comparisons (e.g., intra-class correlation coefficien ≥ 0.9).

Rhythm Matching Evaluation Subsystem.

This subsystem is used to detect how well the dance movements match the music. Here, we will use a rhythm extraction module which is mainly based on *librosa* to extract the drumbeats (bass and snare) and detect the meter (music measure and beat numbers) of the music piece. The drumbeat will be used to synchronize different recording parts of the same music piece to make sure the user's moves can be evaluated at the right time since the meter can provide the global timing information of the music beats independent of the spontaneous variations of the drumbeats. [3]

Similarly, the corresponding dance movements should also have a strong emotional expression, which can be simply reflected in the dramatic change in the acceleration of the arm during the movement. The acceleration data will be collected by our smart bracelet to the acceleration signal processing module for further analysis. We will combine these data with 3D motion information to calculate the kinetic velocity, base on which, we calculate the kinetic beats to see the correlation of kinetic beat and music beat. This "Beats Alignment Method" reflects how well the dancer's movements correspond to the beat. [4] And the rate of ground truth and dancer's correlation will show how well the dancer performs compared to the standard one.

If it's the first time to analyze the music, we will use the Rhythm Extraction & Music Segmentation Module (Figure 3)to extract its unique beats, meter, and music section, then store them in storage. At the same time, we will load this information into our compare module. The compare module will be based on our extracted music feature to check whether the dance movement can match the beat and the mood change of the music. And produce the scores for the display.

Requirements	Verifications
1. The system must be able to extract the drums and beats of different music and achieve a minimum of 95% correctness. 2. The system must be able to synchronize the music that starts at any time.	1. It can be verified by randomly selecting a piece of music for manual beat checking and calculating the error of automatically extracted beats. The mismatching beat rate should not exceed 5%. 2. It can be verified by randomly selecting a part of music, then according to the beat and other features to find the corresponding start and end point in the original music file. The deviation of the waveforms of the two music clips should be less than 5%.

Vital Evaluation Subsystem

In addition to the visual effects of dancing, dancing is also a great way to exercise. We incorporate information about the dancer's vital signs during the dance into our evaluation system with the aim of bringing out the positive effects of dancing on the body's strength and coordination. This system will be able to obtain the dancer's vital signs in real-time via Bluetooth from the dancer's bracelet, including the heart rate and blood oxygen. Then the evaluation subsystem assesses the user's exercising effect based on scientific exercise assessment methods, which shows whether the exercise is too heavy or too light, or exactly of an appropriate amount.

Requirements	Verifications
1. The system shall be able to obtain real-time vital signal as soon as possible from the user's bracelet via Bluetooth. 2. The system shall be able to give an exercise effect evaluation consistent to users' subjective evaluation. 3. The system evaluation should be able to give a scientific exercise evaluation, which reflects the objective vital health conditions.	1. This can be verified by calculating the difference between the outgoing signal time and the receiving time to calculate the delay time, which should be no more than 0.5 second. 2. Test the system 3 times by 3 different users. Record their heart rate, blood oxygen level and users' subjective evaluation towards the exercise. If all those three measurements are consistent with the vital evaluation subsystem's output, the reliability of this subsystem could be verified. 3. While doing the verification test above, record the heart rate, blood oxygen level before and after dancing with certified monitor. Calculate the accuracy of our design's measurements with those from a certified monitor. If the difference percentage is within the 10%, the accuracy of our evaluation system could be verified.

2.3.3 Storage Subsystem

In order to effectively evaluate dancers' performances and due to the large volume of data required, we have implemented a specialized storage subsystem designed to efficiently organize data for easy retrieval.

Our system is composed of several components, including a vast collection of standard dancing videos that are stored in a cloud-based storage system for training model parameters for each dance music. The cloud system will be enriched when users have agreed to share their dance videos gathered by our robot as training data and experts have made professional rates by hand. To optimize data access and minimize retrieval time, we have implemented a cache system that stores the model parameters for the most recently visited dancing music locally. This cache system operates on the principle that recently and frequently accessed data is more likely to be reused, thereby improving system performance. As the cache size approaches its limit, the least recently and frequently used data is removed to make space for new entries.

We have also included a cloud-based storage for dancing music, and a cache to store their processed signals for rhythmic evaluation. Whenever there is an evaluation of a specific dance whose music is retrieved from the cloud, the dance music is transformed into a rhythm signal in the evaluation subsystem and will also be sent back and cached locally.

As part of our commitment to providing a comprehensive user experience, we have also developed an individual cloud-based storage system for each dancer's historical scores for each dance. This feature allows users to conveniently monitor their progress and track their improvement over time. By incorporating these advanced storage subsystems, we are able to provide accurate and efficient evaluations of dancers' performances, while also offering a seamless user experience.

Requirements	Verifications
1. The cache subsystem must be able to effectively manage its size and prioritize recently accessed data. 2. The individual cloud-based storage system for each dancer's historical scores must be secure and accessible only to the respective dancer and authorized personnel.	1. We will verify this requirement through testing and analysis of the cache system's performance under varying workloads. We will simulate high-traffic scenarios and evaluate the system's ability to manage its size and prioritize frequently accessed data. We will also monitor cache hit rates and eviction rates to ensure that the system is effectively removing the least recently and frequently accessed data to make space for new entries. 2. We will verify this requirement through testing and analysis of the access control mechanisms in place to ensure that only the respective dancer and authorized personnel can access the stored data. We will perform penetration testing to ensure that the storage system is secure against unauthorized access and data breaches. We will also verify that the storage system is able to scale effectively to accommodate a growing number of users and their data while maintaining high levels of security and privacy.

2.3.4 Human-Computer Interaction Subsystem

This subsystem is designed to improve the user experience. We will add a user-interactive interface to the display that will guide the user through the following actions: selecting a dance song, viewing past ratings, restarting the current dance, etc.

Requirements	Verifications
1. The system must be user-friendly. 2. The system should show our evaluation from different aspects directly.	1. We will verify this by testing whether the interaction interface is clear and straightforward and whether it can be quickly get started in short time by users who have not used it before. 2. We will verify this by checking whether the display can give scores from different aspects as well as give a total score. It also should show the dancer's progress by presenting historic scores in graphic form.

2.3.5 Display Subsystem

The display system connects the user with our dancing scoring system output. From the display module, users receive the evaluation results from our evaluation subsystems. First, the display subsystem could show the real-time heart rate and blood oxygen level during the dancing. Second, dancing evaluation results could be shown on the display system as soon as all evaluation subsystems finish processing. Third, the display UI should be well-designed and user-friendly, so that the users can read the information easily. As our design gives out scores from different aspects, the UI design should clearly label the scores

Requirements	Verifications
1. The display system should have a user-friendly interface for displaying the scores and other relevant information. All sub-scores and their corresponding evaluation could be easily understanded from the display interface. 2. The heart rate and blood oxygen level shown during the dancing should be real-time or within small delay.	1. Show the testing display system to three different potential users, collect their opion about the UI. If all of them agree that it is easy to understand the displayed information, then the user-friendliness is verified. 2. Monitor the vital information received from the bracelet. Compare the displayed vital information and the bracelet output. If the time delay is within 1 second, the real-time is verified.

2.4 Tolerance Analysis

The potential design level risk happens mainly on the human-computer interaction part, the bracelet sensing system

From the mechanical level, as the bracelet design consists of the electronic hardware platform, the soft wrist strap and the 3D printed connection, the only potential failure is the heat distribution that would possibly make the user's skin uncomfortable. This problem could be solved by collecting the heat generation data from bracelet working context and calculating the design that results the largest heat radiation with air while the least heat conduction with user's skin. The simulation could be done by using feat transfer finite element analysis.

The pulse sensor might be unable to work ideally as it is optical based. It may challenge the light conductivity of the lower bracelet face. From our current research, the manufacturing material of bracelet face should allow 500nm light to go through.

The other design level risk might come from the video. While the images analyzed may not be perfectly continuous, our skeleton reconstruction might twist, which increases the difficulty of pose identification. This problem could be solved by adding the necessary robust module.

3 Cost and Schedule

3.1 Cost Analysis

Subsystem	Item	Source	Cost(CNY)
Bracelet (Electronic)	MPU6050	taobao	7.70
	STM32f103c8t6	taobao	77.00
	MAX30100	taobao	6.50
	TPS64020	taobao	18.70
	5V battery	taobao	26.50
	CH340	taobao	4.50
	CC2541	taobao	18.01
	Wires	taobao	5.62
	Soldering	Electronic Lab	0.00
Bracelet (Mechanical)	Strap	taobao	24.00
	3D printing	Design Lab	0.00
Deep Camera	Orbbec Astra Pro	taobao	389.00
Motion Camera		ZJUI Lab	0.00
Total			577.53

Table 2: Costs from hardwares and external devices.

Our fixed development costs are estimated to be 12.5CNY/hour, 10 hours/week for four people. We consider approximately 60% of our final design in this semester (8 weeks), neglecting the central server, mesh network optimization, and partnerships with NGOs:

Labor: (For each partner in the project)

Assume a reasonable salary,

$$(12.5\text{CNY/hour}) \times 10\text{hours/week} \times 8\text{weeks} = 1000\text{CNY}.$$

Costs from hardwares and external devices: Refer to Table3.1.

3.2 Schedule

Week	Chuxuan Hu	Xiaohan Zhu	Heyue Wang	Yiyuan Chen
3/13/23	Literature review on motion evaluator, including Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM[2], mask r-cnn[1], DeepDance[5], Tac-Trainer[6]. Decide on the backbone of motion evaluator.	Read paper about audio signal processing, music analysis, dance motion generation.	Find reference design, select sensors.	Read paper about how to use accelerometers to estimate energy.
3/20/23	Implement and test the backbone (Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM[2]) ; collect and label dance videos; research camera usage.	Self-learning audio signal processing. Extract features of one sample music clip.	Purchase electronic components, learn the serial port communication.	Ran a rough regression model for prediction.

3/27/23	Adjust Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM[2] to fit in our tasks and videos; Set up process environment; Explore 3D motion extractors.	Use extracted beat to synchronize music time. Explore AIST+++ dataset. Server environment setting. Try motion camera.	Tuning the accelerometer.	Improve the model with a more detailed dataset.
4/3/23	Decide on which camera to use; Test Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM[2] with our own recorded videos.	Combine the kinetic information from 3D motion dataset with acceleration from bracelet to calculate the kinetic velocity. Calculate kinetic beat.	Tuning the pulse sensor	Test the model with our own accelerometer.
4/10/23	Build 3D pose matching framework and do simple tests; Integrate the 3D pose matching function with Self-Attentive LSTM and Multi-scale Convolutional Skip LSTM[2] backbone.	Test the accuracy of kinetic beat and music beat. Calculate rhythm matching evaluation scores.	Build Bluetooth communication between bracelet and the computer	Test the vital sign. Combine the vital sign with energy consumption model.
4/17/23	Research and build storage subsystem.	Build an app or a webpage for human computer interaction.	Adjust the bracelet electronic system.	Get the output data to the app or webpage.

4/24/23	Connect storage subsystem with other subsystems; test on its functionality.	Connect rhythm matching evaluation subsystem with other subsystems. Import evaluation scores to interaction interface.	Model and 3D print the bracelet shell	Improve the interface.
5/1/23	Connect everything; fix bugs if any.	Adjust the systems and improve if possible.	Connect the hardware with the evaluation system. Design the robot appearance	Adjust the display system.

4 Ethics and Safety

4.1 Ethics

Our dancing scoring robot raises several ethical concerns related to fairness and user privacy. In this response, we will examine these concerns through the lens of the Institute of Electrical and Electronics Engineers (IEEE) and Association for Computing Machinery (ACM) Code of Ethics [7], [8].

According to the IEEE Code of Ethics [7], engineers are required to ”treat all persons with dignity and respect and avoid illegal discrimination or harassment.” The dancing scoring robot must ensure that all participants are treated fairly, regardless of factors such as age, gender, ethnicity, or physical ability. The algorithm used to score the dancers should thus be designed to eliminate biases and be based on objective criteria such as technique, rhythm, and musicality. The scoring system should also be periodically reviewed and audited to ensure that it is functioning as intended and that any issues are identified and corrected promptly.

The ACM Code of Ethics [8] emphasizes the importance of avoiding harm and ensuring that technology is used in ways that benefit society. In the context of a dancing scoring robot, fairness would require that the robot does not cause harm to any participant or negatively impact their self-esteem. The robot should be programmed to provide constructive feedback that helps participants improve their dancing skills rather than being overly critical or punitive. Additionally, the robot should be designed with accessibility in mind, accommodating all types of dancers, regardless of their physical abilities.

The IEEE Code of Ethics [7] also states that engineers should ”protect the privacy and confidentiality of their clients or employers’ information, including personal information.” In the case of a dancing scoring robot, this would require that any personal information collected from the participants, such as name or age, is kept confidential. Additionally, any video or audio recordings of the participants' performances should be stored securely and only used for the purpose of scoring and providing feedback.

According to The ACM Code of Ethics [8], the participants should be informed of what data will be collected, how it will be used, and who will have access to it. They should also be given the option to request that their data be deleted after usage. The robot's system, especially the cloud storages, should be designed with appropriate privacy safeguards and controls to ensure that the participants' data is not misused or exposed to unauthorized parties.

4.2 Safety

Safety is the top priority during our designation of the dancing scoring robot. We mainly consider two aspects, its operating safety and environmental safety.

To ensure users' safety, the robot should meet the following requirements:

- The robot be equipped with a variety of sensors that can detect its surroundings and any potential hazards, such as people or objects in its path. These sensors should be able to detect movement and measure distances accurately to ensure that the robot can navigate around obstacles safely.
- The robot should have emergency stop buttons located in easily accessible areas. These buttons should be clearly marked and easily identifiable in case of an emergency. Additionally, the robot should be designed with redundant safety features to ensure that it continues to function properly even if one component fails.
- The robot should be designed to be lightweight and have a low center of gravity. This will help prevent the robot from tipping over or losing control during high-speed movements, which could cause serious injury to competitors or spectators.

We should also minimize the robot's impact on the environment from the following aspects:

- We should use low-energy components that consume less power during operation. This can include using energy-efficient motors, batteries, and lighting systems.
- We can also use environmentally-friendly materials in the construction of the robot. For example, the robot's chassis could be made from recycled materials or biodegradable plastics. This will help reduce the amount of waste generated during the production and disposal of the robot.
- The robot should be designed with sustainability in mind. This means that it should be designed to be easily repairable and upgradable, with components that can be easily replaced or reused. This will help extend the lifespan of the robot and reduce the need for frequent replacements, which can have a significant impact on the environment.

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