ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Dancing Scoring Robot

Team #29

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1 Introduction

1.1 Problem

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 a personalized evaluation 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.

1.2 Solution

Our team has devised a solution to achieve 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 and sequences match the standard movements. 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. While the implementation of this solution is not yet determined, our approach is explicit and concrete, ensuring the successful execution of this project.

1.3 Visual Aid

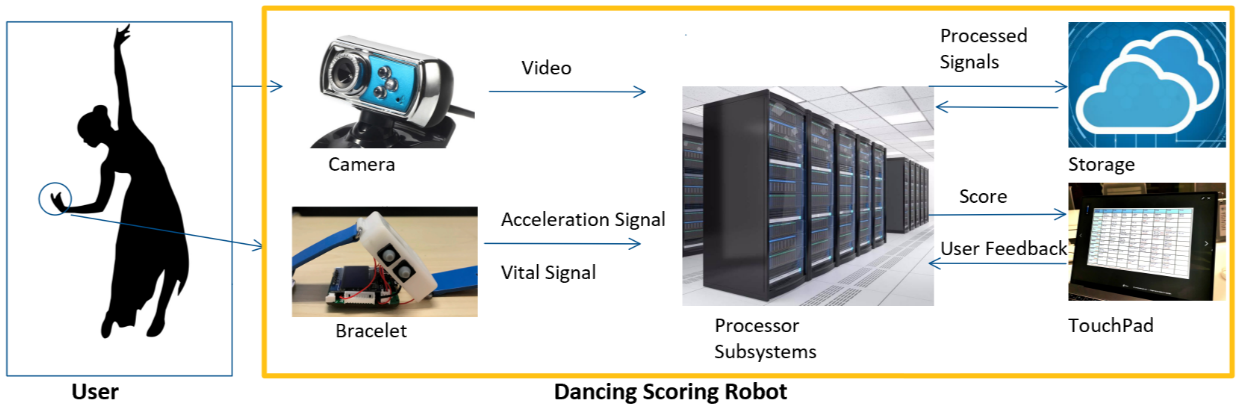

Figure 1: Visual Aid for Dancing Scoring Robot - Internal System

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

1.4 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 & Requirements

2.1 Block Diagram

The block diagram is shown in Figure 3.

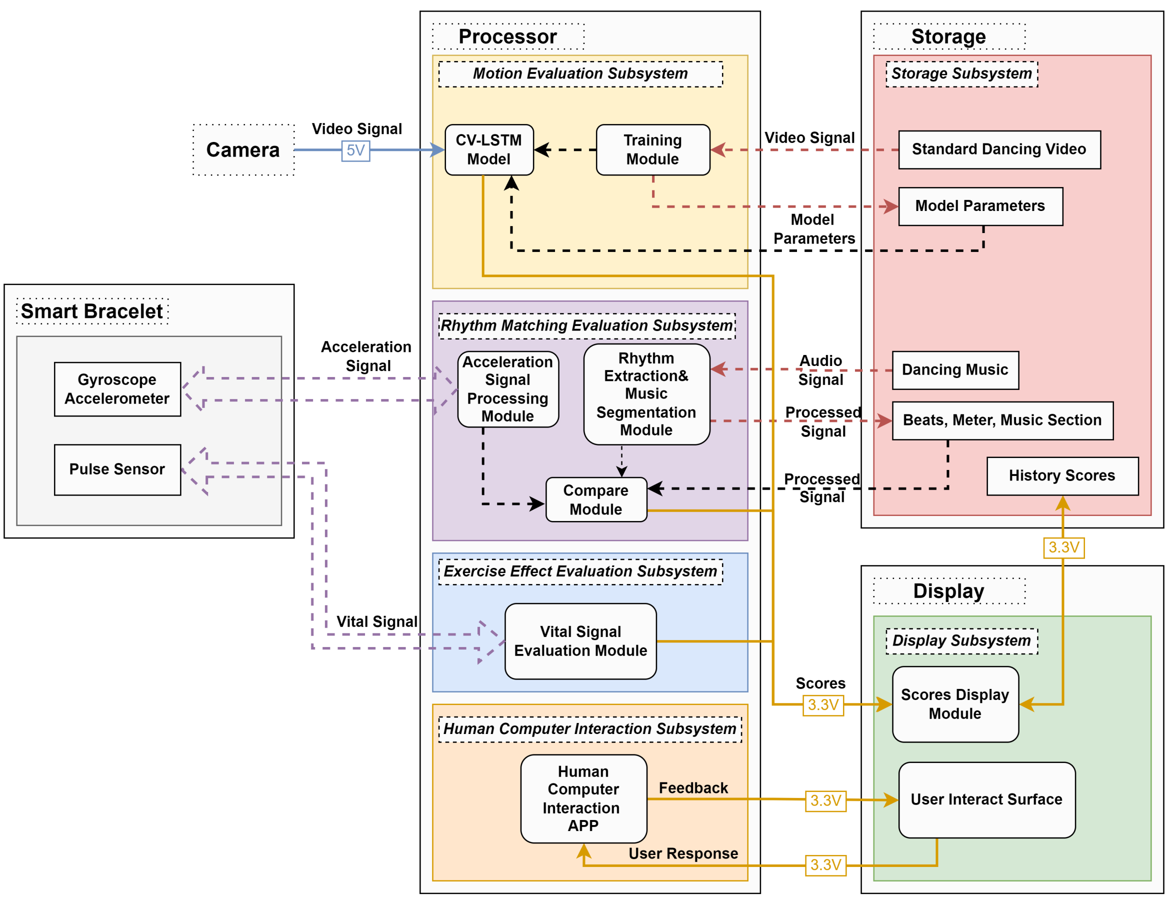

Figure 3: Block diagram

2.2 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.

2.2.1 External Devices

We are utilizing two major external devices.

Bracelet.

The smart bracelet includes 2 parts of sensing modules. One subscribes the kinematics data, including a 3-axis gyroscope and 3-axis accelerometer. The other focuses on health monitoring, including a pulse sensor.

For the kinematics monitoring module, the acceleration signals are collected through the IMU and transmitted to the microprocessor on the board. The signals are converted from measured analog signals into digital signals through ADC. The microprocessor preprocesses the data to identify the current movement, count the number of certain movements. The processed kinematics data is transmitted to the Rhythm Matching Evaluation Subsystems through a Bluetooth mesh network.

For the health monitoring module, it uses the Pulse sensor to collect the real-time heart rate. The heart rate collected is transmitted to the Exercise Effect Evaluation Subsystem through the Bluetooth network. This vital signal monitoring the user health and gives the necessary information for personalized evaluation process.

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.

2.2.2 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.

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 to extract the drumbeats (bass and snare) and detect the meter (music measure and beat numbers) of the music piece. The drumbeat can be used to synchronize the dance moves while the meter can provide the global timing information of the music beats independent of the spontaneous variations of the drumbeats. [3]

Then, we will use the music segmentation and intensity labeling module to segment the music piece into sections according to the intensity of the music. Basically, both rhythm features and instrumentation features are relevant to intensity perception. For instance, the chorus part of music normally contains more instruments than the verse section and is perceived with higher energy. [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.

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 into 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 to the display.

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 connected to the dancer's bracelet via Bluetooth to obtain the dancer's vital signs in real-time, including but not limited to heart rate and blood oxygen, to assess the dancer's forging effect in dance according to scientific exercise assessment methods.

2.2.3 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 cloud, the dance music is transformed into rhythm signal in the evaluation subsystem and will also be sent back and cached locally.

As part of our commitment to providing 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.

2.2.4 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.

2.2.5 Display Subsystem

As the output of the evaluation system, the display screen and evaluation systems are connected using wires, which would provide a stable and reliable connection between the two systems.

The display system is the most important part in the interaction between users and the whole system. The display system is responsible for presenting visual information to the user or audience. Its primary function is to display the dance score or other relevant information in a clear and visually appealing manner.

We display the scores given by the evaluation system for different aspects of the performance, such as how it fits with the music and how well the pose matches the standard. These scores can be shown in real-time during the performance, as well as at the end of the performance.

2.3 Subsystem Requirements

To ensure that the dancing scoring robot works properly, the subsystems should meet the following requirements.

2.3.1 External Devices

Bracelet. The smart bracelet should meet the following requirement to function properly:

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

Camera. The camera should meet the following requirement to function properly:

- The camera should be capable of recording at least 1080p resolution video to ensure high-quality video capture. The resolution can be verified by examining the recorded video footage and checking the resolution settings in the camera's specifications.

- The camera should be able to focus quickly and accurately on the dancer's movements. This can be verified by testing the camera's autofocus capabilities and observing the speed and accuracy of the focus adjustments.
- The wire used to transmit video signals from the camera to the evaluation system should ensure minimal interference and signal loss. This can be verified by testing the video signal quality during transmission and observing any degradation in signal quality.
- The camera should be able to move around flexibly on a rotatable base to capture the dance performance from different perspectives. 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

The evaluation subsystems should meet the following requirements to generate reasonable outputs.

Motion Evaluation Subsystem

The system must achieve an accuracy rate of at least 90% on existing dance videos and expert ratings. To verify the effectiveness and fairness of the scores given by the subsystem, we divided 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 1. the error rate between system-generated scores and the expert ratings should be ≤ 0.1, and 2. the correlation coefficient between the system-generated scores and the expert ratings must achieve at least 0.9 on this subset of dance videos.

Rhythm Matching Evaluation Subsystem

The system must be able to extract the drums and beats of different music and achieve a minimum of 80% correctness. At the same time, this system must be synchronized with the dancer's vital signs signals returned in real-time through the drumbeat, tempo and the music start time. This system should be able to tell how well the dancer performs the emotion expressed by the music and whether the dancer's movement matches the beat.

Vital Evaluation Subsystem

The system must be able to receive real-time vital signals from the smart bracelet, as well as record the information within the time of one piece of music and finally make a total assessment of the dancer's body movement based on the stored information. This assessment is required to reflect the dancer's real movement status, and the evaluation system is adjusted by asking about the dancer's personal feeling of movement in the final human-computer interface.

2.3.3 Storage Subsystem

The storage subsystem should obey the following criteria.

- The subsystem should be able to handle a large volume of data efficiently, minimizing retrieval time and maximizing system performance. The performance of the subsystem should be measured in terms of retrieval time, data throughput, and cache hit ratio.
- The subsystem should organize the data effectively, making it easy to retrieve specific videos, model parameters, and historical scores. The data organization should be verified by performing a search for specific videos and verifying that they can be retrieved quickly and easily.
- The cloud-based storage system should be tested to ensure that it can handle large volumes of data and provide high availability and reliability. The cloud storage should be tested by simulating high traffic and verifying that the system can handle the load.
- The cache system should be tested to ensure that it can efficiently store and retrieve recently and frequently accessed data. The cache hit ratio should be measured by monitoring the number of cache hits versus the number of cache misses.

2.3.4 Human-Computer Interaction Subsystem

We will use the touchpad to make the user interaction experience better, our interaction interface should be wrapped in an APP, the interaction interface should be clear and straightforward, and can be used in a short time for users who have not used it before to quickly get started, the interface will contain detailed scores for all aspects of the dance evaluation system, and the historical scores should also be in the form of graphs to better present the score changes to the user.

2.3.5 Display Subsystem

The display subsystem should be capable of receiving data from the evaluation subsystem and updating the player's score in real-time while dancing. It should also provide a clear and easy-to-read display that can be interacted with a touchpad. The subsystem should be designed to be compact and versatile, using a touchpad for the display.

To verify that the subsystem meets the specified requirements, the following tests can be conducted:

- Test the display subsystem to ensure that it is capable of receiving data from the evaluation subsystem and updating the player's score in real-time while dancing. This can be done by performing a dance routine while monitoring the score on the display, and comparing it to the actual score.
- Test the display subsystem to ensure that the display is clear and easy to read. This can be done by having a group of users with different visual abilities interact with

the display and provide feedback on its readability.

- Test the touchpad to ensure that it provides a responsive and intuitive touch interface. This can be done by having a group of users with different levels of touch familiarity interact with the display and provide feedback on its ease of use.

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 Ethics and Safety

3.1 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 [4], [5].

According to the IEEE Code of Ethics [4], 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 [5] 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 [4] 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 [5], 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.

3.2 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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