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Smart plate for powerlifting

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Abstract
Powerlifting is a sport where athletes tries to do barbell exercises with an excessive weight. When some athlete has significant muscle imbalance or when beginner which does not know the correct exercise technique tries to begin with powerlifting, it may leads from overtraining failure to injury. Therefore, it is important to measure the balance and velocity of the barbell during each repetition, analyze it in realtime and alert the athlete if there is something wrong. The created smart plate device as a sport equipment allows directly tracks balance and velocity of barbell during the exercise using advanced filter fusing data from included accelerometer and gyroscope sensors and also finds out the top down peaks of movement between each repetition. All measured data can be send to the mobile application for future analysis in an interactive chart. Therefore it helps to athlete to have more detailed informations about the accuracy of an exercise and allows to warn of imbalances in time. It also helps to count the number of repetitions during each session. And also there was created a dataset for future algorithm improvements.

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1. Introduction

When the powerlifting sport athletes do the exercises with heavy overload weights, it is especially useful for beginners to be able to track the barbell balance and velocity during these movements, because it can prevents them against failure that may leads to an injury due to incorrect technique or muscle imbalance of the athlete.

There are several approaches used in the practice. Some of them try to estimate the difference from a right pose using one or more cameras and computer vision algorithms [1]. Another approach [2] uses special boards with strain gauges on the floor to measure imbalance in weight. Both solutions targets to the trainers because they require special setup are expensive and not easy to use.

The goal of this work is create compact, portable, low cost, easy to use and open source solution based on MEMS sensors and advanced signal processing that can provide feedback in real time without complicated setup and requirement of a mobile phone.

2. Smart plate with IMU sensor inside

To track the barbell balance and movement there was proposed to use a single plate placed on barbell with custom electronic board contained ESP32 and IMU sensor Bosch BMI160 inside. The initial experiments with a prototype created using 3D printer demonstrated, that this solution has a sufficient accuracy to determine the barbell movement and there is no need to have plates on each side of the bar which will double the costs.

The device is powered by 3600mAh Li-Ion 18650 battery with external circuit, that contains step-up booster to 5V output voltage and special charging circuit with USB-C connector which protects battery before short-circuit, under or over charge states.

To increase the battery life, the hardware is in deep sleep mode while not used. This mode is deactivated by an interrupt from its touch input pin which is measuring capacity change around the center hole. When the plate is mounted on barbell, then the metal inside a plate's center hole changes the capacity on the touch pin and hardware wakes up to be ready for measuring. After vibration calms down and there is no another movement for a while, main FSM control algorithm will start tracking the linear movement of the barbell. When user starts the exercise, device saves the computed tilt and velocity during it into its cyclic array buffer located in RAM.

Obtaining these data is a non-trivial task, which is why a special advanced fusion filter was implemented for

computation the barbell tilt from accelerometer and gyroscope. Data is sampled at a frequency of 200Hz and 4g range, 1000dps respectively. When the tilt is known, linear acceleration is computed by extraction gravity vector from total measured acceleration vector and it is used to determine the movement velocity at each timestamp.

3. Smart wireless display

In addition to the smart plate, a display as a part of proof of concept was developed. The display is independed and optional device wirelesly communicate with ESP-now protocol and it can be used for quick feedback during the exercise.

This gadget contains of four LED displays. Left display warns if the balance is heavily skewed to the left. Similarly, the right display warns if the balance is heavily skewed to the right. Two displays in the middle is used to show the actual count of repetitions of exercise every time when the upper peak is reached. There are also dots that show if actual balance state is shifted to the left, right or perfectly centered.

Due to the excessive current consumption by the fact that the wireless communication must be active the whole time and the usage of LED displays, it is recommended to power the device with external 5V USB-C adapter. To improve the battery life, the device goes to the deep sleep when the connection between smart plate and display is lost (more than 15 seconds without response). Then will be must used the touch pads placed around the LED displays and keep fingers in touch around 1 seconds to wake up the device again.

4. Service web mobile application

As the smart plate records the data from a training, there is a possibility of transferring measured data using WiFi communication. User can use its web application on a smart phone to record the movement and saves it for the future more detailed analysis.

When the smart plate device is ready it turns on WiFi access point. Then anyone who connects to it will be automatically redirected into home page of web application which is available thanks to internal asynchronous webserver. All of HTML5, Javascript and CSS code is gziped and compiled as a constant string in the device firmware code. Therefore, the web application does not require any external or cloud libraries.

There is special algorithm on both sides which keeps structured raw data in the ESP32's RAM memory, sends them through WebSocket in binary form and web application deserealizes them back into normal values in array. Because of used ESP32 does not have much free space in RAM for all measured data, the connection between web application and smart plate may be online during recording the movement, else some part of them may be lost. A special sample counter is also implemented to track this issue. Processed data the device sends about each 250 milliseconds.

In the application, user can view the detailed charts of the recorded balance and the movement of barbell up and down during each repetition of exercise. These peaks are also marked on the timeline, and there are also statistics on the average and maximum velocity or how smoothly the exercise was performed. Also useful is the ability to upgrade the device firmware in the settings screen of the application.

5. Annotated dataset

As a part of this work, an annotated dataset consisting of accelerometer and gyroscope data was collected for future improvements of the detection algorithm. Several sets of squats with 20kg (without any aditional weight) and 50kg barbell were measured from beginners to advanced athletes. After evaluating the data, the assumption was confirmed that advanced athletes have a much more accurate technique of performing the exercise and the weight has an effect on the correct technique, especially for beginners.

6. Conclusions

There are a lot of ideas how to extend device features and do it much more useful for training, but the main basic goals – track the barbell tilt and movement velocity, test it and create the annotated dataset were achieved successfuly.

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