An IMU Sensor Application to Measure the Hands Amplitude at Exercise Performing in Gym

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***Abstract*—Digitalization of sport training equipment enables sensor-based applications for recognition of human movement at exercise performing in the gym. In this work-in-progress study, we present our demo sensor application to recognize the athlete's performance of the "Bench Press from the chest" exercise (measuring the hands amplitude in real-time). A training machine is provided by MB Barbell™(http://www.mbbarbell.com/). An IMU sensor (Inertial Measurement Unit) is used to measure the movement in the 3D physical space. Our experiments show that our sensing and data processing technique is feasible for development of a digital referee counting the performance of approaches to the bench press (so replacing a human referee).**

I. Introduction

Digitalization of sport training equipment is progressing towards Ambient Intelligence (AmI) services in Internet of Things (IoT) environments [1]. Such a service can measure the athlete's performance using sensors and recognize the movement quality. In particular, this approach enables various digital referees that replace human in making decisions on pass/fail the exercise in competitions [2]. Such sensors can be employed as Inertial Measurement Unit (IMU) to measure the movement in the 3D physical space, e.g., using wearable devices in basketball [3]. Comparison of IMU with video sensorics can be found in [4] (for a case study on fencing).

In this study, we show our demo of an IMU sensor application to recognize the athlete's performance of the "Chest Press" exercise on a "Chest Press / Bench Press" training machine. The IMU sensor is a three-axis accelerometer. The sport training machine equipped with the IMU sensor is provided by MB Barbell™(http://www.mbbarbell.com/) for the experiments. The experimental stand is deployed in Artificial Intelligence Center of Petrozavodsk State University (PetrSU).

Our prototype the IMU sensor application evaluates the initial and final positions of the athlete's hands. The hands movement is evaluated when the athlete is performing her/his exercise on the sport training machine, see Fig. 1. Calibration is performed in advance to take individual characteristics of each athlete into account (in respect to the individual characteristics of the training machine).

The rest of the paper is organized as follows. Section II introduces the recognition problems of a digital referee at exercise performing in the gym. Section III describes our algorithms to solve the recognition problems. Section IV demonstrate the results of our experiments with the IMU sensor. Section V summarizes our study.

II. Problem

Most of the powerlifting competitions are conducted with no digital system responsible for fair evaluation of athlete's performance. The evaluation is carried out by judges (human referees). The following problems can occur due to the human factor.

- Errors of checking the correctness of exercise performing (e.g., fatigue, low attention, subjected vision).
- Many judges are needed when many sport training

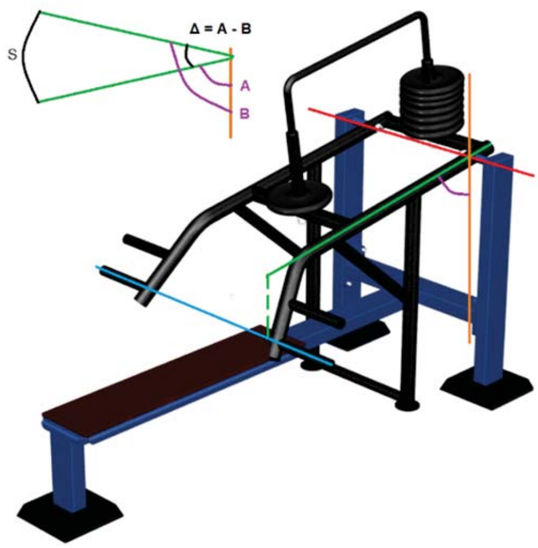

Fig. 1. Schematic view on the "Chest Press / Bench Press" training machine provided by MB Barbell™

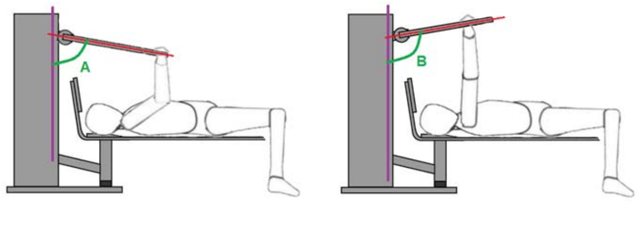

Fig. 2. Initial and final positions of the athlete's hands: angles A and B

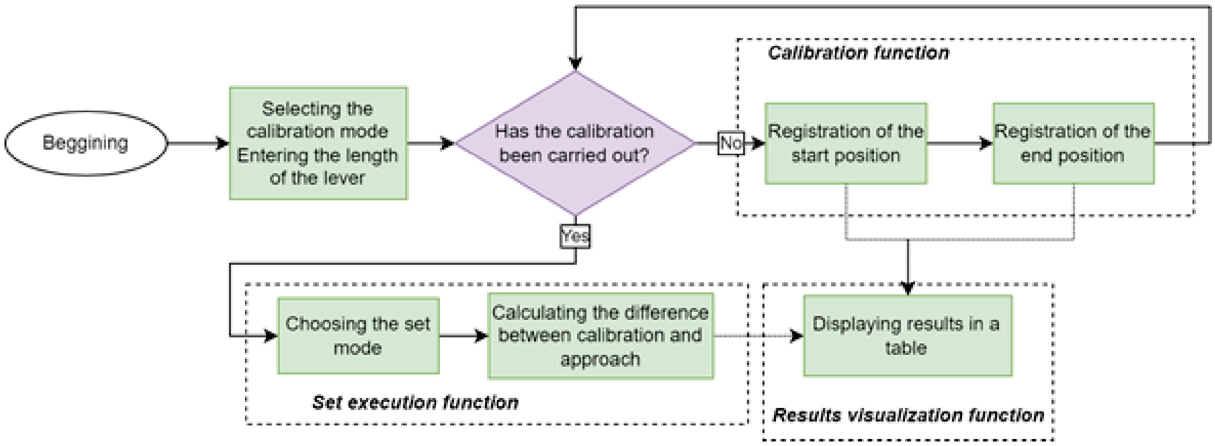

Fig. 3. Application workflow

machines are used in competition.

- Errors in recording the results (manual data input).

Our idea is to delegate the referee function to an application. The IMU sensor measures the hands amplitude at exercise performing in gym. A demo prototype is implemented to recognize the athlete's performance of the "Bench Press from the chest" exercise. The application runs in real-time based on the readings of the three-axis accelerometer. The schematic view on the sport training machine is shown in Fig. 1.

The first recognition problem is distance evaluation. From the sensor readings, the initial and final positions are computed for the athlete's hands. As a result, we can estimate the distance as a difference between the positions. Therefore, the evaluation of athlete's performance is reduced to checking the measured distance to satisfy the lower and upper bounds.

The second recognition problem is evaluation of the proper lower and upper bounds, i.e., amplitude bounds evaluation. The bounds essentially depend on individual characteristics of a given athlete, the training machine, and the position of the athlete on the bench. Therefore, calibration is needed before exercise performing in gym.

The functional requirements to the IMU sensor application are the following.

- Distance evaluation is performed without human participation (judge). Distance measurement provides metrics of the correctness of exercise performing in gym for particular athlete and training machine.
- Bounds evaluation is performed using calibration before real exercise performing by each athlete. The individual bounds serve as a pattern to check for amplitude on its correctness.

Both functions are executed in real-time. The results are summarized on the public electronic scoreboard.

III. Algorithms

Consider the recognition problem of distance evaluation. Hand positions are determined with angles A and B, see Fig. 2. To estimate A and B, accelerometer readings are used for roll, pitch, and yaw angles (3-axis accelerometer readings). Then, the passed distance is characterized with $\Delta = A - B$.

Assume the lever length is L, which can be measured manually for a given training machine. The hands amplitude can be geometrically estimated as the chord or arc. In particular, the arc S is computed as

$$S = \frac{\pi}{180}\Delta L \tag{1}$$

Consider the recognition problem of amplitude bounds evaluation. For a given athlete and training machine, individual calibration is performed, i.e., a kind of service personalization. The athlete makes several repetitions on the training machine with empty weight. The evaluation of the individual extreme positions of the hands using (1).

All calibration estimates are summarized in the calibration table. The average amplitude S_{amp} of the athlete's hands movement is evaluated. Note that deviation in estimations should be low since outliers indicate a measurement problem.

The metric provides the following criterion for decision making on the exercise is passed or not.

$$S > S_{\text{amp}} + \varepsilon, \tag{2}$$

where ε is a parameter to tune the recognition for the accuracy. For instance, ε can be formulated in terms of the variance or percentiles.

Let the athlete perform real exercises (in competition). For every exercise the amplitude S is estimated using (1). If criterion (2) is satisfied then the digital referee counts the exercise as passed. The results are visualized on the application screen and summarized in the public electronic scoreboard. The overall scenario for the application is shown in Fig. 3.

IV. Experiment

The properties to evaluate is the feasibility of the proposed sensing and data processing technique. The accuracy and the real-time performance are subject to our experimental study. The experimental stand is deployed in Artificial Intelligence

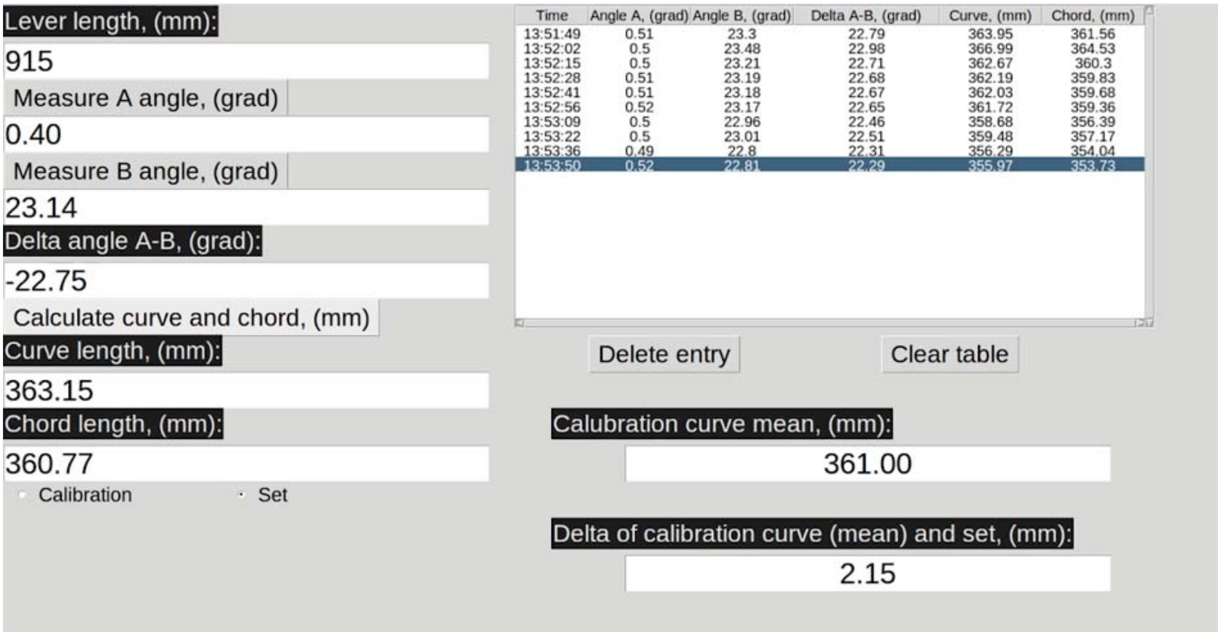

Fig. 4. The application screen for the sport training machine

Center of PetrSU. For a given volunteer, ten calibration repetitions are used. Exercise performance is evaluated with weight of 80 kg.

The following properties of the prototype are experimentally tested.

- Measurement ability to estimate the angle of the hands position using the IMU sensor.
- Achieved accuracy is 1 cm or better.

The expected result is that the deviation of the readings of the working approach from the calibration for the movement of the athlete's hands should not exceed 1 cm.

The experimental setup is constructed as follows.

1) Installing the IMU sensor by magnetic mounting on the frame in such a way that the planes formed by the XZ axes of the accelerometer and the rotation of the frame are parallel.
2) Connecting the IMU sensor to a computer using a USB type A (M), miniUSB type A (M) cable.
3) Running the program for processing the sensor reading.
4) The lever length is manually measured and added to the application as input parameter. The distance is measured from the center of the sensor mounting point to the axis of rotation of the lever;
5) Setting the operation mode to Calibration.

In the experiment, the following scenario is executed.

1) Preparatory step. The athlete comes to the training machine.
2) The athlete's hands are in the lowest position.
3) Fixation of the lowest position is performed using the "Measure A angle, (grad)" button. The measured angle is displayed in the field below this button.
4) The athlete's hands are in the highest position.
5) Fixation of the highest position is performed using the "Measure B angle, (grad)" button. The measured angle is displayed in the field below this button.
6) Estimation of the hand movement using the "Calculate curve and chord, (mm)" button. The measured calibration values are collected in the table with timestamps.
7) To perform calibration, steps 2–6 are performed the required number of times.
8) Starting the exercise by the volunteer using the "Set" mode.
9) For every exercise the difference $|S - S_{\mathrm{amp}}|$ in the amplitudes is displayed in the "Delta of calibration curve (mean) and set, (mm)" field.

The executed steps of the volunteer athlete in our experiment are shown in Table IV. The numerical measurement and evaluation results are summarized. The experiment leads to the following conclusions.

- The feasibility is confirmed. The application measures the angles of the lever with the given IMU sensor in real-time.
- The required accuracy of 1 cm is achieved. The difference between the calibration values and real exercise values is of several millimeters.

The following problems are observed, which need further research and development.

- The position of athlete on bench affects the recognition of the initial and final angles. As a result, the hands amplitude can vary in different exercises. It is important to keep the same position of the athlete on the bench, both for the calibration and when performing real exercises. The problem can be tackled

TABLE I. EXPERIMENTAL RESULTS

Step	Description	Angle A	Angle B	Result
1	Calibration repetition 1	0.51	23.30	Amplitude-363.95mm
2	Calibration repetition 2	0.50	23.48	Amplitude-366.99mm
3	Calibration repetition 3	0.50	23.21	Amplitude-362.67mm
4	Calibration repetition 4	0.51	23.19	Amplitude-362.19mm
5	Calibration repetition 5	0.51	23.18	Amplitude-362.03mm
6	Calibration repetition 6	0.52	23.17	Amplitude-361.72mm
7	Calibration repetition 7	0.50	22.96	Amplitude-358.68mm
8	Calibration repetition 8	0.50	23.01	Amplitude-359.48mm
9	Calibration repetition 9	0.49	22.80	Amplitude-356.29mm
10	Calibration repetition 10	0.52	22.81	Amplitude-355.97mm
11	Average arc is evaluated based on the calibration value	—	—	Average arc value is 361 mm
12	Weight is set to 80 kg for exercises	—	—	The weight is set, the mode "set" is enabled
13	Exercise is performed with weight 80 kg	0.40	23.14	Amplitude is 363.15 mm
14	Difference between the calibrated value and the performed exercise	—	—	Difference is 2.15 mm, less than required 1 cm

using explicit control of the athlete's position on the bench.

- The calibration value of the hands amplitude can be unreached due to the deformation of the joints under the working weight. The similar result can be due to the "stretching" of the shoulder girdle. The problem can be tackled using the parameter ε in (2) or advanced AI-methods for human physical activity recognition [5].

V. CONCLUSION

In this work-in-progress study, we present our demo IMU sensor application to recognize the athlete's performance of the "Bench Press from the chest" exercise. The athlete's performance is recognized using readings from a three-axis accelerometer (for roll, pitch, and yaw angles). The key metric to evaluate is the hands amplitude; this distance is geometrically estimated as the arc the lever has passed in the exercise. Our early experiment confirmed 1) the sensing feasibility, i.e., the angles to estimate the hands amplitude can be measured in real-time and 2) the achieved accuracy is better than 1 cm even when using a simple IMU sensor.

We consider the two important directions for further research. First, control is needed for the athlete's position on the bench, since the position can be changed when the athlete performs several exercises. Second, elimination is needed for the influence of the exercise weight and other factors in the hand amplitude estimation in the gym.

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