Design of Human Activity Monitor for Push-Up Exercise using IMU

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Abstract*: *The detection of exercises and evaluation of the performance is one of the key techniques used by many sports personnel to maintain track of their training. Inertial measurement units are efficient in such applications where the motion of the body has to be periodically monitored. This work aims at developing the custom activity monitor for fitness assessment. A circuit of 10 pushups was done by the subjects, with the device affixed on either left or right bicep. Algorithm is developed to detect the different fitness assessment parameters and is simulated in MATLAB®. The algorithm is further implemented on the hardware designed. The accuracy of detection of the push-ups is observed to be 95%.

Index Terms: Activity Monitor, Fitness, IMU, MCU

I. INTRODUCTION

The term physical activity monitors or trackers refer to the wearable devices, which ceaselessly track the particular exercises done by the person and record it. The idea of physical activity observation grew out of the written log sheets that individuals made use to record the parameters associated with fitness of a person. The technology advancement in early twenty first century paved way to the development of the business grade instrumentation (which are utilized in gyms) and shopper grade devices by the year 2010. Nowadays, completely different types of smart watches with immense capabilities are available and additionally in reasonable cost. But the current devices are not suitable for the fitness assessment scenario where the results should be made available to the concerned person only, or as required by the user. In this paper, the customized wearable fitness monitor is developed for fitness assessment that can fill in the drawbacks of the existing devices. This device is developed for the push-up exercise. In section II, the background work for the paper is reviewed. Further, section III discusses the design and implementation of the device. Section IV analyses the results obtained by the device and also the simulation results of algorithm. Finally, the section V concludes the paper.

II. BACKGROUND WORK

There are entirely different methodologies adapted by ma ny researchers all round the world for the detection of exercises. Collectively in many papers referred, one can observe the variations among the activity considered for the study. Incorrect exercise performance (i.e. faulty exercise kind and technique) would possibly result in ineffective coaching job, inadequate rehabilitation, equally as increasing the chance of coaching job evoked injuries. Usually this can be, often significantly, found pertinent for athletes who train with free-weights [1]. Coaching job evoked injuries are typically caused by excessive tissue loading as a results of aberrant exercise kind and technique [2]. Therefore, feedback on exercise performance is crucial, so that athletes perform prescribed exercises properly.

The paper [3] seeks to analyze whether a single lumbar-worn IMU is capable of distinguishing seven ordinarily determined squatting deviations. Twenty-two volunteers (18 males, 4 females, age: 24 to 30 years, height: 1.75 to 1.89m, body mass: 70 to 85 kg) performed the squat exercise properly and with 7 induced deviations. These results indicate that one IMU can successfully discriminate between squatting deviations. A larger data set should be collected and a lot of complicated classification techniques developed so as to make a stronger exercise detecting system.

Similarly, in [4] the sensor data analysis for various position of the sensor on the body is seen. The work [5] tries to beat the constraints of economic devices that are available for weight coaching, exploiting machine learning technique (particularly linear discriminant analysis, LDA) for analyzing data returning from wearable inertial measurement units, (IMUs) and classifying/counting such exercises. Computational necessities are compatible with embedded implementation and reported results verify the practicability of the projected approach, giving a median accuracy for the detection of exercises of 85%.

From this background study, it can be seen that the fitness assessment of an individual can be done reliably using IMUs. Also the researches have indicated that positioning of the sensor on the body of the subject will depend on the type of the exercise being done. Hence an implementation plan has to be followed which can ensure the results are error free.

III. DESIGN AND IMPLEMENTATION

The following methodology is adapted for the implementation of physical activity monitoring. The different phases of the work are listed as follows.

1. Data collection using IMU and analysis of data for push-up exercise
2. Formulation of algorithm to obtain required fitness assessment parameters from data

Revised Manuscript Received on June 15, 2019.

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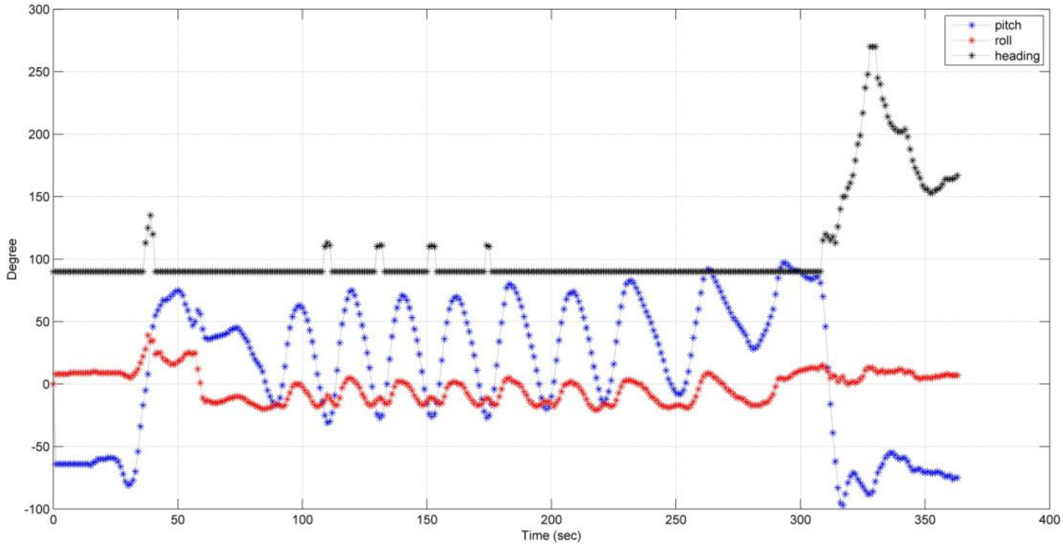

Fig. 1: MATLAB plot of data obtained from IMU

3. Design of hardware and embedded software

Each of these phases is elaborated in this section as follows.

A. *Preparation phase*

In this phase, the data collection using IMU is done for push-ups. The procedure followed for collecting the data from IMU is as given below.

1. Sampling rate of sensor is set to 20Hz.
2. IMU is configured to output Euler Angles.
3. Data is stored in .txt file in micro SD card.
4. Device is fixed on right arm of subject.
5. Exercise is performed by the subject.
6. Data is plotted in MATLAB.

The data obtained from this phase is in terms of pitch, roll and heading (yaw). A plot of angles versus time is plotted for all the three Euler angles as shown in Fig. 1.

From the plot of pushup data, it can be observed that the pitch (blue color plot) data has the most periodic variation for the duration of exercise and also with less noise. These angle variations are dependent on the particular orientation of the sensor on the subject's body.

B. *Formulation of Algorithm*

In this phase, an algorithm is designed to extract the fitness assessment parameters. The variation seen on the pitch data is most suitable for the development of algorithm. The steps followed in the algorithm are as follows:

1.Start

2.Load 3 values of pitch: prev, curr, next

3.while curr == next

a. Discard the data

4.if prev < curr && next < curr

a. Detects peaks and stores in pv_arr

5.if prev > curr && next > curr

a. Detects valleys and stores in pv_arr

6.avg_amp = ((pv_arr(i-2) - pv_arr(i-1))+(pv_arr(i) - pv_arr(i-1)))/2;

7.time = pv_ind(i) - pv_ind(i-2);

8.if avg_amp > 50 && avg_amp < 200

9. if time > 15 && time < 60

a. Increment count

10. End

The peaks and valley are detected in dataset in the beginning of the algorithm. Then based on upper and lower bound on the average amplitudes of rising and falling edges of the waveform, and also time between the peaks, the push-ups are counted. The algorithm was simulated in MATLAB®, the results of which are as shown in the section IV.

C. *Implementation phase*

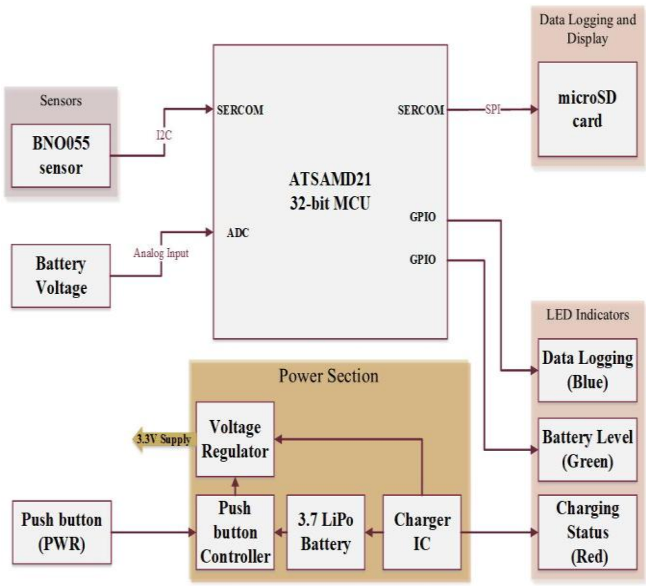

Fig. 2: Block diagram of the overall system

For the real time implementation of the above designed algorithm, the hardware and embedded software was developed. The Fig. 2 shows the block diagram of the hardware design. The BNO055 sensor (IMU) is employed to obtain the Euler angle data. For the storing the sensor data and the extracted fitness parameters, the SD card is interfaced with the MCU through the SPI protocol. The power section consisting of the battery, charging circuit, pushbutton controller (along with the pushbutton) and the voltage regulator, is used to

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power up the entire circuit. The microcontroller used is the Microchip ATSAMD21, which is a low power device with 32 pins in TQFP

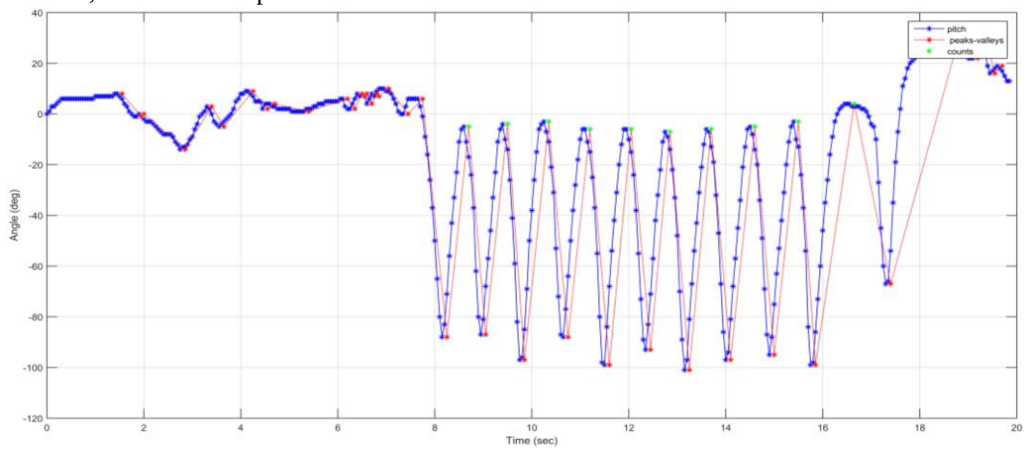

Fig. 4: Simulation of Algorithm for Push-up data.

package. LED indicators are provided for data logging, battery status and the charging status.

The software control flow of the embedded software for the designed hardware is as depicted in the Fig. 3.

The software control flow is majorly driven by the timer, which is configured to generate the interrupt at every 50ms. This allows setting the data sampling rate to 20Hz. At every timer interrupt, the data from the BNO055 sensor is read and is processed by the algorithm to obtain the number of push-ups done.

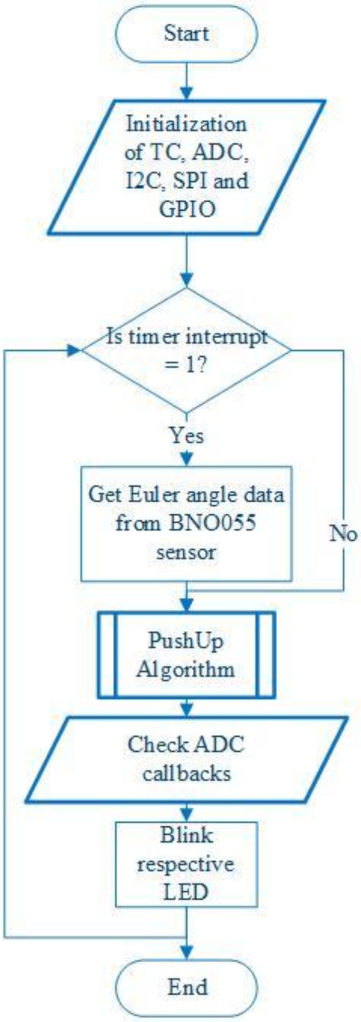

Fig. 3: Software control flow

Further, the ADC callbacks are checked to continuously monitor the battery voltage, based on which the LEDs are blinked.

Fig. 5: The device developed

Fig. 6: PCB view of device

The Fig. 5 shows the device developed for the fitness assessment of an individual for push-up exercise. The textile straps are provided which are convenient for the user to wear the device. In Fig. 6, the top view of the PCB can be observed.

In the next section, the results obtained are analyzed in detail.

IV. RESULTS AND ANALYSIS

The simulation of the algorithm on the data set can be shown in the Fig. 4.

The pitch data is plotted in

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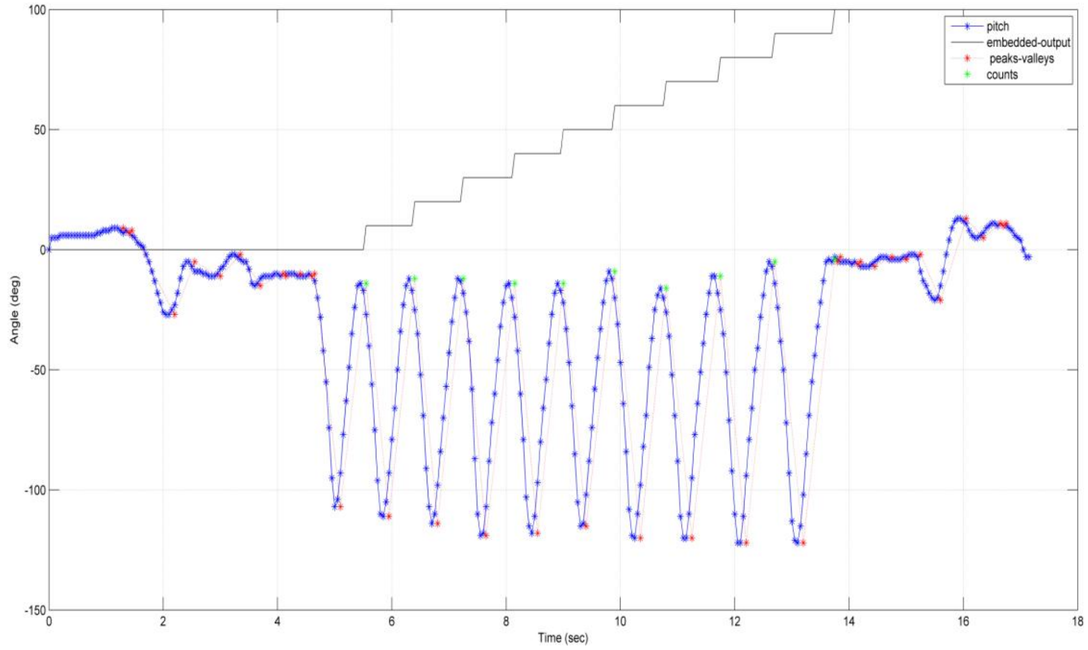

Fig. 7: Plot of MATLAB result along the embedded output

blue with the peaks and valley marked in red and push up counts marked in green. The simulation results correspond to the exact activity done by the subject.

The upper and lower bounds of the average amplitude and the peak to peak time are set by trial and error method. The current bounds are optimum to ignore the noise amplitudes are also suitable for most of the users.

The Fig. 7 shows the result of embedded software which is indicated in the black line. It can be observed that the increase in the count of the push-ups corresponds to the MATLAB simulation results.

The testing was done on 10 subjects, who are in the age group of 25 – 30 years, who also have regular practice of doing the exercise. The outputs were observed to be 95% accurate. The accuracy is limited by the variation in the sampling rate, which is due to the output variation of timer module of MCU. Also the human error was observed while using the device, which led to missing of count in the embedded software output.

V. CONCLUSION AND FUTURE SCOPE

The importance of the fitness assessment parameters in sports training is predominant, since it gives a conclusive feedback of the amount of exercise and also rate of the exercise done. The selection of data on which the algorithm is developed is of utmost importance, due to the fact that the complete device is dependent on it. Also it can be noted that the variations that are considered are periodic in nature. Hence the results obtained are reliable. The designed device is capable of detecting the push-up exercise with an accuracy of 95%.

As a part of future work of this paper, the algorithm can be developed for the different exercises of similar type, i.e. upper body exercises, with two state movements. Also the efficiency of the device can be improved in terms of the power consumption.

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