Implementation and Evaluation of the Personal Wellness Coach

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Abstract

This paper describes the design and evaluation of a wearable Personal Wellness Coach system that supports a range of activities including health data collection, interpretation, feedback and self-monitoring. We implemented a wearable computing platform consisting of an array of sensors and application software to motivate users to reach fitness goals and prevent harm in a real-time environment. Evaluation and testing were done on 65 users in four groups: students, health club members, ROTC members and Baby Boomer-age individuals. Comparing the Personal Wellness Coach against an existing exercise product, our results indicate that this system is an effective tool that is less intrusive and in some cases can perform like a personal trainer and help improve user efficiency.

1. Introduction

The main concept of the Personal Wellness Coach (PWC) is to merge the advantages of personal fitness trainers with the features in current wearable exercise products. Existing exercise products log statistics such as distance, calories burned, and heart rate activity. Personal trainers can interact with their client, motivating and encouraging them to ensure they achieve their fitness goals. However, their time is expensive and appointments must be scheduled in advance. Our goal is to employ the latest wearable computing technologies to design and evaluate a virtual coach that intelligently interacts, encourages and motivates the user.

The following features are explored in this research:

- System adapts to different body shapes and sizes
- Real-time counting of exercise repetitions
- Real-time monitoring of heart rate
- Interactive audio feedback for motivation
- Detection of different user exercise states (normal and struggling)
- Prevent harm and warn user of overexertion based on vital signs
- Automated logging of exercise data
- Use exercise history to help user efficiently reach future goals

The virtual coach can be used to help in training for most anaerobic and aerobic exercises. Anaerobic or weight-training exercises involve short bursts of exertion performed through repetitions, using free weights, exercise machines, or one's own body weight. These exercises are typically done in sets, with the weight and number of repetitions varying depending on the workout goal. Common goals include increasing stamina, body definition, strength and muscle mass.

During anaerobic exercises, the PWC provides real-time feedback to the user by detecting and counting out loud each repetition, and recording the exercise weight and number of repetitions completed. Feedback is used to motivate the users to reach their set goal by identifying the user's exercise state in real time. In addition, the system uses the user’s past performance to encourage them to increase the weight or do more repetitions according to their workout goal.

Aerobic exercises involve elevated heart rate and increased breathing for a set period of time. Typical examples include jogging, swimming, cycling, and walking. The PWC monitors the heart rate and keeps the user within a target zone for a defined period of time. The PWC varies the playback rate of the user's music selection according to their current heart rate, which guides the user to stay within their target zone.

To evaluate the effectiveness of the PWC, a diverse group of people were tested varying in age, body shape and sizes, fitness levels and exercise goals.

In section 2, we describe the wearable hardware architecture. Section 3 explains the approach and

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methodology, while Section 4 summarizes the experimental results of the four different user groups. Conclusions are presented in Section 5 and suggestions for future work in Section 6.

2. Architecture

To track user movement, the system uses accelerometers from the BodyMedia® SenseWear™ armband. The sensor is a 2-axis micro-electro-mechanical device that measures motion, aligned in the transverse and longitudinal planes. Built-in algorithms take into account gravity and can determine the orientation in which the armband is being worn.

Figure 1: BodyMedia® SenseWear™ armband being worn and Polar® Heart Rate Monitor

To monitor user heart rate, the system relies on the Polar® heart rate monitor and armband. The armband has a custom board to receive pulses transmitted by the heart rate monitor which detects the user's heart beat. Heart rate and accelerometer data are sent by the armband using a 916.5MHz RF frequency to a laptop for real-time data processing. The laptop has an Intel Pentium M processor running at 1.3Ghz and 512MB RAM. Audio and music feedback are output via the laptop speakers or through a Bluetooth headset useful in noisy environments, such gyms. Wireless communication allows the laptop to be up to 30 ft. from the user allowing free motion.

3. Approach and Methodology

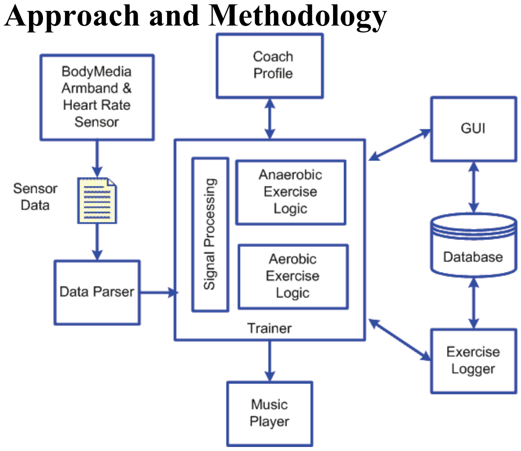

Figure 2: System Architecture

The software was written in Java using the Eclipse integrated development environment. The PWC system architecture is shown in Figure 2. The heart-rate and accelerometer sensor data are transmitted wirelessly from the armband to the laptop where the data is recorded into a log file. Accelerometer and heart-rate data are retrieved from the log file and parsed in real-time.

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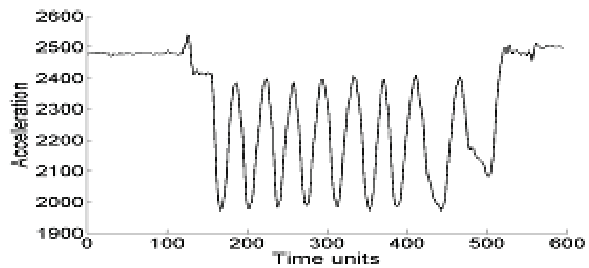

Figure 3: Filtered accelerometer data

The raw accelerometer and heart-rate data are influenced by noise. To prevent noise-peaks and high frequent noise, all values are pre-filtered with a low pass mean filter. The result can be seen in Figure 3.

The order of the mean filter depends on the signal shape. To be able to track movement such as fast pushups, the order of the mean filter must not be high for the anaerobic exercise logic. Preliminary experiments showed that a filter order around 3-5 gives accurate results for anaerobic exercises.

In contrast the heart-rate does not change very quickly, so the mean filter order can be high for the aerobic exercise. Preliminary experiments for this mode showed that a filter order around 14-16 gives accurate aerobic results. After preprocessing, the data is used by the trainer logic modules, which is the core of the system.

3.1 Anaerobic Exercise Logic

The main goal for the anaerobic trainer module is to increase workout performance with every session. The armband is worn on the part of the body appropriate for the exercise (e.g. Arm for pushups, or ankle for leg-extensions). The system suggests a new goal for the actual session based on the history data of past sessions (Section 3.7).

Our studies show that signal shapes of different users and exercises follow a similar waveform. The pulse-width of the accelerometer signal is a good indicator for the user's exercise state (normal or struggling). While the user is doing his exercise normally, the pulse-width of the accelerometer signal is constant. When the user begins to struggle, the proportion of time within the resting-state is longer.

For recognition of struggling states, it is useful to have a binary-type representation of the analog waveform. The waveform can be identified into two distinct states, *Active* and *Resting*, as shown in Figure 4. This insight is used to detect struggling, allowing the system to give feedback to encourage the user to reach their goal.

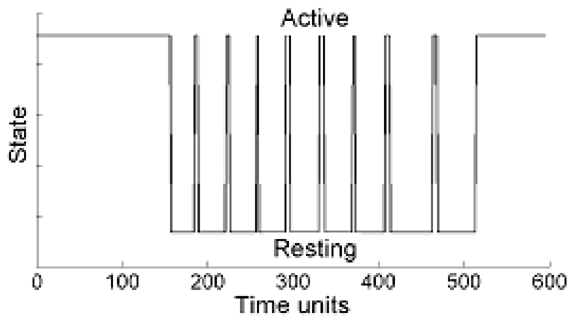

Figure 4: Binary signal corresponding to user exercise state: *Active* and *Resting*

3.2 Anaerobic Signal Processing

Through experimental testing, the accelerometer data was preprocessed using an order 3 mean filter to recognize fast movement and higher acceleration values. This value was found to be accurate through experimentation starting with an order 10 mean filter and decreasing the order with every test.

Since the accelerometers indicate dynamic and static acceleration the scale used is not m/s^2. The axis corresponds to the numerical output of the sensor.

The accelerometers used for this mode measure dynamic and static acceleration. Fast movements cause high dynamic acceleration values. Rotating or tilting the armband causes high static acceleration.

Anaerobic exercises consist of a periodic pattern (Figure 5) with repetitions counted by finding the number of periods, i.e. by counting the rising or falling edges.

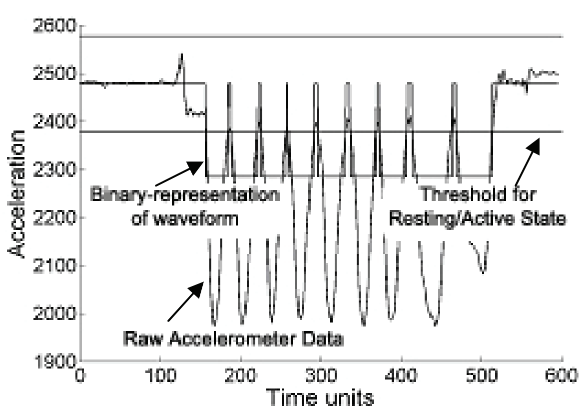

Figure 5: Anaerobic signal processing

Since all users have different body sizes, arm lengths etc. it is necessary to calculate the threshold to determine active and resting state transitions at the beginning of each exercise. Therefore the static acceleration in the starting position is measured, averaged and used as a base for choosing this threshold. Crossing this threshold means switching from active to resting state and vice-versa as shown in Figure 5. The number of time unit samples in each phase (resting and active) corresponds directly to the time in that state. This information is used for recognizing struggling states. Moreover every upward edge of the binary-type representation signal indicates a new repetition.

The resting state duration is averaged over the first few periods (e.g. 3) at the beginning of the exercise. Afterwards a time-threshold, slightly higher than the measured resting duration, is set based on the duration of this average value. If the resting phase exceeds this threshold the system recognizes this state as struggling and encourages the user by playing a motivational sound.

3.3 Aerobic Exercise Logic

Aerobic exercise studies indicate that a person's target heart zone depends on size, weight, age, gender and fitness level. The Karvonen Formula is a known method for determining cardio-intensity levels. The maximum heart rate is calculated as shown in Table 1.

The user can choose between three different workout modes as shown in Table 2. The PWC will calculate the optimal target zone range for the user based on the user's goal, such as fat burning.

Table 1: Calculation for maximum heart rate based on age and fitness level

Gender / **Fitness Level**	Male	Female
Non-Athletic Max Heart Rate	$220 - age$	$226 - age$
Fit Max Heart Rate	$205 - \frac{age}{2}$	$211 - \frac{age}{2}$

Table 2: Target training zone defined by maximum heart rate and training goal

Training Goal	**% of Max Heart Rate**
Fat Burning	60 to 70%
Cardio Training	80 to 90%
High Intensity	90 to 100%

An absolute maximum and minimum heart rate range (ARH, ARL) is determined in addition to the target heart zone to prevent harm and to ensure workout efficiency:

ARH = 1.15 Target Training Zone High (TTZH)
ARL = 0.85 Target Training Zone Low (TTZL)

If a user exceeds his/her absolute maximum heart rate (e.g. in case of overexertion), a warning message is played. If the user is not trying hard enough (the heart rate is far below his minimal target heart range), a message encourages him to increase his pace. Preliminary experimentation indicated that an easy way to notify a user to increase or decrease their speed is to change the rhythm of the music they listen to.

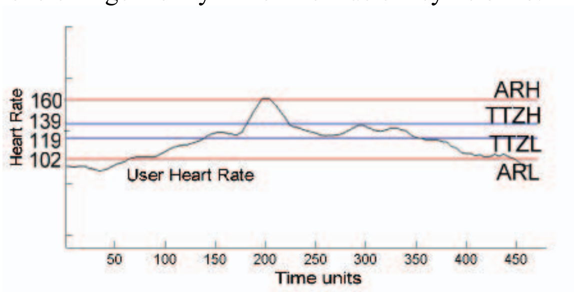

Figure 6: Sample user aerobic waveform

TTZH and TTZL are used as thresholds to change the music speed. If the user is going too fast, his/her heart rate exceeds the upper level and the music slows down. Our user studies show that people reduce their pace when the rhythm of the music slows down. On the other hand, faster music encourages the user to increase his/her pace. The change of music speed can thus be seen as non intrusive encouragement and motivation as further described in Section 4.

3.4 Aerobic Signal Processing

The heart rate data is obtained at approximately 800ms intervals from the armband sensor. To reduce the effect of noise, the received data is filtered with an order 15 low pass mean filter as described earlier. The different music speeds are implemented by changing the sampling rate of the music file.

3.5 Coach Profile

Our user studies have shown that people respond differently to diverse types of motivation and encouragement. Some find a soft female voice the most encouraging while others prefer a militant drill sergeant to get maximum workout efficiency. The system offers flexibility by allowing the user to switch between different coach profiles.

3.6 Graphical User Interface

The system relies mainly on audio and music feedback to minimize a user's distraction. However, the prototype includes a graphical user interface to give the user full control of the system and provide easy input capabilities. The GUI allows the user to create/select a profile, create/select the type of exercise, view history data of past sessions, control the duration and types of each exercise, and assess the other functions.

3.7 Exercise Logger

The exercise logger module collects data such as number of repetitions, weight, laps and exercise duration. The exercise logger can be used to record the time within and outside the target heart zone.

Studies have found that documenting exercise data and tracking user progress increases exercise adherence [1]. This helps motivate users by allowing them to keep track of their goals.

The exercise logger is useful in conjunction with a personal trainer or phone coaching program [2]. When a personal trainer is not present, automated exercise logging holds users accountable, which has been shown to improve exercise adherence [3].

4. Experimental Results

4.1 Preliminary Testing

During preliminary testing, feedback variable rate was fine-tuned and the database was created to enhance the motivation logic. As the system detected the user struggling, the authors created an algorithm to output feedback at a suitable pace to avoid annoying the user. The accuracy of the motivational feedback was improved by providing positive or negative comments if the user surpassed or missed exercise goals. The feedback's timeliness was also improved to provide positive encouragement when the system detected that the user's exercise goal was near.

Figure 7: Student and Baby-Boomer

In addition to audio and music feedback, armband vibration was explored but ruled out as it was not enjoyable for the user. Text messages with comments flashing on the screen and were deemed as requiring too much attention from the user. The approach chosen was to imitate a personal trainer and use audio interaction. Computer generated text-to-speech was used originally but proved to be too impersonal. The authors recorded 65 static phrases comprising of positive and negative comments, warnings, commands and numbers used to count repetitions of a 23-year-old female voice. Example positive comments include: *Good Job! Keep it up! You're almost there!*

4.2 User Group Experiments

The PWC was tested on 20 students, 20 Baby Boomer adults, 15 health club members and 10 ROTC members. Each of these groups were asked to record their age, gender, height, how often they exercised, and their fitness levels (not fit, medium fit, or fit).

Members of both genders were tested for all of the groups and their heights varied from 60" to 76". Table 3 shows the group demographics including their age ranges, fitness levels and how often they exercise.

Table 3: User group demographics

Group / **Ranges**	Student	Boomer	Health Club	ROTC
Age (Average)	21 to 26 (23)	37 to 72 (52)	20 to 45 (27)	18 to 52 (30)
Fitness Level	Not fit to Fit	Not Fit to Fit	Med Fit to Fit	Med Fit to Fit
How often Exercise (times/ week)	Never to Several	Never to Several	Once to Several	Several

4.3 Timeliness and Accuracy

Users participated in a range of anaerobic activities such as arm curls, push-ups and leg raises. The armband was placed on the body relating to the exercise such as on the back of the upper arm for pushups, forearm for arm curls and ankle for leg raises. Users were asked to do one or two sets of 15-20 repetitions of two different exercises requiring the armband to be placed on different parts of the body.

Users performed aerobic exercises using the heart rate monitor and armband. Those tested in the gym utilized cardio machines such as treadmills and exercise bikes, while others were asked to jog in place in the absence of exercise machines. The aerobic tests typically lasted 3-5 minutes in duration.

After participating in the aerobic and anaerobic exercises, the users were asked to rate the timeliness and accuracy of the system (see Table 4) using criteria such as whether the system output repetition feedback too slow or too fast, whether the system was properly issuing motivation when the user was struggling and whether the system was detecting all of the repetitions. Users were asked to rank each category using a 1 to 5 scale with 5=outstanding and 1=poor.

Table 4: Timeliness and Accuracy rating

Category / **Group**	Mode	Timeliness	Accuracy
Boomer	Anaerobic	4.10±1.10	4.48±.850
	Aerobic	4.29±.588	4.35±.606
Student	Anaerobic	4.20±1.06	4.10±1.07
	Aerobic	4.27±.961	4.53±.640
Health Club	Anaerobic	4.50±.645	4.42±.641
	Aerobic	4.46±.660	4.54±.519
ROTC	Anaerobic	4.60±.516	4.44±.882
	Aerobic	4.30±.483	4.20±.632
Average	Anaerobic	4.29±.923	4.34±.891
	Aerobic	4.33±.695	4.42±.599

The accuracy and timeliness results for the system were consistent between the four groups as shown in Table 4. The table lists each group's mean followed by the standard deviation. Those that submitted lower scores for the timeliness commented that the system was too slow outputting feedback. This would cause the user to wait for the system before starting the next repetition.

Users who performed the exercises at a very fast pace or irregularly (i.e. slow, fast, slow pace) caused the system to miscount repetitions and output motivation incorrectly based on the initial resting and active state as described earlier.

4.4 Non-intrusiveness and Wearability

Users rated the non-intrusiveness of the system and its wearability. Non-intrusiveness is the attention needed to follow the audio and music feedback prompts while exercising. Wearability is the body interference to exercise and perceived comfort to the person [4], [5]. Users placed the armband on the forearm, upper arm and ankle to evaluate how well the armband fit with different parts of the body during the tests.

Seven out of the 16 users that rated the wearability as fair or neutral (2 or 3) were less than 67 inches tall. A general criticism from this group is that the armband is too bulky or heavy to be placed on the forearm or ankle while performing the exercise.

Users giving a low non-intrusiveness rating did not prefer audio feedback. Visual feedback would be less intrusive to these users. Another reason is that the feedback was too frequent or distracting. Sixteen users gave the system a 3 or less for non-intrusiveness or wearability. A correlation exists between 'use in future' and 'overall value' as seen in Table 6. The accuracy ratings were also significantly lower for the group that indicating intrusiveness or low wearability.

Fifteen users considered themselves to be unfit. They valued the anaerobic and aerobic system higher than the fit group or those that use gyms. They had the highest rating for future use, suggesting that the system most benefits those who exercise infrequently.

Table 5: Non-intrusiveness and wearability rating

Category / Group	Mode	Non-intrusiveness	Wearability
Boomer	Anaerobic	4.35±.875	4.45±.945
	Aerobic	4.35±.996	4.65±.786
Student	Anaerobic	4.20±1.01	4.00±.918
	Aerobic	4.00±.926	4.13±.743
Health Club	Anaerobic	4.15±.689	4.50±.500
	Aerobic	4.35±.747	4.54±.519
ROTC	Anaerobic	4.50±.707	4.70±.483
	Aerobic	4.60±.516	4.70±.483
Average	Anaerobic	4.29±.851	4.36±.825
	Aerobic	4.30±.853	4.49±.691

Table 6: Overall value and use in future rating

Category / Group	Mode	Overall Value	Use in Future
Non-intrusiveness or Wearability ≤ 3	Anaerobic	3.15±1.14	2.69±1.60
	Aerobic	3.93±.616	3.43±1.60
Non-intrusiveness or Wearability > 3	Anaerobic	4.16±.717	4.27±1.06
	Aerobic	4.39±.782	4.39±1.04

4.5 Group Overall Value

The four user groups valued both the anaerobic and aerobic system differently. The aerobic system scored higher for all the groups except for the ROTC group as shown in Figure 8.

Comments from the ROTC group suggest that the system would be most beneficial for those in remedial training (behind in physical shape). A strong emphasis is placed on reaching standard requirements such as a targeted number of push-ups, sit-ups and other exercises based on age. If these physical requirements are not met, the ROTC member would be forced out of the program. Thus the ROTC group valued the anaerobic system to help reach these standards more than the aerobic mode.

The two groups that valued both the anaerobic and aerobic systems the most were the health club and Baby Boomer group. Both groups highlighted the automatic record-keeping and system-suggested workout routine ability of the anaerobic system. Currently, health club members are forced to remember or write down information such as the exercise name, weight and number of repetitions for each set. This is done automatically by the PWC, improving workout efficiency.

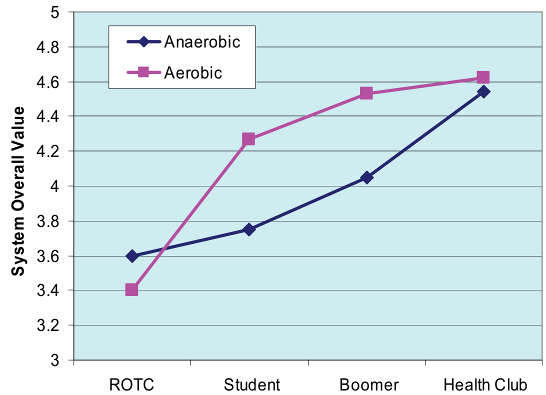

Figure 8: User group system overall value

Many users commented favorably on the active nature of the aerobic mode. The system audibly tells the user to speed up or slow down and encourages him to follow the pace of the music to enable the user to stay within his target heart zone.

4.6 Aerobic Competitor Comparison

The Polar A3 device uses the heart rate monitor to display real-time heart-rate data to a watch worn by the user. The initial user setup requires the user to enter in his birth data allowing the system to automatically set the target heart zone.

Tests were conducted with 12 students running outside, using treadmills or jogging in place. Carnegie Mellon students ranged from ages 21 to 26, heights ranged from 66” to 73”, fitness levels from not fit to fit, and all of them exercised at a gym at least once a week. The users were asked to evaluate the A3 device with the same criteria as the PWC aerobic mode.

The accuracy and timeliness ratings were similar for both the A3 watch and PWC aerobic mode, however the non-intrusiveness, overall value and use system in future ratings differed as shown in Table 7.

The A3 watch utilized both audio and visual feedback when the user was out of the target heart zone. Although users commented that the blinking and beeping was an effective notification method, it shortly became annoying. The students also monitored the watch for heart-rate information causing it to be intrusive. In comparison, the PWC aerobic mode utilizes music fluctuation and audio feedback such as telling the user to slow down or speed up when he/she is out of the target heart zone.

Table 7: Polar® A3 Watch and Personal Wellness Coach aerobic mode student comparison

Device \ Criteria	Non-intrusiveness	Overall Value	Use in Future
A3 Watch	2.83±.577	3.08±1.08	3.00±1.47
PWC Aerobic Mode	4.00±.926	4.27±.704	4.07±1.49

The aerobic mode's advantage is that it tells the user what to do rather than the user needing to first interpret his/her heart-rate and then decide whether to speed up or slow down. This allows the user to avoid having to look at the watch. Most users of the aerobic mode responded well to the music fluctuation giving a high overall value and high use in future ranking.

5. Conclusion

The Personal Wellness Coach is an interactive mobile wearable system that provides many of the advantages of a professional fitness trainer with the convenience of time and ease of use.

The anaerobic logic accurately counts and records repetition of various exercises, and motivates the user to reach their goals by identifying normal and struggling states. The aerobic logic uses a novel method to help the user maintain their heart rate target zone by modifying the music playback rate.

Field testing provided valuable user feedback. Users responded positively to the system and consider it to be beneficial to their exercise routine. The system demonstrates effective use of audio feedback where user's attention is very limited.

The aerobic mode for the PWC was evaluated against the A3 Watch. The watch was more intrusive to the users than the PWC's music fluctuation method. The results suggest that if users find the system intrusive, they are less inclined to use it in the future.

6. Future Work

A long-term exercise adherence study of the PWC used with and without a professional fitness trainer or phone coach could provide more concrete results on the overall benefits of the system.

Currently, the PWC does not monitor the user's nutrition or caloric expenditure. Extending the system to recommend nutrition, an exercise routine based on their nutritional intake and daily activities may further improve the system. For example, if a someone spends a day walking, the system may indicate that only one more mile is needed to meet a fitness goal.

Future work includes miniaturization of hardware necessary for data processing such as moving it to a PDA platform or all-in-one armband. Combining the heart rate monitor into the armband would be more comfortable.

By integrating the PWC with ARIUS [6], which provides sophisticated unsupervised learning algorithms, the virtual coach can automatically differentiate each exercises and possibly detect incorrect or bad form.

The PWC can also be applied to the biomedical field. Tracking user vital stats, logging exercise data and aiding in the detection of overexertion could be used by hospitals and rehabilitation centers.

7. Acknowledgements

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