The Virtual Trainer: Supervising Movements Through a Wearable Wireless Sensor Network

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I. Introduction

Recent technological advances in integrated circuits, wireless communications, and physiological sensing have boosted the development of miniaturized, lightweight, ultra-low power, intelligent monitoring devices. A number of these devices can be integrated to form a Wireless Body Area Network (WBAN), a wireless sensor network whose devices, called motes, are positioned on the body of a person to monitor biometric parameters and vital signs. To this extent, the latest advances in Mirco-Electro Mechanical Systems (MEMS) technology have opened up the opportunity to realize miniaturized accelerometers, a sensing element that measures acceleration.

These are the two main enabling technologies to realize a wearable system for computer assisted exercises for fitness and rehabilitation. Such system can help the user during the exercise providing him a feedback to avoid errors which can cause hurts. In fact, in many situations like home rehabilitation or fitness exercises, there cannot be a trainer who continuously supervises the user. As an example almost in every gym there is a trainer that teaches, the first time, how to do an exercise and next times the exercise is execute individually by the clients.

However, great care should be paid when performing fitness exercises, since a wrong execution can even damage muscles or articulations. In this case and in other situations like tele-monitoring or remote training can be useful to have an automatic system that controls movements to know if we are doing the exercise in the correct way or not. An interactive interface can also help user motivation in doing individual exercises, eventually turning the training or the rehabilitation session into a game.

There is a good deal of research and commercial products to identify, and recognize human movements with accelerometers [1], [2] for medical applications. Other systems monitor only the physical activity of a person to relate it with mobility reducing disorders such as osteoarthritis, obesity, stroke, chronic pulmonary disease, multiple sclerosis and Parkinsons disease [3], [4]. Moreover some simple system uses accelerometers to monitor elderly person detecting falls [5]. We claim here that WBANs geared with accelerometers can be used also for extracting quality features of the detected movements and/or exercise.

To this extent, the aim of the presented work is to showcase an integrated system to monitor execution of fitness and rehabilitation exercises and to provide a feedback to the user in order to correct errors and avoid hurts. The focus of our work is to analyze a simple fitness exercise like biceps curl by using a network of wireless sensors equipped with two-axes accelerometers. The sensed data from the acceleromenters is delivered to a PC which runs a graphical interface and a movement analyzer which returns in real-time the ”goodness” of the performed exercise. Moreover, the analyzer also generates a more accurate analysis of the exercise which is returned to the user upon completion of the movement.

To detect if repetitions of the selected exercise are done correctly we control the following features:

- To allow a relative release of tension in muscles between repetitions, the elbow must be kept fixed to the sides or at least should only travel forward slightly allowing forearm to be no more than vertical
- Every repetition should take about 6 seconds and movement should be fluid. In particular, to prevent hurts, the weight should not be dropped without control during the descent.

The implementation of effective systems for movement tracking and detection requires efforts in different fields; first of all, wearable sensor should be made as less intrusive as possible. To this extent, the dimension of the batteries, which are the biggest and heaviest component in commercial products, should be highly reduced. In turn, the energy consumption of WBAN should be limited. To this end, we implement in our system an energy-aware routing protocol which is optimized for biometric data collection. Another central requirement is to gather data in real-time and analyze them as quickly as possible.

The novelty of our work is to present a real and complete implementation of a wearable system for computer assisted rehabilitation and fitness exercises. We implement both the wireless network side software and the application software on the PC. On the network side we developed a robust and energy-efficient routing protocol with a small memory footprint based on the IEEE 802.15.4 standard. On the PC side we have also

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implemented the software application to collect data, evaluate execution and interact with the user.

II. System Description

In our solution we use Crossbow Micaz motes [6] equipped with a Crossbow MTS310 sensor board that provides a two-axes accelerometer [7] in order to monitor the movement of the arm. Two sensors are fixed on the wrist and on the elbow with elastic bands (fig. 1). A third sensor connected to a pc works as a gateway to collect data from the WBAN. The sensor fixed on the wrist allows us to detect the rise and descent of the weight, rather the device on the elbow controls the elbow's position during the exercise. We developed our network application under TinyOs [8], a free and open source component-based operating system for wireless embedded devices with reduced computation and memory capabilities. We further implemented a routing protocol, called *Personal Activity Monitoring - Low Energy Master Alternating protocol (PAM_LEMA)*, to reduce energy consumption, to avoid data losses and network failure. There are a large number of research papers dealing with energy-efficient protocol which share similar ideas as PAM_LEMA , for example LEACH [9]; however, all these protocol are usually developed for large-scale wireless sensor networks, instead our protocol is much simpler and specific for WBAN applications. All sensors within the WBAN are grouped in a cluster and one mote is elected as cluster head. Every mote sends its packets to the cluster head with low transmission power since all sensors, located on the body, are close enough. The cluster head receives all packets and forwards data to the gateway node with a higher transmission power because the distance between the two motes is usually greater than the distance between the other nodes. With this system the energy consumption of all nodes, except the cluster head, is reduced due to limited transmission power and reduced number of collisions. To spread the energy consumption among all nodes, the protocol schedules every 10 seconds a procedure of cluster head election during which a new cluster head is chosen in a random way: every node calculates a random number and sends it to the old cluster head, the mote that sends the largest number is chosen as the new cluster head. This election procedure is prone to error due to the unreliability of the wireless channel; for this reason, we foresee the usage of procedures to prevent network blocking states. For example if it is impossible, due to channel interference, for a period of time to advise a node about the address of the new cluster head, the network continues to work and when the node tries to send data to the old cluster head, it will be notified about the address of the new cluster head, thus updating the routing table.

We also implemented a Java application with a user-friendly graphical user interface (fig 2) where video is streamed showing a virtual trainer performing the exercise correctly and the user must follow him. We also supply feedbacks about execution in a colored text label. To give these feedbacks we constantly monitor the time elapsed between the beginning and the end of every repetition, the synchronization of the

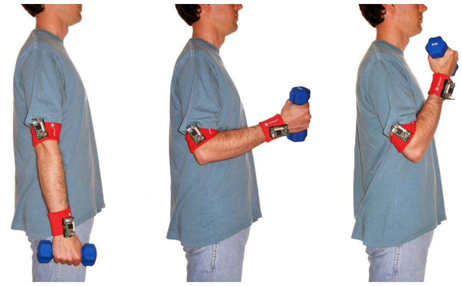
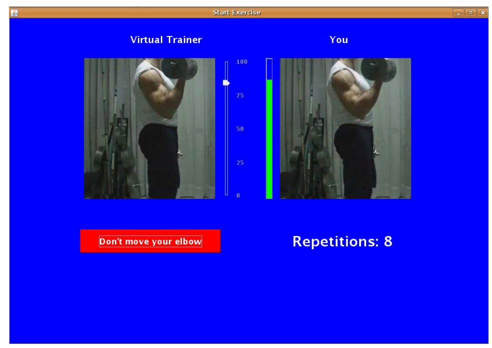


Fig. 1: A correct execution with the two sensor positioned on the arm



(a) Exercise window

(b) Score window

Fig. 2: User interface

user movement with the virtual trainer and the movement of the elbow. Analyzing the first parameter we can determine if the execution is too slow or too fast; in the first case the benefit of the exercise is reduced, in the second one it could be dangerous for the articulation. By monitoring synchronization of the movement between the user and virtual trainer, we can detect if the movement is not fluid and regular.

The elbow movement tells if the execution is correct or not. When one of these anomalous situations occurs a warning is displayed on the screen with a suggestion on how to correct the error. When the exercise is complete the system performs a more accurate evaluation of recorded data. In particular it analyzes the mean duration of repetitions and standard deviation to figure out if the speed of execution is correct and uniform during all the time. We experimentally observed that if a person is tired tends to slow down during execution. To detect if the movement is fluid the system also compares a preloaded data of a correct execution with the current recorded data. The comparison is done calculating the normalized Discrete Fourier Transform of the two signals and comparing the ratio between the first harmonic and the sum of the second and third ones. We found experimentally that this ratio remains almost constant in correct exercises and differs in irregular ones.

The last parameter measured is the number of times that the acceleration recorded on the elbow is over a fixed threshold to count the number of wrong repetitions. At the end a new window is shown to the user where he can see the scores obtained for every feature analyzed. These scores are calculated measuring the difference between the computed value and the same value of the preloaded exercise. Moreover a global score is calculated using a variable weighted mean of all single scores. We use a variable weighted mean because an execution where only the speed is out of range (for example is too fast) must be penalized also if the movement is correct because it could be anyway dangerous. To take into account this border line situations we chose to use a variable weighted mean where if only one parameter is too bad we increase its weight in the mean computation.

III. Demo Setup

The demonstration will show how our system works during an exercise to help users increasing their performance. During the demonstration, a user (most likely a conference attendee) wearing the two sensors on his arm, will perform the exercise. The person must stand in front of the PC running the visual interface which reports, on the left-hand side, a video of a virtual trainer correctly performing the exercise, and on the right-hand side the reconstructed movements of the current user. The entire exercise consists of a series of ten repetitions. During the execution real-time analysis is performed on a set of parameters to give an immediate feedback about major mistakes in order to let the performer correct them. Suggestions are visible in the text box under the virtual trainer image.

At the end of the exercise the system takes some seconds to calculate the score of the performance and then the user is prompted with a window reporting a detailed analysis of its exercise which can be useful to evaluate the execution.

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