Monitoring of Physical Activity

1. PURPOSE

Nowadays, the lifestyle in urbanized and industrialized countries is reducing the level of physical activity. There are studies of World Health Organization (WHO) [4] indicating that more than 60% of the global population is not sufficiently active. Many medical experts affirm that this physical inactivity is the cause of many cardiovascular and diabetic diseases, the metabolic syndrome [1]. In USA, some studies estimate 25% of the population suffers of metabolic syndrome.

Surely, change the day by day lifestyle represents the first step to improve the own quality of life: to increase the activity associated with a specific nutrition program could reduce hypertension, abnormal blood lipids and obesity. A middle-aged woman doing less than one hour of exercise per week doubles her of dying from a cardiovascular event compared to a physically active woman of the same age.

Recently, the American College of Sports Medicine (ACSM) has introduced some international guidelines[1] to redact a specific physical activity program. Any patient is checked up and monitored in order to receive a personalized Exercise Testing and Prescription (ETP). Since, the monitoring of the life style become crucial for the correct diagnosis of patients but, up to day is frequently associated with a simple questionnaire on the physical activity conducted, which is implicitly not reliable.

In this paper, the authors would introduce a new instrument able to monitor the basic parameter of the physical activity by implementing a recorder of the movements. The movements are recorded through an instrumented suit based on MEMS sensors and its results are correlated with the energy consumption (calories), the heart rate, and other parameters.

2. BACKGROUND

The healthcare expenses are increasing in all the countries, the main governments are facing with a growing request to prevent treatment before chronic and communicable diseases occurs. This is moving the population request to the so called “wellness and self empowerment of patients” [5]. Practically, the patient would choose the better own care with the support of their general practitioners and not the contrary as happens until some years ago.

Under this point of view many nongovernmental and independent organizations are studying prescriptions and guidelines for the patient’s wellness. One actor in this field is the American College of Sports Medicine (ACSM) with their specific physical activity programs. In fact, exercise has the capability to improve many aspects of health, yet national surveys have indicated that the general population is not exercising sufficiently for such benefits to accrue. Moreover, recent studies have proven that continuous feedbacks from trainers increase the person’s motivation to continue the exercise. Although, a one to one ratio between trainer and patient would be the optimum, it is not conceivable due to high cost of specialized people. The remote monitoring is the obvious solution to maintain a direct contact between trainers and people.

There are several technologies to achieve the remote monitoring of physical activities, such as optical or image-based looking the body movements from an external point of view or, such as mechanical, magnetic, acoustic, electronics gazing the movements with a suited system.

For example, optical motion capture systems are preferred in the computer-animation community, in the film industry and medical contexts. They offer a reliable and accurate way to record the motion of complex systems. But unfortunately this approach is expensive and has poor portability. In fact, these systems use 3D markers, such as light-emitting diodes, placed on the body. They compute the exact locations of the markers from the images recorded by the surrounding cameras using triangulation methods; therefore they can be used only in structured environments, for it`s impossible in the everyday life monitoring normal activity life gardening example people who are gardening Fig. 1. Image-based solutions use computer vision techniques to obtain motion parameters directly from video footage without using special markers, but these approaches are less accurate than optical systems.

Fig. 1: Gardening is an example where a monitoring through an optical method is not reliable.

Mechanical system techniques require wearable exoskeletons. In this case, there is a direct measurement of the joint angles (e.g., using electrical resistance), rather than an estimation of point positions on the body. However, exoskeletons can be uncomfortable to wear and the person is not totally free to move. Acoustic systems use the time-of-flight of an audio signal to compute the marker locations, but the directionality of the transmitters/receivers strongly affects the performance of the device. Moreover, magnetic systems have the drawback of managing a limited number of markers and of being sensitive to external magnetic fields.

A very promising frontier for wearable and reliable physical activity monitoring is based on Inertial Measurement Units (IMUs) that can be used virtually anywhere. Some commercial systems based on IMUs already exist on market; the pedometer is one example of that, it is based only on MEMS accelerometer sensor. However pedometer is not useful in activity that not imply walk (see Fig. 2), for example housework.

2 Kcal / minute 5 Kcal / minute 3 Kcal / minute

Fig. 2: Some examples of housework with the relative calories calculated for an overweight woman of 85 Kg.

Commercially, already exists some wearable systems to monitor human body movements, these provides a high level of performance in terms of accuracy, but these have only a niche market due to the high cost. To open these technologies to physically activity monitoring for lifestyle improvement, it is necessary to have a solution easily wearable and not so expensive.

3. The Monitoring Suite

The monitoring suite should be able to acquire all the parameters related to the physical activities (accelerations, angular rates, etc.) through a wearable self –contained system. This has to correlate the movements with energy consumption in order to make an evaluation of the metabolism, the nutrition, the lifestyle of the people.

The basic idea of the wearable suite is based on a track suit equipped with one Collector Unit (CU) and MEMS-based IMUs (Inertial measurement Unit) distributed throughout key points on human limbs.

Each of these IMUs is provided with a 32-bit RISC microcontroller (MCU) and miniaturized MEMS sensors: 3-axis accelerometer, 3-axis gyroscopes and 3-axis magnetometer. The MCU collects measurements from the sensors and implement the sensor fusion algorithm: a quaternion-based Extended Kalman Filter (EKF) to estimate the attitude and the gyroscope bias.

A fundamental aspect to correctly reconstruct physical activity through the human movement lies in the biomechanical model of the body, and its accuracy is reflected in the final results. Starting from a perfect biomechanical model of a human body, it may be possible to create a system [Fig 3] in which the IMUs are placed at fixed key points thanks to a dedicated suite or by using special elastic band. In this way, the reconstruction of movement, from the estimations of absolute orientations computed by the IMUs, is carried out using forward kinematic laws.

Each IMU is tasked with calculating the orientation and heading of one segment, and transfer this information to a Central Unit through wireless or wired communication. The CU collects the orientation data coming from the IMUs, computes the forward kinematics, and starting from the patient information make an elaboration of her/his status of physical activity.

Fig. 3: Architectures of the wearable solution.

To insecure wearability and comfort of the system particularly attention has to be placed in the choice of IMU modules, the iNEMO IMU fit very well these requirements. The INEMO-M1 System-on-Board [6] completely senses and assimilates linear acceleration, angular velocity, earth gravity and heading, enabling users to precisely detect their direction, orientation and movements in all three dimensions. The sensing accuracy can be further enhanced with the 32-bit processing unit capability to embed dedicated sensor-fusion software, integrating the outputs from all the sensors and employs sophisticated prediction and filtering algorithms to automatically correct measurement distortions and inaccuracies.

The overall system can be easily seen as a Surface-Mount Device (SMD) that features 28 pins in only 169 mm2. It means that in this, very small size, all the components are placed on the top layer and at its edges metalized areas realize the module pin out. In this way the module can be directly soldered in the user system as a single component.

As briefly sketched, the designed architecture is made up of a 32-bit microcontroller unit (MCU), a geomagnetic module (3-axis accelerometer and a 3-axis magnetometer) and a 3-axis gyroscope (Fig. 4). The microcontroller is a STM32F103 from STMicroelectronics and it features ARM Cortex M3 architecture [7]. This MCU has a maximum core frequency of 72 MHz, a computational capability of 1.25 DMIPS/MHz, 64 Kbyte of RAM and 512 Kbyte of flash memory.

The gyroscope is the L3G4200D (also from ST) [8], a 16-bit digital sensor with user-selectable full-scale and bandwidth: the former is between ±250°/s and ±2000º/s while the latter is between 100 Hz and 800 Hz. Its package form factor is 4x4x1.1 mm^3.

The geomagnetic module is the LSM303DLH (from ST) [9]. It unifies in a single tiny package (3x5x1 mm^3) both the accelerometer and the magnetometer: the former full-scale, user modifiable, is between ±2g and ±16g; the latter, also user-selectable, full-scale are between ±1.3 gauss and ±8.1 gauss.

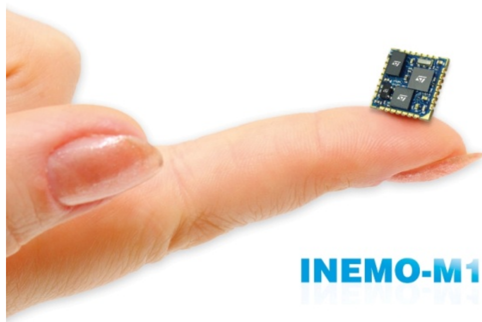

Fig. 4: The INEMO-M1 System on Board.

To monitor the full body movement the system has to be composed by several modules placed in the interesting points of human body. In its simplest implementation it counts 10 sensors: two per each limb plus two through the spine. Additional sensors could be mounted on wrist, ankles and head. All the modules are connected together trough a serial bus or a wireless star connection to the CU.

Embedded Software

The idea to combine digital processing and calibrated sensor measurements to provide an absolute orientation data to the host application processor is achieved through an Extended Kalman Filter (EKF) [10], running on the embedded MCU, that manages the smart sensor fusion to obtain the benefit of each sensor in orientation estimation. Even if the EKF theory is beyond the scope of this paper, it is useful to remark that its discrete time formulation try to estimate the state of a generic non-linear system from a system model and multiple noisy sensor measurements.

Its algorithmic procedure iterates through cycles and each of them can be easily divided in two main parts: prediction phase and correction phase.

As showed in [10], after the prediction phase updates the state using the model of the process, the output is corrected through the measures and Kalman gain computation.

The L3G4200D gyroscope measures are used for strap-down integration in the prediction phase while both accelerometer and magnetometer (LSM303DLHC) measures are used to compensate the angular-rate integration drift in the correction phase [11]. In particular the accelerometers provide an attitude reference using gravity acceleration projections while the magnetometers provide a heading reference using the earth's magnetic field vector.

The implemented filter is based on quaternion vector $q = [q_0, q_1, q_2, q_3]$ estimation and therefore they are part of state vector. The quaternion's formulation ensures, at the same time, the lack of representation singularities typical of Roll, Pitch and Yaw (RPY) based filters and an efficient mathematical framework. Nevertheless both rotation matrices notation and RPY orientation representation are internally computed and available as outputs.

It must be noticed that, without a filter structure and a sensor fusion algorithm, considering only separate independent measurements, as usually done in current application, the orientation data would easily be far from the true trajectory due to: noisy integration (typical of gyroscopes), low-pass filtering (accelerometer) and magnetic disturbances (compasses problems).

Furthermore, a dedicated care has been dedicated to reduce the influence of all the external disturbances due to external accelerations (i.e. different from gravity) and perturbing magnetic fields. In this way, the proposed physical activity monitor could be suite also in presence of mobile phone, tablet, or other electrical equipments which generally create unreliable a system based on electronic devices. In this way the individual sensor error is estimated dynamically from measures.

Efficiency

The system proposed is made around the INEMO-M1 SoB module, it permits to monitor the physical activity of people during their daily life and:

- help to manage the daily energy consumption, compare it to the objective suggested by the doctor or the trainer,
- aid to compare the energy consumption with the energy ingest through the diet,
- permit to person to choose when and where monitor the own movements, without the need to go in gymnasium,
- it is able to sense any movement, also the smallest ones connected to the daily activities such as: stay in office, homework, gardening, and so on,
- assists the self empowerment of the patient on her/his own level of daily physical activity,
- its reduced dimension (only 13 x 13 mm) and light weight (only 0.6 gr) facilitate the wearability from all the patients.

Moreover, its capability to be suited everywhere permits a correct analysis of patients with high reliability respect to the questionnaire or the monitoring only during the gym sections.

4. Conclusions

The evaluation of the spontaneous activity and the correlated life style represents a fundamental phase for personalized Exercise Testing and Prescription (ETP). The information coming from an objective analysis of the patient behavior during the day helps to educate and self empower the people on their activities and their capabilities. Moreover, thanks to a continuous monitoring of the spontaneous activity, it is possible to recommend the right corrections to the life style, in other words become possible to indicate the physical activity as a prescription.

The scientific results and the guideline of the American College of Sport Medicine demonstrate that using a physical activity monitor permits to improve shortly the parameters correlated with the cardiovascular and diabetic diseases.

Finally, it is also important highlight that these instruments are affordable both for the single users than for the public health organization.

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