A jerk threshold-based involuntary lateral movement algorithm

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Abstract

Algorithms for automatic fall detection are often studied in the field of ambulatory human health supervision. These algorithms are developed to generate hospital emergency alarms. In the present paper, Involuntary Lateral Movements (ILM) are presented. ILM are a premature sign of health deterioration. Therefore, this algorithm embedded in a sensor device could be used for continuous health monitoring in ambulatory situations.

Several studies show that human bodies try to minimize acceleration body movements, so they are based on minimum jerk. The proposed algorithm is based on a jerk threshold detection. In this work it is supposed that ILM will produce important jerk values above other daily movements, so that they can be distinguished using a threshold.

1. Introduction

Health services constantly face new challenges due to different factors, such as the increase of health care expenditure, socio-demographic changes, progressive aging of population (with the consequent appearance of new chronic diseases), etc. All these phenomena promote new hospital care specialized services beyond the traditional scheme of hospitalization.

Domiciliary hospitalization stands out among new forms of medical care. It is considered as a first step towards integral patient care in many diseases and in different moments of an illness. In these cases, health supervision using a tele-assistance system could be a complement to domiciliary hospitalization because it would allow a permanent supervision of the patient. In this sense, there is a lot of research on fall detection. These algorithms are used to trigger alarms to hospital emergency rooms.

In the present paper, Involuntary Lateral Movements (ILM) are studied since they denote changes in health status, an increase on the risk to fall down or they could simply be a premature sign of health deterioration. This supervision has to generate a history that will be analyzed by a medical center in order to make a future diagnostic.

The evaluated algorithm is based on a jerk threshold detection. Several studies demonstrate that movements in human body minimize acceleration changes [6] [1] and then they are based on minimum jerk theory. In this paper, it is supposed that involuntary movements will produce elevate jerk values, higher than the values produced in daily tasks, so they can be distinguished using a threshold.

The final goal is to combine the use of this algorithm with others that also evaluate inertial sensor outputs (mainly falls detection [2] [3] [8] and energy expenditure [4]) and with specifically medical sensors such as ECG, arterial pressure, heart rate, etc., building a complete health supervision architecture which would allow the patient evaluation anywhere and regardless of the task being carried out.

2. Involuntary lateral movement

We describe Involuntary Lateral Movements (ILM) as insecurities that subjects can suffer in a rehabilitation period, or elderly people by walking.

2.1. Methodology

The experiment has to allow the detection of ILM, with only an inertial sensor placed in a person.

In order to carry out the present research, it is used a MT9 Xsens which is a complete inertial measurement unit capable of providing 3D linear acceleration, 3D rate of turn and 3D magnetic field data. It has been chosen to perform the experimental analysis on MATLAB, which allows detecting and supervising the movements of a subject in real time (see Figure 1).

The followed methodology has consisted in implementing the jerk calculation algorithm in the three-axis and, in a first moment, to apply lateral movements onto the sensor itself, in order to establish a threshold and finally to detect it. Next, ILM have been applied on a single subject by analyzing the detection feasibility using a single inertial sensor, and studying the best location for this, i.e., performing experiments placing the sensor on the waist and the breast of a person.

The specific tests carried out are:

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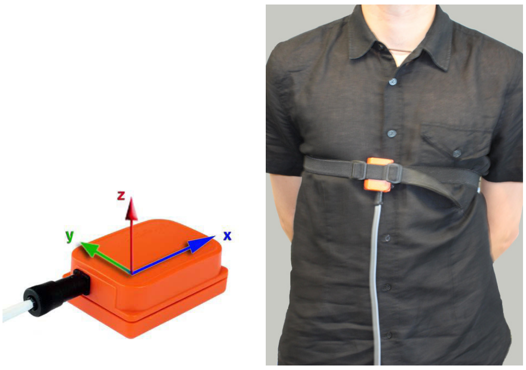

(a) Sensor coordinate system (b) Sensor position

Figure 1. Experimentation coordinate system.

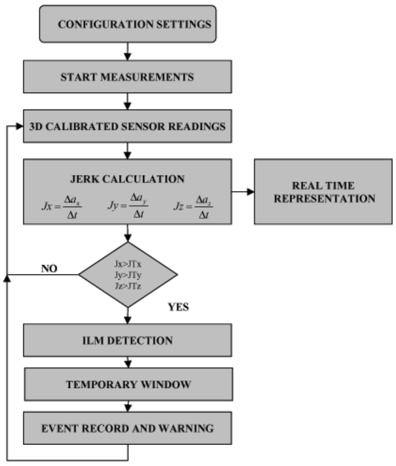

Figure 2. ILM detection flow diagram.

1. ***Experimentation 1: real ILM***

   30 seconds of experimentation carrying out movements every 5 seconds (at 5, 10, 15, 20 and 25 seconds)

2. ***Experimentation 2: chair stand up / sit down movements***

   45 seconds of experimentation carrying out movements every 5 seconds (at 5 seconds stand up, at 10 seconds sit down, at 15 seconds stand up, etc.)

3. ***Experimentation 3: sofa stand up / sit down movements***

   45 seconds of experimentation carrying out movements every 5 seconds (exactly the same procedure performed with the chair)

2.2. The implemented algorithm

The 3D accelerations from the sensor are used to calculate the derivatives in each axis. This calculation is performed on each sample and, also in each sample the acceleration and the derivatives are represented in real time and it is checked out if the derivatives' values overcome a certain threshold. Therefore, in the initialization, in addition to some specific settings of the sensor (sample rate, COM port, baudrate, data format, etc.), it is necessary to establish the jerk thresholds' values and a temporary window.

In case an ILM is detected, the algorithm is in charge of recording the time when the movement has occurred and a temporary window is applied in order to record only one movement, even though during that time period the derivatives of the acceleration overcome the thresholds at more than one occasion (see Figure 2).

2.3. Experimentation

The lateral movements that are carried out during the experimentation have to be similar to those that elderly people can suffer in their daily life. For this reason, besides trying not to make excessive movements (particularly easy to detect), free and lateral movements have been carried out and also forward movements (quite usual) and backward movements. In addition stand up and sit down movements from a chair and a sofa have been made in order to validate the robustness of the algorithm. Moreover, in the sitting case, the movement in its final moment has been made almost like dropping down (trying to replay the sit down movement of an elderly person). Walking and other daily tasks tests have also been carried out.

The sensor was placed at the height of the breast and the waist, checking the right fastening of the sensor.

Initially the jerk thresholds (JT) were set at some values that, in a preliminary investigation, previous to the methodological experimentation, it has been observed that they could approach the calibrated values $[m/s^3]$:

JTx=300;

JTy=100;

JTz=100;

Therefore, the experiments following the methodology described above will be used to set the final threshold values.

Taking into account that the experiment purpose is to detect lateral movements, but also forward and backward movements, it is considered that an ILM takes place when the following condition is satisfied:

$$ILM = \left(\left(\left| \frac{dax}{dt} \right| \geq JTx \right) AND \left(\left| \frac{day}{dt} \right| \geq JTy \right) \right)$$
$$OR \left(\left(\left| \frac{dax}{dt} \right| \geq JTx \right) AND \left(\left| \frac{daz}{dt} \right| \geq JTz \right) \right)$$

3. Results

The Figure 3 shows experimental graphics corresponding to the methodology described above and placing the sensor on the breast.

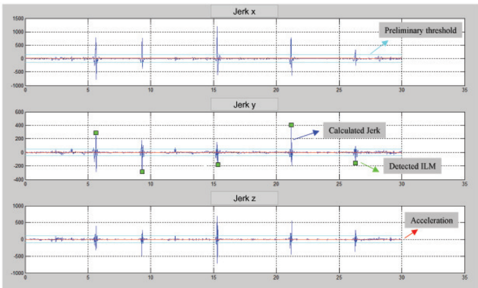

Figure 3. Experimentation 1 (real ILM)

The evaluated algorithm allows the ILM detection because it produces high values of jerk that are distinguishable from other daily movements.

Taking into account that the purpose of the experimented algorithm is the ILM detection, a priori it seems a good option to place the sensor at the height of the breast. We have seen that the jerk values produced in this case are quite higher than those produced when the sensor is located on the waist. Anyway, as expected, high jerk values are also detected in other daily activities such as sitting on a chair. Therefore, problems appear when the purpose is to distinguish between these movements and the others, which can also produce important changes in the acceleration, such as sitting down.

After evaluating the acceleration derivatives values in the movements made when sitting on a sofa and on a chair, it is observed that the impact produces the highest values. Consequently, the sitting on the chair movement is the one that produces the peak.

The question is whether it is possible to find a threshold to ensure the distinction between these usual actions.

The tests carried out with the sensor placed on the waist show that the minimum values of ILM can be higher than the maximum values in the actions of sitting (on a chair as well as on a sofa).

Consequently, it is determined that the best location in the case of working with a single sensor is the breast.

The axis with the smallest gap for the distinction between sitting on a chair and an ILM is the vertical one (x-axis). Then, even though initially the use of the x-axis derivative was considered, because it had been observed in the previous tests that this derivative was significantly affected by an ILM, as a result of a more accurate analysis, it is determined to do it without. It seems even more coherent with the fact of wanting to detect lateral movements (to the side, i.e., y-axis, and forward, i.e., z-axis). Therefore, the formula presented before would be simplified in the following way:

$$ILM = \left(\left|\frac{day}{dt}\right| \geq JTy\right) OR \left(\left|\frac{daz}{dt}\right| \geq JTz\right)$$

The threshold is set halfway between the minimum jerk that we want to detect if an ILM occurs and the maximum value produced by the action of sitting down, placing the sensor on the breast. It is shown in Figure 4.

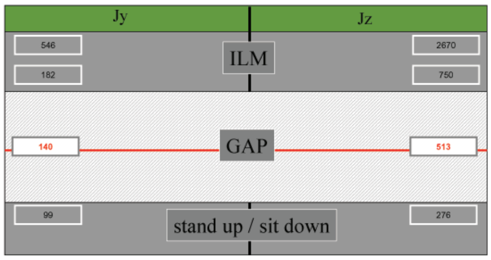

Figure 4. Threshold setting.

The Table 1 contains the proposed threshold values:

JTx	–
JTy	140
JTz	513

Table 1. Jerk threshold values

4. Conclusions

The proposed algorithm has been checked out for the detection of ILM by carrying out tests placing the sensor in different parts of the body and performing various daily movements, especially those that are considered critical movements, and trying that they approach the real movements of elderly people, thus validating its robustness. That is, to many elderly people the act of sitting on a chair implies a less controlled movement than to younger people, so the formers can produce higher accelerations.

The first results are satisfactory. Anyway, as explained in the future work, it is necessary to carry out the experiment in a representative sample.

To check the reliability of the algorithm, as it has been tested in this study, it is interesting that the algorithm does not detect false ILM if the subject carries out usual actions like sitting on a chair or on a sofa. It is less severe that a fall generates a false ILM, because in itself, the usefulness of ILM is the premature detection of health deterioration and, the act of falling down, is even a more critical sign. It would be more severe that a sudden movement generates a false fall alarm.

Anyway it is necessary to remember that there are studies that claim the detection of falls and other daily activities with a reliability of 100%, then, considering that the implemented algorithm only aims to detect ILM, it is possible to combine the developed algorithm with other existing ones. In addition, other studies are not based on jerk calculation but on information directly generated by the sensor (angular velocity or acceleration). Thus, a priori the combination of both of them would not be incompatible.

It is also important to say that the research carried out in this study has been made using a single sensor and it is only based on a threshold detection. Therefore, if the results of combining the implemented algorithm with other ones -also based on thresholds- are still not optimal, more alternatives could be studied, such as using more sensors or implementing other algorithms not only based on thresholds.

As regards the use of several sensors, the idea of accelerometers is to place them where it is wanted to detect the movement. So it is clear that the movement of sitting down is easily detectable by placing sensors in the corners of legs and arms [9].

In the case of implementing an algorithm that uses other techniques not based on thresholds, it is important to say that when heterogeneous tasks are carried out, the resulting jerk signal varies beyond the generation of different thresholds' values. That is, an ILM generates a jerk signal similar to an impulse. However, the act of sitting down is a slow movement, even though there is an impact in its final itinerary due to not having a total body control.

If the proposed solutions in this paper were not sufficient, it is clear that there would be other possibilities that can make this distinction among tasks. For example, performing a temporal or frequency signal analysis and, of course, using a Neural Network.

5. Future work

At the present point, in which an algorithm that allows the ILM detection is achieved, it is necessary to check its validity in a representative group of people.

In order to carry out this assessment, it is expected to do an essay based on laboratory experiments with different subjects and then evaluate their effectiveness on elderly people. Moreover, it is important that this experimentation is carried out under some medical supervision to ensure that simulated movements are really similar to the real ones expected to be detected on elderly people under supervision.

The ultimate goal is to build a health supervision architecture in which the implemented algorithm runs together with other algorithms that also evaluate inertial sensor output (in order to detect falls and estimate energy expenditure) and to obtain data from other medical sensors.

The aim is to create an architecture as described in [7]. Therefore, there will be several sensors distributed on the body of the person that will communicate with a personal server, a PDA, using a wireless Personal Area Network (PAN). The PDA will choose the appropriate service depending on the importance of the information to transmit. Namely, if an emergency occurs (such as a fall), an SMS will be directly sent to the emergency medical services. Otherwise, if a report information is sent (containing for example the occurred ILM report), this information will be collected on a Home Web Server using a wireless Local Area Network (WLAN). This home server will be connected with the servers belonging to the medical centers, eventually in order to perform a medical analysis.

Although the communications system proposed in [5] puts emphasis on its scalability and redundancy, it is interesting because the server is built exclusively on open source technologies (JBoss Application Server and MySQL database) and the server receives real-time data from the sensors using Java Message Service (JMS) protocol.

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