Monitoring and Localization of Intervention Agents in Special Applications based on BSN

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Abstract: - During hazardous activities, continuous human motion monitoring can be a step forward towards increased safety standards. Many situations bring people like firefighters, soldiers or policemen inside indoor spaces where different factors may put their life at risk. The paper presents a multilevel sensor network architecture to monitor the movement of people in indoor spaces with poor visibility and aggressive environment (like fire smoke) and do not allow the use of video systems in good condition. Data collected from the accelerometers (components of primary network nodes) are analyzed in order to detect the distances traveled, the type of movement, activity, falls. For analysis and validation were used commercial accelerometers and relay nodes. Attempts were made with different sampling frequencies and positioning. The experimental results show the possibility of remaking the road map or the positioning inside a building with several levels. The system architecture (femtocell type) allows embedding sensors in protective equipment and wireless local communication.

Key-Words: - dead reckoning, activity recognition, motion recognition, local filer, body sensor network, accelerometer, monitoring, localization.

1 Introduction

Recent development in sensing technology brings a large variety of sensors into human activities. More often we hear about continuous health monitoring and body sensors based on wireless technology. These may act as a full time companion keeping track of different parameters without interfering with the daily human activities.

Thanks to the advanced MEMS (Micro Electro Mechanical Systems) accelerometers we now have at our disposal high frequency, high fidelity, three axis acceleration measurements.

Human body movement investigation has become more convenient after the discovery of accelerometers. First researches using accelerometers began in the 1950s. Still, more than 60 years ago accelerometers were very expensive, had a very large size and were unstable. All these facts were great obstacles for the wide employment in the early stages.

As technology has advanced, accelerometers have become less noisy [1], but in the same time, their price, dimensions and energy requirements are now significantly reduced, making them affordable to be employed in large scale monitoring systems. MEMS technology is now known mostly as part of the smartphone industry which benefits from its capabilities making their applications more interesting, user friendly and intuitive.

The discoveries in intelligent low power sensors and integrated circuits opened the way to the creation of Wireless Body Area Networks (WBAN). WBANs can be described as a gathering of low power, miniaturized and lightweight wireless sensor nodes with the role of monitoring human body parameters or the ambient environment. At the moment, WBANs have a great variety of applications in different domains like entertainment, healthcare or military.

As the market has showed a great interest and need in WBANs, a lot of research has been concentrated in healthcare solutions. WBANs can continuously acquire a lot of information from a large variety of sensors, for a long period. This is a very important fact because having a person’s body parameter values can be

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a valuable indicator in detecting and preventing a lot of medical problems.

As a conclusion, WBANs combined with a user friendly interface represent a very powerful tool in preventing a person's current and future illness.

2 Requirements and solutions for special indoor applications of tracking and localization

2.1 Indoor tracking and localization in special cases

The present paper proposes a solution using wireless sensor networks for monitoring and localizing in hostile environments. By hostile environments we understand places that have low or non visibility, caused by different issues like smoke or dust. Also, this hostile environment does not contain the possibility of having a wired infrastructure for communications. Therefore, wireless sensors represent the best approach in offering an accurate solution for tracking and localization. On the other hand, GPS localization is not possible due to the hard environmental situations (like large concrete walls). In addition, in environments where high temperatures, smoke, dust and steam are present, the cameras and the ultrasonic sensors do not perform well.

Thus, the only solution is the use of accelerometers. An accelerometer will be attached to each person that moves in this environment. The accelerometer is physically included in the protective equipment and functional in a network of sensors that is attached to the person. This network has a specific ID and represents a node in the global network. This way, one can identify that the received data is from the correct person.

By interpreting the gathered data, all the actions done by the specialized persons involved in the incident can be analyzed. So, fall detecting can be recognized and the required actions are finally taken.

Every person is considered as a node of the global wireless sensor network (femtocel). Another requirement is that every node of the network can communicate with the closest node. This way, a multi-hop network is created. There are multiple advantages for this multi-hop approach: the distance that the sensor has to communicate the date is greatly reduces and energy consumption is smaller than in the case where all sensors communicate only with the gateway.

2.2 Application context

The proposed sensor network architecture is based on an embedded system employing accelerometers, gyroscope, compass sensors and wireless capabilities. It is considered the case of firefighters entering a potentially hazardous indoor location. During his mission, there is no possibility for the other firefighters to know one's status and location, except for the direct voice communication.

But under extreme circumstances, it is easy to get lost even for a trained and experienced professional. Even more, unexpected situations may change the entire context in a split second, making voice based communication an inconvenient tool for this task. In those moments when time is crucial and help is needed, knowing the location of a potential injured person and its' behavior can make a big difference.

By wearing an accelerometer based wireless tracking system, gathered data can be sent to a central processing unit in real time. This can recreate the person's track assessing the location in a 3D environment at every moment. In addition to this, the system can assess the behavior and body position of the monitored person.

If something wrong happens, help can be directed to the known location and the potential injuries can be largely anticipated based on the body position. This might be extremely helpful in order to choose the needed first aid materials and extrication tools.

Therefore, the system reduces the needed time which is necessary to find a potentially wounded victim and helps assess the needed materials in order to save her.

Because the wireless channel can handle more than the amount of data gathered by the accelerometer sensors, real time data from other sensors like thermometers or gas sensors can also be sent to the incident management center. This kind of data can help assess more accurately the situation around the person wearing the device, and can even trigger an alert if the conditions are becoming life threatening.

In order to withstand the harsh operating conditions, a special case should protect the sensors from the surrounding environment. In the special case of gas sensors, the protection layer should enable the admission of a direct flow of air without becoming a weak point in the human protective clothing.

2.3 Related work

One of the most important branches of accelerometer based applications is the human activity monitoring systems. The large majority of these systems are intended to help physicians monitor patients' behavior over long periods of time. Some of these applications and their characteristics are presented in [2], [3] and [4].

Using accelerometers for localization purposes is another interesting application. This tracking method is known as "dead reckoning" because of its' possibility to rebuild one's track based only on the initial starting position and accelerometer data.

Its' importance has been stressed by the possibility to track movement in indoor locations where other methods as GPS, signal trilateration or fingerprinting can't be employed as mines, tunnels, caves [5] or even large indoor areas or damaged buildings [6].

One way to implement it is by gait detection [7], [8]. Combined with NFC tags to recalibrate and assess the starting position and compass to detect the motion direction, this is a useful tool for tourists using smartphone in order to receive information based on their location [9].

Another way to track someone's motion is by using accelerometers and gyroscopes in order to assess their covered distance by double integration (odometry).

All these methods weak point is their accuracy over time which tends to rapidly decline. Equipment calibration and data processing increase the accuracy to a level which allows us to use these applications over longer periods of time without achieving catastrophic error margins.

In [10] the authors presented an approach to collaborative distributed mobile platforms to estimate different parameters in outdoor environment. Every platform contains an energy-aware module based on *Crossbow* technology able to acquire and transmit information about environmental parameters and location.

The main steps regarding accelerometer selection, data acquisition, feature selection, extraction and classification are reviewed in [11].

3 Indoor Activity Assessment and Tracking System

3.1 System architecture

System for tracking and monitoring environment, physiological parameters and localization uses the femtocell concept [12], [13] in a wider sense. It is considered like a local sensor network which offers services of measuring, monitoring or control, communication and has a short range wireless connection over a limited area. A femtocell contains intelligent sensor networks (ISNs) attached to persons and a management node. Each ISN has two sections: a body sensor network (BSN), inside the protective equipment, and an environment monitoring section (ASN), also attached to the equipment, acquiring data on the environment. Because sensor nodes have a short communication radius, each network has a router function to retransmit data from other networks to the management node. As is seen in Fig. 1, the proposed architecture is a multi-hop network of networks.

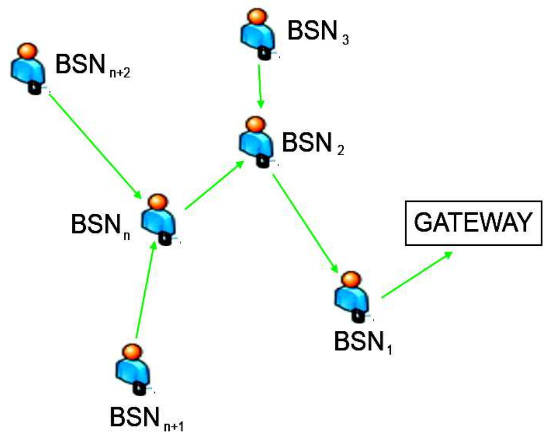

Fig.1. Architecture of the BSN section

Except for EKG, heart beat or arterial pressure sensors, all the BSNs contain accelerometers. Because of the sensor limitations regarding communication over large distances, it is absolutely mandatory that each node will communicate with the closest node. This way, data loss caused by long distance communication errors and intense energy consumption is avoided, making the whole network more reliable. In Fig. 1, every node represents a specialized person during an incident.

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The specialized person wears both ambient and body sensors. Therefore, inside a special designed vest there are the mentioned sensors (EKG, GSR, heart beat, temperature, humidity and the most important one for this paper, the accelerometer), and on the exterior part of the vest we have the sensors that monitor the ambient (like outside temperature, humidity, pressure, light, etc).

3.2 Node implementation

All the sensors are personalized and calibrated. This is very important when trying to road of the specialized person, because the length of a step is different among different persons. Therefore, an accelerometer should be assigned to only one person and calibrated according to the step's length. For this purpose an algorithm of learning/measuring is used (Fig. 2). Preprocessing phase consists of noise rejection, highlighting the extreme, thresholding, while the features refer to particular aspects of motion, activity characterization and falls.

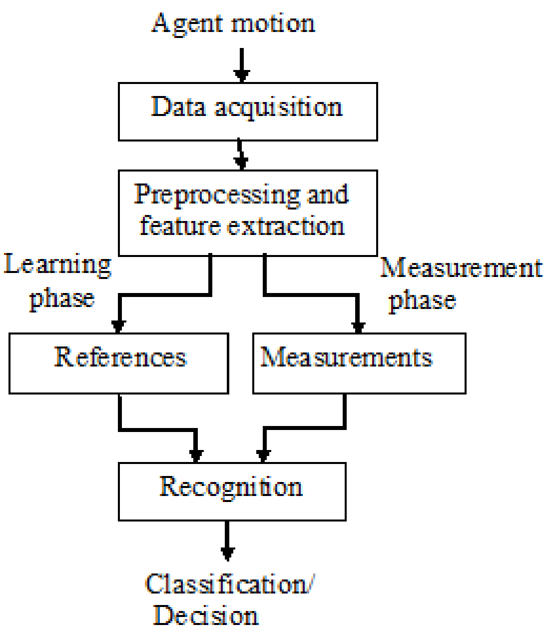


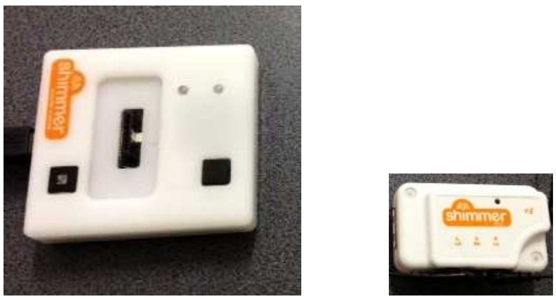
Fig.2. Calibration and measurement for accelerometer.

According to the idea that the vest contains sensor that monitor both the exterior and the person's status, the system can contain two different approaches:

The first approach is dedicated only to the ones that monitor the specialized persons that are in the first line of the incident. The accelerometers are vital for their main job, which is to recreate the steps of their colleagues that are in the first line and take decisions (in case a fall has been detected, it is mandatory that someone else will go and rescue the person in danger). Also, body temperature is a very important sensor as it allows the ones who monitor to prevent unfortunate events. It is very important that these back-end personal has a map of the place where the incident takes place. This way, the map can be loaded during the time spent to arrive at the location and the road that will be taken by the front-end specialized personal can have a highly improved accuracy.

The second approach is dedicated only to the persons situated in the first line of the incident. They are the ones that have to face the real danger, that is, why it is very important that some extremely important pieces of information are provided. A special designed set of glasses can be designed in order to show the specialized persons their temperature, the exterior temperature, their number of heart beats per minute, outside visibility percentage, smoke density or ambient humidity and pressure.

For experimental results it was used a Shimmer module [14]. Thus, Fig. 3 represents both the gateway of the Shimmer module and the accelerometer. Every front-end person has unique accelerometer (it is recommended that accelerometers are personalized in order to have a higher accuracy of the step's length). Every accelerometer has its own ID, assuring the validity of the received data.



a) b)

Fig. 3. Shimmer module: a) gateway, b) accelerometer.

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The Shimmer modules offer the possibility of having more sensors connected at the same time. As it can be seen in Fig. 4, this interface can be used in order to enable or disable different types of sensors and set the sampling rate, accelerometer range and GSR range.

Fig. 5 represents the MoteView interface used for receiving data from the sensors.

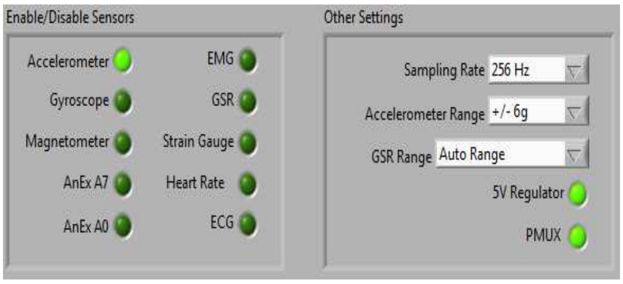

Fig. 4. Interface for sensor selection.

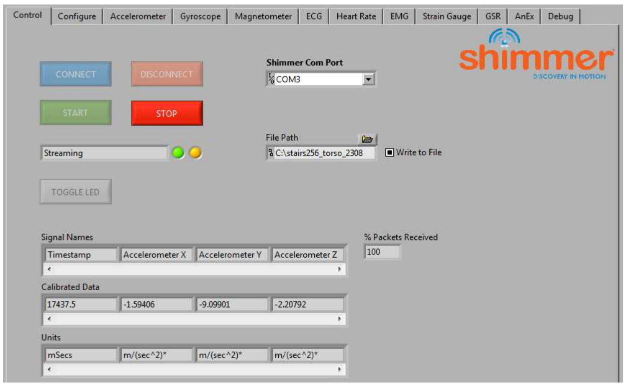

Fig. 5. Data sensor interface

3.3 Accelerometer signal processing and interpretation

In order to find the best approach, we tried two different dead reckoning localization methods.

The first method uses the algorithm presented in [9] in order to detect gait and assess the location by using four parameters:

- Starting location;
- Number of steps taken;
- Heading for each step;
- Calculated step length.

This approach is proved to be optimal when walking over limited distances in a classic environment, without any special features which would require other ways of movement (climbing stairs, crawling, jumping, etc.).

In Fig. 6 we can see how from every step can be plotted according to its' orientation and therefore we can track the movement of the person carrying the device.

For a more general approach, we try to use a method that covers every kind of human motion. Therefore we will use the double integration method in order to assess the displacement.

Using (1) and (2) formulas, we can assess the velocity and the distance by only having the accelerometer readings at our disposal.

$$\vec{v} = \int (\vec{a})dt \tag{1}$$

$$\vec{s} = \int \left(\int (\vec{a})\, dt \right) dt \tag{2}$$

Where:

- $\vec{a}$ is the acceleration vector;
- $\vec{v}$ is the calculated velocity;
- $\vec{s}$ is the covered distance;
- t is the difference time interval.

Using our acceleration samples, gathered by the tracking device, the (1) and (2) formulas can be translated into (3) and (4):

$$v_{n+1} = v_n + \frac{a_{n+1} + a_n}{2} \cdot T \tag{3}$$

$$d_{n+1} = d_n + \frac{v_{n+1} + v_n}{2} \cdot T \tag{4}$$

Where:

- T is the sampling period;
- a_n are the acceleration samples;
- v_n are the calculated velocity samples;
- d_n are the calculated displacement samples.

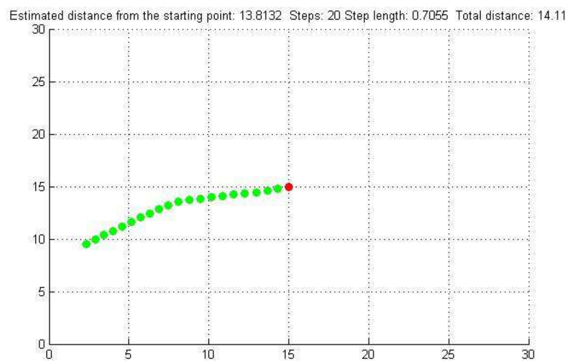

Fig.6. Gait detection based localization system

Using these formulas, we can simulate the displacement motion of a tracking device (Fig. 7).

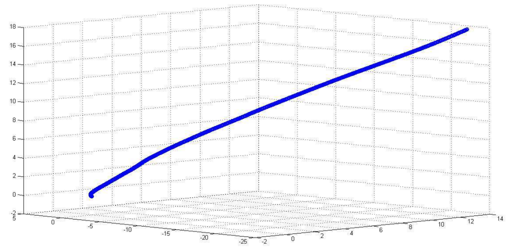

Fig.7. Calculated displacement based on 3D acceleration samples

This method provides a general approach towards dead reckoning localization, but it lacks precision. Therefore, a better sampling rate, better calibration and data filtering might make it more precise. On the other hand, an increasing value of sampling rate leads to loss of transmission data. Because of this, a compromise must be achieved on the sample rate. For example, in the case study presented in chapter 4, a sampling rate of 256 Hz was chosen.

Generally, the signal received from accelerometer is very noisy and, therefore, local filters are necessary.

Since noise rejection and edge preservation call conflicting operations, there is also a compromise on the choice of window size filtering. A larger filtering window removes more noise but reduces signal peaks which mark the shift (steps).

Also, the sampling rate of the signal influences the choice of window size. A higher rate allows the choice of large windows but it can cause losses of information packets.

If the sensor samples are S_k, then the local average $\mu_S(k)$ [15] and standard deviation $\sigma_S(k)$ [16], which are used in localization and tracking test are defined as (5) and, respectively, (6) and is calculated from n samples.

$$\mu_S(k) = \frac{1}{n}\sum_{i=0}^{n-1} S_{k-i} \qquad (5)$$

$$\sigma_S(k) = \sqrt{\frac{1}{n-1}\sum_{i=0}^{n-1}(S_{k-i} - \mu_S(k))^2} \qquad (6)$$

where the set $\{k-n+1, k-n+2, ..., k\}$ is the observation window, before the moment k, and $S_{k-1}, i = 0,1,..., n-1$ are the measurements (samples) inside the observation window.

4 Experimental results

The following experiment was conducted [Fig.8]: 20 steps were done on horizontal ground (A-B), afterwards 14 stairs were climbed (B-C), followed by 3 steps round-about (C-D) and finally 14 more stairs were climbed (D-E). The sensors were placed alternatively on the leg and torso, as presented in Fig. 9.

Charts presented in figures 10, 11, 12 and 13 represent these different approaches. In Fig. 10, accelerometer was positioned on the leg and the frequency of harvested data was set to 256 Hz. Due to the high frequency, as it can be seen, data communication errors exist, therefore using a lower frequency could be a better solution. A lower frequency was selected (51.2 Hz compared to 256Hz) in order to avoid data communication errors (Fig.11).

In Fig. 12, accelerometer was positioned on the torso. The used frequency was 51.2Hz in order to maintain better data interpretation.

Figure 13 was intended to simulate a real case scenario of running on the stairs, followed by a fall. In the last part of the signal the fall detection can be easily observed.

The tests were: identifying the horizontal portion (AB, CD, EF), identifying portions stairs (BC, DE) distances traveled on the horizontal portion, the number of stairs climbed / descended.

The experimental results were compared with real measurements (lengths, number of stairs). The matching rate was good (Table 1).

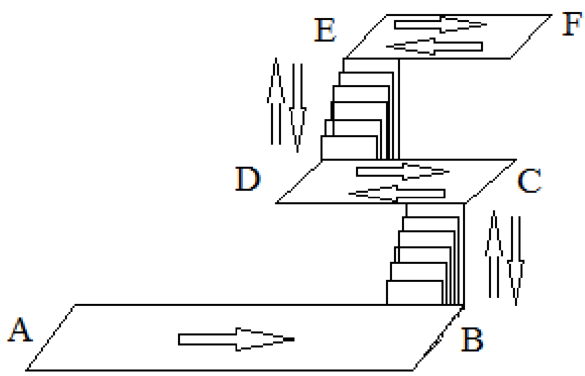

Fig. 8. Indoor test configuration.

a) b)

Fig. 9. Accelerometer placement: a) torso, b) leg

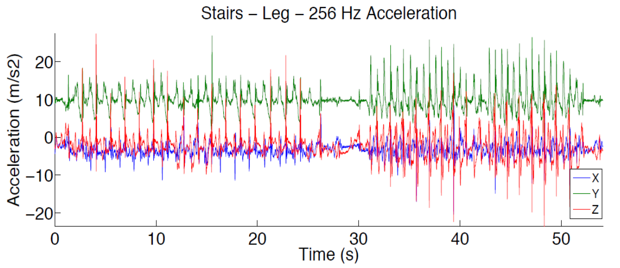

Fig. 10. Move horizontally and up stairs – leg – 256Hz

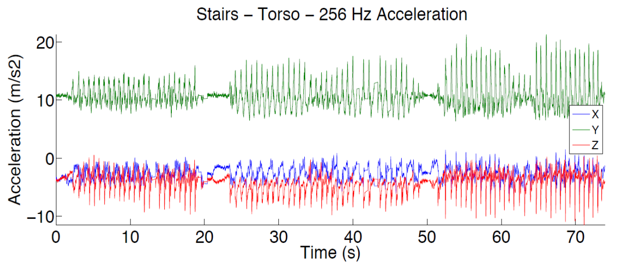

Fig. 11. Move horizontally and up and down stairs – torso – 256Hz.

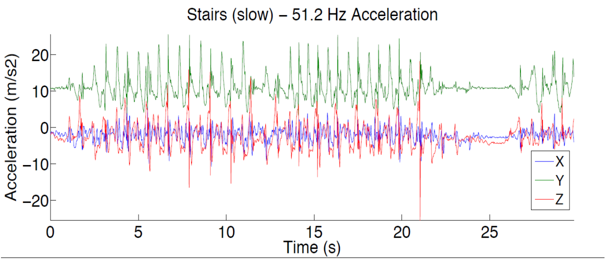

Fig.12. Move up stairs - 51.2 Hz

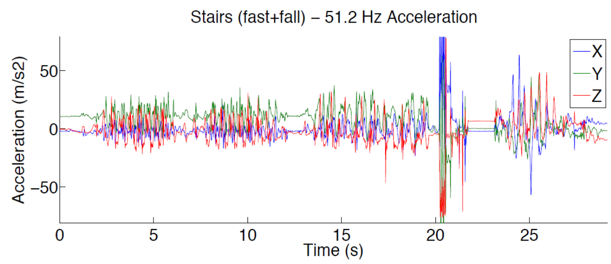

Fig. 13. Move up and down stairs (fast and fall) - 51.2 Hz

Table 1. Method efficiency.

Fig.	Route	Speed	Smpl. frecv.	Interpret.	Rate of rec.
10	A-B-C-D-E-F	low	256	High freq. Low speed Leg	95%
11	A-B-C-D-E-F-E-D-C-B	low	256	High freq. Low speed Torso	98%
12	B-C-D-E-F-E-D-C-B	low	51.2	Middle freq. Low speed Leg	98%
13	B-C-D-E-F-E-D-C-B	fast	51.2	High freq. High speed Leg Fall	85%

5 Conclusion

Using wearable sensors like accelerometers in femtocell applications, in order to gather data from persons involved in rescue indoor applications incidents, that take place in a hostile environment, can greatly improve the efficiency in localization and person tracking, and also decrease death risks. Choosing intelligent sampling rate and accelerometer placement in the protective equipment also leads to increased accuracy of location, possible falls and route tracking. The fact that outside/ inside equipment parameters like temperature, pressure/ heart rate, blood pressure and saturation, etc can be easily monitored by the same BSN (which contains the accelerometer) offers a great advantage in taking decisions that could save lives.

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