

A Personalized Fall Detection System for Older People

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Abstract—Recent developments and emergent technologies in medicine have improved life quality and increased life span, thus, caused a dramatic increase in the old adult population. This has increased the need for the care of the older people, particularly to deal with problems caused by advancing age, such as physical handicap and activity deficiencies. One of the most serious threats is falling, which can be fatal in the case of the older people who live alone. Several fall detection systems are in use, but there is a high need for a cost effective, compact and individualized system because of drawbacks in current versions, such as cost and privacy issues. We propose a tracking system which monitors people and detects falls using a personal device (a sports watch). The watch is strapped to the chest of the patient, and the 3-axis accelerometer data is used for real time fall detection. The system also allows for personal calibration to adapt to personal movement styles, such as dancing, walking and sleeping, therefore allowing a dramatic decrease in the amount of false fall alarms. In addition, the proposed system enables the monitoring of up to 1024 people in a same location using only one computer without cameras; hence, it avoids privacy problems in institutions, such as rest homes where cameras would be intrusive. An experimental study has been carried out to test the system with 40 participants of various ages and 2 mannequins. In the experiment, the system was calibrated separately for all individuals using their ADLs (Activity of Daily Life). The results showed approximately 85% accuracy in fall detection and 98% in false fall alarm reduction. Proposed system is very cost effective (less than \$50 for a patient) and able to detect falls with significant accuracy levels, and differentiate between the falls and other ADLs.

Keywords—older people tracking; fall detection; patient monitoring, telecare

I. INTRODUCTION

In the last century, dramatic improvements in technology and healthcare system have led to a significant increase in average lifespan and, therefore the number of older people worldwide. Figure 1 shows the average life expectancies in global population pyramid published by WHO (World Health Organization) [1]. This has caused an increase in needs stemming from old age, such as providing comfort and dealing with emergencies by tracking the movements of people.

The older people may be faced with situations which require emergency action and in which they require urgent assistance. One of the most serious situations is a fall, which

can be fatal for those with weakened bodies, and needs immediate attention for those living alone, the threat is much greater. In order to prevent these fatal situations, many old adults prefer to live with a carer (usually with a member of the family) or in a rest home.

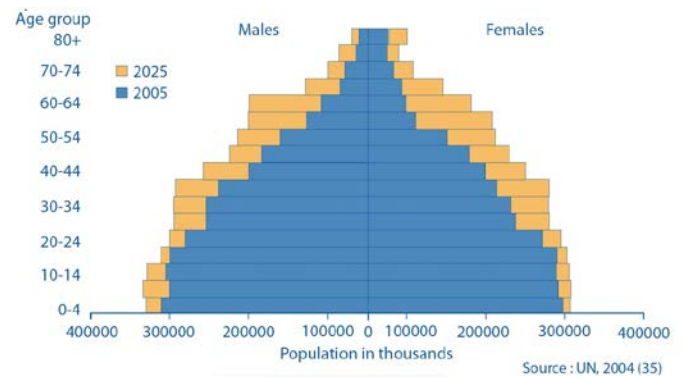


Fig. 1. Global population pyramid in 2005 and 2025 [1]

Moreover, the most widely used practices for the caring of older people are rest homes and personal carers (see for illustration in Figure 2). However, both of these have several disadvantages. In a rest home, the older person cannot be accompanied at all times, because the number of carers is limited and they can only help over limited periods, such as administering medication and invitation. A personal carer seems a good solution, however, it may be very costly, and still may not provide total supervision. Hence, there is still a need for a cost effective and easily applicable method for monitoring older people in emergency situations.



Fig. 2. An illustration of personal carers and resting homes

In this paper, we present a real time fall detection system. The system consists of software which helps to monitor daily life activities of the older people (usually patients), and a sports watch (ez430 Chronos), which sends data about the wearers' current position and action to the software. In brief, we aim to fulfill the requirement for a low cost and easily applicable fall detection system.

II. RELATED WORKS AND MOTIVATION

Although there are a number of fall detection systems currently described in the literature, a perfect solution has not yet been developed, and there are still several serious drawbacks in current systems, such as great cost, accuracy and privacy issues. Hence, there is still a great need for a low expensive, more secure and more accurate system, and this proposal intends to fulfill this requirement. In addition, several parameters, such as age, daily activities and abilities (walking speed etc.), are also very significant in fall detection. Each user has a different profile, so systems must be able to distinguish a fall from a normal movement such as sitting down for each profile. Such parameters are important for the accuracy of the system. Furthermore, systems also need to account for different physical abilities.

Fall detection systems which use cameras to track the actions of people require multiple cameras to cover all of the rooms, thus this increases the cost, and it may violate privacy (e.g. in bathrooms) [2, 3]. Another problem with cameras is the difficulty in keeping track of all the actions of an individual, in the case of more than one person in the same place. This reduces the accuracy of cameras, which need to recognize identified individuals.

Another group of fall detection systems use floor pressure and gravity sensors. These systems are very costly and likely to be inaccurate because of the requirement of using many sensors to cover all the living places [4]. Moreover, a System which uses 3D tags and ultrasonic sound receivers around the rest home room may be smart solution, however this requires redesign of the environment, and it may fail due to the reflections of the sound waves by walls [5].

Dinh et al. proposed a system consisting of a wearable device on the patient's chest with a gyroscope to collect data for the fall detection using an appropriate algorithm. However if the device's battery voltage decreased under +3.0V, the gyroscope stops working, and battery is only able to hold its power for 70 hours [6]. Furthermore, their system is not personalized; therefore fall detection accuracy is not as expected.

A current care monitor system which is commercially available uses movement detectors installed in a position where regular movement occurs. However, this approach only gives an alarm for the lack of regular movement or the presence of irregular movements, such as night wandering, therefore, in most cases a fall would not be detected until many hours after it occurred [7].

Two other commercially available older people care systems use sensors with accelerometers worn on a belt loop or attached to a pocket. These systems are able to detect falls and

distinguish a fall from daily life activities, but lack personal calibration (they cannot account for age and ability) and have very high costs [8, 9].

Another fall detection system uses a mobile phone, which uses the accelerometers of the mobile phone. However, this approach requires the patient to wear a mobile phone in a shirt with left side chest pocket with the phone facing in the correct position. This can raise health concerns, due to proximity to the patient's heart [10]. A system proposed by Chang et al., performs a similar action using a mobile phone and accelerometer, however, it has never been tested in case of unconsciousness patients [11].

In this paper, we propose an individualized system that uses a sport watch (with a price of less than \$50) strapped onto the patient's chest, and a computer with internet connection. Moreover, in the case of institutions, such as rest homes, a computer is enough to track more than one patient.

III. THE PROPOSED SYSTEM

The proposed system, GeTraSys (Geriatric Tracking System), is composed of a watch to detect falls and, a computer connected to the Internet, to store, interpret and transmit data to medical center. The system is a real-time tracking system which commonly monitors people (it can also be used to track children) and detects falls and movement anomalies using the sports watch with an appropriate algorithm embedded. If the system detects any anomaly on the body to which the watch is attached, it informs the medical centers about current status of that body, such as possible current position, amount of the time that the body has stayed in the same position. Figure 3 shows the infrastructure of the proposed system.

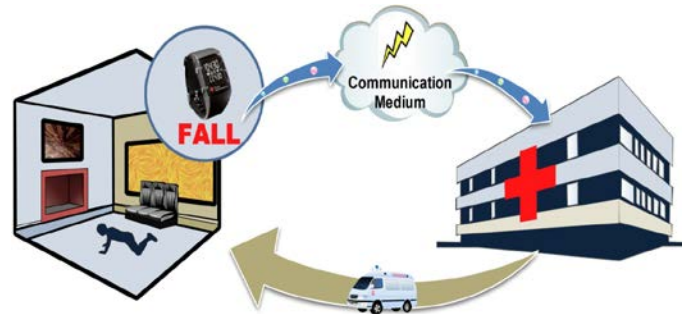


Fig. 3. The infrastructure of the proposed system

In the proposed system, a real-time fall detection is performed. When detected, a signal will be sent via a wireless transceiver embedded on the watch to the medical center or carer's PC or any device with an internet connection, such as mobile phone and smart devices. This real-time tracking and informing method enables the immediate notification of the related medical persons about the falls. Hence, because of the possibility of the person fallen being unconscious or unable to raise the alarm, an alarm is automatically triggered by a fall. Figure 4 shows the high level design and workflow of the system.

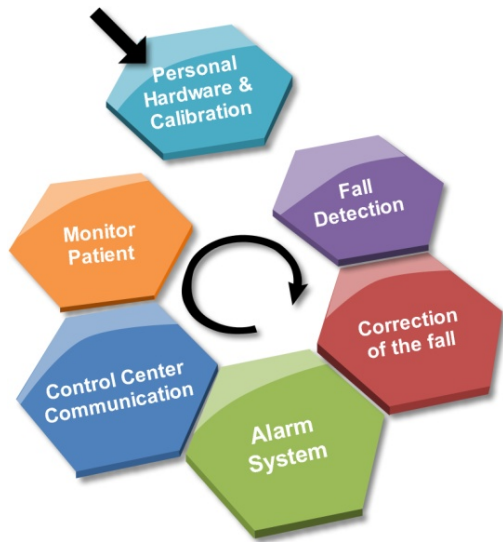


Fig. 4. High level design and workflow of the proposed system

The system workflow begins after the device (watch) is attached to the body and calibrated. If a fall is detected, a fall signal is sent to the main computer with all related data. If the signal verified, then an alarm actuator is stimulated. Then information about the alarm and current body status is sent form the computer to the control centre, usually a carer’s device or medical centre, which interprets the data and begins to monitor the body status.

A. Personal Hardware & Calibration

In this proposal, a sports watch (Ti-Chronos) is selected as the personal device (hardware) which is a highly integrated and wearable wireless development system that integrated into a fully functional sports watch. It has an ultra-low power microcontroller unit with integrated wireless transceiver. It includes a 3-axis accelerometer, pressure sensor, temperature sensor and a battery voltage sensor. In contrast, most current fall detection systems require cameras or at least one accelerometer or devices with high energy consumption, which are costly [11, 12, 13, 14, 15, 16].

This device connects to a PC via a USB-based wireless interface, and it can be reprogrammed with a custom application, either wirelessly or by disassembling and using a USB programming interface. The watch is a very compact device with low power usage, which is very comfortable to wear [17].

The watch is first strapped to the user’s chest (Figure 5), and the 3-axis accelerometer generates real-time data about body position. During the first day, the data generated is continuously collected and stored, and used for calibration and a threshold value for fall detection is determined. There is a danger that normal activities (ADL) can be mistakenly identified as falling, because of similar patterns of activities. Therefore, it is very important that all possible actions, including dancing walking and waking up, are identified in the calibration period. At the end of this period, the watch is ready for using as an individualized device for fall detection.

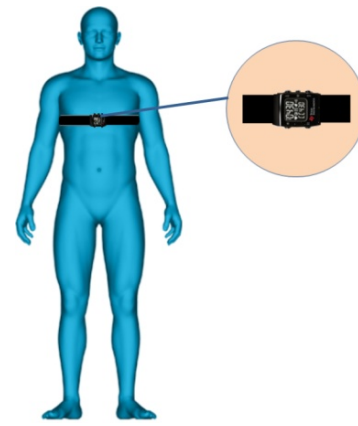


Fig. 5. The device with Chest Strap

B. Fall detection and Correction

Figure 6 shows several examples of possible fall actions’ directions and how the body moves in different axes.

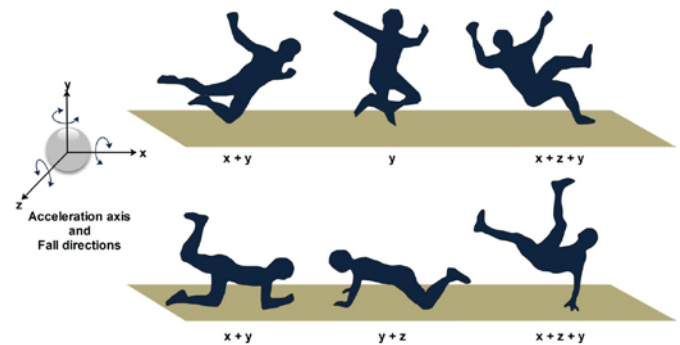


Fig. 6. Examples of possible fall patterns

In this study, a number of different fall scenarios and the possible changes in accelerometer data were identified. When the system is initiated, the data continuously generated by the accelerometer is tracked. An accelerometer reads data at a frequency of 13 – 15 times per second, and the last 20 differences between the accelerometer readings are stored in the watch memory. Every time the accelerometer data is read, the last 20 differences are checked to determine if more than 2 values are above the predetermined threshold value. In addition, it detects sudden changes in the 3 dimensional orientation of the watch, from the x, y and z values provided by the accelerometer. A detection of sudden changes in two axes (exceeding threshold value) that potentially match fall patterns previously identified causes, the axis data to be sent to the main computer. Figure 7 shows a sample fall data that is generated by an accelerometer [18].

The computer then checks the similarities between the fall data sent against previously recorded ADL data. If there is no match, a fall should be considered. Whereas a match indicates an ADL with no need to actuate an alarm situation.

If a fall is detected, there are three possibilities, depending on the action of the patient. First, if there is no fall (false alarm), the patient uses the cancel button to stop the alarm and inform the software of the false alarm. Second, if the patient

falls, but needs no help, another button is pressed to stop the alarm and inform the software, which is then notifies the doctor and carer. Finally, if the patient is unable to use button (this means a fall), an alarm is sent to the doctor and carers. Meanwhile, in all cases, the watch alarm is set off.

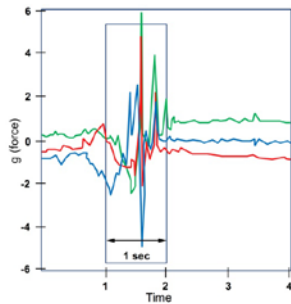


Fig. 7. A sample graph of a falling person [18]

Moreover, since the system allows for personal calibration to adapt to personal movement styles such as dancing, walking and sleeping, it results in a significant decrease in the amount of false fall alarms. In addition, the proposed system enables it to monitor up to 1024 people in the same location using only one computer, hence, it can efficiently be usable in rest-homes without the need for intrusive cameras.

C. The Application Software

The application is used to monitor patients. As mentioned, after the watch is calibrated for a patient, the fall detection algorithm is started, and the watch is connected to the application via the USB wireless access point. Figure 8 shows an example interface of the application.



Fig. 8. A screenshot of user interface of people monitoring system

The list on the left provides basic information about the patients, such as name, age and address. The color of the bar above each patient shows their current status as follows: Green, online, the patient is well; Grey, offline; Yellow, an event needing attention; Red, a fall needing immediate attention. An alarm sounds when a fall is detected (any of patients).

When selected from the list, detailed information about a patient is shown in the center of the interface, including the height, age, weight and history. This screen can also be used to edit and view the details and the medical records of the patient. Moreover, when an event occurs (such as a fall or low battery), a screen under the selected patient gives this information.

The map on the right side of the interface shows the address of the selected patient. A graph of x, y and z values can be seen below the map. However, due to the previously discussed performance related problems of sending the acceleration values, this feature is used only in a fall.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

In this study an experimental setup was designed, and the system tested on 16 participants (humans) with ages ranging from 21 to 55, and 2 Mannequin weighting 50kg and 80kg respectively. Tolkiehn et al. tested their systems on young people only, potentially resulting in a lower accuracy, therefore we add several older people in test [12]. The test was carried out 288 times with 11 main daily life activities and 10 different types of fall.

The tested daily life activities are: Sitting, lying down, dressing and undressing, showering, using the toilet, coughing, sneezing, shivering, slow dancing, washing the dishes and retrieving an object from the floor. The tested falling types simulated by the participants were based on directions: Forward, backward, to the left and right, and passing out. The older test subjects were requested to sit down quickly rather than fall due to health concerns. The thresholds in the test have been determined based on patients' own daily life activities. The test results are shown in Table 1.

TABLE I. EXPERIMENTAL RESULTS

No	Age	Gender	# of falls	Falls detected	Detection accuracy (%)
1	22	Male	10	6	60.00
2	22	Male	10	9	90.00
3	22	Male	10	5	50.00
4	24	Male	10	9	90.00
5	23	Male	10	5	50.00
6	22	Male	10	5	50.00
7	26	Male	10	7	70.00
8	25	Male	10	7	70.00
9	21	Female	10	3	30.00
10	50	Female	2	2	100.00
11	52	Male	2	2	100.00
12	22	Male	10	10	100.00
13	22	Male	10	8	80.00
14	21	Male	10	8	80.00
15	55	Female	2	2	100.00
16	51	Male	2	1	50.00
17	-	Mannequin (50kg)	80	76	95.00
18	-	Mannequin (80kg)	80	79	98.75
Total			288	244	84.72

The results show the overall accuracy of 84.72%, and overall false positive during ADL (false positive = the device captures a fall but it is a wrong detection) as 1.94%. Although the experiments revealed impressively accurate results, some of the participants' fall detection accuracy is lower than expected. Possible reasons for these inaccurate detections are as follows: It is difficult to record all possible daily behaviors (ADL) in a limited time period. Another issue is that the participants were anxious about a real fall, which can cause serious physical damage, and therefore, the deliberate falls that were recorded were unnatural, resulting in a lower fall detection accuracy.

For the young participants and mannequins, the fall detection ratio is 83.45% and the false positive during ADL is 1.89%, while for the older participants, these figures are 87.50% and 2.08%. The system has higher fall detection accuracy with the older, because they tend to have slower daily life activities compared to young people, and therefore have lower threshold values.

In this project, the firmware of the watch was modified because when a wireless connection is made with the device, the original firmware sends acceleration data (x, y, z values), and this causes many problems regarding performance when more than one watch is connected to a single USB access point. As the number of connected patients increase, the workload on both the PC and the access point rises dramatically. To overcome this problem a new fall detection algorithm was programmed onto the microprocessor (20 MHz) of the watch. Therefore, every watch independently performs real time fall detection and sends a signal wirelessly to a computer when a fall is detected. This system allows more than a thousand watches to be connected to one computer with a single USB access point. The workload of the computer is dramatically reduced by this wireless system, and also by the fact that data is sent as necessary rather than in continuous transmission. This results in lower overall computational load when compared to other fall detection systems (e.g. Goldfrey et.al. 2011) that use wearable devices.

Every watch is manually assigned a unique ID, which is paired with a patient. When a fall detection signal is sent from the watch, this ID is used to determine the identity of the patient. To adjust the sensitivity of the fall detection algorithm, we use a threshold value calculated in a calibration period. This is an innovative approach in this type of systems. The benefits of this system, which use thresholds that change according to patients to provide flexibility, more accurate detection and fewer false positives can be seen in contrast to constant threshold systems, such as that proposed by Raymond et.al, 2011.

We list possible advantages and drawbacks of the system as follows:

Advantages:

- The proposed system has a great advantage due to the personalized real time fall detection feature, which increases accuracy and reduces the number of false positives.

- The proposed system uses only one watch (device) per patient at a costs of less than 50\$, resulting in overall lower costs.
- The device is a very compact device with an ultra-low power microprocessor. Even with constant fall detection, the battery, which costs \$1.00, needs to be replaced only once a month.
- Every watch runs its own fall detection algorithm, and instead of a continuous data transmission, signals are sent either when a fall is detected or when an event of similar importance occurs. This allows a large number of patients to be connected to the system at the same time.
- The watch is responsible for most of the computational workload of the system. The watch sends only signals, which are received via a U SB wireless access point connected to the computer. Therefore, the software on the computer only processes signals from the watch, corrects the fall, and communicates with a server using the internet. This results in very low system requirements for the PC.
- The system uses only a w earable device without cameras or other devices which could raise privacy concerns. Therefore, the patient can use the system in places such as the bathroom, where other devices would be intrusive.

Drawbacks:

- Although, it is possible to monitor thousands of patients from one PC, due to the limited range of the wireless transceiver of the watch, 100 meters in an open environment but decreased when indoors, the maximum number of patients could be limited. Hence, several access points might be required for mass tracking.
- The system requires the watch to be strapped to the chest of the patient at all times. This could be a discomfort for patients unused to such a device. Therefore, for some patients, alternative positions should be considered, such as lower leg.

V. CONCLUSIONS

This proposal describes the design and application of a personalized fall detection system for older people using a sports watch. In addition, a real time algorithm with low computational workload was developed specifically to be executed on the watch, which can detect the moment of impact. Test results have shown that the algorithm is able to detect falls with significant accuracy levels (approximately 85%), and differentiate between the falls and other ADL. In addition, the system needs only a single computer with internet connection and one watch per patient, therefore, more than one thousand devices can connect to one PC simultaneously, making the system suitable for both rest- homes and personal use.

The proposed system is a very low cost and highly reliable system. It is easy to setup and use, and provides a simple method of monitoring multiple patients simultaneously. In

most cases, the wearable device causes no limitation of movement. Furthermore, no information that could violate privacy is available to others, so the system can be used without restrictions. Moreover, the system has potential to detect a range of movement disorders and anomalies meaning that a single device can be used for different purposes. For future work, expanding the system to monitor other health related functions, such as heart rate, can be considered.

REFERENCES

- [1] WHO: World Health Organization. "WHO Global Report on Falls Prevention in Older Age", World Health Organization, 2007 pp:4 [cited 2012 May 10]; Available from: http://www.who.int/ageing/publications/Falls_prevention7March.pdf
- [2] F. Cardile, G. Iannizzotto, F. La Rosa, "A vision-based system for elderly patients monitoring", In: Proceedings of 3rd Conference on Human System Interactions; 2010 May 13-15; Rzeszow, Poland; 2010. p. 195-202. DOI:10.1109/HSI.2010.5514566
- [3] Y. Miao, S.M. Naqvi, J. Chambers, "Fall detection in the elderly by head tracking", In: Proceedings of IEEE/SP 15th Workshop on Statistical Signal Processing (SSP'09); 2009 Aug 31 - Sep 3; Cardiff, United Kingdom; 2009. p. 357-60. DOI:10.1109/SSP.2009.5278653
- [4] J. Ho-Youl, S.H. Park, S.J. Park, "Detection abnormal pattern in activities of daily living using sequence alignment method", In: Proceedings of 30th Annual International Conference of the IEEE (EMBS 2008); 2008 Aug 20-25; Vancouver, Canada; 2008. p. 3320-23. DOI: 10.1109/IEMBS.2008.4649915
- [5] T. Hori, Y. Nishida, H. Aizawa, S. Murakami, H. Mizoguchi, "Sensor network for supporting elderly care home", In: Sensors, 2004. Proceedings of IEEE; 2004 Oct 24-27; Vienna – Austria; 2004. p. 575-78. DOI: 10.1109/ICSENS.2004.1426230
- [6] D. Anh, D. Teng, C. Li, S. Yang, C. McCrosky, J. Basran, V. Del Bello-Hass, "Implementation of a Physical Activity Monitoring System for the Elderly People with Built-in Vital Sign and Fall Detection", In: Information Technology: New Generations, 2009. ITNG '09. Sixth International Conference; 2009 Apr 27-29; Las Vegas – Nevada; 2009. p. 1226-231. DOI: 10.1109/ITNG.2009.60
- [7] SenCit. "Care Monitoring Device". 2012 [cited 2012 June 20]; Available from:<http://www.sendtech.co.uk/Sen-Cit/index.shtml>
- [8] Wellcore. "Wellcore Personal Emergency Response System With Automatic Fall Detection". 2012. [cited 2012 June 20]; Available from:<http://medical-alert-systems-review.toptenreviews.com/wellcore-emergency-response-system-review.html>
- [9] FreedomAlert. "Freedom Alert Newest DECT Model Personal 911 Emergency Response System". 2012 [cited 2012 June 20]; Available from:<http://www.medicalalert-911.com/>
- [10] M. Kaenampornpan, T. Anuchad, P. Supaluck, "Fall detection prototype for Thai elderly in mobile computing era", In: Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2011 8th International Conference; 2011 May 17-19; Khon Kaen – Thailand; 2011. p. 446-49. DOI: 10.1109/ECTICON.2011.5947871
- [11] S.Y. Chang, C.F. Lai, H.C.J. Chao, J.H. Park, Y.M. Huang, "An Environmental-Adaptive Fall Detection System on Mobile Device", Journal of Medical Systems. 2011, 35(5), pp:1299-312. DOI: 10.1007/s10916-011-9677-2
- [12] M. Tolkiehn, L. Atallah, B. Lo, G.Z. Yang, "Direction Sensitive Fall Detection Using a Triaxial Accelerometer and a Barometric Pressure Sensor", In: 33rd Annual International Conference of the IEEE Engineering-in-Medicine-and-Biology-Society (EMBS); 2011 Aug 30 – Sep 03; Boston – MA; 2011. p. 369-72. PMID: 22254325
- [13] E. Auvinet, F. Multon, A. Saint-Arnaud, J. Rousseau, J. Meunier, "Fall Detection With Multiple Cameras: An Occlusion-Resistant Method Based on 3-D Silhouette Vertical Distribution", IEEE Transaction on Information Technology in Biomedicine. 2011, 15(2), pp:290-300. DOI: 10.1109/TITB.2010.2087385
- [14] S. Khawandi, B. Daya, P. Chauvet, "Implementation of a Monitoring System for Fall Detection in Elderly Healthcare", Procedia Computer Science. 2010, 3, pp:216-20. DOI: 10.1016/j.procs.2010.12.036
- [15] A. Godfrey, A.K. Bourke, G.M. O'laighin, P. van de Ven, J. Nelson, "Activity classification using a single chest mounted tri-axial accelerometer. Medical Engineering & Physics", 2011, 33(9), pp:1127-35. PMID: 21636308
- [16] Y.W. Raymond, A. Lee, J. Carlisle, "Detection of Falls Using Accelerometers and Mobile Phone Technology", Age and Ageing. 2011, 40(6), pp:690-696. DOI: 10.1093/ageing/afr050
- [17] Texas Instruments. "Ti_Chronos". 2012 [cited 2012 June 20]; Available from:http://exosite.com/project/ti_chronos_pc_gateway
- [18] C. Park, J. Kim, J.C. Sohn, H.J. Choi, "A Wrist-Type Fall Detector with Statistical Classifier for the Elderly Care. KSII", Transactions on Internet and Information Systems. 2011, 5(10), pp:1751-69. DOI: 10.3837/tiis.2011.10.004