[1] C, T. & D, S. 2004. What are the main risk factors for falls among older people and

what are the most effective interventions to prevent these falls? Available in“http://www.

euro.who.int/\_\_data/assets/pdf\_file/0018/74700/E82552.pdf” by the World Health

Organization, Last Visited at 01-07-2011.

[2] Center for Disease Control, P., for Injury Prevention, N. C., & Control. 2010. Falls among

older adults. “http://www.cdc.gov/homeandrecreationalsafety/falls/adultfalls.

html”. Last Visited at 01-07-2011.

[3] Yoshida, S. 2007. A global report on falls prevention epidemiology of falls. Available

in“http://www.who.int/ageing/projects/1.Epidemiologyoffallsinolderage.

pdf” by the World Health Organization, Last Visited at 01-07-2011.

[4] Noury, N., Rumeau, P., Bourke, A., ÓLaighin, G., & Lundy, J. 2008. **A proposal for the classification and evaluation of fall detectors.** IRBM, 29(6), 340 – 349.

Offers a table of terminologies based on commercial fall detection products as well as experimental done by other research groups.

A second difficulty is the location of the sensor on the body relative to the point of impact. Depending on whether or not the sensor is near the point of impact, the signature of the signal recorded at the time of the shock can be significantly different, and it thus becomes more difficult to recognize a fall when it occurs, thus leading to a significant number of “false positives”.

[5] Charles Brown, Carol Lehtola, W. J. B. 2009. **Preventing injuries from slips, trips and falls.** Available in “http://edis.ifas.ufl.edu/as042” by the University of Florida, Last Visited at 01-07-2011.

[6] Stalenhoef, P. A., and. J André Knottnerus and. Luc P de Witteb, J. P. D., & Crebolder,

H. F. 2000. The construction of a patient record-based risk model for recurrent falls among

elderly people living in the community. Available in“http://fampra.oxfordjournals.

org/content/17/6/490.abstract” by Oxford University, Last Visited at 01-07-2011.

[7] Zhang, T., Wang, J., Liu, P., & Hou, J. 2006. **Fall detection by embedding an accelerometer in cellphone and using kfd algorithm.** In International Journal of Computer Science and Network Security, Vol. 6 no. 10 pp 227–284.

This group integrated a device with tri-axial accelerometer, a single chip modem, a MCU device and some other peripherals, to a cellphone. They used this for fall detection with the use of 1-class SVM for preprocessing the signals and KFD (Kernel Fisher Discriminant) and k-NN (Nearest Neighbor) algorithm for precise classification. They reported a 93.3% accuracy for a limited number of scenarios.

[8] Dai, J., Bai, X., Yang, Z., Shen, Z., & Xuan, D. 29 2010. Perfalld: **A pervasive fall detection**

**system using mobile phones.** In Pervasive Computing and Communications Workshops

(PERCOM Workshops), 2010 8th IEEE International Conference on.

Combining accelerometer with a microphone for audio sensing or magnetometer

3.1% false negative

7.7% false positive

[9] Li, Q., Stankovic, J., Hanson, M., Barth, A., Lach, J., & Zhou, G. 2009. **Accurate, fast fall**

**detection using gyroscopes and accelerometer-derived posture information.** In Wearable

and Implantable Body Sensor Networks, 2009. BSN 2009. Sixth International Workshop on,

138 –143.

Using several of the same sensors placed on different body location – thigh and trunk. They used 2 tri-axial accelerometers and gyroscopes on two different body parts.

Specificity – 92%

Sensitivity – 91%

[10] Bourke, A., van de Ven, P., Gamble, M., O’Connor, R., Murphy, K., Bogan, E., McQuade, E., Finucane, P., ÓLaighin, G., & Nelson, J. 2010. **Evaluation of waist-mounted tri-axial accelerometer based fall-detection algorithms during scripted and continuous unscripted activities.** Journal of Biomechanics, 43(15), 3051 – 3057.

Measures the falling-edge time and the rising edge time.

tfe is the time from when the RSS signal last goes below the LFT until it reaches the UFT

tre is the time from when the LFT is last exceeded until UFT is exceeded. This is always a subset and smaller than tfe.

[11] Yu, X. 2008. Approaches and principles of fall detection for elderly and patient. In e-health

Networking, Applications and Services, 2008. HealthCom 2008. 10th International Conference

on, 42 –47.

[12] Ng, S., Fakih, A., Fourney, A., Poupart, P., & Zelek, J. 2009. Towards a mobility diagnostic

tool: Tracking rollator users’ leg pose with a monocular vision system. In Engineering in

Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the

IEEE, 1220 –1225.

[13] Perry, J., Kellog, S., Vaidya, S., Youn, J.-H., Ali, H., & Sharif, H. 2009. Survey and evaluation

of real-time fall detection approaches. In High-Capacity Optical Networks and Enabling

Technologies (HONET), 2009 6th International Symposium on, 158 –164.

[14] Noury, N., Fleury, A., Rumeau, P., Bourke, A., Laighin, G., Rialle, V., & Lundy, J. 2007. **Fall detection - principles and methods.** In Engineering in Medicine and Biology Society, 2007. EMBS 2007. 29th Annual International Conference of the IEEE, 1663 –1666.

[15] Ketabdar, H. Detecting physical shock by a mobile phone and its applications in security

and emergency.

[16] Degen, T. & Jaeckel, H. 2003. **Speedy: a fall detector in a wrist watch.** In In Proceedings.

Seventh IEEE International Symposium on Wearable Computing, 184–189.

It is a wearable, acceleration-based device. The system measures velocity, shock and inactivity. First, a high velocity towards the ground has to be detected. Then, within 3 seconds an impact has to be detected, or the event will be discarded. After the impact the general activity will be observed for 60 seconds. If during this interval at least 40 seconds of inactivity are recorded, the system will generate an audible alarm. It only has a sensitivity (see sec 2.5) of 65%.

[17] Popescu, M., Li, Y., Skubic, M., & Rantz, M. 2008. **An acoustic fall detector system that**

**uses sound height information to reduce the false alarm rate.** In Engineering in Medicine

and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE,

4628 –4631.

The paper used an array of acoustic sensors aligned vertically, which is mounted on targeted places on the patient’s room (ambiance system). It has less false positives because it filters out some of the noise. Then height calculation is also involved to remove false alarms. The array of sensors compute the height of the sound produced. If the signal is computed to be less than two feet, it will be considered as a fall, and it will be sent for further analysis before finally stating that it is a fall. Even with the improvement added by using height computation, the false positive rate is still high. When tested, their system gave five false alarms per hour.

[18] Bourke, A. & Lyons, G. 2008. **A threshold-based fall-detection algorithm using a bi-axial**

**gyroscope sensor.** Medical Engineering Physics, 30(1), 84 – 90.

Angular-based (body angle/orientation, angular velocity and angular acceleration) approach using gyroscopes is also possible, although in practice this is usually done with combination of accelerometers. [18] uses a bi-axial gyroscope worn on the trunk of the user. Experimentally, it is one of the most successful fall detection system since it has a result of 100% specificity and 100% sensitivity (More about sensitivity and specificity in section 2.5). This is of course only measured under controlled environments with selected number of falls to simulate.

[19] Aud, M. A., Abbott, C. C., Tyrer, H. W., Neelgund, R. V., Shriniwar, U. G., Mohammed, A.,

& Devarakonda, K. K. 2010. **Smart carpet: Developing a sensor system to detect falls and**

**summon assistance.** J Gerontol Nurs, 36(7), 8–12.

Pressure Based Approach

[20] Alwan, M., Rajendran, P., Kell, S., Mack, D., Dalal, S., Wolfe, M., & Felder, R. 0 2006. **A**

**smart and passive floor-vibration based fall detector for elderly.** In Information and Communication

Technologies, 2006. ICTTA ’06. 2nd.

Vibration Based Approach

[21] A. Sixsmith, N. Johnson, & R. Whatmore. 2005. **Pyroelectric ir sensor arrays for fall**

**detection in the older population.** J. Phys. IV France, 128, 153–160.

Infrared (body-heat) Based Approach

[22] Bourke, A., O’Brien, J., & Lyons, G. 2007. **Evaluation of a threshold-based tri-axial accelerometer**

**fall detection algorithm.** Gait Posture, 26(2), 194 – 199.

Using several of the same sensors placed on different body location – thigh and trunk

Tested the Upper and Lower Fall Thresholds.

[23] Tzeng, H.-W., Chen, M.-Y., & Chen, J.-Y. 2010. **Design of fall detection system with floor pressure and infrared image.** In System Science and Engineering (ICSSE), 2010 International Conference on, 131 –135.

combining the use of infrared sensors and pressure sensor on the floor.

reliability – 90%

[24] Salomon, R., Luder, M., & Bieber, G. 29 2010-april 2 2010. **ifall - a new embedded system for the detection of unexpected falls.** In Pervasive Computing and Communications Workshops (PERCOM Workshops), 2010 8th IEEE International Conference on, 286 –291.

Combining accelerometers with air pressure sensor to sense the altitude of the device.

The iFall application has additional methods to reduce the

number of false positives. We allow the amplitude’s upper

threshold described in the ’Fall Detection’ section to be

variable. The application displays a small list of configuration

options when the phone’s *menu* key is pressed. One option

is to adjust the sensitivity, the capacity to detect a fall [17].

So the less sensitive, the higher the upper threshold is. Given

information such as age, weight, height, and level of activity

are also factored into the equation [15], [26].

To adapt for different carrying methods, we dynamically adjust the upper threshold and staring position.

[25] Mitja, L. & Bostjan, K. **Fall detection and recognition with machine learning.** Technical report, Jožef Stefan Institute, Department of Intelligent Systems, 2009. http://dis.ijs.si/mitjal/documents/Fall\_detection\_and\_activity\_recognition\_with\_machine\_learning-Informatica-09.pdf”, Last Visited at 01-07-2011.

A visual-based system. By using markers, they tag different points on the body and use these markers as reference points. They found that the reference points and the angles being formed between them is a very reliable data source for extracting features. Among the different machine learning algorithms, SVM (Support Vector Machine) was reported to have performed the best, followed by Random Forest.

[26] Ralhan, A. S. **A study on machine learning algorithms for fall detection and movement**

**classification.** Master’s thesis, University of Saskatchewan, “http://library2.usask.ca/

theses/available/etd-12222009-144628/”, 2009. Last Visited at 01-07-2011.

Comparing 5 different supervised learning methods for a fall detection system:

* Naive Bayesian Classifier – chosen as the best method in the end with a 93.3% accuracy
* Radial Basis Function (RBF)
* Support Vector Machine
* C4.5
* Ripple Down Rule Learner

[27] Caruana, R. & Niculescu-mizil, A. 2006. **An empirical comparison of supervised learning**

**algorithms.** In In Proc. 23 rd Intl. Conf. Machine learning (ICML06), 161–168.

[28] Caruana, R., Karampatziakis, N., & Yessenalina, A. 2008. **An empirical evaluation of supervised**

**learning in high dimensions.** In In International Conference on Machine Learning

(ICML), 96–103.

[29] Lindemann, U., Hock, A., Stuber, M., Keck, W., & Becker, C. 2005. Evaluation of a fall

detector based on accelerometers: a pilot study. Med Biol Eng Comput, 43(5), 548–51.

[30] Jantaraprim, P., Phukpattaranont, P., Limsakul, C., & Wongkittisuksa, B. may 2010. Improving

the accuracy of a fall detection algorithm using free fall characteristics. In Electrical

Engineering/Electronics Computer Telecommunications and Information Technology (ECTICON),

2010 International Conference on, 501 –504.

[31] Kangas, M., Konttila, A., Lindgren, P., Winblad, I., & Jämsä, T. 2008. Comparison of low complexity fall detection algorithms for body attached accelerometers. Gait Posture, 28(2), 285 – 291.

Uses velocity thresholds in three different types of algorithms.

1. checks for both impact and posture
2. uses LFT + UFT (w/in 1 second) or threshold based on Z2 + Monitoring of Posture.
3. uses LFT + threshold based on velocity + UFT (w/in 1 second) or threshold based on Z2 + Monitoring of Posture.

[32] Nguyen, T.-T., Cho, M.-C., & Lee, T.-S. sept. 2009. **Automatic fall detection using wearable biomedical signal measurement terminal.** In Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE, 5203 –5206.

Upper Lying Peak (ULP)

Lower Lying Peak(LLP)

[33] Salomon, R., Lux0308 andder, M., & Bieber, G. july 2010. ifall - case studies in unexpected

falls. In Industrial Electronics (ISIE), 2010 IEEE International Symposium on, 1645 –1650.

[34] 2011. Survival store. Available in “http://survivalstore.com/r6s15lcb2.html”, Last

Visited at 01-07-2011.

[35] 2011. Alert 1. Available in “http://www.alert-1.com/”, Last Visited at 01-07-2011.

[36] 2011. Hjelp 24. Available in “http://www.hjelp24.no/alarmsentral/”, Last Visited at

01-07-2011.

[37] 2011. Securitas. Available in “http://www.securitas.com/no/no/Kundesegmenter/

Helse-og-omsorg/”, Last Visited at 01-07-2011.

[38] 2011. ilife. Available in “http://www.ilifesolutions.com/products.html”, Last Visited

at 01-07-2011.

[39] 2011. Brickhouse. Available in “http://www.brickhousealert.com/howitworks.html”,

Last Visited at 01-07-2011.

[40] 2011. Seekwellness. Available in “http://www.seekwellness.com/LPs/fall-alarms.

htm”, Last Visited at 01-07-2011.

[41] 2011. Tunstall. Available in “http://www.tunstall.co.uk/Products-and-services/

Product-overview-”, Last Visited at 01-07-2011.

[42] 2011. Fall alert. Available in “http://www.macworld.com/appguide/app.html?id=

416637&expand=false”, Last Visited at 01-07-2011.

[43] 2011. Mover. Available in “http://www.androidzoom.com/android\_applications/

health/mover-m\_nly.html”, Last Visited at 01-07-2011.

[44] 2011. Cradar. Available in “http://actionxl.com/CRADAR.html”, Last Visited at 01-07-

2011.

[45] Boyle, J. & Karunanithi, M. 2008. Simulated fall detection via accelerometers. In Engineering

in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International

Conference of the IEEE, 1274 –1277.

[46] Lane, N., Miluzzo, E., Lu, H., Peebles, D., Choudhury, T., & Campbell, A. sept. 2010. A

survey of mobile phone sensing. Communications Magazine, IEEE, 48(9), 140 –150.

[47] 2011. Android. Available in “www.android.com”, Last Visited at 01-07-2011.

[48] Hansen, T. R., Eklund, J. M., Sprinkle, J., Bajcsy, R., & Sastry, S. 2005. Using smart sensors

and a camera phone to detect and verify the fall of elderly persons. In In European Medicine,

Biology and Engineering Conference.

[49] 2011. Oppenoffice:calc. Available in “http://www.openoffice.org/product/calc.

html”, Last Visited at 01-07-2011.

[50] 2011. Labview. Available in “http://www.ni.com/labview/whatis/”, Last Visited at 01-

07-2011.

[51] Bourke, A. K., O’Donovan, K. J., Nelson, J., & OLaighin, G. M. aug. 2008. Fall-detection

through vertical velocity thresholding using a tri-axial accelerometer characterized using

an optical motion-capture system. In Engineering in Medicine and Biology Society, 2008.

EMBS 2008. 30th Annual International Conference of the IEEE, 2832 –2835.

[52] Bourke, A., O’Donovan, K., & ÓLaighin, G. 2008. The identification of vertical velocity profiles

using an inertial sensor to investigate pre-impact detection of falls. Medical Engineering

Physics, 30(7), 937 – 946.

[53] B. Brown. An Acceleration Based Fall Detector: Development, Experimentation, and Analysis. Summer Undergraduate Program in Engineering Research at Berkeley (SUPERB), University of California, Berkeley, 2005. <http://www.eecs.berkeley.edu/~eklund/projects/Reports/GarrettFinalPaper.pdf>

*B. Pattern Recognition*

*1) Fall Patterns:* In many types of falls, the acceleration

seems to follow some type of pattern (see Fig. 14). This

pattern can be difficult to recognize, however, due to different

characteristics such as physical stature of the user, fall speed,

distance fallen, obstacles encountered during fall (see Fig. 15),

and ending orientation but there are still some accleration

schematics which may be consistent enough to establish a

satisfactory pattern.

*2) Non-Fall Patterns:* Beyond the realm of simply recognizing

fall acceleration patterns, there also seems to be

potential for establishing patterns to recongize other common

activities such as walking (see Fig. 16 and 17), sitting,

climbing stairs, etc.

With stringent transformation procedures and close analysis, it

is possible to eventually define transformation characteristics

specific enough to distinguish falls from nonfalls. This idea

could potentially lead to more defined observation and detection

algorithms and hopefully more accuracy in terms of fall

detection.

*2) Least Mean Squares Adaptive Learning Algorithm:*

Going beyond the analysis of magnitude-detection algorithms

discussed in this paper, there is a promising idea of using

an adaptive learning algorithm to begin constructing a pattern

recognizing fall-detection algorithm. As mentioned in the

results section, there does appear to be a pattern in a majority

of fall types. By using a strong analytical method, such as

the least mean squares method, we can sort of train a filter

to produce a given output from a given input. If we have

an input signal and a known intended output, such as a falldetected

signal, the algorithm uses a least-squares approach

to tune its own parameters such that it minimizes the error

between its processed output and the desired output. Across

several iterations, this should construct the filter such that it

will produce an intended output for any given input. In theory,

any type of fall then should have the basic pattern as our filter

was trained to recognize and should then produce a strong

correlation in pattern resemblence resuting in a fall-detection.

*3) Acceleration Correlative Movement Library:* Another

hopeful idea is that there will be enough room on the fall

sensor to begin a library of various actions. Eventually,

with enough analysis of various actions, the fall sensor may

eventually be able to go beyond simply detecting falls, but

also provide continuous monitoring on the user’s actions

and condition. A possibility for doing this takes the same

basic approach as the previous idea with the least means

squares adaptive algorithm. If enough data is processed into

separate initial filters, it may be possible to produce a filter

for recognizing not only a fall, but also other actions, such

as walking, running, sitting down, etc. Then, as data is read

in from a sensor on the user, it can be passed through all

the specific filters and its action then be designated by the

filter which provides the strongest pattern correlation, thereby

providing a means to monitor and predict a user’s actions with

a strong degree of certainty.

[54] S. Abbate, M. Avvenuti, G. Cola, P. Corsini, J. Light, and A. Vecchio. Recognition of False Alarms in Fall Detection Systems. CCNC, IEEE, Italy, 2011, pp. 23-28.

Fixed threshold approach: In this case a fixed kinematic

threshold is used to determine if a fall has happened. In [3]

the authors describe a system based on the magnitude of

acceleration values, while [2] presents a technique based on

measures of the angular velocity obtained from gyroscopes.

The critical issue in this approach is the definition of a proper

threshold: if the value is too high the system may miss some

real falls (sensitivity < 100%) but never generates false alarms

(100% specificity), while if the value is too low the system

successfully detects all actual falls (100% sensitivity) but, at

the same time, may generate some false alarms (specificity

< 100%). This happens because several ADLs, like little

jumps or fast sitting, are characterized by kinematic peaks

similar to those of real falls. Thus, the overall detection

accuracy of the system is a compromise between sensitivity

and specificity.