Limitations of the Use of Mobile Devices and Smart Environments for the Monitoring of Ageing People

Ivan Miguel Pires[1,2,3], Nuno M. Garcia[1,3,4], Nuno Pombo[1,3,4], and Francisco Flórez-Revuelta[5]

[1]*Instituto de Telecomunicações, Universidade da Beira Interior, Covilhã, Portugal*

[2]*Altranportugal, Lisbon, Portugal*

[3]*ALLab - Assisted Living Computing and Telecommunications Laboratory, Computer Science Department, Universidade da Beira Interior, Covilhã, Portugal*

[4]*Universidade Lusófona de Humanidades e Tecnologias, Lisbon, Portugal*

[5]*Department of Computer Technology, Universidad de Alicante, Spain*

impires@it.ubi.pt, {ngarcia, ngpombo}@di.ubi.pt, francisco.florez@ua.es

Keywords: Activities of Daily Living, Elderly People, Recognition, Mobile Devices, Smart Environments.

Abstract: The monitoring of the daily life of ageing people is a research topic widely explored by several authors, which they presented different points of view. The different research studies related to this topic have been performed with mobile devices and smart environments, combining the use of several sensors and techniques in order to handle the recognition of Activities of Daily Living (ADL) that may be used to monitor the lifestyle and improve the life's quality of the ageing people. However, the use of the mobile devices has several limitations, including the low power processing and the battery life. This paper presents some different points of view about the limitations, combining them with a research about use of a mobile application for the recognition of activities. At the end, we conclude that the use of lightweight methods with local processing in mobile devices is the best method to the recognition of the ADL of ageing people in order to present a fast feedback about their lifestyle. Finally, for the recognition of the activities in a restricted space with constant network connection, the use of smart environments is more reliable than the use of mobile devices.

1 INTRODUCTION

Over the last few years, research on recognizing activities using sensors available on technological devices is growing because of new techniques and new devices. Based on (He, Goodkind, and Kowal, 2016), the number of older people in the world is growing, with 8.5% of the people in the world being 65 or older, and technology can promote independent living, reduce solitude and isolation among other benefits (Age, 2010). The promotion of independent living may include recognition of the activities of the elderly using artificial intelligence methods in the day-to-day care systems of the elderly, health-related systems, social assistance systems, telecare systems, including Others (Age, 2010). Due to the increase in the number of elderly, the development of care systems is of great importance for improving the quality of life of older people (Jin, Simpkins, Ji, Leis, and Stambler, 2015), which is included in the development of the systems Ambient Assisted Living (AAL) and Enhanced Living Environments (ELE) systems (Botia, Villa, and Palma, 2012; Dobre, Mavromoustakis, Garcia, Goleva, and Mastorakis, 2016; Garcia, 2016; Garcia, Rodrigues, Elias, and Dias, 2014; Goleva et al., 2017; Huch et al., 2012; Siegel, Hochgatterer, and Dorner, 2014).

However, the development of these systems may have limitations in the recognition of the activities performed, including the positioning of the sensors in smart environments, the environmental noise, the implementation of the developed methods, the large number of activities performed by older people, the limited resources of the mobile devices, and other software and hardware limitations. This paper will explore this limitations and present the possible solutions for each limitations, finalizing with a real environment analysis of some limitations.

This paragraph finalizes the Section 1 of this paper, which introduces its topic. Section 2 presents the background of the recent development in this topic. Our view of this topic and the validation of the problem will be presented in the Section 3. Section 4 presents the discussion and results obtained. Finally, the conclusions of this study will be presented in the Section 5.

2 BACKGROUND

The monitoring of the activities performed by ageing people may be performed in controlled or uncontrolled environments. Firstly, the controlled environments considered in this study are the smart environments (*e.g.,* smart homes), where the ageing people are living, equipped with several sensors for the recognition of the activities. Finally, the uncontrolled environments considered in this study are the different environments in real life, using the mobile devices for the data acquisition and further recognition of the activities.

Smart environments used for the recognition of the activities performed by ageing people may be equipped with cameras, temperature sensors, altimeter sensors, accelerometer sensors, contact switches, pressure sensors and Radio-frequency identification (RFID) sensors. The recognition of the activities in these environments are performed using server-side processing methods. Botia et al. (2012) used the cameras for the recognition of the presence of the ageing people in home office, kitchen, living room and outdoor spaces, and several activities, including making coffee, walking on stairs and working on a computer.

In (Chernbumroong, Cang, Atkins, and Yu, 2013), the authors used the altimeter, accelerometer and temperature sensors for the recognition of brushing teeth, feeding, dressing, sleeping, walking, lying, ironing, walking on stairs, sweeping, washing dishes and watching TV. (Kasteren and Krose, 2007) implemented a method that used pressure sensors, accelerometer sensors and contact switches for the recognition of bathing, eating and toileting activities.

The accelerometers and RFID sensors may be used for the recognition of pushing a shopping cart, sitting, standing, walking, phone calling, taking picture, running, lying, wiping, switching on skin conditioner, hand shaking, reading, jumping and hair brushing activities (Hong, Kim, Ahn, and Kim, 2008).

Other studies making use of only one type of sensors available in smart environments. Firstly, other authors used only accelerometer for the recognition of making coffee, brushing teeth and boiling water activities (Liming, Hoey, Nugent, Cook, and Zhiwen, 2012). Secondly, other authors used only RFID sensors for the recognition of phone calling, preparing a tea, preparing a meal, making soft-boiled eggs, using the bathroom, taking out the trash, setting the table, eating, drinking, preparing orange juice, cleaning the table, cleaning a toilet, cleaning the kitchen, making coffee, sleeping, getting a drink, getting a snack, using a dishwasher, using a microwave, taking a shower, adjusting the thermostat, using a washing machine, using the toilet, vacuuming, leaving the house, reading, receiving a guest, boiling a pot of tea, doing laundry, boiling water, brushing hair, shaving face, washing hands, watching TV and brushing teeth activities (Cheng, Tsai, Liao, and Byeon, 2009; Danny, Matthai, and Tanzeem, 2005; Hoque and Stankovic, 2012). Finally, other authors used ZigBee wireless sensors for the recognition of watching TV, preparing a meal and preparing a tea activities (Suryadevara, Quazi, and Mukhopadhyay, 2012).

Related to the use of the data acquired from the mobile devices, the implemented methods for the recognition of activities may be implemented locally on the mobile devices as a mobile application or server-side, requiring a constant network connection. Another challenge in the use of the mobile devices for the recognition of activities is related to the positioning of the mobile device, that affects the reliability of the recognition methods. In addition, the use of these devices should be adapted to the hardware condition of these devices, such as limited processing, battery, and storage capabilities.

The most used sensor for the recognition of activities is the accelerometer sensor embedded in the mobile devices, enabling the recognition of several activities, including rowing, walking, walking on stairs, jumping, jogging, running, lying, standing, getting up, cycling, sitting, falling and travelling with different transportation facilities (Büber and Guvensan, 2014; Cardoso, Madureira, and Pereira, 2016; Ivascu, Cincar, Dinis, and Negru, 2017; Khalifa, Lan, Hassan, Seneviratne, and Das, 2017; Tsai, Yang, Shih, and Kung, 2015).

The combination of the data acquired from the accelerometer and the Global Positioning System (GPS) receiver embedded on the mobile devices can increase the number and accuracy of the recognition of activities, including the sitting, standing, walking, lying, walking on stairs, cycling, falling, jogging, running, playing football and rowing (Ermes, Parkka, Mantyjarvi, and Korhonen, 2008; Fortino, Gravina, and Russo, 2015; Zainudin, Sulaiman, Mustapha, and Perumal, 2015).

Table 1. Relation between the activities recognized in smart environments and with mobile devices.

Activities:	Smart Environments:	Mobile devices:
Adjusting the thermostat; brushing hair; cleaning a toilet; cleaning the kitchen; doing laundry; getting a drink; getting a snack; receiving a guest; setting the table; shaving face; taking a shower; taking out the trash; using a dishwasher; using a microwave; using a washing machine; vacuuming; washing hands; preparing orange juice; making soft-boiled eggs	RFID sensors	-
Bathing	pressure sensors; accelerometers; contact switches; RFID sensors	-
Boiling water; hair brushing; hand shaking; phone calling; pushing a shopping cart; switching on skin conditioner; taking picture; wiping	Accelerometer; RFID sensors	-
Brushing teeth; dressing; Feeding; washing dishes; Ironing; sweeping	Altimeter; Accelerometer; Temperature sensor	-
Cleaning the table	RFID sensors	Accelerometer; Microphone
Cooking; Driving; Shopping; Using a smartphone	-	Accelerometer; Microphone
Cycling	-	Accelerometer; Microphone; GPS receiver
Drinking; leaving the house	RFID sensors; Cameras	Accelerometer; Microphone; GPS receiver
Eating; toileting	pressure sensors; accelerometers; contact switches; RFID sensors; Cameras	Accelerometer; Microphone; GPS receiver
Falling; Jogging; Playing football; Rowing	-	Accelerometer; GPS receiver
Getting up; Travelling	-	Accelerometer
Jumping	Accelerometer; RFID sensors	accelerometer
Lying	Altimeter; Accelerometer; Temperature sensor	Accelerometer; GPS receiver
Making coffee	Cameras; Accelerometer; RFID sensors	-
Preparing a meal; preparing a tea	RFID sensors; ZigBee sensors	-
Reading	Accelerometer; RFID sensors	Accelerometer; Microphone
Running; Sitting; standing	Accelerometer; RFID sensors	Accelerometer; GPS receiver
Sleeping	Altimeter; Accelerometer; Temperature sensor; RFID sensors; Cameras	Accelerometer; Microphone; GPS receiver
Walking	Altimeter; Accelerometer; Temperature sensor; RFID sensors	Accelerometer; GPS receiver
Walking on stairs	Cameras; Altimeter; Accelerometer; Temperature sensor	Accelerometer; GPS receiver
Watching TV	Altimeter; Accelerometer; Temperature sensor; RFID sensors; ZigBee sensors	Accelerometer; Microphone
Using a computer	Cameras	Accelerometer; Microphone

The combination of the data acquired from the accelerometer and microphone embedded on mobile the mobile devices allows the recognition of cycling, cleaning table, shopping, toileting, cooking, watching TV, eating, working on a computer, reading, using a smartphone, driving, sleeping and nursing activities (Inoue, Ueda, Nohara, and Nakashima, 2015; Nishida, Kitaoka, and Takeda, 2014).

Finally, the combination of the sensors available in smart environments, *i.e.,* cameras and RFID sensors, and the sensors available in the mobile devices, *i.e.,* accelerometer, GPS receiver and microphone, may increase the accuracy of the recognition of activities, including leaving the house, toileting, sleeping, eating and drinking (Ordonez, de Toledo, and Sanchis, 2013).

Table 1 summarizes the activities recognized by sensors presented in this section as example of activities that may be recognized in smart environments and/or with mobile devices.

Regarding several studies (Alam, Reaz, and Ali, 2012; Arif, El Emary, and Koutsouris, 2014; Jakkula, 2007; Montoro-Manrique, Haya-Coll, and Schnelle-Walka; Poslad, 2011), the main problems using smart environments for the monitoring of the activities of ageing people are:

- The positioning of the sensors in the smart environment may affect the correct identification of the object, environment and/or people;
- The sensors should cooperate between them and, in case of fails, the system will return incorrect results;
- These environments require a constant connection to a server and, when the sensors fails, the activities are not recognized or have invalid results;
- The different number of sensors available may affect the recognition of the activities;
- Due to the use of distributed systems, the security and the resilience of the data is important for the recognition of the activities.

Regarding several studies (Arif et al., 2014; Bert, Giacometti, Gualano, and Siliquini, 2014; Choudhury et al., 2008; Montoro-Manrique et al.; Poslad, 2011; Santos et al., 2016), the main problems using the sensors available in mobile devices for the monitoring of the activities of ageing people are:

- The use of multiple sources for the data acquisition (*i.e.,* smartphone and smartwatch sensors) allows the acquisition of more physical and physiological parameters, but it required a constant connection by Bluetooth between them;
- The use of the sensors and the Bluetooth and/or Wi-Fi connection increases the speed of battery draining;
- The execution of the data processing in the mobile devices may decrease their performance;
- Due to the low resources of these devices, the accuracy of the sensors may not be constant during the data acquisition process;
- The user may not use their equipments in the correct placement during the data acquisition process;
- Some studies present methods that require a constant data connection for further processing of the data acquired;
- The different number of sensors embedded in the mobile devices may affect the recognition of the activities;
- Due to the use of multiple devices, the security and the resilience of the data is important for the recognition of the activities;
- Finally, the ageing people commonly do not use these devices and they needs a familiarization with these devices.

3 METHODS AND MATERIALS

For the research about the limitation of the use of mobile devices and smart environments technologies, we have discovered several limitations of these technologies in the regular use for the recognition of the daily activities of ageing people, but these limitations may be reduced with lightweight methods. Mainly, the limitations of the use of mobile devices are related to the low resources and the limitations of the use of smart environments are related to the positioning of the sensors.

Based in a mobile application that implements the framework described in (I. Pires, N. Garcia, N. Pombo, and F. Flórez-Revuelta, 2016; Pires, Garcia, and Flórez-Revuelta, 2015; I. M. Pires, N. M. Garcia, N. Pombo, and F. Flórez-Revuelta, 2016), we used the mobile application in four mobile devices (*i.e.,* Sony Ericsson Xperia Neo, Sony Ericsson Xperia Live Walkman, BQ Aquarius 5.7 and Samsung Galaxy J3) in order to verify the restrictions in the use of these applications, focusing on the speed of battery draining, the performance of the mobile devices during the use of the mobile application, and their adaptation to the number of sensors available in the mobile devices. This mobile application captures 5 seconds of the sensors' data every 5 minutes and processes the data acquired with machine learning methods for the recognition of the activities performed. During the performance of these experiments, the mobile devices are in use continuously with other tasks, including receiving and making calls and/or text messages, accessing to the Internet and others.

The recognition of the activities does not need a constant data acquisition and processing, and the use of a technique to enable and disable the acquisition and processing of the sensors' data over the time may reduce the effects in battery consumption and processing capabilities. The effects depending on number of sensors can be avoided with the construction of mobile applications with methods that should be a function of the number of sensors available at the moment of the data acquisition and processing. The unique limitation that is difficult to control is the positioning of the mobile devices related to the users' body, however it is possible to stop the data acquisition when the data seems to be inconsistent.

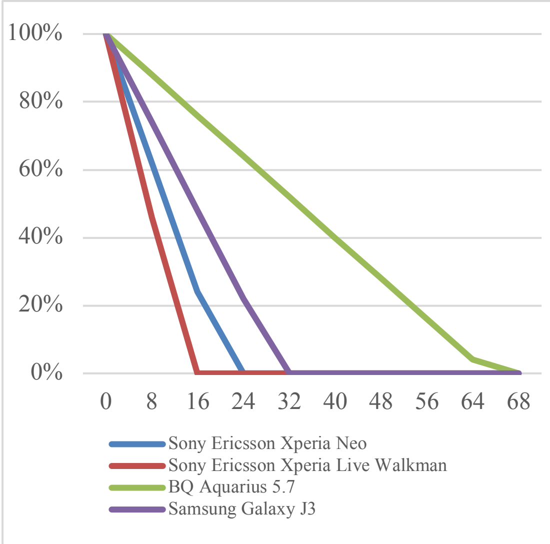

Figure 1. Battery Consumption using the mobile application for the recognition of activities. The horizontal axis represents the time between the fully charged and empty battery (h). The vertical axis represents the level of battery charge (%).

4 DISCUSSION AND RESULTS

Regarding the experiments performed, we verified that the performance of the mobile devices is only affected during the data acquisition and processing process. In general, the battery consumption is affected, as verified in the figure 1, but the minimum time between the fully charged and the empty battery (16 hours) was achieved with the Sony Ericsson Xperia Live Walkman (2011) that is an old device. The maximum performance and battery life was achieved with the BQ Aquarius 5.7 (2013) that is more recent than Sony Ericsson Xperia Live Walkman (2011), reporting approximately 68 hours of battery life.

As verified, our study confirms the findings that the data acquisition and process of the sensors' data affects the battery life and the power processing capabilities, but we verified that the minimum value is 16 hours of battery life. Thus, the recognition of activities using the mobile devices may be used, because currently these devices should receive a daily recharge. The different implementations of the methods can reduce this impact, and the methods that should be implemented in the mobile devices should be lightweight methods. The server-side processing and the use of multiple device for the data acquisition may have a lot of connectivity issues, needing a constant connection to the Internet or between devices. Regarding the use of the mobile devices, the more stable solution consists on the use of the local processing with methods that needs low resources. Finally, regarding the use of smart environments, the implementation of backup systems and more sensors in strategic placements may increase the reliability of these systems. However, the use of network connections should implement methods to minimize the security and privacy problems.

5 CONCLUSIONS

Currently, the use of the technological equipment is increasing with the ageing people to maintain the contact with other people and it may be used for the monitoring of the ageing people, promoting the well independent living.

This paper confirms that these devices have several restrictions. In the case of the use of smart environments, the main problems are related to the connectivity issues and positioning of the sensors. In case of the use of mobile devices, the problems are related to the low resources, the placement of the mobile device and the connectivity issues.

We performed some experiments with different devices for the recognition of activities using a mobile application with local processing methods, verifying that the battery drains with different speeds, between 16 and 68 hours. The performance is affected, but it is reduced acquiring a small window of sensors' data in every defined time interval.

The technology can promote the independent living of ageing people, helping in the emergency situations, controlling their lifestyle and increasing their life's quality.

ACKNOWLEDGEMENTS

This work was supported by FCT project **UID/EEA/50008/2013** (*Este trabalho foi suportado pelo projecto FCT UID/EEA/50008/2013*).

The authors would also like to acknowledge the contribution of the COST Action IC1303 – AAPELE – Architectures, Algorithms and Protocols for Enhanced Living Environments.

REFERENCES

Age, U. (2010). Technology and older people evidence review. *Age UK, London*.

Alam, M. R., Reaz, M. B. I., and Ali, M. A. M. (2012). A Review of Smart Homes—Past, Present, and Future. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 42*(6), 1190-1203. doi:10.1109/tsmcc.2012.2189204

Arif, M. J., El Emary, I. M., and Koutsouris, D. D. (2014). A review on the technologies and services used in the self-management of health and independent living of elderly. *Technol Health Care, 22*(5), 677-687. doi:10.3233/THC-140851

Bert, F., Giacometti, M., Gualano, M. R., and Siliquini, R. (2014). Smartphones and health promotion: a review of the evidence. *J Med Syst, 38*(1), 9995. doi:10.1007/s10916-013-9995-7

Botia, J. A., Villa, A., and Palma, J. (2012). Ambient Assisted Living system for in-home monitoring of healthy independent elders. *Expert Systems with Applications, 39*(9), 8136-8148. doi:10.1016/j.eswa.2012.01.153

Büber, E., and Guvensan, A. M. (2014, 21-24 April 2014). *Discriminative time-domain features for activity recognition on a mobile phone.* Paper presented at the 2014 IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP).

Cardoso, N., Madureira, J., and Pereira, N. (2016). Smartphone-based Transport Mode Detection for Elderly Care. *2016 Ieee 18th International Conference on E-Health Networking, Applications and Services (Healthcom)*, 261-266. doi:10.1109/HealthCom.2016.7749465

Cheng, B.-C., Tsai, Y.-A., Liao, G.-T., and Byeon, E.-S. (2009). HMM machine learning and inference for Activities of Daily Living recognition. *The Journal of Supercomputing, 54*(1), 29-42. doi:10.1007/s11227-009-0335-0

Chernbumroong, S., Cang, S., Atkins, A., and Yu, H. (2013). Elderly activities recognition and classification for applications in assisted living. *Expert Systems with Applications, 40*(5), 1662-1674. doi:10.1016/j.eswa.2012.09.004

Choudhury, T., Borriello, G., Consolvo, S., Haehnel, D., Harrison, B., Hemingway, B., . . . Wyatt, D. (2008). The Mobile Sensing Platform: An Embedded Activity Recognition System. *IEEE Pervasive Computing, 7*(2), 32-41. doi:10.1109/mprv.2008.39

Danny, W., Matthai, P., and Tanzeem, C. (2005). Unsupervised activity recognition using automatically mined common sense *Proceedings of the 20th national conference on Artificial intelligence - Volume 1 %@ 1-57735-236-x* (pp. 21-27). Pittsburgh, Pennsylvania: AAAI Press.

Dobre, C., Mavromoustakis, C. x., Garcia, N., Goleva, R. I., and Mastorakis, G. (2016). *Ambient Assisted Living and Enhanced Living Environments: Principles, Technologies and Control*: Butterworth-Heinemann.

Ermes, M., Parkka, J., Mantyjarvi, J., and Korhonen, I. (2008). Detection of Daily Activities and Sports With Wearable Sensors in Controlled and Uncontrolled Conditions. *Trans. Info. Tech. Biomed., 12*(1), 20-26. doi:10.1109/titb.2007.899496

Fortino, G., Gravina, R., and Russo, W. (2015, 6-8 May 2015). *Activity-aaService: Cloud-assisted, BSN-based system for physical activity monitoring.* Paper presented at the 2015 IEEE 19th International Conference on Computer Supported Cooperative Work in Design (CSCWD).

Garcia, N. M. (2016). A Roadmap to the Design of a Personal Digital Life Coach *ICT Innovations 2015*: Springer.

Garcia, N. M., Rodrigues, J. J. P. C., Elias, D. C., and Dias, M. S. (2014). *Ambient Assisted Living*: Taylor and Francis.

Goleva, R. I., Garcia, N. M., Mavromoustakis, C. X., Dobre, C., Mastorakis, G., Stainov, R., . . . Trajkovik, V. (2017). AAL and ELE Platform Architecture.

He, W., Goodkind, D., and Kowal, P. R. (2016). *An aging world: 2015*: United States Census Bureau.

Hong, Y.-J., Kim, I.-J., Ahn, S. C., and Kim, H.-G. (2008). *Activity Recognition Using Wearable Sensors for Elder Care.* Paper presented at the Future Generation Communication and Networking, 2008. FGCN '08. Second International Conference on, Hainan Island.

Hoque, E., and Stankovic, J. (2012, 21-24 May 2012). *AALO: Activity recognition in smart homes using Active Learning in the presence of Overlapped activities.* Paper presented at the Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on.

Huch, M., Kameas, A., Maitland, J., McCullagh, P. J., Roberts, J., Sixsmith, A., and Augusto, R. W. J. C. (2012). *Handbook of Ambient Assisted Living: Technology for Healthcare, Rehabilitation and Well-being - Volume 11 of Ambient Intelligence and Smart Environments*: IOS Press.

Inoue, S., Ueda, N., Nohara, Y., and Nakashima, N. (2015). *Mobile activity recognition for a whole day: recognizing real nursing activities with big dataset.* Paper presented at the Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing, Osaka, Japan.

Ivascu, T., Cincar, K., Dinis, A., and Negru, V. (2017, 22-24 June 2017). *Activities of daily living and falls recognition and classification from the wearable sensors data.* Paper presented at the 2017 E-Health and Bioengineering Conference (EHB).

Jakkula, V. (2007). *Predictive Data Mining to Learn Health Vitals of a Resident in a Smart Home.* Paper presented at the Seventh IEEE International Conference on Data Mining - Workshops.

Jin, K., Simpkins, J. W., Ji, X., Leis, M., and Stambler, I. (2015). The Critical Need to Promote Research of Aging and Aging-related Diseases to Improve Health and Longevity of the Elderly Population. *Aging Dis, 6*(1), 1-5. doi:10.14336/AD.2014.1210

Kasteren, T. v., and Krose, B. (2007, 24-25 Sept. 2007). *Bayesian activity recognition in residence for elders.* Paper presented at the Intelligent Environments, 2007. IE 07. 3rd IET International Conference on.

Khalifa, S., Lan, G., Hassan, M., Seneviratne, A., and Das, S. K. (2017). HARKE: Human Activity Recognition from Kinetic Energy Harvesting Data in Wearable Devices. *IEEE Transactions on Mobile Computing, PP*(99), 1-1. doi:10.1109/TMC.2017.2761744

Liming, C., Hoey, J., Nugent, C. D., Cook, D. J., and Zhiwen, Y. (2012). Sensor-Based Activity Recognition. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 42*(6), 790-808. doi:10.1109/tsmcc.2012.2198883

Montoro-Manrique, G., Haya-Coll, P., and Schnelle-Walka, D. Internet of Things: From RFID Systems to Smart Applications. *Upgrade: European Journal for the Informatics Professional, XII*(1).

Nishida, M., Kitaoka, N., and Takeda, K. (2014, 9-12 Dec. 2014). *Development and preliminary analysis of sensor signal database of continuous daily living activity over the long term.* Paper presented at the Signal and Information Processing Association Annual Summit and Conference (APSIPA), 2014 Asia-Pacific.

Ordonez, F. J., de Toledo, P., and Sanchis, A. (2013). Activity recognition using hybrid generative/discriminative models on home environments using binary sensors. *Sensors (Basel), 13*(5), 5460-5477. doi:10.3390/s130505460

Pires, I., Garcia, N., Pombo, N., and Flórez-Revuelta, F. (2016). From Data Acquisition to Data Fusion: A Comprehensive Review and a Roadmap for the Identification of Activities of Daily Living Using Mobile Devices. *Sensors, 16*(2), 184.

Pires, I. M., Garcia, N. M., and Flórez-Revuelta, F. (2015). *Multi-sensor data fusion techniques for the identification of activities of daily living using mobile devices.* Paper presented at the Proceedings of the ECMLPKDD 2015 Doctoral Consortium, European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases, Porto, Portugal.

Pires, I. M., Garcia, N. M., Pombo, N., and Flórez-Revuelta, F. (2016). *Identification of Activities of Daily Living Using Sensors Available in off-the-shelf Mobile Devices: Research and Hypothesis.* Paper presented at the Ambient Intelligence-Software and Applications–7th International Symposium on Ambient Intelligence (ISAmI 2016).

Poslad, S. (2011). *Ubiquitous computing: smart devices, environments and interactions*: John Wiley and Sons.

Santos, J., Rodrigues, J. J. P. C., Silva, B. M. C., Casal, J., Saleem, K., and Denisov, V. (2016). An IoT-based mobile gateway for intelligent personal assistants on mobile health environments. *Journal of Network and Computer Applications, 71*, 194-204. doi:10.1016/j.jnca.2016.03.014

Siegel, C., Hochgatterer, A., and Dorner, T. E. (2014). Contributions of ambient assisted living for health and quality of life in the elderly and care services--a qualitative analysis from the experts' perspective of care service professionals. *BMC Geriatr, 14*, 112. doi:10.1186/1471-2318-14-112

Suryadevara, N. K., Quazi, M. T., and Mukhopadhyay, S. C. (2012, 26-29 June 2012). *Intelligent Sensing Systems for Measuring Wellness Indices of the Daily Activities for the Elderly.* Paper presented at the Intelligent Environments (IE), 2012 8th International Conference on.

Tsai, P. Y., Yang, Y. C., Shih, Y. J., and Kung, H. Y. (2015, 6-9 Sept. 2015). *Gesture-aware fall detection system: Design and implementation.* Paper presented at the 2015 IEEE 5th International Conference on Consumer Electronics - Berlin (ICCE-Berlin).

Zainudin, M. N. S., Sulaiman, M. N., Mustapha, N., and Perumal, T. (2015). Activity Recognition based on Accelerometer Sensor using Combinational Classifiers. *2015 Ieee Conference on Open Systems (Icos)*, 68-73. doi:10.1109/icos.2015.7377280