Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Curriculum in Ingegneria Informatica, Gestionale e dell'Automazione

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Data exploitation at different levels for Behaviour Analysis in real-world scenarios

Ph.D. Dissertation of:
Rama Pollini

Advisor:
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XVI edition - new series

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Imagination is more important than knowledge

Acknowledgments

Thanks, gracias, merci, hartelijk dank, grazie!

Ancona, November 2017

Rama Pollini

Abstract

Understanding behaviour in modern science has always been one of the most studied aspects. In recent years, the rapid evolution of technologies has made data (and information extracted from it) increasingly important also in the field of behavioural analysis. Data in all its forms is now an increasingly used resource, but in many areas (from industrial to professional sectors) the explosion of data poses difficulties in their management. To support this growth, new tools and techniques have been developed that allow the processing of large amounts of data and the extraction of relevant information. The exploitation of data allows us to offer end users the most advanced services and tools adapted to their specific needs.

This thesis is focused on the study, management and use of data for the analysis of behaviors in Ambient Assisted Living (AAL), industry 4.0 and web consumer scenarios.

Behaviour analysis is addressed in the AAL framework at the infrastructure level by collecting and analysing data in order to ensure the user's safety.

In the Industry sector, user learning was improved in the training on-the-job phase. The collection and analysis of data in this case was carried out at the interface level, in order to retrieve useful information to improve usability.

In the consumer web area, the study focused on user behaviour during the process of browsing e-commerce sites. The aim is to analyze and exploit the collected data to create a personalized purchasing process for each user.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The research was carried out in the field of behavioural analysis, with the aim of exploiting and re-elaborating different types of data, offering the basis for new developments and methodologies within a given scenario. The analysis of behaviour has been addressed in 3 real-life scenarios.
In Ambient Assisted Living (AAL) has been created an architecture based on the "Zabbix" platform that can monitor and collect data from different smart objects in a home automation house. In this context, the main objective was to exploit the data collected to define and outline anomalous behaviours of elderly people in their homes, implementing an intelligent system based on machine learning algorithms capable of triggering alarms; an innovative aspect of this system is the ability to cross alarms from multiple SOs ensuring a decrease in false positives. The project involved 16 companies and 2 universities.
In Industry 4.0, an application has been developed for augmented reality, usable through smart glasses and aimed at training on the job. The project stems from the collaboration of Intermac, a company specialized in stone, glass and metal processing. The goal is to train the operator in carrying out a task by means of 3D animations and informative labels. Considerable attention has been paid to the study of wearable devices' usability because it is one of the main critical aspects of this technology.
In the field of E-commerce, a study has been conducted on the navigation data of users who have made purchases within the e-commerce website. These data, suitably filtered and grouped in navigation sessions, allow to train neural networks (Long Short Term Memory networks – usually just called "LSTMs") in the recognition of action sequences. The main objective is to improve the user's purchasing process by proposing products based on the operations carried out on the e-commerce portal.
The analysis of behaviour was then addressed at different levels: at a low level in the AAL field because at infrastructure level, at a high level in the Augmented Reality (AR) field because we have dealt with the user interface and finally at a medium-high level for the e-commerce field because web-analytics data have been analyzed and re-elaborated. The work presented in this thesis was made

possible thanks to the collaboration with the IT company Apra Spa which co-financed the doctorate with a EUREKA scholarship. In each of the areas covered in this work, the company actively participated and made its resources available with the aim of integrating research studies into future applications.

1.1 Structure of the Thesis

The thesis is organized in 4 chapters that describe the different approaches used for the study and analysis of behavior in the 3 fields: AAL, Industry 4.0 and Web consumer.

Chapter 2 describes the backgrounds in the field of artificial intelligence: an overview of the Machine learning and Deep learning concepts and the main approaches used for the implementation of predictive models used in research work. Chapter 2 also describes the analysis of behaviour for each of the scenarios studied and the main related works in the state of the art.

In chapter 3, the technical solutions implemented for each of the 3 areas are described and the results obtained from the experiments carried out are reported. Finally, conclusions and discussions are written in chapter 4, as well as some future research directions.

1.2 Main Contribution

In summary, main contributions and results are about:

- Within AAL my contribution to the development of the Hdomo project is about research in the development of the interoperable system able to retrieve data from the different smart objects in the home automation. My contribution is also about the development and testing of a machine learning system capable of highlighting anomalous behaviour. An innovative aspect of this system is the ability to cross alarms from multiple SOs ensuring a decrease in false positives.

- In Industry, my contribution is related to the implementation of an augmented reality application for improving the training-on-the-job. This work poses considerable attention to the behaviour analysis, studying the usability of the HDM device and the readability of the information and paves the way towards new forms of training-on-the-job, to be used in advanced industrial scenario.

- In the field of e-commerce, my contribution is related to the implementation of a system of recommendations able to study the behaviour of users within an e-commerce site in order to learn and propose products of interest to the user. An innovative approach based on deep learning algorithms was used to create this system.

Chapter 2

Historical perspective of behaviour analysis

2.1 Behaviour Analysis in AAL

In recent years, particularly in the industrialized countries, society has been moving towards an important demographic change also known as the ageing society. This change is due to improve life expectancy, which causes the ageing of population. In order to contain the expenses for the health care within the limits of economic possibility, it is necessary to find productive and innovative solutions [1, 2]. According to the World Health Organization [3], the number of elderly people (people of 60 years of age and older) in the world is about 650 millions and by 2050 it will reach 2 billions. European population will keep on growing older a well. In 2008 the population over the age of 65 was over 17%, and in 2060 it will rise to 30%, while, the population over the age of 85 will go from 4% to 12% [4]. Considering this trend, it is important to implement smart solutions for elderly care since they should remain independent and able to work for a longer time. This can be achieved with technology. For this purpose, Ambient Assisted Living (AAL) applications have attracted a growing attention in the scientific community since they involve emerging and innovative technological solutions, providing embedded systems in the home environment. The aim of AAL is to improve the quality of life, to reduce costs for independent living [5, 6, 7, 8], to increase the self-confidence and the autonomy of elderly or ill people while enhancing their security. The technology is now mature and attention is increasingly shifting to the person (user-centered) trying to provide support during the daily activities, facilitating tasks or signaling and intervening appropriately in cases of emergency and danger. This is made possible thanks to technological development that makes available systems of increasingly higher capacity able to detect and manage (monitor, record, record, process, communicate,...) everything that happens within a controlled environment. The intelligence that an environment can be endowed with modern technologies has led to improvements in the conditions and independent living standards of fragile people (especially the elderly and people with disabilities) who need particular support, both physical and cognitive. Some negative events, especially unforeseen ones, can have such consequences that the residual capacity of a person can be nullified, and this unfortunately leads to a loss of autonomy and independence (rehospitalization and hospitalization). The ability to "detect" a problem and put the person in safety in a short time can be fundamental as it minimizes the negative consequences and avoids that other functions not directly involved in the event can be compromised. Behavioural analysis is dependent on and related to the recognition of events and activities. Through environmental monitoring and activity recognition, it is possible to obtain information that can lead to the (automatic) identification of behavioural changes and implement the precautionary measures necessary to limit the negative consequences. In particular, the recognition of an activity enables the possibility of checking its regularity and, possibly, changes over time, which are often symptomatic of some 'change' in the "person-environment" context [9].

2.1.1 Related works

In this section, we briefly describe some projects related to AAL. This list is not exhaustive, since in recent years there have been a lot of projects providing innovative ideas for ambient intelligent applications. To have an overview of works and projects and to get an idea of the state of the art concerning smart environments see the works of Chan et al. [10] and Alam et al. [11]. They make a review of smart homes considering different aspects: comfort, healthcare, security [11], and arranging the projects according to country and continent [10]. We can divide the work into two macro-categories, ASSISTANCE (this includes all solutions for home control, Physical Disabilities and Cognitive Disabilities) and MONITORING (this includes activities of daily living, health monitoring and fall detection): The first broad category of applications concerns assistance. Home control is the very basic assistance that can be offered in a smart home to the elderly people to improve their quality of life and independence. There has been a lot of research concerning different modalities of interaction to control the home appliances. Starner et al. [12] have presented a wearable device that recognizes the user hand gestures and that is as an alternative way to perform home control especially for people with motor and vision impairments. Valles et al. [13] present a multimodal home control system that can be used by the elderly and disabled people with mobile touch-based input as well as voice commands. Blenkhorn [14] introduces a number of technologies to help the visually impaired people that could be adapted in an ambient assisted living environment. There has also been a huge amount of research on solutions to improve the quality of life of the elderly suffering from dementia and Alzheimer's disease in their dwellings and nursing homes. For instance, Mihalidis et al. [15] present a series of assistive devices based on context awareness principles for elderly people with dementia. MEMOS [16] and MemoJog [17] are examples of memory assistants developed for elderly people as cognitive aids. Petrie et al. [18] have introduced MOBIC which is a travel aid for elderly and blind people that helps with planning journeys. The second broad category of applications concerns monitoring. Activities of Daily Living monitoring concerns gathering data regarding the activities of the person in his/her living environment in order to discover the habits and patterns of activities in the daily living. Rashidi and Cook [19] present their approach to discover daily routines using data mining techniques in the context of an assisted living project. Tamura et al. [20] have developed a health monitoring system that is unobtrusive and collects health-related data from bath, toilet, and bed of the elderly person in an automatic way. Finally, the aim of monitoring could be detection of emergency situations such as fall in case of the elderly people. Various methods have been exploited to detect falls and send an alert to call for help. Mubashir et al. [21] have reviewed the literature of fall detection techniques. The sphere of home automation and smart home suffers due to the wide variety of specifications and standards that do not allow communication among different devices. Considering also previously cited works [10, 11], this problem is being tackled on several fronts. Blasco et al. [22] proposed a Smart Kitchen implementation which provides AAL services for elderly and disabled people; it is based on a modular architecture based on a OSGi (Open Service Gateway initiative) that makes it possible to build a complex system composed of small modules devices. The system concept and its implementation are innovative, merging many different technologies to build the smart environment: RFID (Radio-Frequency IDentification) technology, wireless sensor networks, distributed computing, artificial intelligence, etc. Ishikawa, in his recent work [23], highlights the issues of the standardization activities from the mobile phone and cloud server points of view. The author claims that such technologies control and manage specific home appliances, and so there is a lack of technologies and standards for controlling and managing heterogeneous home appliances in a consolidated manner. To solve these issues, the author proposed overlaying networking protocols and metadata technologies as a solution for controlling and managing heterogeneous home appliances connected to home networks. For this purpose Peer-to-Peer Universal Computing Consortium (PUCC) was founded to deploy an architecture oriented towards de facto standardization. The European Union has invested heavily in ICT for Ageing Well projects in recent years. The programme is part of Horizon 2020, the new Framework Programme for Research and Innovation (it has a total budget of 80 billion euro from 2014 to 2020).

Some of the main projects are OPPORTUNITY (http://cordis.europa.eu/project/rcn/89026_en.html), RUBICON (http://cordis.europa.eu/project/rcn/97731_en.html) and DOREMI (http://cordis.europa.eu/project/rcn/94439_en.html).

2.2 Behaviour Analysis in Industry 4.0

Recent technological advances in different domains allowed the paradigm of *Industry 4.0* to become paramount at a worldwide scale. The fourth industrial revolution, stemmed through the union of various skills, is aimed at making industrial production entirely automated and interconnected. This revolution is divided into nine pillars of enabling technologies. (i) The manufacturer advanced solutions ensures effective interconnection between machines. (ii) Additive Manufacturing allows the connection between digital 3d printers and software development, (iii) Augmented Reality applied to support manufacturing processes, (iv) Simulation allows to optimize the machines testing them in real time, (v) Horizontal / Vertical Integration ensures integration of data and systems across the value chain, (vi) Industrial IoT, the set of technologies that interconnects devices, (vii) Cloud manages and stores data on the network, (viii) Cyber-security protects the systems and the network from potential threats, (ix) big data and Analytics allows the collection and analysis of a large number of data from different sources to support decision making. In line with the recent research trends, Augmented Reality (AR) is one of the emerging technologies involved in the new Industry environments. Despite AR is still considered an emerging technology, have proved to be a valuable solution for several purposes: cultural heritage [24], environmental monitoring [25], medicine [26] just to mention some. Nowadays, it has reached a degree of maturity that make it ready for being used within the production environments. The production processes may generate problems which make the operations less efficient and potentially dangerous for the technicians during their work. The main problems are: (i) Human error: even the most experienced workers can make mistakes due to the high number of procedures to be remembered and the difficulty in identifying the precise points of intervention. (ii) Inefficiencies: due to inadequate training received by engineers and poor access to statistics on the operations carried out. Also very often paper manuals used for training are not updated, thus creating further confusion. (iii) Costs: errors and inefficiencies involving higher personnel costs, longer execution times, recurring errors and accidental damage to components due to incorrect execution of the procedures.

Potential uses of AR are various and can be potentially applied in all activities taking place in the companies. The main usage scenarios can be summarized as follows:

- **Production**: any operation which provides step by step procedures can benefit from the use of AR; installations and assemblies are just few examples where the AR can make a difference by making the fourth-generation factory.
- **Quality control**: with the AR support in quality control processes, you can check whether the objects are produced according to the standards of production.
- **Safety management**: AR makes available the tools needed to manage the risks and the safety of workers and goods inside the factories.
- **Maintenance and remote assistance**: maintenance activities require the allocation of significant human and financial resources to ensure the effectiveness and efficiency of operations. In this context, AR would ensure the reduction of the execution time and human errors.
- **Training**: the use of augmented reality can be very effective for the companies in which the training processes involve a large number of technical geographically dispersed over a vast territory pier. The benefits are both on new staff and technical experts to form in new tasks.
- **Logistics**: AR tools can improve the efficiency of store management during indoor navigation and picking.
- **Design**: AR provides instruments able to improve the prototyping and visualization in the design phase.

2.2.1 Related works

AR is a technology that is gaining considerable successes in the field of maintenance task [27]. Several subcategories can be identified as servicing, installation, repair, assembly, testing, but one of the categories of greatest interest is that of 'assemblage'. In their works [28], [29], the authors have empirically demonstrated that the use of instructions in AR (using monitor-based display or head-mounted display) in a sequence of assembling (assembly task) significantly reduces the percentage of errors rather than using a printed manual. In [30] the authors demonstrate improved speed and accuracy in the assembly of Psychomotor Phase of Procedural Tasks than when using 3D-graphics-based assistance presented on a stationary LCD. From their studies is showed that the user's mental effort is lower because part of the work is performed by the AR system. In literature there are many cases of AR applied to the maintenance through the use of hand-held display; in [31] is described an assembly system in

AR overlapping images and simple 3D objects to interact with. In [32], a similar approach is used in the medical field by displaying pre-rendered animations on hand-held display to describe an anesthesia machine. While [33] conducted an experiment comparing the use of AR with and without feedback showing that that AR + feedback significantly improves the user experience during the task performance. The work of [34] proposes an alternative solution using a large projection screen. The use of head-mounted display is minor compared to the hand-held display but is spreading in recent years with the advent of new devices. One of the first uses that can be found in literature is the work performed to facilitate the operations in aircraft manufacturing [35]. In [36], the authors use the monocular optical see-through assembly to the doorlock into a car door. In [37] the user is guided step-by-step through the furniture assembly process in a very intuitive and proactive way. In [38] the authors realize a framework to self-supplied that generated all the necessary data for user intervention and use a robust marker-less tracking. In [39] was proposed a model general assembly in order to define a standardization of performance metrics applicable in various fields. Zheng et al. [40] have made a comparison between Eyewear-Peripheral e Eyewear-Central conditions. Eyewear-Central was faster than Eyewear-Peripheral. In [41] a comparison has been made among tablet, hmd, in-situ projection and paper, discovering, unlike what has been said above, that HMD is the slowest. On the contrary of [40], central Eyewear is less powerful because it blocks their field of view. In both works, it is noticed that the participants used the tablet or paper instruction with both hands, thus interfering in the assembly task.

2.2.2 Display devices

There are three different types of technologies: Video see-through, Optical see-through [42] and Projective based. The video see-through is closer to virtual reality (VR), the virtual environment is replaced by a digital video of the physical world and the virtual content is superimposed on the video frame. The optical see-through allows to have a greater perception of the real world, contents in AR are superimposed through mirrors and transparent lenses. The projection based technology allows to project the digital content directly on the real object.

Video see-through Video see-through is the most economical technique and offers many advantages; (i) The devices that use this technique may be HMD or mobile device (smartphone or tablet); (ii) the current environment is digitized (via video) and it is easier to interact with the real world by superimposing virtual objects; (iii) the brightness and contrast of the virtual objects can be easily adapted in the real world; (iv) it is possible to match the perception of delay between the real and the virtual environment. The main disadvantages are: (i) the low resolution of the camera; (ii) the limited field of view; (iii) in many devices the focus distance can not be adjusted; (iv) In HMD devices, the user may be disoriented because the camera is near the eye positioning.

Optical see-through Optical see-through technique is applied to the HMD devices, AR content is mirrored on a curved planar screen. The main advantages are: (i) the display is ideal for a long period of use as it does not create discomfort effects on the user and leave unchanged the real vision; (ii) the user has a direct, unmodified view to the real world, without any delays; the AR objects depend only by the resolution of the display. (ii) They have a low energy consumption compared with see-through video. The disadvantages are: (i) the projection of images on the lenses has a contrast and brightness reduced therefore are not suitable for outdoor use; (ii) The reduced field of view can lead to the leakage of the projection from the edges of the lenses; (iii) it requires difficult and time-consuming calibration (user- and session-dependent).

Projective Projective technique is based on the projection of the digital content on real-world objects. The advantages are: (i) it does not require lenses to wear; (ii) it allows to cover large surfaces generating a wide field of vision. The main disadvantages are: (i) the headlamp shall be recalibrated if the surrounding environment or the distance from the projection surface changes; (ii) it can be only used in indoor environments because of the low brightness and contrast of the projected images.

2.2.3 Main types of available devices

In the Table 2.1, some of the best known HDM (Head Mounted Device) devices for AR commercially available and that allow to develop custom solutions for are shown. The table shows the comparison of some of the major features available. In [43] was made a comparison between the google glass and the vuzix M100 (the device chosen for our experiment).

2.3 Behaviour Analysis in Web Consumer

There are currently more than 1 billion websites. In 1995, the total number of Internet users was less than 1% of the world's population. In 2015 it reached 3.4 billion (about 46% of the world's population). The value of the worldwide e-commerce retail market is estimated at $1,915 billion in 2016, more than $200

Table 2.1: Features of Main HMDs

Model	*Resolution*	*Field of view*	*Touch pad*	*Opt. See through*	*Gestures*	*Binocular*	*Stand-alone*
XOne	/	/	X	/	X	X	V
Golden-i	800x600	32°	V	X	X	X	V
Google glass	640x360	12°	V	V	X	X	V
Vuzix M2000AR	1280x720	30°	X	V	X	X	X
Vuzix M100	400x240	14°	V	X	X	X	X
Vuzix Star 1200XLD	852x480	35°	V	V	X	V	X
Recon Jet	400x240	14°	V	X	X	X	V
Atheer One	1024x769	65°	X	V	V	V	X
Meta Pro	1280x720	40°	X	V	V	V	X
Epson Moverio	960x540	23°	V	V	V	V	V

billion more than 2015, and 8.7% of the total retail market. While the growth rate for retail sales is declining overall, the digital share continues to expand quickly, with a growth rate of 23.7% in 2016. E-commerce sales will reach $4,058 billion in 2020, accounting for 14.6% of total spending in the year. The B2C e-commerce market in Italy generated revenues of 31.7 billion Euros in 2016, an overall increase of 10% compared to 2015. There are many trends and approaches to try to increase profits, for example by extending sales abroad, offering multiple payment methods, offering a customised purchasing process tailored to customer needs and offering a guided and interactive browsing experience. One of the most interesting approaches is the ability to analyze and study user behavior and act accordingly by offering a personalized experience. The ability to manage and exploit the large amounts of data of different types and origins and the ability to analyse them in an aggregated manner and with different levels of detail are crucial for growth and competitiveness. More and more companies are implementing data analysis methods, using software developed internally or by third parties, which allow on the one hand to read and present data in an intelligible way in order to obtain indications for the strategy, on the other hand to activate further tools that allow the use of such data in real time. The use of advanced data analysis tools allows to analyze every possible point of conversion and intervene accordingly. Search results will always be different for each user; even shopping experiences are becoming different and multiple for each user. Every user has access to unique content during their shopping experience: advice on products and add-ons chosen according to their preferences, geographic location, market trends, demographic group, past purchases and brand interactions - all in a fully automatic way. The next visit will still be different because it will be based on the previous one, current promotions and other contingent factors. This is possible thanks to the systematic collection and analysis of data and the implementation of platforms that allow the effective use of such data. These systems allow you to show the customer only what is important to him, such as search results and filtered recommendations based on recent online activity. Using the huge amount of data collected through customer interactions and profiling, vendors can use predictive analysis methods to understand customers' buying habits, preferences and even future purchases based on the behavior of other customers with similar profiles. Predictive analysis is part of the research field related to artificial intelligence and can be implemented through machine learning and deep learning approaches.

2.3.1 Related works

The vector based models are the most popular and used machine learning methods in e-commerce, including neural networks and logistic regression with feature engineering. The vector based models work with characteristic vectors with fixed length input [44]. The aim is to predict consumer behaviour; so it is necessary to transform the consumer data into fixed sets of features. In order to ensure that the prediction is accurate, it is necessary to design a reliable set of features. This phase requires a long human work and many interactions of experiments. The outcome of the forecast, in terms of individual consumer actions, should then be explained on the basis of vector models. [45] Consumers need transparency on how algorithms determine the individual experience of use. Predictions must therefore be easy to explain in order to provide easy responses to consumers [46] The greater the understanding of trained models, the better the service offered by web-shop providers will be. [47] In recent years deep learning approches have become popular in predicting consumer behaviour, despite the fact that they are not able to explicitly model sequential behaviours. For example in the field of mobile telecommunications, the deep learning approach has been applied to predict the collapse of customers [48, 49] by converting sequential consumer data (calls and expenses etc...) into images instead of using RNNs. Deep belief networks (DBN and DAE) have been used as generative probabilistic processes to predict sessions with orders coming from interactions with consumers. [50] Non-recurring deep learning models, have been applied to learn abstract product representations to predict future sales [51]. The RNNs were introduced into e-commerce scenarios, not to shape consumer behaviour in terms of actions, but were applied to predict the click rates for advertisements displayed to consumers on the search results pages [52]. Other approaches use RNNs to develop natural language in order to predict consumers' purchases from the content of twitter messages. In this case, therefore, consumer behaviour is not modelled through sessions and types of actions [53]. Other approaches introduce several changes to classical RNNs, such as the ranking loss function that makes them more suitable for specific applications [54]. The interpretability of RNNs models has been studied in recent years [55, 56]. It is argued that vector models very often do not appear to be more interpretable than deep learning models [45]. The explanation of the RNNs forecasts has not yet been thoroughly investigated [57].

2.4 Background

2.4.1 Machine Learning

Machine Learning (ML) is essentially a form of applied statistics aimed at using computers to statistically estimate a complex function. In 1997, Mitchell provided the following definition of Machine Learning:"An algorithm learns from experience E regarding a class of T problems with a measure equal to P, if its performance on T problems, measured by P, increases with experience E". In essence, ML is a set of techniques that enable the machine to "learn" from data and then make decisions or predict them. A Machine Learning system can be applied to a base of "Knowledge" from multiple sources to solve different tasks: facial classification, speech recognition, object recognition, etc. Unlike heuristic algorithms (the algorithms that follow a specific set of instructions to solve a given problem) Machine Learning enables a computer to learn how to recognize "perceptive configurations" alone and make predictions about them. Machine Learning can be adapted to three different types of tasks: Classification, Clustering, and Prediction. One of the most popular applications of Machine Learning has been Computer Vision One, for many years. Most Machine Learning algorithms can be divided into the two categories of Supervised Learning and Unsupervised Learning depending on whether the training set is supervised (i. e. with target information associated with the trainer, label or label) or not. Typical Machine learning algorithms are: Random Forest, Linear Regression/Logistics, Decision Trees, Support Vector Machines, PCA, K means, ICA, Naive Bayes, etc.

Support Vector Machine (SVM)

Support Vector Machine (SVM) [58, 59] is a constructive learning algorithm, that belongs to a family of generalized linear binary classifiers. It maps an input feature vector into a higher dimensional space and find a hyperplane that separates samples into two classes. In this way that the margin between the closest samples in each class is maximized. In high dimensional data classification, it has shown great promise [60] and it has been successfully employed to AAL/biomedical data mining [61].

Evaluation

A n-fold cross-validation has been applied to ensure the robustness of performance estimate [62]. The performance of different classifiers and feature sets was evaluated in terms of precision, recall and F1-score (F1) using weighted macro-averaging over n folds.

To evaluate the performance of the algorithms the following metrics are employed:

- *Accuracy*: approximates the effectiveness of the algorithm by showing the probability of the true value of the class label [63]:

$$Accuracy = \frac{t_p + t_n}{t_p + t_n + f_p + f_n} \tag{2.1}$$

  where t_p is the number of true positives and f_n the number of false negatives.

- *F1-score*: is a measure of a test's accuracy.

$$F1 - score = \frac{(\beta^2 + 1) \times precision \times recall}{\beta^2 \times precision + recall} \tag{2.2}$$

  The F1-score is evenly balanced when $\beta = 1$. It favours precision when $\beta > 1$, and recall otherwise. The F1-score can be interpreted as a weighted average of the precision and recall.

- *Recall*: is a function of its correctly classified examples (true positives) and its misclassified examples (false negatives).

$$recall = \frac{t_p}{t_p + f_n} \tag{2.3}$$

- *Precision*: is a function of true positives and examples misclassified as positives (false positives).

$$precision = \frac{t_p}{t_p + f_p} \tag{2.4}$$

- *Support*: is the number of occurrences of each class in ground truth (correct) target values.

The information about actual and predicted classifications done by a oocytes classification system is depicted by confusion matrix. Confusion matrix is a specific table layout that allows visualization of the performance of an algorithm, where each column of the matrix represents the instances in a predicted class and each row represents the instances in an actual class.

2.4.2 Deep Learning

Deep Learning is a sub-area of Machine Learning that makes use of the "Deep Neural Network", equipped with many layers and new algorithms for data pre-processing for model regularization (word embeddings, dropouts, data-augmentation, etc.). Deep Learning is inspired by Neuroscience, since Neural Networks are a model of neuronal brain activity. Unlike the biological brain, where any neuron can connect to any other neuron under certain physical constraints, the Artificial Neural Networks (ANNs) have a finite number of layers and connections, and finally have a predetermined direction of information propagation. In recent years, Artificial Neural Networks have become an important tool in the field of research thanks to the increased computational potential of computers.

RNN and LSTM

Artificial neural networks (ANNs) purpose is not that of to simulate brain behavior, but to effectively manage the patterns of the domain of interest through the use of approximate techniques. One of the simplest neural network models is the perceptron multilayer (MLP), composed of a series of layers of neurons connected to each other with a feed-forward topology, thus obtaining a graph without cycles. Recurring neural networks (RNN) are an extension of feed-forward networks, characterized by the presence of cycles. This feature allows them to have a sort of memory, and to be able to exhibit a dynamic behavior, making them in fact suitable for dealing with temporal sequences.

RNNs take sequences $X = (x_1, ..., x_T)$ of varying length T directly as inputs. RNNs are built as connected sequences of computational cells. The cell at step t takes input x_t and maintains a hidden state $h_t \epsilon \mathbb{R}^d$. This hidden state is computed from the input x_t and the cell state at the previous time-step h_{t-1} as

$$h_t = \sigma(W_x x_t + W_h h_{t-1} + b) \tag{2.5}$$

where W_x and W_h are learned weight matrices, b is a learned bias vector and σ is the sigmoid function. A hidden state h_t captures information from the input sequence $(x_1, ..., x_t)$ up to the current time-step t. Information from early inputs can thereby be preserved over time. The dimensionality d of the hidden state is a hyperparameter that is chosen according to the complexity of the temporal dynamics of the scenario. RNN have difficulty in managing long-term dependencies within the sequences. I can only manage short-term ones. For this reason, LSTM networks were used, a sophisticated network typology that is better in preserving long-term dependencies LSTMs maintain an additional cell state C for long-term memory and calculate hidden and cell states h_t and C_t in the following cascade of gating operations:

$$f_t = \sigma(W_f\,[h_{t-1}, x_t] + b_f) \tag{2.6}$$

$$i_t = \sigma(W_i\,[h_{t-1}, x_t] + b_i) \tag{2.7}$$

$$\hat{C}_t = tanh(W_c\,[h_{t-1}, x_t] + b_C) \tag{2.8}$$

$$C_t = f_t C_{t-1} + i_t \hat{C} \tag{2.9}$$

$$o_t = \sigma(W_o\,[h_{t-1}, x_t] + b_o) \tag{2.10}$$

$$h_t = o_t tanh\,(C_t) \tag{2.11}$$

where W and b are learned weight matrices and bias vectors. The final hidden state h_T of an RNN can be used to classify a sequence: h_T is input into a prediction network, which can be a simple linear layer or a sequence of non-linear layers.

During training, the parameters W and b of the computational cells are adapted to detect signals in the input sequences that increase prediction accuracy. Input sequences X are compressed by this process into suitable feature vectors h_T . Often the compression process is viewed as feature learning from raw inputs and is the reason why workintensive human feature engineering is not required before applying RNNs. The complexity of RNN models, however, yields longer processing time for learning and predicting when compared with vector-based methods. Model tuning RNNs can also be more complex for the same reason: there are more architectural choices and hyperparameters to tune. Nev-ertheless, we show here that even simple RNN architectures outperform vector-based approaches.

Chapter 3

Technical solutions for behaviours Analysis

3.1 Smart sensor integration for an active and independent Longevity of the Elderly

We propose the HDOMO (Human Based DOmotics) project, which aims to improve the life of older people and/or people with disabilities by ensuring their independence in their familiar, domestic environment. The home becomes smart, interacting with people and executing commands given but it is also able, if necessary, to act independently, in case of emergency (for example a person falls on the floor or when the presence of smoke is detected). A series of actions are immediately triggered to ensure the safety of people and a timely arrival of relief efforts. An important aspect to highlight is that home automation 2.0 does not impact living conditions in any way. Its first objective was to create highly technological objects of domestic use making them non-invasive and easy to use, to facilitate hard and uneasy tasks and take them much simpler. In their home, older people live better, are more at ease, maintain contact with a known environment, keeping intact their "world". HDOMO is an Italian project (supported by indirect EU funding in the POR action of Marche region) which involves 16 SMEs and 2 research institutes [1] and is mainly focused on Human Behaviours Analysis (HBA) in AAL. This project aims to propose an innovative idea of an interoperable embedded intelligent system where a series of low cost smart sensors can analyse human behaviours to obtain interactivity and statistical data, mainly devoted to HBA in intelligent AAL environments. HDOMO defines a framework that can be described and split in modules: a low level indoor smart sensor family (which manages localization, access management, interactions, and gesture analysis), a gateway installed inside AAL environment capable of smart sensor management and low level interoperability, a communication layer sending data to a cloud based web

[1] `http://vrai.dii.univpm.it/aal`

architecture responsible of HBA classification and alarm management. One of the innovations of the system is the use of vision sensors (both RGB and RGBD) for people tracking and interaction analysis, where the depth data has been used to prevent problems with changes in appearence variation and to evaluate users' activities inside home environment. In addition, the set of interactions are monitored and analysed with the main goal of having a better knowledge of users' activities, using real data in real time. All information coming from this HBA tool can be used to provide basic data gathered in real time for an AAL environment. This data paired with classical home automation data is used to classify correct and incorrect behaviours using a machine learning approach. In summary, the following objectives of the HDOMO project can be specified:

- The implementation of an innovative and integrated system able to improve the quality of life of older people (both self-sufficient and with frailty and chronicity associated with ageing), enabling them to remain independent in their home, to maintain good health conditions and to have an active role in managing their own health.
- The design and implementation of an open, free and accessible "intelligent framework", as a supporting structure and enabling tool for various and multifunctional fields (energy, comfort, safety and security management), able to learn the customs of users, to know their capabilities, to monitor their interactions and to infer from and to react to unusual behaviours, enabling alarms or activating procedures of internal checking, which may include user interaction.
- The study and the development of innovative and technological solutions for behaviour analysis, integration with next generation of smart objects (SOs) for localization applications, interaction, analysis of vital parameters, basing much of their analysis of data on the possibility of using audio and video analysis systems.
- The development of methodologies and technologies for advanced Human Machine Interaction, implementing user interfaces that are holistic and adaptive ("User-Centred Design"), accessible by the different types of users ("Design for All").

In the state of the art there are projects that achieve only a few of the objectives listed. The HDOMO project aims to achieve all of them in one single project effectively.

Innovation of HDOMO Figure 3.1 shows the general logic architecture of the HDOMO framework. The main contributions of the proposed project are

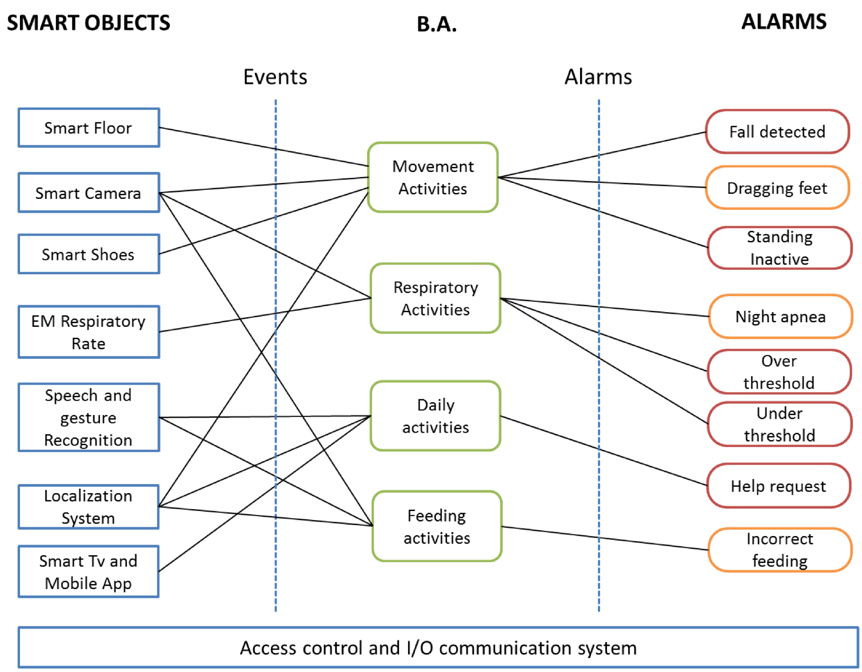


Figure 3.1: HDOMO logic architecture: 7 different SOs, based on multiple sensors, process data at low level to perform 4 different Behaviour Analyses (B.A.), which are processed at high level in the cloud infrastructure and are able to generate 8 different alarms on two levels: level 1 (critical alarm—red) and level 2 (non critical alarm—orange).

on the ability to mix different highly accurate SOs on a real scenario. Seven different SOs, based on multiple sensors, process data at low level to perform four different Behaviour Analyses (B.A.), which are processed at high level in the cloud infrastructure and are able to generate eight different alarms on two levels: level 1 (critical alarm red in the figure) and level 2 (non critical alarm orange in the figure). This architecture allows a high level of accuracy and reliability for a system with its main innovation in the intelligent data fusion and interoperability among different low cost SOs. The architecture is flexible and reusable in any AAL project where there is more than one device capable of monitoring the same behavior or activity. One of the big problems in AAL projects is the lack of accuracy in recognizing behavior because the monitored subject can perform it in many different ways. In addition, accuracy decreases because the device must not be invasive for the monitored subject. Through the use of cross data and sensor interoperability, it has been possible to increase the accuracy and reliability of the entire system.

3.1.1 System architecture and methods

The HDOMO project offers an agent and agent-less monitoring, scalable, distributed and extensible architecture able to connect smart objects that use different standards. This allows to add any home equipped with a smart object to the centralized platform. Figure 3.2 shows a simplified representation of HDOMO data processing, communication and security architecture. It consists of two main functional blocks: the first identifies HDOMO home and the second identifies the AAL as a Service (AALaaS) platform of HDOMO project. The platform is based on a virtualization infrastructure that uses VMware ESX Server, which offers high availability. The communication between the home and SaaS platform is protected thanks to a Virtual Private Network (VPN) connection, ensuring a secure transmission of data. The main nodes of the platform are:

- Monitoring server based on Zabbix (`www.zabbix.com`);
- Contact management server based on vTiger;
- Presentation server for aggregate data that provide remote management of homes (based on Liferay);

Liferay platform, CRM [2] server and Zabbix server are all integrated with a Single Sign on system based on a Central Authentication Server (CAS). These nodes are flanked by Analytics services based on Pentaho Data Integration (the classification system based on Weka), and by other nodes, which provide supporting backup and data restore services, and send alerts via SMS. The architecture provides the development and the integration of different devices introduced as SOs, which must monitor and support users in their daily activities. The project provides also devices able to detect anomalous situations and eventually interact with the user or send a distress alert. Each SO has different functional feature s and so different ways and technologies to access the information collected during normal activities of daily life. The communication system has to create a link among different objects, by promptly and completely providing all the information detected by all objects. Information that must be managed in real time belongs to the alert signal category, while signals which need longer time to be processed belong to the interactions category. Typically, information concerning interactions between the user and the surrounding environment can be more complex and voluminous and for this reason it is necessary to use a mass memory to save a large amount of data, and it can be externally transmitted when necessary (Memory Events in Figure 3.3). Another important feature of the communication system is its

[2] vTiger

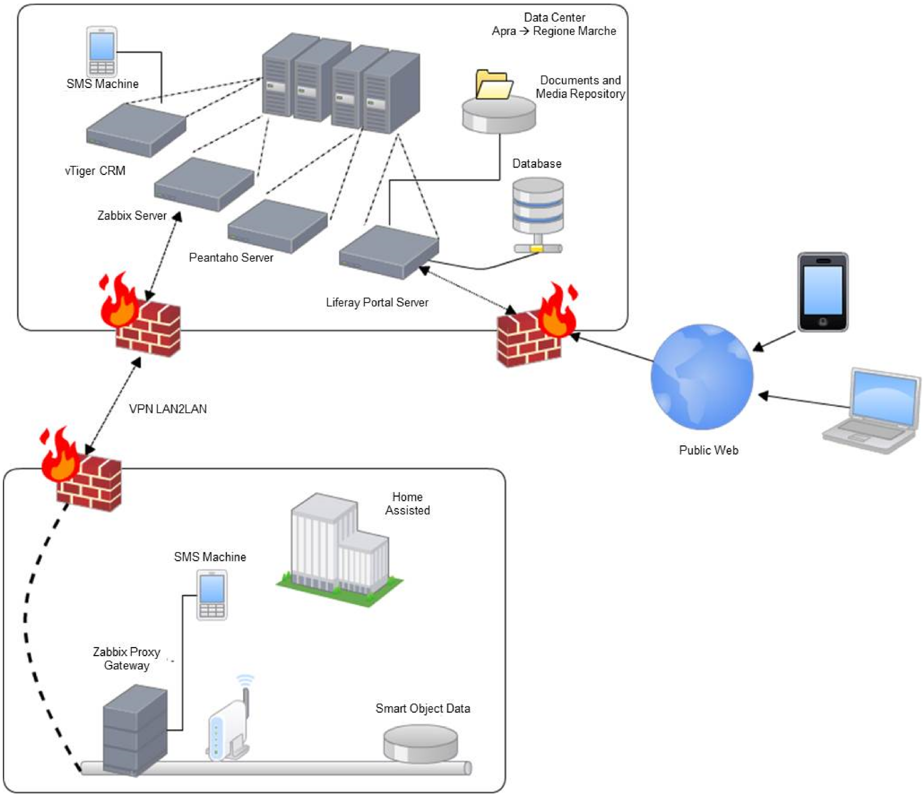


Figure 3.2: General data processing, maintenance and security architecture of HDOMO project.

modularity, necessary to manage systems different for the number and the categories of SOs. This aspect makes it possible to introduce even if they were not part of the original plan, and build systems tailored to the characteristics of the environment and the real needs of the user to be assisted. After having received information, the communication system makes it available to the outside using standard technologies compatible with most popular communication services.

Figure 3.3 represents the communication system composed of three main blocks that together manage alarms, interactions and communications towards the outside. SOs responsible for the detection of dangerous events are considered by the communication system as alarm signals and therefore have the highest priority compared to all other types of reports. In the analysis of the management of alarm signals dangerous events have been identified as most probable and most important:

1. falling down;
2. irregular heartbeat;

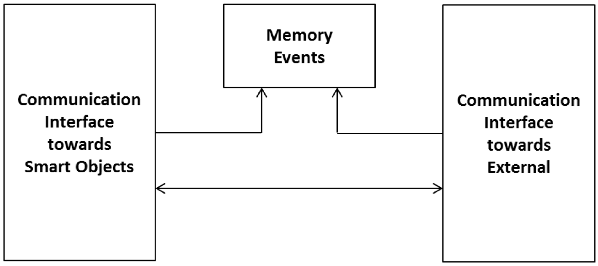


Figure 3.3: Block diagram of Communication system (ref. Figure 3.2, Zabbix Proxy Gateway).

3. fire;
4. flooding;
5. intrusion of strangers;
6. distress call;
7. excessive humidity in the environment;
8. malfunctioning communications systems;
9. therapy-mandated drug delivery;
10. anomalies in the habits of the assisted;

The first five kinds of events are considered active because smart objects enabled to recognize these events trigger automatic alarms when the event occurs and the sixth event provides an explicit request from the assisted and is therefore considered passive. The last four types of events are also active and are reported after a variable observation period, and therefore considered to be slow. These are the possible alarm systems: light and acoustic signals, phone call, sending of SMS messages, sending e-mail and audio-video connection. The light and acoustic signal involves a very limited zone but it can be useful when there is the operator responsible of the assistance nearby. The phone call is the most easily-implemented system and it can manage both the distress calls and the step of interaction between the patient and the operator in preparation of the assistance intervention. Sending SMS messages is easy to manage but does not always guarantee the immediacy of information delivery and does not offer the interaction with the patient during the preparation of the intervention. Sending SMS messages can also handle very complex information such as photos and video but this is not a problem for the operators. Audio-video connection is definitely the most complete but binds the operator and the assisted to the use of expensive technologies and communication channels that are not always available in all areas. Interaction management provides the exchange large amounts of more complex information concerning events such as posture of the assisted, position of the assisted inside his home during the daily life, as he interacts with the television and other home appliances, if he receives visits from other people, and so on. To manage a large amount of information a local system that can store all the events and when necessary to transfer all the information to an external processing center has been used. Considering the various technologies and existing systems which provide information transfer, the communication system must be arranged so that it can accommodate all the technologies provided by SOs as also chosen in a particolarly installation. Such a general system it is expected to identify a technology that can handle both large and small amounts of data and that has a high transfer speed. Observing Figure 3.4, the interfacing between the SOs and the management system of communications called gateway provides both the direct connection compatible to the standard used by the SO and the connection to the management system of the communications through a pre-defined bus standard.

Depending on the type of information to be transferred to the outside, two main types of communications are defined: phonic and data. The communication channels available for the management of various types of communications are: fixed telephone network, mobile connection, and the Internet. Phonic communications are used for reporting and managing alarm events directly addressed to operators or friends or relatives of the assisted that can receive calls via landline and/or mobile phone. Data communications include both large amounts of information about the historical of everything that has happened in a day, video, audio, and so on. The telephone network and/or mobile phone are primarily used for phonic communications and towards service centres such as call centres that handle the emergency. For the management of communications between the gateway and the communication system, standard ethernet found in all computer networks both wired and WiFi has been used, for the following reasons: is very common, is a worldwide standard, provides very high data transfer rate up to Gigabit and beyond, provides both wired and wireless connection and the components necessary to realize the interfaces are easily available at very low cost. For connection to the outside, standard interfaces of telephonic line have been realized while for data communications have been used ADSL standard modem and for wireless connections UMTS modules as Figure 3.5 shows.

The gateways that connect SOs and interfaces towards the outside have been directly managed by the communication platform. For the manage of phonic communications towards operators, friends and relatives, a reduced communication system have been developed that can help the main platform.

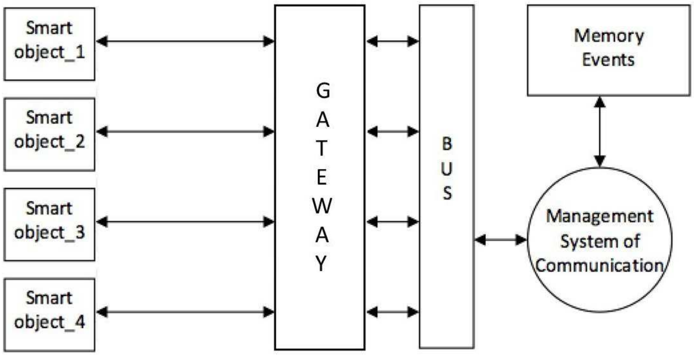


Figure 3.4: Block diagram of communication interfaces towards SOs (ref. Figure 3.2, Home assisted).

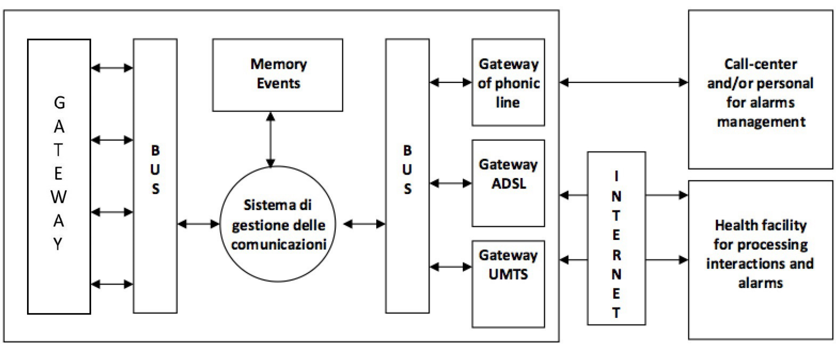


Figure 3.5: Block diagram of communication interfaces towards the outside (ref. Figure 3.2, Entire).

Distributed Monitoring: Zabbix

Since the project includes a 24-h monitoring of the home and so of the SOs, to verify the correct functioning of objects, applications, and in general services, Zabbix has been chosen as monitoring software. Zabbix is a centralized monitoring software of server systems. It is a classical agent-server based architecture. Each system to be monitored can be equipped with an agent that allows a very precise and constant data collection since it is continuously connected with the main monitoring server Zabbix. Several are the advantages of Zabbix, among these we listed: agent and agent-less monitoring, scalable and distributed architecture, easily extensible with plug-ins or agents, storage for monitoring data based on database, opportunity to generate real-time graphics with instant alert, and others (in Figure 3.4 SOs are equipped with Zabbix agents that send data to the proxy Zabbix server installed in the gateway). The flexibility of Zabbix is an important element that distinguishes it from other existing open source solutions as it allows virtually monitor and intervene on any element of the infrastructure through a various number of standard protocols (Zabbix Agent, Agent-less, SNMP v1/v2/v3 & trap poll, Log parsing, ODBC, Java, SSH, Telnet). It also allows the acquisition of data through custom scripts definable by the user. Zabbix provides a very scalable monitoring system that starts from a traditional centralized solution to complex distributed architectures on multiple control nodes and proxy data acquisition, this solution is useful for HDOMO project, where complex systems interface.

The Figure 3.6 describe the exchange of data that occurs between the zabbix server (located in the data center) and the gateway within a dwelling. The main functions of the Zabbix server maintenence, delivery, and management of alerts from gateway.

The SMs are connected (via different connection types) to the gateway which acts as a central home control. Then it is up to the gateway to communicate with the outside of the house (the cloud). The gateway can be divided into three main parts:

- Zabbix Proxy: combines all monitoring data sent by the “Zabbix Agent”. The Zabbix agent are demons that allow to communicate (actively or passively) with the Proxy by sending the information of changes in the state of SM monitored.

- SO Driver: Not all SOs are compatible to accommodate one “Zabbix agent” then the gateway provides the ability to install specific drivers so as to establish communication with the server.

- Rest/APi Service: is a module that provides rest / soap services to allow SMs to be able to communicate with Zabbix server without the help of

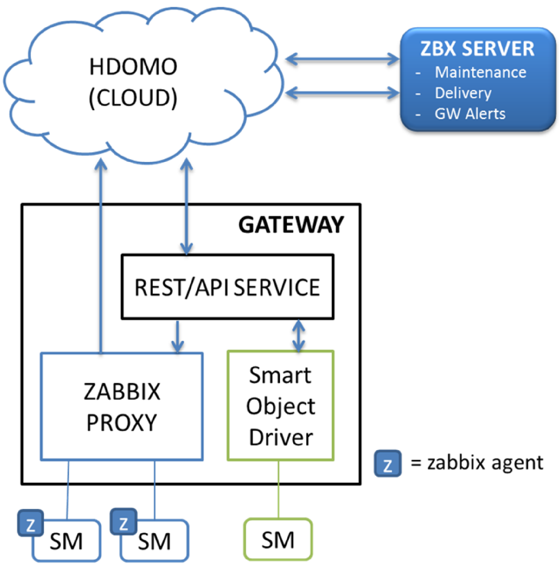


Figure 3.6: Communication system between zabbix server and gateway

Zabbix Proxy. This module increases the degree of AngelHome system interoperability. The module is called Planet Automation. An SM that requires registration through rest/soap services must provide the following information: Type of MS (recognition identifier), Protocol version with which began bordering, Any user identifier associated, and Lease time to update your subscription

Data Management: CRM vTiger

CRM server handles personal data of homes and users. A required information to be loaded into the CRM is the telephone number of the SIM installed in the BOX of the home; additional information can also be managed, such as: personal mobile phone number and other information. For each user information about the "Contacts" are managed, people that are referents: family, doctor, doctor on call number, 118 and others. For each referent must be inserted a telephone number, since CRM is connected to a VOIP switchboard. The reception of a call or SMS implies the automatic opening of a Ticket, which consists of the following information:

- First and last name of the caller (automatically proposed);
- The contact associated with the user;
- The list of available contacts, with highlighted phone numbers, associated to the user;

- The reason for the call;
- The identification data of the operator who is completing the Ticket;
- The status of the Ticket;
- The ability to manage the progress of the state, a number of states of the ticket will be the default: Open, Check, Waiting response, Closed, and so on.
- For each change of state is required to enter a description and, automatically, the operator 'logged in'.
- Managing the priorities of the ticket
- Possibility of passage of managing tickets from one operator to the next
- Wherever it is visible a contact telephone number, the system allows a management as 'Click to Call', the ability to quickly call a number by clicking on the number displayed on the screen.
- There is a link to the documentation of the operating protocol for the operator.

The CRM has thus been customized to handle the typical entities of a project AAL.

- The registry of the house.
- The registry of users;
- The registry of SO (to exploit the capabilities of asset management of CRM).

Data and Alarm Consulting and Process Management: Liferay

The project uses the Open Source Liferay platform for system management, provisioning, alarm management and presentation of information. Liferay is a platform focused on the aggregation of resources and generally to applications and services. The platform can aggregate communications deriving from SOs, process them according to the precise specifications by giving automatic alert facilitating the realization of services and intervention. Liferay supports the mechanism of workflow and "out of the box" by providing the Kaleo Workflow engine. It is available through a portlet. It is used during the testing phase, but successively it can be replaced using the most functional and flexible Activiti process engine.

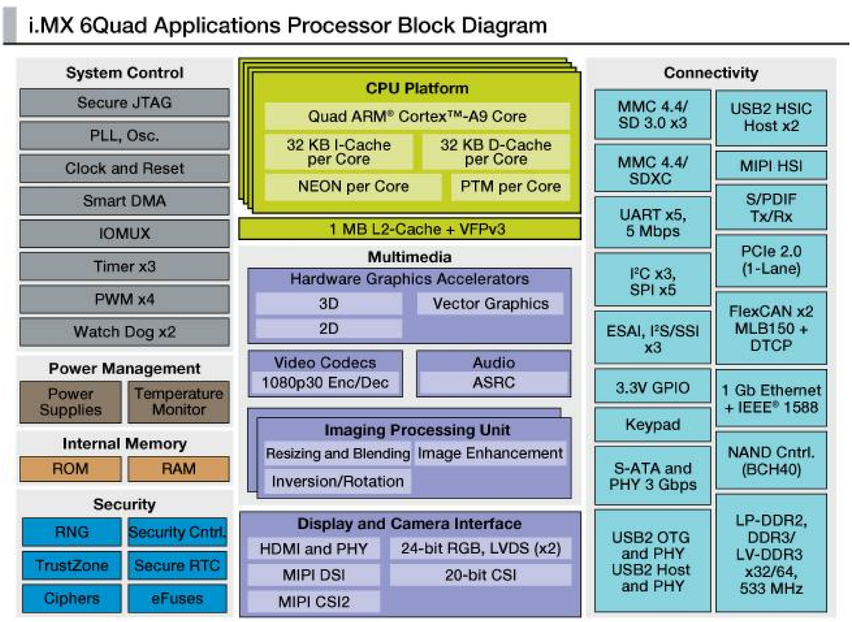


Figure 3.7: Architecture of the processor used in the main unit of gateway.

Interoperability among Heterogeneous Devices: Architecture of Hdomo Gateway

The gateway provides the necessary services to the connection of SMs used within the Hdomo context, in order to ensure interoperability. The SMs operate with different communication protocols, either standard or proprietary, on wireless and wired channels, and even at the data-link layer. The gateway is able to manage the information coming from the various devices even in absence of a supervisor PC. It consists of two macro-blocks:

- Main Unit: constituted by a IMx-6 platform, used to manage and perform high-level and computationally onerous operations, since it has a high capacity of calculation. The main units offers several wired and wireless communication interfaces: 1 Gigabit Ethernet ports, two USB 2.0 ports, a Wi-Fi 802.11 and serial ports as RS232 / RS422 / RS485 interface. The main unit must reprocess data coming from the secondary drive;

- Secondary Unit: is realized as an active component and equipped with a low-performance microcontroller (k60 microcontroller). It is responsible for managing operations of the lowest level. Another task of secondary units is the interaction with the home SO. The communication of the secondary unit with combined primary and manufactured by one of the two

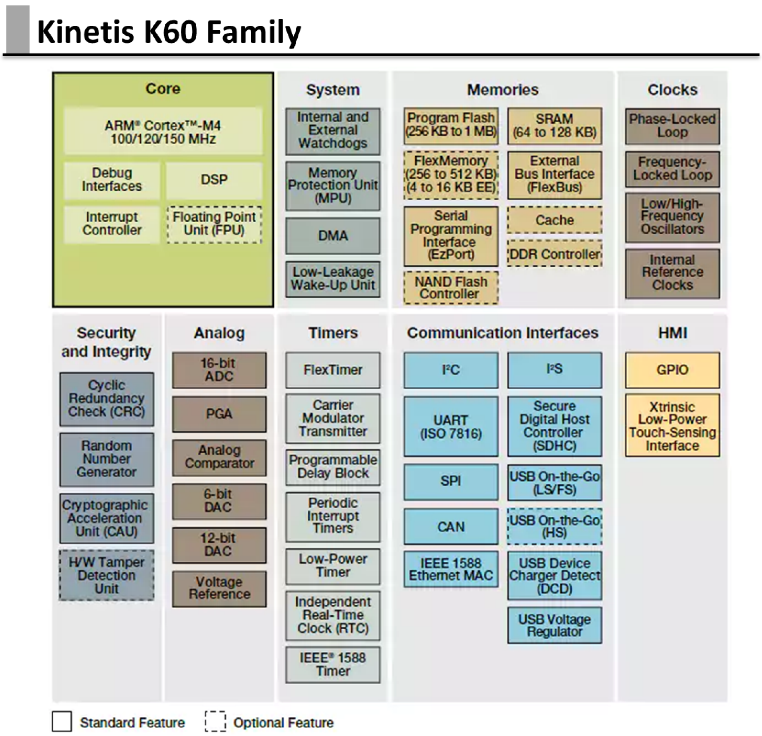


Figure 3.8: Architecture of K60 micro-controller used in the secondary unit of gateway.

RS232 ports. The unit constitutes an additional front of expandability in respect of the smart devices taken into account in the context of Hdomo;

The communication between the main unit (i.MX6) and the secondary unit (K60) occurs through UART, with 19,200 bps baud rate.

3.1.2 Description of main Smart Objects

The Hdomo project involves 16 small and medium-sized enterprises and 2 research institutes. Each of them has offered their own knowledge and expertise at the service of the project. A series of intelligent devices have been defined to be developed in every field of competence of the actors involved in the project. Each smart object can work independently but is designed to be easily connected to the HDOMO architecture. In the supervision system are developed and integrated the following SOs:

1. Localization system;

2. Smart floor with energy harvesting and localization functions;
3. RGB and RGB-D smart cameras for the analysis of the presence, of the postures and of the interaction between user and environment;
4. Smart shoes with localization functions and analysis of motor activities;
5. Smart tv and app for devices management and the information;
6. Audio analysis system for speech recognition and novelty detection;
7. System of gesture analysis;
8. Non-invasive analyser of respiratory rate;
9. Videocitofonia system for easy access at home in an emergency situation.

The following subsections are dedicated to describing in detail each integrated object as part of HDomo project.

Localization System

The system of presence detection has to be able to know at any time the position of the person with the remote control and can instantly configure Smart Objects installed in the same environment. In this way, HDOMO system could automatically turns on or off a light when the user moves from one room to another, enable the electronic locks positioned for example in the kitchen, which otherwise might be blocked in the presence of children in the home. The technology chosen to localize a person within the home is a small semi active transponder (about $3.0 \times 2.5 \times 0.7$ cm) inserted in a portable control device (remote control). An antenna is installed close to the entrance of each room to locate the user's position and direction of movement (Figure 3.9).

Smart Floor with Energy Harvesting and Localization Functions

The floor must be considered as a multifunction device, whose functions are manifold: mechanical support, adequate response to the needs of heating and damping of mechanical noise, satisfaction of aesthetic requirements of the environment, all obviously with acceptable costs. The floor of a room can be transformed into a floor-sensor that detects and controls the behaviour of people and allows a collection of new support functions [64]. The falls are one of the biggest health risks among the elderly. The smart floor pressure sensing systems have a number of characteristics that make it an obvious choice for user localization: users always walk over, it can sense information not only about users but also about objects. It is also possible to identify dangerous situations thanks to information on the pressure distribution on the surface of

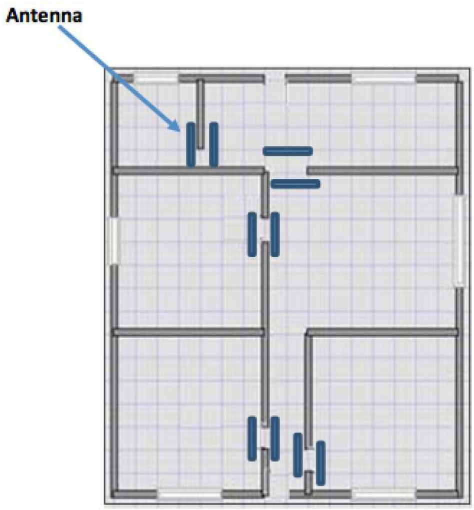


Figure 3.9: Position of antennas in the house.

the floor and in the time. The smart floor also works fine when the room is noisy and dark, and it does not care if a view of the user is occluded. Figure 3.10 shows different phases of the step. The top of the figure represents the foot showing the curvature angle. The bottom of the figure highlights the correlations between the forces exerted by the body weight and the instance of the step.

In a daily life situation, when the assisted user falls down there is a multiple activation of the sensors and then the system autonomously sends an alert if the multiple sensors are not disabled this corresponding to a situation in which the person remains on the ground. The alarm is not sent when the person gets up again, and so the sensors are activated and then deactivated.

RGB and RGB-D Smart Cameras

Currently the most frequently used techniques for fall detection are focused on wearable sensors, such as gyroscopes and accelerometers. [65] The problem is that, these devices often generate false alarms, because some activities of daily living (ADLs) are manifested with fast moving down, that can be classified as a fall from a detector based only on inertial sensor [66] Hdomo proposes an automated RGB-D video analysis system that recognizes dweller activities that are crucial for assistance purposes, focusing the attention on the detection of falls. The movements of the users are on line recorded using a database, so that their physical activity can be supervised anytime. Observing Figure 3.11, the physical architecture of the system consists of a RGB-D sensor installed in

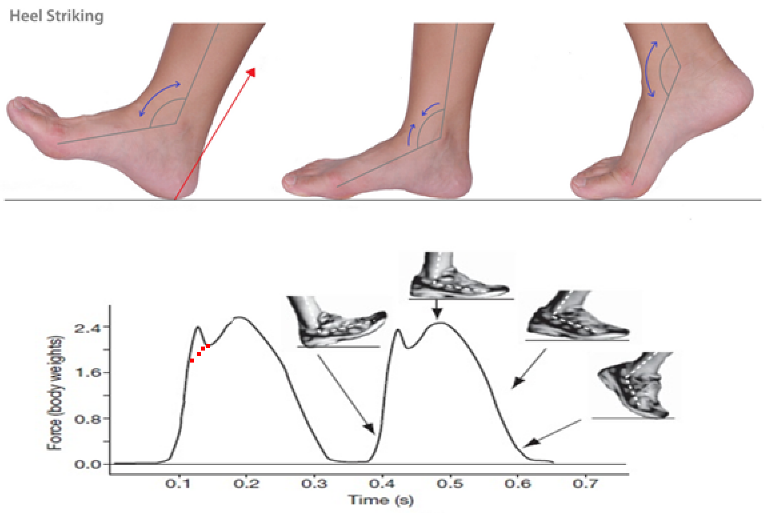


Figure 3.10: On the top, the movement of the foot. On the bottom, the forces exerted by different states of support.

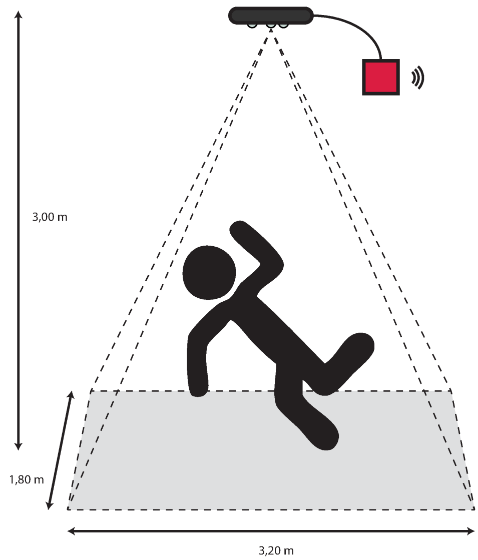


Figure 3.11: Representation of the RGB-D camera position.

a top view configuration. An embedded system manages the sensor acquisition processes the depth stream extracting measures of the people on the camera view.

The RGB-D camera was used also for the analysis of frail user activity and

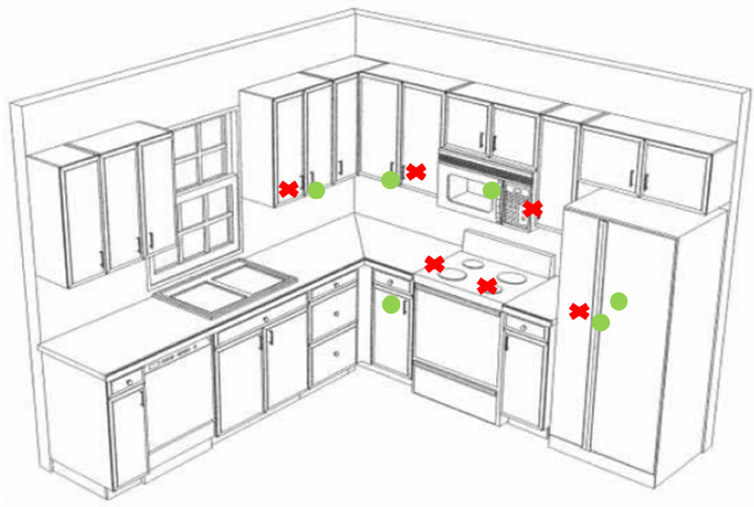


Figure 3.12: Example of interaction map.

their interactions with the surrounding environment e with the objects inside it. Figure 3.12 shows an example of a home environment (i.e., a kitchen), where the map of interactions is showed. A positive interaction (circle) means that the object (e.g., a pot or cooking product) is taken from the cupboard and used. Negative interaction (crosses) means that the object was picked up and stored immediately without using it. Memorizing and then processing this information it is possible to establish which is the normal behavior of the user, identifying anomalous situations that can activate alarms (for example a wrong feeding). The experimental phase has demonstrated that the system is able to monitor user behaviors, interactions with other subjects and in particular interactions with the objects. Moreover, users can develop actions using vocal commands and in case of alarm, a series of agreed words can activate a VOIP communication.

Smart Shoes with Localization Functions and Analysis of Motor Activities

Taking into account wearable electronics devices, the most efficient systems for energy capturing are those use Energy Harvesting systems [67] inserted into the shoes. These systems are installed into the soles where, during the walking and the running, the force is exerted. Using piezoelectric elements and electromagnetic induction systems, this force allows to recover high quantity of electrical energy useful for sensor supply and complex monitoring systems [68, 69]. For that, it is necessary to analyse the pressure distribution along the sole of the shoes during the walking and/or the running [70], in order to

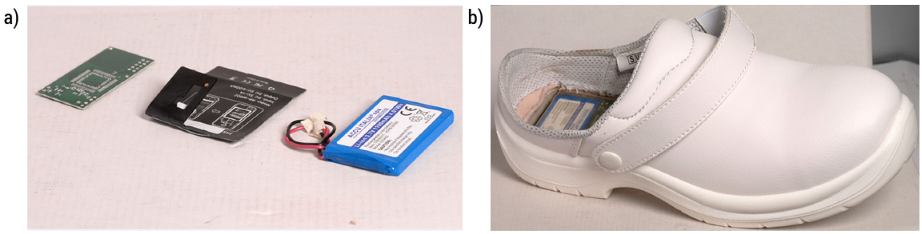


Figure 3.13: Components (a) inserted in the heel and the shoe prototype (b).

optimize the positioning of the elements useful for the energy recovering. For further details see [71]. In this project, the main hypothesis of using smart shoes is related to data acquisition (data logging) for which the system, after it was shod, is able to acquire data and to storage them inside the micro-controller memory, basing on its dimensions.

The system to be inserted in the heel of shoes is made in Figure 3.13 from left to right:

- Electronic board;
- system of recharge at induction;
- Battery;

Shoes are in a prototype phase so the model has been chosen to be worn inside the home and suitable for an elderly person. An operator wears smart shoes and moves in the home environment, and the software recognizes the exact position of the operator. Moreover, the operator tests possible states provided by the firmware:

- falling;
- standing idle;
- extended idle;
- extended active;
- standing active;
- slow/dragging walking;
- normal walking;
- fast walking;
- running;
- anomalous situation;

Smart TV and App for device and information management

A smart TV is an application program that runs on an application engine inside digital television connected to Internet. It is possible to develop novel applications that integrates and extends the offering for users that use smart TV. The use of commercial product offers two main advantages:

- To reduce time to market and the scalability of products using focusing on the application development rather than the platform.
- To reduce the distribution complexity and the application management focusing on the resolution of possible application problems rather than the software distribution.

Our project choice is oriented on the suite of "Samsung Smart TV" products, to have:

- Distribution channel of native software (also eventual upgrades);
- Production Line widely distributed and available on the market;
- Wide range of products that guarantee the functioning of applications on a range of different (but compatible) installations.

The Samsung Smart TV service offers the ability to extend functionalities of the TV by applying a wide range of web functionalities that can be customized by users. With the installation of Samsung Smart TV, users can directly run Internet applications on the TV screen. The user interface of the application is designed to be usable by an elderly person. It is assumed that a caregiver helps the elderly person in the preliminary learning phase of the application.

Audio Analysis System for Speech Recognition and Novelty Detection

The most versatile and minimally invasive sensor for the AAL is the microphone that allows to capture a continuous signal from the home. Examples of audio framework related to the automatic recognition of controls and emergency calls within a domestic environment are processed in the following articles [72, 73]. A microphone continuously monitors acoustic sounds present in a dwelling identifying among them the words through a Voice Activity Detector (VAD). Concerning the VADs, many algorithms have been developed all based on the energy of signal recognized as word: assuming that at the beginning of the audio there is no words pronounced, this energy level is recognized as threshold and only whenever this is exceeded, it is possible to identify a word and then pulling it out from the background noise [74].

Gesture Analysis Systems

In HDOMO, a user detection system has been developed to detect user movements. The system provides a natural interface that can be used without the help of external devices and that makes it easy for users with injury or disability to interact with other HDOMO devices. After the study on the state of the art of sensors and after having examined the systems considered most interesting, we decided to use the Kinect and Asus Xtion for the following reason:

- The sensor does not require any peripheral, even passive to wear by the user;
- The sensor allows to have a sufficiently large (57° in horizontal) and until to 8 m of distance;
- The sensor is easily available, economic and easy to install;
- There are alternatives from other manufacturers equal and compatible;
- The system is supported by libraries and drivers from Microsoft and third parties.
- The sensor is able to contemporary detect gestures of one or more users;
- The sensor in indoor environment can ignore the quality of illumination and it has not problems of chromaticity with clothes of user. Even if it has the only restriction that the zone is not struck by sunlight and that possible obstacles do not prevent, however, the direct and complete view of the user.

A protocol of communication between sensor and user has been defined. It is based on TCP-IP standard communication with messaging in XML. To allow the user to configure the commands underlying each gesture, a special web interface has been created. Below there is some of available movements that can be associated with an action (e.g., switching lights on or off, raising or lowering the cooker hob, opening kitchen cabinets, turning on smart TV, etc.):

- left-hand-hand-push: press with the left hand.
- Right-hand-swipe-right: Move the right hand from left to right.
- Zoom-in: Extend both hands horizontally.

Figure 3.14: The stand-alone realtime device working at a single frequency.

Non-Invasive Analyser of Respiratory Rate

The respiration rate is one of the physiological signals (also known as vital signs) that are generally monitored in patient observation because it is considered an important predictive parameter for many pathologies. A possible approach to the problem is represented by the use of electromagnetic (EM) technology [75, 76], which is able to ensure: non-contact measurements at significant distances (a few meters), and most importantly, it can work also through tissues (i.e., bed sheet, blankets, clothes), because common fabrics are generally transparent to EM waves. Moreover, an EM system may be installed inside a home without compromising end user privacy and may be hidden into the wall or ceiling so not having a significant impact on the appearance of the rooms where it will be installed. Figure 3.14 shows the final device boxed: on the left are visible the TX/RX antennas, while on the right the display (with touch screen) of the Linux system.

With this device it is possible to detect changes in the respiratory rate so alarms can be triggered when the breath drops or drops or rises above a certain threshold. It is also able to detect apnea events, a serious problem that affects adults and infants and can lead to irreversible brain damage and even to death.

System for Easy Access at Home in an Emergency Situation

The communication system consists of three major devices:

- Phone Device: offers simplified call to relatives, caregivers, hospital etc. It provides automatic response mechanism with hands-free activation for preset numbers (useful in the event that the person has an illness).

- GSM and Control Electrical Network Device: The GSM device monitors the status of the electrical network and, in case of interruption, send an SMS to predefined numbers, also provides a simulated telephone line to

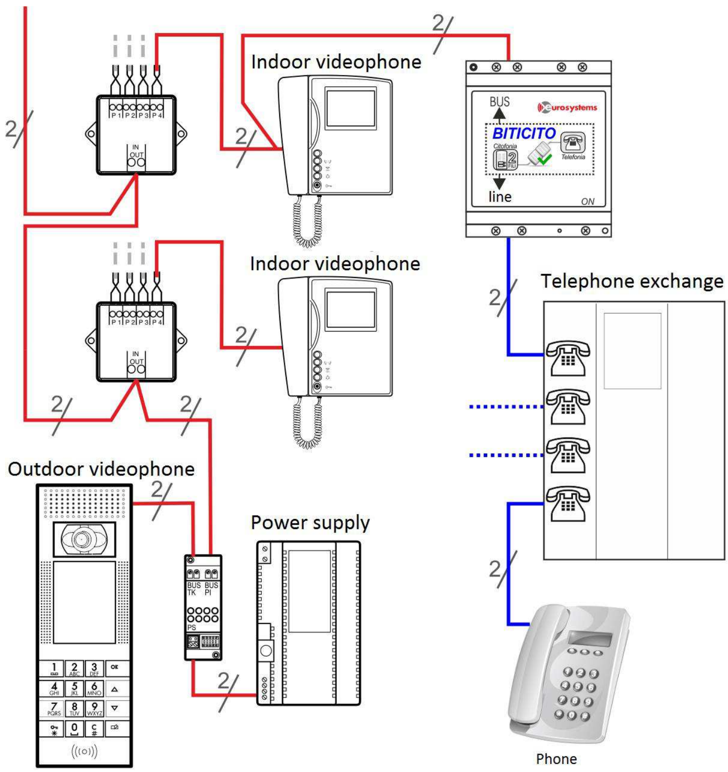


Figure 3.15: Description of the videophone system.

which any telephone terminal can be connected to make or receive calls and a relay controlled by specific SMS messages.

- Video entry device with smart reader: this device allows the access control house via RFID proximity reader (TAG Reading compatible EM4002 at a distance of 3–5 cm—Operating frequency 125 KHz). The smart object can be connected directly to the telephone line or extension, the GSM device, and when a call coming, can answer and open the doors through specific codes entered from the keyboard.

Figure 3.15 shows the connection of video door entry system. The outdoor device is connected with the indoor device using a GSM module. The BITICITO module allows you to connect the videophone to external phones/smartphones.

3.1.3 Experiments and Results

Test Case of HDOMO

The aim of this section is to describe a possible HDOMO scenario that allows to have an overview on the interaction among different SO and the consequent chain of events that is generated when a specific alarm occurs. This case study also aims to show how the entire system is able to react to an alarm event and the ability of the gateway of the house to coordinate in parallel and automatically many sequences of actions designed to secure the elderly person. Finally, this test made it possible to prove the robustness of the system in case of possible connectivity problems. We assume that an elderly person lives alone inside his domotic home. The elderly falls on the floor and is unable to get up after the fall. The floor through its sensors detects the person falls on the ground and then sends an alarm signal to the central gateway, the device that acts as interface towards the outside home. Then the Gateway performs three tasks:

1. Send a message of alarm to the automatic switchboard capable of starting in a completely automatic way a telephone call to the health professional. Through a virtual assistant the operator knows the type of accident occurred. The virtual assistant remains pending to receive a voice notification of receipt of the message. The switchboard addition to the call is able to send SMS useful to alert relatives of the elderly.

2. Send a message of alarm to the web cloud platform for remote management. Automatically also the web platform will notify to the automated switchboard the fall to obtain an alert mechanism structured on several levels and therefore more robust to possible network problems. Cloud service allows to maintain a history of all activities conducted by SOs and then it is possible to also verify previously calls and to control the timing of rescue.

3. Send a message of alarm to the videophone of the dwelling that automatically enables an array of RFID tags predefined for this type of alarm. The healthcare provider that has the RFID will enter in the home of the assisted only after to have inserted his pass-partout code.

When the operator receives the call alert, can try to call the patient equipped with a GSM unit can automatically respond to the phone and set the speakerphone. In this way, the operator can hear what is happening inside the house (around the phone) and can groped to reassure the patient.

Figure 3.16 shows a scheme of the sequences previously described. Departing from the accidental occurrence until help arrives.

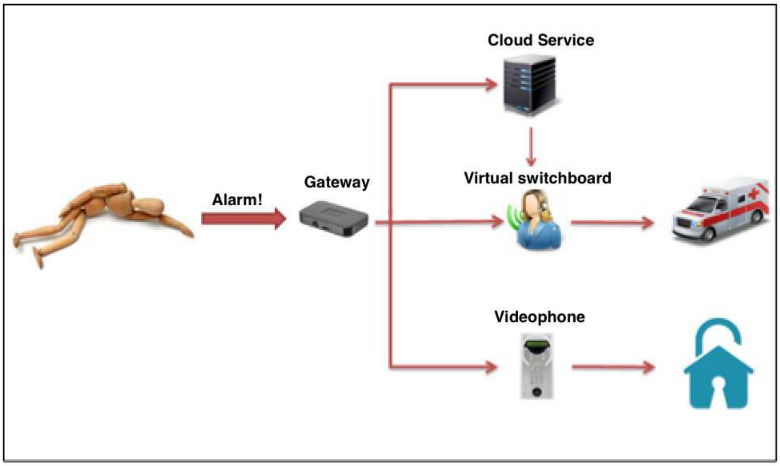


Figure 3.16: Example of possible HDOMO scenario.

HDOMO Demo Environment

The Demo environment was set up with two rooms of a HDOMO test home: entrance and kitchen. In the environment, there are all the HDOMO SOs and two gateways. Figure 3.17 shows the virtual environment, recreated on the zabbix platform, corresponding to the real demo environment (Figure 3.18).

The experimental set-up is structured in an interactive path able to involve the user the benefits of introducing systems developed by HDOMO. The main purpose of creating this environment was to be able to carry out the tests presented in the next section using a real environment and collecting real data. HDOMO test case is currently an open lab in Italy that helps SMEs to develop new products for AAL. In particular, the user can test different functionalities in an environment endowed by several SOs. As for example:

- Use an interphone able to prove an easy access to the house in case of alarm, through a slim distribution of virtual keys (numeric codes or QR);
- Interact with the environment through interaction systems made easier for the weak user: a remote control for interacting with the environment, a voice recognition system in Italian and in the local dialect for access to the management of the lights and the handling of kitchen cupboards;
- Use gestures to interact with other SOs (for example, to turn on the lights the cooker hood or open a door);
- Collect interactions data between user and kitchen to understand behaviors related to feeding habits and the risks of the kitchen (as in Fig-

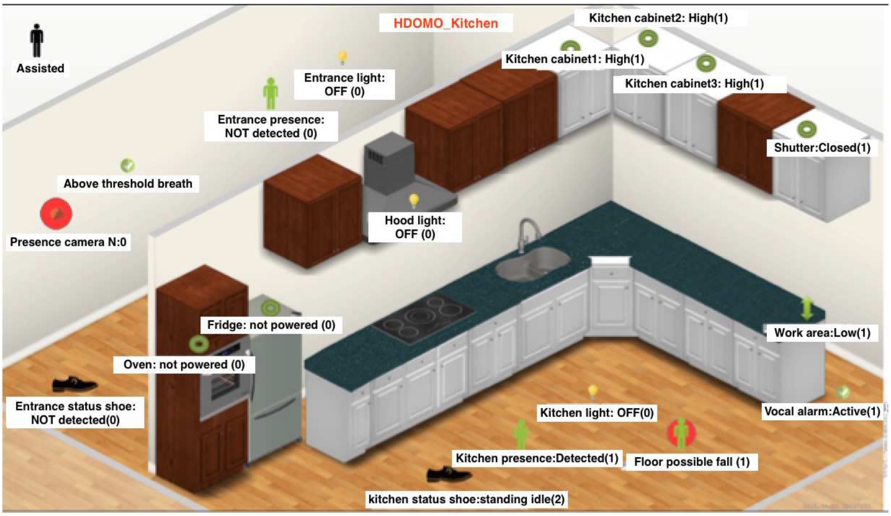


Figure 3.17: The virtual HDOMO Demo environment from Zabbix Platforms.

ure 3.17).

- Localize people through more alternative or complementary systems: an innovative camera battery, a bracelet or a remote control locatable in the home, a smart floor and so on;

- Obtain in real time information on falls both through vision that through interactions with the smart floor;

- Analyze breath in non-invasive way and collect data in the cloud area of HDOMO management to handle alarms;

- Use an innovative smart shoe able to localize, identify falls, estimate the daily moving of the user, using a self-recharge system;

- Having an innovative telephonic console able to intelligently manage incoming calls and outgoing.

All data generated by aforementioned systems are collected and managed by internal gateways that communicate to a cloud infrastructure all information necessary to classify behaviours and handle alarms. All user interfaces are usable through three platforms in HDOMO project developed: a Web portal that provides all the advanced features, two applications (for tablet and smart TV) with sub functions useful for the user or the assistant.

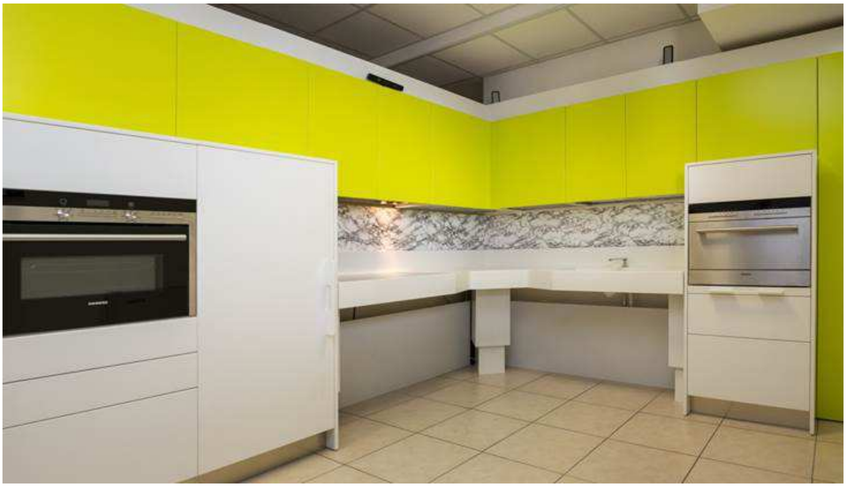


Figure 3.18: The real HDOMO Demo environment

HBA and Machine Learning

Data collected in the AAlaaS system are in real time processed for alarms management. The possibility to extract information in the form of raw data resulting from monitoring, makes the monitoring software used in HDOMO an extremely powerful tool for carrying out analysis. The main purpose was to be able to learn from correct processes and classify, and then manage and detect any abnormal behavior which may be attributable to alarm situations inside the home. This system was implemented in the WEKA framework for classification and data mining. In the experimental phase the most relevant items for the analysis of the system are considered:

- Breath analysis: You can create alerts based on the change in respiratory rate. Many studies [77, 78, 79] suggest that this analysis allows to detect many diseases.
- Interaction with the kitchen counters and appliances: You can study the behavior of the individual within the home automation kitchen in order to identify the frequency of daily meals, the hours in which they are consumed etc.
- Floor: you can control the behavior of an elder in the house watching the paths that performs daily and generate alarms if emerging attitudes and abnormal movements.

For each system was done an initial training using a manually labelled dataset that describes a normal behavior. In general, most of items give a binary output

(ON-OFF) and to each item it is linked a timestamp describing the instant in which the data has been received. Concerning the floor, it is not possible to provide a depth experimental analysis since the prototype consists of only three tiles. Possible future developments are very interesting because it will be possible to control the behavior of the elderly inside his home by observing the paths that he daily performs and generating alarms if there are attitudes and unusual displacements that indicate any loss of memory. Other information concerns the walk of the elderly, in fact the system could signal an anomalous situation if the average time between a step and the other is different from a normal value.

In HDOMO has been used machine learning approach mainly to prove that the set of Smart Sensors here proposed and integrated on the same architecture can benefit from this approach to perform an intelligent integration of data coming from every sensor in behavior detection. The approach used is the Support Vector Machine (SVM) described in the 2.4. Then for the solution to this problem a cross-validation (CV) procedure is applied. The approach chose for this problem is k-fold CV, so the training set is split into k smaller sets. In the next section, it is reported the accuracy of every sub-system and of the integrated system based on the previously described methods.

Reliability Test of the Data Acquisition and Analysis System

The demonstrative environment has been used to conduct simulated tests to verify the reliability of the network infrastructure and the data acquisition system in receiving events from smart objects. The controlled environment test was carried out on 6 volunteer researchers who alternated in the execution of predefined tasks (the actions to be performed were specified but not the order in which they should be performed). At this stage we did not consider it necessary to test with elderly people because the main objective was to have a high number of activated alarms with an annotated dataset shared among SMEs working on the different SOs development. For 7 days different types of alarm were artificially created and detected by smart objects, verifying through visual inspection whether the alarm was actually detected by the system as well. The purpose of this test was to analyze system reliability by distinguishing correctly detected alarms, false positives and false negatives, applying a collaborative approach between the SOs. It is important to note that the alarms/events detected by smart objects are read on Zabbix interface and not directly from the smart object. Table 3.1 shows the 7 smart objects selected to detect alarm situations and the type of events they are able to detect (e.g., shoe can detect walking, running, falling, standing idle, etc). Table 3.2 shows the behavior of SOs in recognizing 6 types of alarms. The "# Events" column represents the number of events, established in advance, that will be executed by the

Table 3.1: Type of event detected by SOs.

Smart Object	Event Type
Smart Floor	Standing idle, slow/dragging walking, normal walking, falling
Smart Camera	Location tracking, falling, Kitchen interaction
Localization System	Location tracting
Smart Shoes	Standing idle, extended idle, extended active, standing active, slow/dragging walking, normal walking, fast walking, running, anomalous situation, falling
EM Respiratory Rate	Normal breath, apnea, breath below threshold, breath above threshold
Smart TV and Mobile App	Interactions with the device, Location Tracking
Speech and gesture Recognition	Help request, Interaction with the device

volunteer in a random sequence (for example, for the Fall alarm, 500 events have been generated that can be recognized by the Smart Floor). The "% Event Accuracy" column represents the number of events correctly detected by the individual smart object compared to the number of events actually occurred and confirmed by a visual inspection (75% of events detected correctly by the smart floor). The "# Alarms" column represents the number of a priori alarm situations that the volunteer will perform within the entire sequence of events (100 fall alarm situations). The column "% Alarm Accuracy" represents the number of alarms correctly generated by the collaboration of all smart objects selected to recognize that particular alarm (94%), based on the ML approaches described before. This type of information cross-referencing makes it possible to obtain a higher degree of accuracy than a single smart object, reducing the number of false positives and false negatives. In each alarm situation, weights were assigned to each smart object based on its ability to recognize that particular alarm.

Table 3.2 describes, for each SO, the number and percentage of the generated alarms (e.g., the alarm triggered by alarms when the breath frequency goes above or below the threshold) together with the overall alarm accuracy (measured in percentage) with respect to the ground truth observed and annotated during the test week. The overall accuracy is really high and the data fusion and concurrent behaviour understanding. We also tested the user interface in terms of usability and acceptance of the system with a total of 100 stakeholder. In general, more than the 90% of the total caregiver that was asked to give a score between 1 and 10 for every alarm kind in term of acceptability and usability reached a quality level major than 9. Results demonstrated the feasibility of the system and its accuracy showing that the correct approach and the main results of HDOMO are related to the correct mix of different SOs that are low cost, easy to install and manage and interoperable. At the current stage HDOMO is the largest set of SOs in Italy and Europe able to interoperate on a common architecture.

Table 3.2: HDOMO Testing scenario and Accuracy Results.

Behaviours	Alarm Type	Smart Object	# Event	% Event Accuracy	#Alarms	% Alarm Accuracy
Movement Activities	Fall Detected	Smart Floor	500	75	100	94
		Smart Camera	300	80		
		Smart Shoes	800	82		
		Localization System	200	90		
	Dragging Feet	Smart Floor	400	61	50	87
		Smart Camera	200	65		
		Smart Shoes	600	79		
		Localization System	100	90		
	Standing Inactive	Smart Floor	400	80	50	96
		Smart Camera	200	85		
		Smart Shoes	600	86		
		Localization System	100	90		
Respiratory Activities	Night Apnea	EM Respiratory Rates	3000	98	150	100
		Smart Camera	50	70		
Daily Activities	Help Request	Speech and gesture Recognition	400	85	100	100
		Localization System	200	92		
		Smart TV and Mobile App	300	95		
Feeding Activities	Incorrect Feeding	Smart Camera	300	90	30	92
		Speech and gesture Recognition	200	85		
		Localization System	50	89		

3.2 Augmented Reality Glasses for the applications in Industry 4.0

In this thesis we propose a case study of a *training-on-the-job* application through the use of glasses for AR. This work was done in collaboration with INTERMAC company, the Biesse Group company specialized in glasses, stone and metal processing technologies. The goal of this joint venture is to develop an AR application (Android based) that allows to assist the operator during the assembly task by replacing the printed manual. Through the use of the head-mounted display (HMD), the user receives step-by-step instructions to assembly the object. The application drives the operator thanks to the aid of both textual information and 3D models of the components overlapping to the real scene. This work poses considerable attention to the behaviour analysis, studying the usability of the HDM device and the readability of the information and paves the way towards new forms of *training-on-the-job*, to be used in advanced industrial scenario.

3.2.1 System architecture and methods

This section describes the activities carried out to develop an augmented reality application for the assembly of machine components. Special attention is paid to the main hardware and software components, as well as a description of the layout design.

Objective of the application The purpose of this project is to test a decrease in the execution time of a task rather than using a printed manual. The application allows to train and drive the user in real time during the assembly

Figure 3.19: Example of a real component used for the development of this showcase; in particular, the object is a cone that one have to mount over a machine for glass moulding.

phase of an object composed by numerous components that must be assembled in a precise order and together with a final verification measurements on some parts of the final object. To speed-up the mounting operation we create the 3D virtual components with exactly the same shape and size of the actual components and for every task we superimposed the virtual component to the real object assembled (the mechanical component used for this test is showed in Figure 3.19).

Once completed, the application has been tested in the Intermac Laboratory ,in order to receive feedback from experienced staff. The application was also tested by untrained personnel during two important fairs of the sector (namely Marmomac and Glasstech respectively held in Verona and Dusseldorf occurred in 2016); in addition to test the application, users were interviewed in order to obtain further information on the application and on the difficulties encountered in the use. In the following, a brief description of each element is provided, together with the way in which they were used.

Hardware components After appropriate research among the available models we chose VuzixM100 device, which have the following hardware features: display with WQVGA resolution, 1GHz dual core CPU, 1 GB RAM, 4 GB Internal Memory expandable up to 32 GB with an external slot, camera 5MP camera with 1080p video recording, 600 mAh battery, which you can connect an external battery of 3,800 mAh, ear speaker and noise canceling microphone, microUSB port, WI-FI and bluetooth 4.0 connectivity support. The device is equipped with 4 buttons, two for scrolling forward and back, one for selection and one for switching on and off. It has a voice recognition system using proprietary libraries but expandable via payment. The operating system is based on Android 4.0 Ice Cream Sandwich in which are installed the proprietary app. you can install your apps developed. Battery life is approximately 1-2 hours when used.

Software components For the implementation of the AR experience, we used the Unity framework and Vuforia libraries.

Unity 3D game engine is a system that allows the development of multi-platform games developed by Unity Technologies that includes a game engine and an integrated development environment (IDE). Supported platforms include BlackBerry 10, Windows Phone 8, Windows, OS X, Linux (mainly Ubuntu), Android, iOS, Unity Web Player, Adobe Flash, PlayStation, Xbox and Wii. The development environment allows to create and manage 3D objects and create simple mobile application.

Vuforia AR SDK Vuforia represents one of the most advanced solutions for the development of AR applications for mobile devices. Vuforia SDK is subdivided into two SDK dedicated to the development of Android and iOS platforms, respectively; Vuforia Unity Extension is also available that allows to use the Unity environment to manage advanced functions for creating augmented reality applications, and all the prefab objects useful for the creation of three-dimensional scene; also allows the release of apps for both Android iOS platforms. The strength of this SDK is given by the possibility of identifying and tracing different types of targets: (i) Image target consists of a simple two-dimensional color image; (ii) Cylinder Target (iii) Multi Target allows to track multiple targets (as long as a portion of the multi-target track is recognized for all others); (iv) Frame Markers are special markers that are identified by a unique code; (v) Object Recognition allows to recognize solid three-dimensional objects. Vuforia provides an online tool that allows to calculate the image quality to target and save it in a suitable format for use in RA. Finally it provides a cloud platform where target images can be saved (or can download directly on the device). Vuforia SDK is offered with a freemium mode, where you can use all the features in development mode but you have to buy a license if you want to market the application.

Mobile System Architecture Figure 3.20 describe the data flow of the development process. The application is shown on the left and it is enclosed in

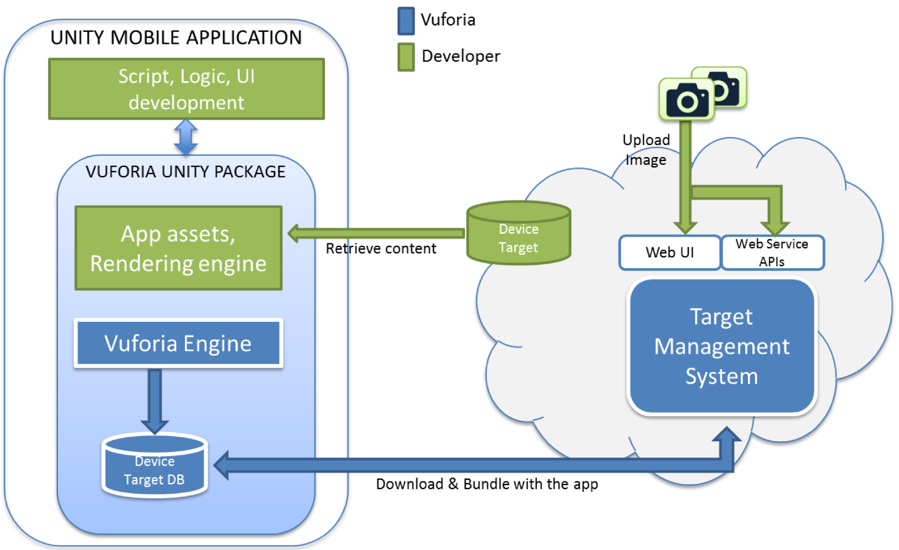
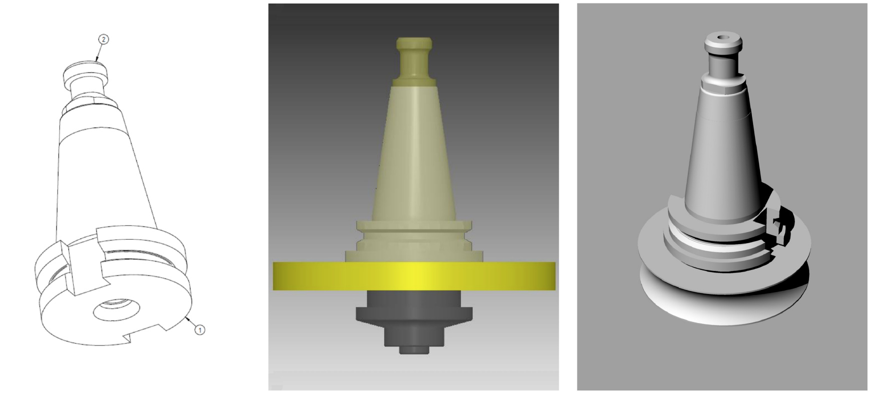


Figure 3.20: Data flow diagram of the development process.

"UNITY MOBILE APPLICATION" block. Inside it there are:

- Script block, Logic, User Interface development: these are the elements and tools offered by the UNITY environment; scripts (C# language) allow the developer to define logic and interaction with the end user, while the development interface allows to create 2d and 3d elements.
- "VUFORIA UNITY PACKAGE": contains tools and elements to create interaction with augmented reality.
- "APP ASSETS, RENDERING ENGINE": Vuforia offers the elements that allow you to add and load the 3d models that will then be superimposed on the marker; these models are loaded manually by the developer and are represented on the schema by the green cylinder "Device Target".
- "VUFORIA ENGINE" and "DEVICE TARGET DB": the vuforia engine is the engine of vuforia that allows to implement augmented reality (through marker recognition algorithms).
- "TARGET MANAGEMENT SYSTEM": allow the developer to to generate the Markers used in the application. It is a tool offered by the web platform of vuforia in which it is possible to upload images or objects that must act as markers. A quality measurement is associated for each marker used. The developer uploads images to the web platform via web ui or API service and exports a dedicated file that can be uploaded into



(a) isometric view (b) front view (c) 3d view

Figure 3.21: Example of virtual component used during the assembly task.

the DEVICE TARGET DB and make it available in the Unity environment.

Application Workflow The development of the application followed a strict pipeline, designed in a close cooperation with the worker and of the experts of Intermac, in order to fulfil with the foreseen expectations of the AR experience.

1. Installation of Unity (version 5.3.6) and importing Vuforia AR Extension (version6.2).

2. Select the image to use as Target Image upon which the virtual elements will be superimposed with the same point of view of the user. Operators must carry out the assembly operation over a 30cmx30cm sheet, which represents the marker to be recognized by the application. We chose to use an image rich of edges so as to make more robust the tracking phase; this was an obliged choice, given the presence of the physical components and the presence of the operator's hands.

3. Creating 3D models for each real component, keeping the same dimensions and shapes. The models were created using Unity and each one has a different color in order to be better identified (Figure 3.21)

4. Creation of the sequence of operations to be performed in chronological order for the object assembling. At each assembly step, the position in which it will go to the real component, is superimposed augmented reality virtual object by a short animation. Also appears a short text at the top describing the operation with keywords to play.

5. Creation of the sequence of operations to be performed in chronological order for the measurements to be performed on the object mounted.

The mobile application has been developed for Android S.O., according to the specifications of the VuzixM100 SDK. In order to switch from one task to the next we decided to use the select button on the device placed near the ear.

Usability and Legibility In accordance with the guidelines defined in [80], we used the black text (without outline) over a white billboard because it is the combination that ensures readability. The font used is Roboto Regular,one of the standard android fonts. The background as well as being white is slightly transparent so you can use the large text without obstructing the operator's field of vision. In this way we are guaranteed a real good view of the object being assembled and virtual components overlay. The background has a red line at the top because red is a color that catches the eye's attention allowing you to direct the eye toward the text to read. We used the color red on animations that describe the steps to take on the real object (screw and measure) to make more explicit the manual operations to be played by the operator. All virtual components have different colors so they are easier to distinguish and then allow to decrease the execution time of the task. An example of the User Interface is showed in Figure 3.22.

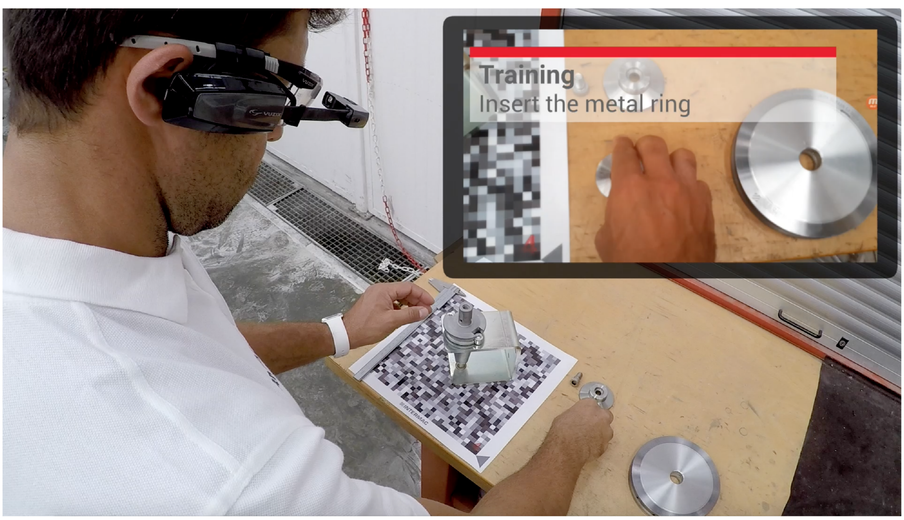
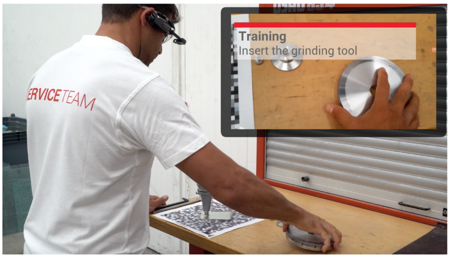
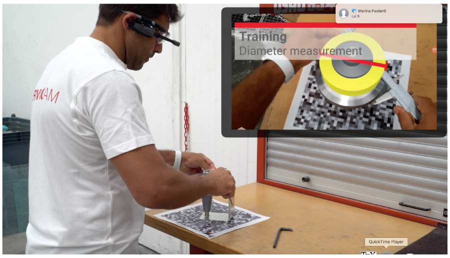


Figure 3.22: Snapshot of the application running on the Vusix M100



(a) Snapshot 1



(b) Snapshot 2

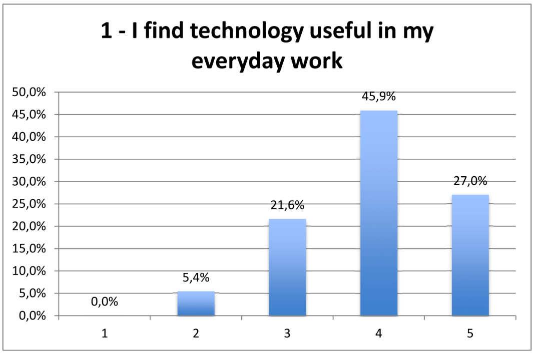
Figure 3.23: Example of different tasks displayed by the application running on the devices

3.2.2 Experiments and Results

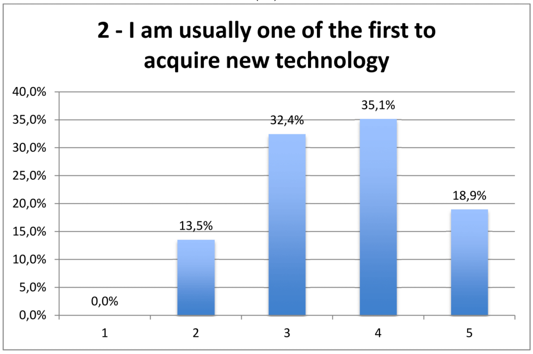
The application has been validated after a number of practical tests carried out by specialized technicians who normally perform this type of assembly. We also worked with the technicians during all phases of the application development, as well as to improve usability and build an application that meets the real needs of end users. In Figure 3.23 is showed a specialist Intermac technician who performs a task assembly with the aid of the Vuzix M100.

Nonetheless, it was also worth to test the application with not experienced users. During two industry trade fairs it has been asked users to test the application to obtain important feedback from users not specialized but which belong to the sector. Figure 3.24 shows the graphs with the results of the survey completed by 50 users during two fairs. The survey consists of 7 questions, which could be answered with a score of 1 to 5 (Figure 3.24). The answers to the survey show interesting results both on the potential of technology in the industrial sector and on its real applicability in the work environment. As a first step, users were asked to evaluate the usefulness of new technologies in everyday life (Graphs a and b). From the answers obtained, there emerges an interest of users in new technologies, and an awareness of their utility in the work environment. The results obtained from the third question (Graph c) show that more than half of users have never had experience of using AR glasses for professional use. As a consequence of the AR eyeglass test carried out by each of the users interviewed, a real usefulness of this approach emerges: the technology was easy to learn and use (Graph d). Nevertheless, the group of respondents expressed mistrust about the acceptability and future evolution of this technology (Graph e). The use of AR is however considered effective in the field of learning on the job (Graph f). Finally, the last question (Graph g) shows a substantial confidence in the usefulness and effectiveness of the technology because it is able to facilitate and speed up work activities.

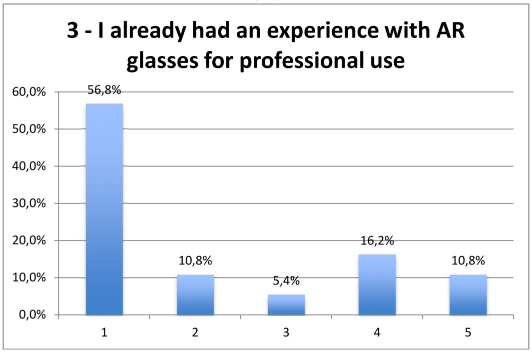
From information gained during the development of the app and the feed-


1 - I find technology useful in my everyday work
50,0%
45,0%
40,0%
35,0%
30,0%
25,0%
20,0%
15,0%
10,0%
5,0%
0,0%
0,0%
5,4%
21,6%
45,9%
27,0%
1
2
3
4
5

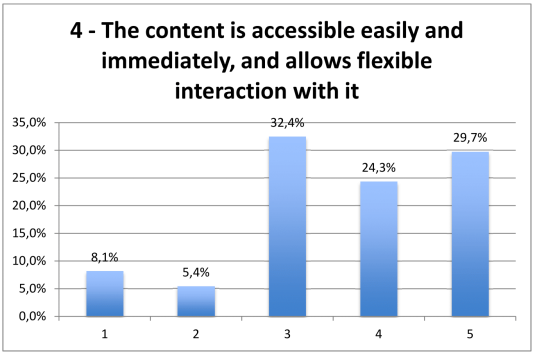
(a)


2 - I am usually one of the first to acquire new technology
40,0%
35,0%
30,0%
25,0%
20,0%
15,0%
10,0%
5,0%
0,0%
0,0%
13,5%
32,4%
35,1%
18,9%
1
2
3
4
5

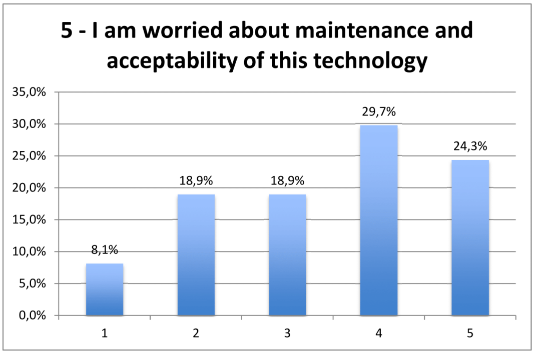
(b)


3 - I already had an experience with AR glasses for professional use
60,0%
50,0%
40,0%
30,0%
20,0%
10,0%
0,0%
56,8%
10,8%
5,4%
16,2%
10,8%
1
2
3
4
5

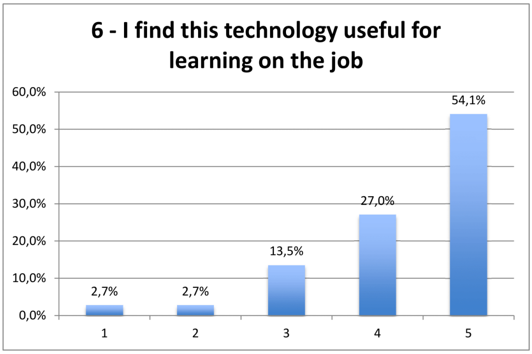
(c)


4 - The content is accessible easily and immediately, and allows flexible interaction with it
35,0%
30,0%
25,0%
20,0%
15,0%
10,0%
5,0%
0,0%
8,1%
5,4%
32,4%
24,3%
29,7%
1
2
3
4
5

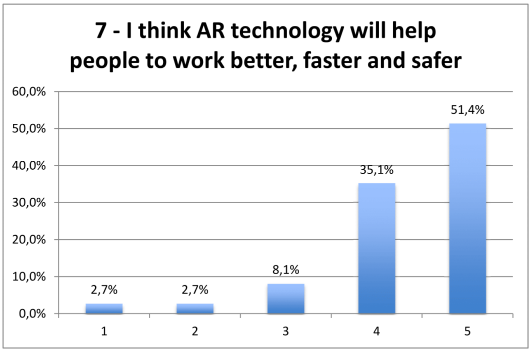
(d)



(e)



(f)



(g)

Figure 3.24: Augmented reality survey results

back received from different types of users, we can state that the use of AR in the industry domain, especially in the branch of *training-on-the-job*, ensures a shorter execution time of a task. The use of a HMD (Head Mounted Device) guarantees the enormous advantage of being able to have both hands free, a key condition in performing manual tasks. The use of the Vuzix M100 has allowed us to quickly develop the application because it allows one to install Android native applications; The Vuzix also provides a SDK (not available for Unity) with specific libraries but most of the features are already exposed. For example, one can use the sensor of gestures, using predefined gesture because they are already mapped with Android basic actions (back button, etc). Moreover, developing an Android app for the chosen devices can be compared to the development of an app for tablets or smartphones, of course taking into account different type of interaction between the user and the application. Even tough we witnessed to the aforementioned positive aspects, emerged different drawbacks that can be summarized as follows: (i) The Vuzix overheats and thus warms the area around the ear. (ii) The hardware of this device is not very performing. Therefore, an AR application can becomes slower, especially using the multi-target tracking or managing heavy 3d models. Hence, the camera allows the recognition of the target by only a limited distance (about 2 meters). The same application running on a latest generation smartphone guaranteed a much faster and performing recognition thanks to a more powerful processor and a higher-resolution camera. Besides, the battery duration is very low (up to 1 hour), this represent a great impediment for a daily usage of the device in normal operational conditions (iv). The video see-through display is too small, hence it has a limited field of view. This oblige the developer to find a right balance between the dimension of the text and the contents. The smaller is the text, the less the text is readable. All these aspects worsen the quality of the experience and may lead to a lengthening of the execution time of the task. However, the rapid development of technologies will allow to increase the quality of the hardware at the same cost providing enhanced performance.

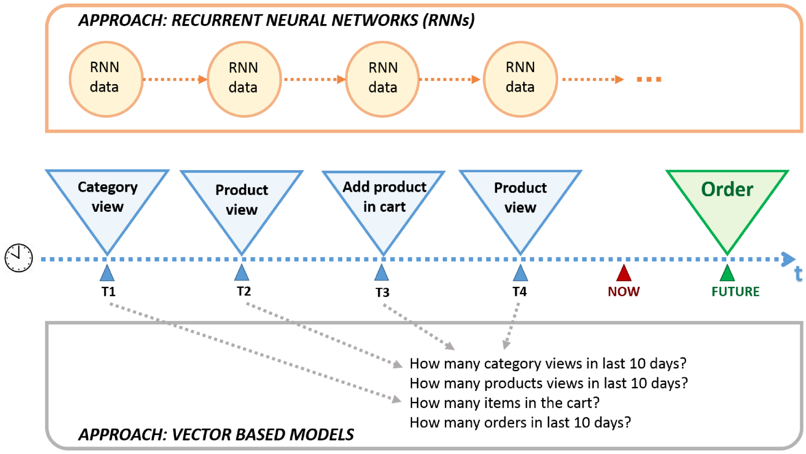


Figure 3.25: Two different approach to model consumer histories: Vector-based methods and RNNs models

3.3 Consumer Evaluation in web data analysis

The study of user behaviour in e-commerce sites can be exploited in many ways. For example, it can be used as a recommendation system, or to propose offers in real time or to detect fraud [81, 48, 53]. Each of these solutions can be implemented by capturing users' behaviour inside the web shop, i. e. by memorizing the history of the interactions that the user makes during the navigation. The aim of this project was to create a system of recommendations based on a Deep learning approach, able to learn from the behaviour of users in an e-commerce site (the actions they carry out within the site) in order to predict for each visitor, some products related to its navigation in real time.

Thanks to the study of the state of the art (related works) it has been understood that the approach most used to model consumer histories is based on machine learning techniques that operate on feature vectors of fixed lenght as input (Figure3.25). This approach is complex to develop and not suitable for problems closely related to the time variable. For this reason, an approach based on RNN (Recurrent Neural Network) has been chosen, where extensive feature engineering is not necessary and also easily adapts to contexts with a high time dependence. Experiments have been done on an Italian e-commerce website for the sale of bicycles (products, spare parts, accessories and clothing) that contains thousands of consumer histories (the exact number cannot be explained for business reasons).

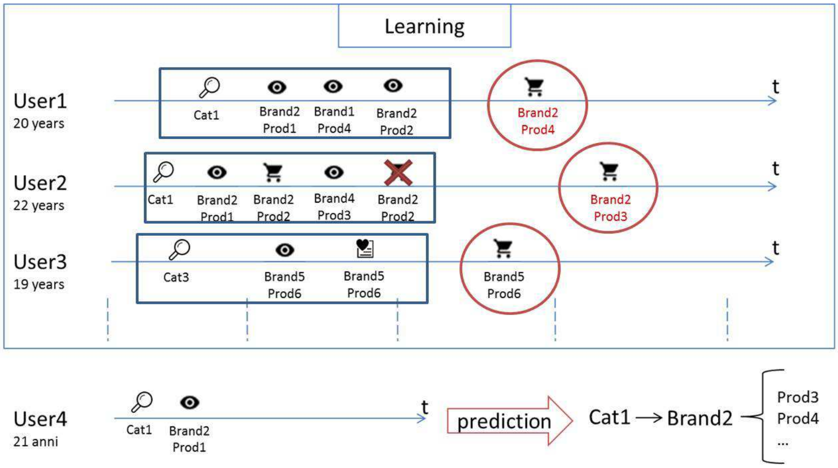


Figure 3.26: Description of learning system through user sessions

3.3.1 System architecture and methods

Context description

The Figure 3.26 describes the approach that has been used to implement the system of recommendations. User sessions are considered. A session represents the set of actions that a user takes from when he logs on to the e-commerce site until he exits it (by inserting the url of another site or closing the browser page). The actions taken into consideration are linked to the click flow that the user makes. Below are some of the possible actions (also shown in the Figure 3.26):

- searching for a category;
- display product page display;
- adding a product to the Favourites list;
- addition of product to cart.

Each action is associated with a timestamp so it is poddible to reconstruct the history of each session. Thousands of user sessions that have loaded at least one product into the shopping cart have been recovered . These sessions allow you to assign an "output" (the product in the cart) to an "observation" (the sequence of actions performed in the session). These sessions were used for the learning phase of the RNN network. At this point the network is able to predict the category or brand to which a user is interested, simply by monitoring the sequence of actions that it has carried out up to time t. With each new action performed by the user, the network will make a new prediction by taking in input the sequence of updated actions. A recommendation system is now able to suggest the best selling products within the Brand or Category of interest.

Software components

Magento Magento is an Open-Source software that gives you the possibility to create your own e-commerce. Was created by Varien in 2008 and is built using the Zend Framework. Currently this software is distributed and published under Open Software License version 3.0. Magento offers powerful marketing, search engine optimization, and catalog-management tools. It offers a variety of plug-ins and themes which can easily enhance a customer's experience. Magento extensions are modules that extend the functionality of the base platform, and can save you time and money otherwise spent on custom development. Trusted marketplaces offer thousands of free and paid extensions to bolt onto your website for features such as enhanced reporting, product filtering, specialized order import/export, personalization, sophisticated search, drop shipping and more.

Piwik Piwik is a web tracking software that analyzes your site access and generates statistics. After Google Analytics is one of the most widely used analysis tools on the network. Below are some of the main functions:

- Statistics on visits to one's own websites: geographical location, visit time, operating system, source site, residence time, etc.
- Establish website targets and analyse them: actions such as downloading specific content, subscribing newsletters etc.
- Information on the speed of data transmission of a website: how fast is the content of a website uploaded.
- Analysis of how to use a website's internal search function: analysis of search terms typed by visitors in a website's internal search bar

Unlike Google Analytics, Piwik leaves the user with control of his own data, storing the information he collects in a mysql database. An advantage in terms of privacy because it allows the user to have full control of their data.

Tensorflow TensorFlow is an open source software library for numerical calculation using a data flow graph approach. It is designed to make parallel computation available on multiple CPUs or GPUs, both on a single machine and in the distributed one. TensorFlow was originally developed by researchers and engineers of the Google Brain Team for research purposes in the field of

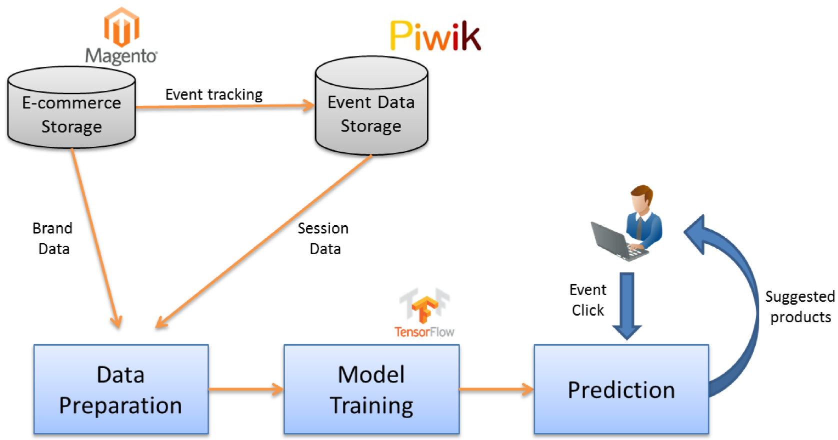


Figure 3.27: Description of the recommandation system dataflow

machine learning and deep neural networks, but was designed with a more general approach so that it could be used in many other different computation applications. It has a number of APIs, including the lowest level, TensorFlow Core, which allows complete control over programming. TensorFlow provides interfaces for different languages, including python and C/C++ with full support. In the specific case of this project it was decided to use the interface python.

System architecture

The Figure 3.27 shows the structure of the project and the steps needed to create a system of recommendations based on RNNs networks (more precisely the LSTM network).

Data preparation Before any prediction algorithm can be applied, it is necessary to extract and organize the data in such a way as to create a usable format from the deep learning models. The first objective was to retrieve raw data on user behaviour within the e-commerce site. A first solution was to take advantage of the logs coming from the magento platform, but it was too complex to extract data of interest (displayed pages, categories, products, brands, loading in the cart) because the logs were extremely verbose. A second solution was that of exploiting the data stored by Google Analytics (one of the most used tools for obtaining statistical information on its website), unfortunately in its free version is not offered access to raw data but can be obtained (through special APIs) only aggregated views of data, unsuitable in this context. Finally, it was decided to use the Piwik platform, because it gives you full access to the raw data used for web-analytics. A dedicated server has been set up to install Piwik and a Mysql (Event Data Storage) database to store all data. Piwik offers a special extension for e-commerce developed in magento able to automatically identify the typical structures and behaviours of an e-commerce site (products and categories visited, loading of product in the shopping cart, purchase of a product etc...). A Python script has been implemented that can extract the data of interest from the numerous internal tables of Piwik. Of the thousands of user sessions, only those that featured a product loaded in your cart (whether purchased or not) have been extracted. Information about the brand of products in the web-shop has been added to the extracted data. This information was not available from Piwik, so it was extracted directly from the Magento platform (Brand data). In the chapter experiment and results, the data structures to be inserted in the deep learning algorithm will be detailed.

Model training In the training model, after preparation, data was used to educate the simple but powerful RNN architecture with LSTM-layer. The model has been implemented in tensor flow using the bookshelves in python language. With the data in possession, several experimental campaigns were carried out using data sets of different sizes. As will be explained in the chapter "experiment and results", the improvement in the quality of learning is proportional to the increase in input sessions used for training.

Prediction In this experimental phase, due to a limited number of available sessions, a recommendation system has not yet been implemented to be applied in production but numerous accuracy tests have been performed using a percentage of the available sessions. The most encouraging results are those obtained from the prediction of categories and brands. Several training models were created using different inputs. For each of them, the accuracy in predicting the correct output for which they have been trained was calculated. The final objective will be to implement an automatic system that can be used in production and that allows to suggest products linked to a category, brand or both, starting from a sequence of interactions of a user that is browsing the web shop. This aspect is innovative because it allows to offer personalized content not only to registered users, but also to users who access for the first time their handset.

3.3.2 Experiments and Results

The following is a description of the data transformation operations and the types of sequences used as observation and output. Finally, the accuracy values obtained from the various experiments carried out are reported, highlighting the increase in accuracy achieved by doubling the number of user sessions.

Data semplification Several transformations and simplifications of the content of user sessions have been carried out in order to reduce the variability of sequences entering the RNN network (observations):

- Reduced session length:
  - User interactions after loading into the cart of a product have been cut.
  - All input sequences have been reduced to a maximum of 50 interactions.
- Definition of macro-categories to merge similar actions:
  - Interactions with the pages of individual products and pages with product lists take different values depending on the type of experiment performed (see next section)
  - Interactions with order pages (to see and manage previous orders) belong to the "Order" category;
  - Interactions with the user account pages (create and manage account) belong to the "Account" category;
  - All other pages and interactions fall within the "Other" category.
- In order to have a greater number of sessions, all those in which there has been at least one loading of product in the shopping cart have been recovered (even if an abandoned cart has been found);
- If there is more than one product in the shopping cart, only the first of them is taken.

Selected observations and outputs Two types of observations were structured:

1. `Input_category`:
   - the pages with the list of products are replaced by the category to which they belong;
   - the pages of the individual product and any interaction within it are transformed with the name of the category to which the product belongs;
   - the remaining pages and interactions follow the rules defined above;
2. `Input_brand`:
   - the pages with the list of products are replaced by the category to which they belong;

- the pages of the single product and any interaction within it are transformed with the name of the brand to which the product belongs;
- the remaining pages and interactions follow the rules defined above

Three types of outputs have been structured where observations in the different experiments can be assigned:

1. `Output_category`: Assigns the name of the product category in the shopping cart
2. `Output_brand`: assigns the brand name of the product category in the shopping cart
3. `Output_cat_brand`: Assign the category and brand name separated by the symbol '_' (example: `category1_brand2`)

Results Experiments were carried out on 3000 and 6000 sessions (with loading a product into the shopping cart) of users in order to highlight the percentage increase in accuracy at doubling sessions. Three different combinations of "Observation" and "Output" have been applied:

1. Observation : `Input_brand`; Output : `Output_brand`
2. Observation : `Input_category`; Output : `Output_category`
3. Observation : `Input_category`; Output : `Output_cat_brand`

The 3.28 shows the accuracy trend in the training and validation phases. The experiments were carried out by applying 200 learning epochs, i. e. 200 consecutive learning cycles. At any given time, the RNN network uses 90% of the training sessions and the remaining 10% to test the network. The training cycle curve tends to be 100% accurate because the network continues to train on the same value sequences. The validation curve reaches its maximum value after n epochs and then stabilizes.

The table 3.3 summarizes the maximum accuracy values in the validation phase for the various experiments carried out.

It can be seen that the highest values have been achieved in the combination of `"input-brand_output-brand"`.
In the combination of `"input-category_output-category"` you get a good increase in accuracy at doubling the number of sessions so you can expect a rapid improvement in accuracy in the case of more sessions. In the combination of `"input-category_output-category-brand"`, although the accuracy levels are on average low, there is still a good increase as sessions double. The latter

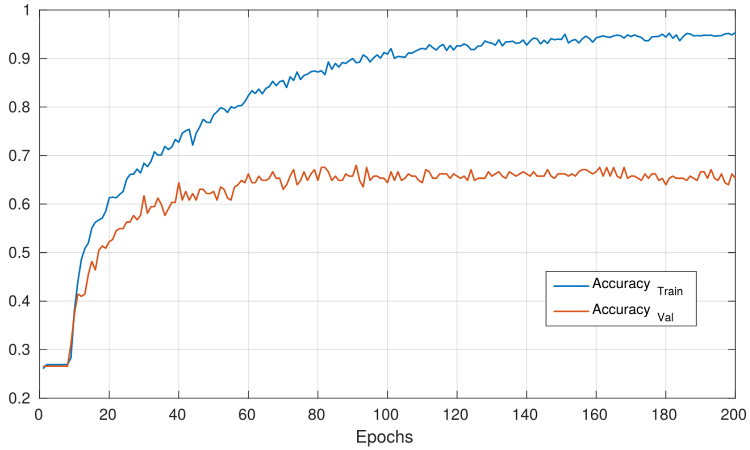


Figure 3.28: Description of the recommandation system dataflow

Table 3.3: Accuracy obtained in experiments with 3000 sessions and 6000 sessions and the increase obtained by doubling the sessions

Observation	**Accuracy 3000 sessions**	**Accuracy 6000 sessions**	**% Increase**
input-brand_output-brand	0,68	0,71	3,8%
input-cat_output-cat	0,48	0,60	25,2%
input-cat_output-cat-brand	0,20	0,22	14,3%

result was predictable because the number of output combinations is significantly higher because it includes both the category and the brand. In general, an increase in accuracy values can be observed as sessions increase. Experiments show that more sessions are needed to implement an applicable system at a production site. The combination of `"input-cat_output-cat-brand"` allows the recommender system to offer more specific products. A possible alternative solution is to implement a system consisting of the union of the first two combinations (this way the same result can be achieved).

Chapter 4

Conclusions and Future Works

In this thesis has been studied the analysis of behaviors in 3 different areas and for each of them available were used to improve the context and offer new approaches and solutions to the problems faced.
The HDOMO project, in the ambit of AAL, proposes an innovative idea of an interoperable embedded intelligent system where different low cost intelligent sensors can analyse human behaviours to promptly respond to the needs of users and to obtain statistical data useful for future processing. The main target was the development and the implementation of a platform for AAL applications that starts from the integration of existing platforms and extends the concept of SO interoperability. The project was financed by Marche Region and faces the challenge of developing different layers of abstraction using different SOs to obtain a very accurate alarm system for AAL. The data management system has been tested by simulating a house equipped with all the SOs HDOMO defined in the project. The aim was to check the behaviour of the elderly people inside the house in order to identify anomalous behaviour and implement procedures for the safety of the person in a short period of time. Several tests were carried out also modifying the frequency with which the system interrogates the various objects (for example every 5 s). The tests highlighted problems relating to the management and storage of data, because the system is arranged to simultaneously monitor hundreds of items without slowing down. It is important, in the real implementation, to considerate the performance analysis of a system connected to hundreds of domotic homes, which therefore must be able to simultaneously handle a greater number of SOs. Considering, for example, 50 items, about 10 Gb will be produced in one year, so that the use of scalable architectures for storage, analysis, and sharing of large amounts of data is necessary. This is one of the future test. Another possible future study concerns the possibility of replacing machine learning techniques with new deep learning methods as they are very suitable for dealing with problems with high temporal dependence.
In this thesis a new Augmented Reality application based on the use of AR glasses was presented. The work was conducted within the activities of a joint

venture between an academic institution and Intermac enterprise, giving an added value in terms of technological transfer. By testing the application in real case environment (with both experts and non experts users) it has been demonstrated how such application can really ease the operational task that field workers have to performing during their daily activities. Bearing in mind the rapidity of changing of the mechanical components, as well as the necessity of delivering the assembling instruction all over the world, the potential of this kind of application is huge, since it can be uploaded on demand with respect to the specifications of each single enterprise. Actually, the training of the workers is made just with the aid of paper book or of long and expensive training courses. The use of AR applications instead will allow to overcome this issue, be replacing, or at least reducing, the time and the costs of training. This test was also useful as a benchmark for the research community, since there was the possibility to test with different users the weakness points of wearable devices that, due to the actual technological limitations, are many. The interaction with the UI is already not advanced and it requires more investigations in order to make the interaction touch less with the aid of sensors or input commands based on voice recognition. Moreover, the low performance of the camera do not allow to get a robust tracking of the scene. The use of QRcodes or artificial marker should be replaced with more advanced system of environmental interpretation and extended tracking. Finally, it is worth to note that human limitations arose, mainly due to the diopters and the ergonomic of the faces, different among different users. A closer investigation is required in this direction, in order to develop solutions that could fit to the majority of every worker.

In the Consumer Web area, the study of user behaviour during navigation within an e-commerce portal has been studied in depth. The objective is to exploit and process the data extracted from a web-analytics tool to build a system of recommendations that can suggest products of interest to the user, based on his previous browsing experience. This is possible thanks to the study of thousands of sessions of other users and the identification of sequences of interactions similar to those stored in the past. The system uses deep learning techniques to learn from user interaction sequences. This type of approach is very suitable and performing in contexts with a strong temporal dependence, unlike machine learning techniques (in which it is necessary to extrapolate specific characteristics in order to classify user behaviour). Numerous experiments have been carried out to identify the best performing data to be used in the learning phase. Of all the thousands of sessions available, only the sessions in which a product was loaded into the shopping cart were used, so as to have a goal to assign to the user's session. The results obtained show the need to have a much larger number of user sessions in order to implement a system of recommendations that can be used in production. Despite this, there has been an increase in accuracy as sessions have doubled, so the possibility of significantly improving results by tripling or quadrupling sessions is assumed. Other possible developments are related to the possibility of using predictive unsupervised approaches in order to use the large number of sessions that are currently discarded.

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