A WEARABLE IoT DEVICE FOR USERS WITH MILD COGNITIVE IMPAIRMENT NEEDS

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TORINO, JULY 2016

ABSTRACT

This project constitutes a technical proposal related to a system of tele-assistance for elderly and disabled people. The target users of the system usually reject new technologies as they considered them an imposed elements which interfere their daily life. The tele-assistance device presents several advantages since it can be easily used and due to its reduced size it can be placed either on any garment or complement such a belt or a wallet, thus becoming a wearable element that does not interfere on the user daily life.

By means of the service offered by the system, it is sought to guarantee a quick and effective service of attendance by means of the identification of possible emergency situations throughout users' daily life. For its functioning, it has been utilized one of the technologies already used for the localization of devices that is based on mobile networks. By using the device and knowing the patient's location, it will be possible to offer a quick and efficient attendance in the event of being required either the patient is inside or outside home.

The project also includes a theoretical study about **Energy Harvesting, a** concept which is considered a keystone to improve power life in this kind of **wearable devices**

ACKNOWLEDGMENTS

This project is the result of the collaboration of two entities of Turin city.

On the one side the POLITECNICO DI TORINO, represented by Professor Mr. Fulvio Corno. On the other side, CARETEK Company, represented by Mr.Luca Feletti.

First, I would like to thank my supervisor, Prof. Corno, for providing me with an incredible opportunity to work with a company in order to finish my studies. I also thank Mr.Corno for being a great mentor and for providing exceptional support whenever I needed it.

I thank all the working team of the CARETEK Company for treating me exceptionally well since day one, and offer me a satisfactory first contact with the business world. I am especially grateful to Giuliano Manciagli; Davide Sachetto and Davide Mantoviani, members of Mr. Luca Feletti's working team since they have helped me with their ideas and knowledge. The six months that I have spent developing this project with them were one of the best experiences in my life in Torino.

I would also like to thank all my friends and family, in particularly my mother Pura for being so supportive and enthusiastic about learning. Without her, all this experience of studying abroad would not have been possible.

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2) INTRODUCTION

According to the article published by World Health Organization about Elderly people, "At world level, the population's segment that is experiencing a quicker growth is the one related to old people. The proportion of centennials is the one that supposes a great increment, followed by the group of people aged 80 to 99." […]."Mortality accelerates as the decades of the life lapse. Starting from the 25 to 34 years of age, the rates of mortality for all the causes are duplicated with each successive decade, as much in men as in women, in almost all the countries."[1]

From the increase of mortality two important facts can be deduced:

- The high grade of current vulnerability in elderly men.
- The earnings social potentials that could produce programs and effective solutions for the prevention of the main causes of mortality.

Great part of mortality is consequence of the lack of communication between the old patient and a medical service or any other helper who are able to offer a quick and effective assistance service in the event of emergency.

Main causes of mortality, such as cardiovascular illnesses, precedes to the patient's fall. This fact, together with the reduced mobility that elderly people usually present, stresses the negative role of the falls in elderly daily life.

[1] http://publications.paho.org/spanish/PC_590_Tercera_edad.pdf

“Regarding elderly, almost 40.000 deaths because of fall occur in the European Union. People from 80 to 90 present a mortality index six times superior than the one regarding 65-79 years old adults, because there are more probabilities for them to fall and even they are also more fragile than the other adults”.[2]

Elderly population segment means an important economic impact regarding sanitary services. Elderly people usually are related to higher medicine and medical services consumption due to their great vulnerability.

For all the mentioned reasons, elderly people constitute a vast and important population's sector in most of developed countries.

Due to elderly people vulnerability, throughout last decades, there have been implemented different services aimed to reduce mortality and improving sanitary assistance in case of accident or emergency. Among the different solutions that have been developed, it is worth mentioning tele-assistance services which definition comes from answering two relevant questions:

-What is tele-assistance? Tele-assistance is a concept generally applied to personal assistance using approaches that comprise the use of a phone network medium as connection tool and technological devices as interface. These services are able to respond to emergency situations such as insecurity, loneliness or social isolation through the provision of preventive supervision, information, social resources and supportive means in order to deal with them.

-Who is tele-assistance addressed to? Tele-assistance service is a preventive service for helping elderly people who require permanent attention due to their disability, social isolation, age, illness or presenting psychosocial or physical risks.

[2] http://www.msssi.gob.es/profesionales/saludPublica/prevPromocion/docs/caidas.pdf

3) PROJECT JUSTIFICATION AND OBJECTIVES

3.1) PROJECT JUSTIFICATION

Generally a tele-assistance system offers a service through a portable device which interconnects wirelessly with the user's home phone. This device is very easy to use by means of a button and do not interfere in the activities performed by patients due to its small size and simple installation.

The portable device has the necessary coverage to transmit an emergency warning from any part of a house. When the button is activated a call is made to a special attention centre from which skilled staff will take appropriate action. Besides, a tele-assistance system makes regular calls to clients' home to monitor and control patient situation. At this point it is important consider that this project is intended to collaborate in avoiding the restriction of the users' home access since it will provide access from other places and out home since the 25-30% of the accidents suffered by elderly people occur outside the user's home.

Almost every developed country has different tele-assistance services, public ones (provided by public health services) as well as private ones.

Generally, elderly people reject the use of new technologies and any other element imposed by someone else since they consider they interfere in their daily activities. In this sense, besides overcoming indoor coverage limitation there is a need to design a product, which usage and installation do not interfere with daily routine. This way the project will get as result a small-sized device which usage instructions are accessible to different users.

The project presented has as foundation a research about Adamo system tele-assistance service provided by Caretek Company.

Adamo System offers a complete tele-assistance service for the patient at home by providing an alarm system connected to a specialized centre that will attend his demands of assistance effectively and at real time.

Among the main characteristics of the service, they highlight the detection of users fall, their location in the house and the control of the activity and inactivity of the users.

Adamo system offers a service of tele-assistance that does not cover certain aspects such as the coverage outside home. It is also remarkable that there is a need of a wearable device, easy to use and practically transparent, for implementing the service to the user implements the service. Therefore, the development process described in this project considers as a starting point the study and the development of a prototype that is able to cover the above mentioned aspects, starting from the characteristics that Adamo service already offers.

3.2) OBJECTIVES

The main objective of this project is to initiate a process of research and development that seeks as result a system that in addition to offer the basic tele-assistance services provided by Adamo system, covers different aspects that are unexploited today by tele-assistance such as the following:

- **Outdoor** as well as indoor coverage. This way it is possible to monitor patient while performing outdoor activities.
- **Wearable** system that could be worn along with different garments and clothing such as a belt, inside pocket, etc.
- Small-sized -no terminal needed- and easy to use system, allowing the patient to use it without needing to avoid to know how it actually works.

Besides, the project covers some basic features already included in Adamo system that are considered of great importance:

- Development of a fall detection system.
- Alarm system for abnormal temperature detection.

In parallel to Adamo service improvement, the study of **Energy Harvesting** is also defined as an important objective: "***Energy harvesting*** *(also known as* ***power harvesting*** *or* ***energy scavenging****) is the process by which energy is derived from external sources (e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy),* *captured, and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks"*[3] […].

This concept will play a key role in the implementation, in future lines, of autonomous tele-assistance devices. So the objective of the project can be synthesized as the study and development of possible improvements in Adamo tele-assistance system while new energy harvesting techniques are investigated.

4) STATE OF THE ART

In this section they will be described some systems similar to the one proposed in this project and also it will be developed a brief analysis of the technology that is the basis of them. Their features will be observed and some basic ideas will be considered to improve the future design. Besides, their limitations will be identified considering as a starting point the objectives of the project.

4.1) CONTEXT

As described above, the main objective of this project is to build a tele-assistance prototype for elderly or disabled users thus allowing them to enjoy outdoor coverage and power efficiency.

Considering it as a key foundation, three basic concepts are defined to complete the scope of this thesis:

- **Location systems:** The prototype must locate the user inside and outside home. Therefore, in this section some products provided by different location systems will be analysed. There are several methods to obtain individual location, so the following analysis gives an overview of the main systems and solutions.
- **Tele-assistance:** The main feature of the prototype is to provide assistance to a particular society group. In this section different tele-assistance services are

[3] Wikipedia

verified in order to identify existing market products and the advantages and disadvantages that are identified as emergent from the developed prototype.

- **Power saving:** From a theoretical viewpoint, a general study about different power saving techniques in existing IOT devices will be developed as well as Energy Harvesting concept will be studied for helping us to to define future lines for forthcoming systems, optimizing their power usage.

4.2) STATE OF THE ART ANALYSIS

4.2.1) Location technologies

The services offered by a location system are based on obtaining the geographic location information from a user by means of a personalized way.

To do this, they will be used the following technologies: Geographic Information Systems (GIS), positioning technologies and network communication technologies to transmit information to an LBS (Location Based Services) application that can process information.

LBS applications intend to ensure geographic real-time services as in maps or routing services.

Among positioning technologies, there are those offered by a satellite system (GNSS) and those implemented directly on the mobile network operator (GSM).

Following, there will be described the different positioning technologies in order to identify the advantages and disadvantages derived from them.

4.2.1.1) Satellite positioning technologies: Satellite System for Global Navigation (GNSS)

4.2.1.1.1) Introduction

A GNSS system is composed by a constellation of satellites used for positioning and location anywhere on the planet. Satellites allow us to determine the geographical coordinates (latitude and longitude) as well as the altitude of a specific point.

4.2.1.1.2) Structure of a GNSS System

A GNSS system has three different blocks or segments:

1) **Spatial Block:** formed by the constellation of navigation and communication satellites of this system.
2) **Control Block:** located in terrestrial stations whose function is to ensure smooth operation of the satellites by means of configurations and corrections.
3) **3) Block User:** located in receivers making use of positioning services. It allows geographical coordinates calculation.

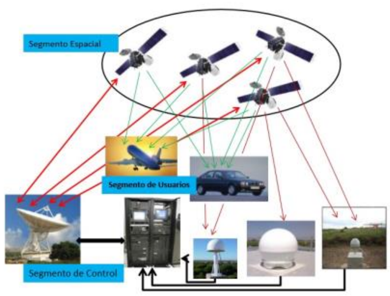


Figure 30: System Gnss arquitecture

4.2.1.1.3) Basic functioning of a GNSS system

Satellite radio-navigation functioning is based on obtaining an Earth surface position, through calculation of distance among that position and at least three satellites that are set in known location.

Satellites transmit synchronization signals containing their position and also the time those signals where transmitted. To guarantee right synchronization, all the satellites of the constellation use the same atomic clock.

The receiver is capable of calculating the elapsed time since the synchronization signal was transmitted for each satellite thanks to an internal watch. By obtaining the "signal flight time" of each constellation satellite the receiver position is defined.

To guarantee adequate accuracy and features, some parameters must be taken into account such as number of satellites, their visibility and the number to select.

4.2.1.1.4) GPS System

The global positioning system is currently the only GNSS system providing whole planet coverage. It was created and developed by USA Defence Department to determine positions on the globe. It consists of a 24-satellite constellation orbiting to 20.200 km of height with synchronized trajectories in a way that cover the entire Earth surface.

When a receiver need to know its position, it connects automatically to at least four network satellites which send back their synchronization signals. By means of these signals, the receiver device synchronizes the GPS clock and calculates the time needed for the signals from the satellites to arrive to the device. Once the elapsed time is calculated, it is obtained the distance of each satellite from the measured point. As the satellites positions are known, the receiver is fully located.

As seen in the features of most analysed devices in the state of the art section, outdoor location is assured by implementing a GPS receiver in those devices.

However, two factors must be taken into account if this technology is intended to be used in the prototype:

1) To assure a device positioning, it is necessary to have direct sight with the satellites. This way, adequate accuracy is obtained in outdoor environments, but it can be an ineffective technology if the device is inside a building or structure blocking correct reception of synchronization signals.

2) GNSS systems high power usage. During the entire connection and time measurement as well as time and distance calculations s among satellites and the receiver, it must remain connected to keep synchronization. This connection is currently done at low speed causing high battery consumption.

This two factors may have two clear disadvantages in comparison with alternative positioning systems because the goal is to guarantee indoor coverage as much as outdoor coverage considering that due to the small size of the device, a low capacity battery will be used.

4.2.1.2) Location technology provided by network operator:Global system for mobile communications (GSM)

4.2.1.2.1) Introduction

GSM is a communication system for digital mobile telephony. GSM services provide connection via a phone with other devices, allowing communication among them. It functioning is based on dividing up available frequencies spectrum. Each operator is assigned a delimited bandwidth which has all frequencies available to use.

4.2.1.2.2) GSM network simplified architecture

Following, there will be described the planning and key elements of a GSM network in order to observe some operation differences in comparison with satellite technologies and to understand the architecture used by mobile networks:

BS-Base Station

BSC- Base Station Controller

Some BS + BSC – Base Station Subsystem

MSC – Mobile Switching Centre

NSS – Network and switching System

HLR- Home Location Register

VLR – Visitor Location Register

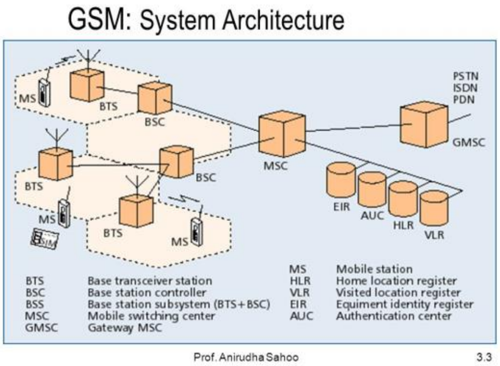


Figure 31: GSM System Architecture

In bandwidth terms, it would be non-viable the usage of a single aerial. A GSM network performs territorial separation thus obtaining several areas called cells. Each cell contains an aerial, a BS that guarantees coverage in all cell surface.

Adjoining cells use distinct frequencies to avoid interference among them. However, to seize available bandwidth effectively, reuse of frequencies in non-adjoining cells is allowed.

The BSC in each BS acts as a proxy between the mobile network and the user while managing power among terminals and BS and dividing up available frequencies.

A configured BS collection by using a BSC make a BSS up which provides a link between a user terminal and a GSM system's network main layer.

Obviously, a user can move between cells without losing the connection. This action is managed by a BSC and it is called *Handover*.

A BSC notifies the MSCs of involved cells (the cell to be left and the cell to be entered) and a terminal, to make the change from a BS to another.

A NSS allows call routing and data storage. Therefore it allows connection and transmissions required by a call.

A MSC is responsible for directing calls by using a BSC and the BS of the customer receiving a call.

The last elements are two registers:

-First, the HLR stores if a user belonging to a network is online or not, his available services and other features. If a user receives a call, the MSC polls the corresponding HLR for the terminal status of the number receiving the call and routes the call in case it is available.

-Second, the VLR contains subscription types and locations in a network of all active users, in that network segment, when a call is happening. If a user is registered in a network, the VLR contacts the user's HLR and verifies if he can make calls according to his subscription.

Although the described network it is strictly not implementing a positioning technology, it is appropriate to describe its architecture to have some knowledge about how it operates so that it could be used to get the position of an element connected to a network.

4.2.1.3) *Positioning using a GSM network*

By using a GSM network, a surface partition into cells is made thus assuring coverage inside each of them. Since the position of all BS cells is known, it is easonable to think that by using the mobile network it could be determined the position of a terminal in a more or less accurate way.

There are two different methods provided by mobile networks that allow to locate a device. Following, the most important ones are briefly described:

a) Cell-ID:

This first technique is the simplest of all. It uses location by cell. Each cell has an identification number to be distinguished from others. Therefore, when a terminal is connected to a BS, its position is determined by a cell area.

In other words, if the BS connected to the terminal is known then the area in which it is located will be also known, as it is under the same coverage area.

The accuracy of this algorithm varies as cell sizes do, depending on cell radius. So, in urban environments with high population density, cell radii are 150-250 meters long, providing a quite adequate accuracy for location systems. However, in rural environments, there can be found cells of several kilometres in length. In these cases, the accuracy offered by this method would be quite ineffective.

a) E-OTD (Enhanced Observed Time Difference):

This method requires synchronization among the different BSs and its operation is based on measuring the time a signal takes from the terminal to another BSs. Thanks to the difference of these times to each BS, the position of the terminal is estimated.

The accuracy of this method comprises a distance from 50 to 200 meters.

a) AoA (Angle of Arrival)

Using this method, the terminal position is calculated thanks to the signal angle during arrival to the BS aerial. At least, it is needed 2 BSs to get proper accuracy.

The main inconvenient of location by means of AoA is the need of equipping aerials with special receivers and additional equipment thus raising costs.

a) RSS (Received Signal Strength)

The last algorithm to be presented considers the strength of received signal and works for one BS as well as for many of them.

From the known BS position, by measuring the strength of the signal receiving from the terminal and knowing the propagation losses in open space, it can be estimated the distance from the BS to the terminal.

Considering a BS, the estimation defines a ring inside the cell with all points matching the level of signal measured.

If the method is applied using various BSs, the intersections among those define the terminal position.

The choice of the technique to be used is defined by a network, being totally transparent for users.

There are networks that implement some of these techniques while the choice of one of them is defined by several factors: urban or rural zone, quantity of obstacles in a zone, types of antenna; etc.

One of the main advantages of location by using a mobile network is its robustness. Thus in almost every place on the planet there is an operational mobile network that assures coverage for its customers. So, a user location is guaranteed as long as he has coverage.

Making a comparison with satellite system, it is observed the following two facts:

- Despite it offers lower accuracy than satellite systems, the use of mobile network can be helpful in urban zones with very high population density or high number of obstacles, making connection to satellites difficult.
- Both technologies require power consumption, but the use of a mobile network reduces greatly connection time and battery consumption in comparison with satellite connection.

Finally, it will be mentioned an extension of GSM networks. Networks using the following service allow location via one or more of the mentioned methods.

4.2.1.2.4) *General Packet Radio Service (GPRS)*

This is an evolution of GSM networks and it is based on data transmission via packet switching.

GPRS allows several services such as Wireless Application Protocol, SMS, Multimedia Messaging System (MMS), internet and email, etc.

To set a connection of wireless GPRS, the user should specify an APN (name of access point) and optionally user's name and a password.

The transfer of data in a connection GPRS is measured by the volume of transmitted information, differing to the communication through commutation of traditional circuits.

Once explained the main techniques employees for the obtaining of the position of an element, there will be analysed different products that offer localization services and user's pursuit or device by using some of these techniques.

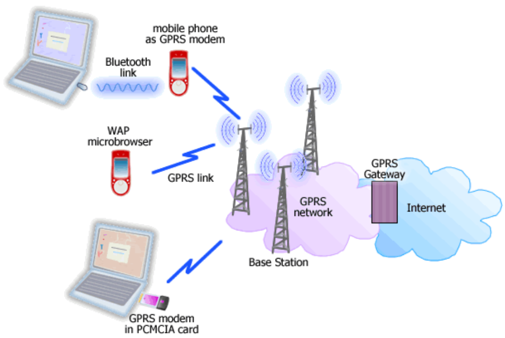


Figure 32: GPRS System Architecture

4.2.2) Location and tracking products

In this section there will be described location systems considered as important in the scope of the designed device.

Most of these products use global positioning system (GPS). That system uses different satellites providing as major advantage a high-accuracy location. However, the main disadvantage that could affect the satellite technology for this project is energy consumption.

Next, there are outlined the main products of location/tracking systems:

1) PocketFinder Personal Outdoor GPS Trackers

This first range of products offers a complete solution for tracking and monitoring of:

- Children
- Adults
- Pets
- Vehicles

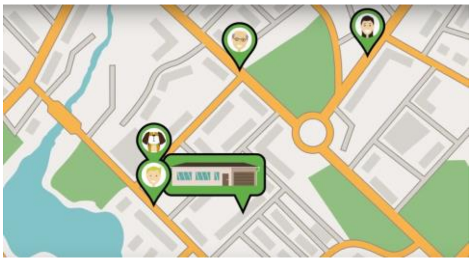


Figure 33: PocketFinder map

On the official website there is a video available explaining how the system works[4]:

The system is based on a device connected to the company own network via satellite.

The main features are the following:

- Use of GPS technology for element outdoor tracking.
- Location representation in Google Maps, at a rate of two minutes.
- Monitoring with Smartphone, Tablet or computer. (**Mobile Apps & Web Portal App)**
- Required service subscription to have access to the monitoring device.

[4] *https://www.youtube.com/watch?v=CWhPiRH5hYE*

- Alarm system configured by the user (vehicle speeding, entering and leaving defined zone).
- Alarm notifications via SMS, email and popup notifications in mobile app.
- Device motion logs with 60-days duration.
- Small-size design, rechargeable and easy to install (inside a pocket or pinned to any garment or accessories).
- Power-saving system (device active only when in motion).

The technical design specifications are the following:

Pocketfinder GPS Tracker Specifications

- Dimension (approximate)
- Width: 2-inches / 5.08 cm
- Height: 2.6-inches / 6.51 cm
- Thickness: 0.875-inches / 2.22 cm
- Weight: 1.4 ounces / 39.7 grams
- Operating Temp: -40°F/-40°C up to +185°F/+85°C
- Battery: Lithium-ion CC/CV 800mAh, 240 hours standby
- Charger Adapter: 110v – 240v, US plug
- GPS/A-GPS
- GSM cellular (quad-band)
- Made in USA

Figure 34: Pocket Finder GPS device

This first product offers a first prototype to people location systems. Although it is out of tele-assistance systems scope, there are common points between Pocket-Finder device and the prototype to develop.

Facts to highlight:

- The product design, stressing design simplicity, small size and easy installation in different garments.
- Existence of an alarm system, although in case of Pocket-Finder this is for notifying different types of emergency.
- Outdoor coverage.

Nevertheless, there are also certain features that are far from this project prototype´s objectives and provide some disadvantages:

- Use of GPS system, which increases device power consumption despite it counts with a power-saving system.
- Need of a computer, Tablet or Smartphone to perform device monitoring. In a tele-assistance service, patient monitoring is completely out of user and relatives' control since that responsibility is taken by a specialized service. The pocket-finder requires a user to access the system from any aforementioned electronic devices to carry out the desired tracking process.
- Generally, the device focuses mainly on control tracking without considering emergency situations that may require assistance.

Figure 35: PocketFinder system

2) GPS SmartSoles

This device has a significant shift in design compared to the previous one.

In this case, the device is incorporated inside a shoes insole, making its use seamless for the user except during recharge.

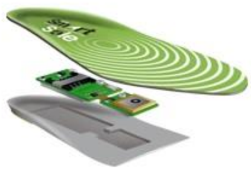


Figure 36: SmartSole design

Leaving design aside, this tracking system is similar to previous one, however its operation is simpler than Pocket-finder’s:

-It is also characterized as a system that provides outdoor coverage using a satellite system and requires a subscription to a mobile data plan to access the service.

-Once again, monitoring is performed by means of a computer, Tablet or Smartphone (with a specific mobile application) and will be carried out by the user or another person.

-It allows to register a zone that will define an alarm system that will be activated when the user enters or leaves it.

-In power terms, the system can be recharged wirelessly but has no added system to reduce satellite services consumption.

Figure 37: Smartsole logo

In comparison with Pocket-finder, there remains the same advantages (outdoor coverage, design) as well as the same disadvantages (high power consumption, Smartphone or computer needed).

The most important advantage of GPS Smartsole solution is its design, which is far better than the previous device, that is, it is more comfortable to have it inside the shoes insole than in an external element that must be pinned in some garment or accessory.

This new design can be useful to define future lines if the main objective is increasing ease and seamless usage for the user.

3) iTraq: The Cellular Tracking Device

This communication system offers a new shift in design as well as a new location algorithm not based on satellite communication.

This is the main reason that led us to consider its analysis as especially important.

This time, design is based on a plastic card with a hole that allows it to be pinned to garments or elements.

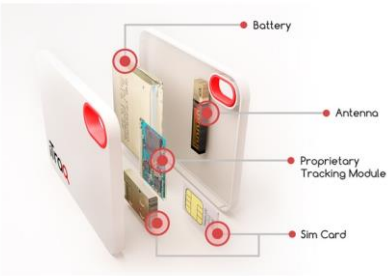


Figure 38: iTraq design

In comparison with previous systems, the most important difference lies in the algorithm that has been used to locate the card.

While the rest of tracking systems use GPS technology, iTraq has a standard functionality by using the mobile network, or what is the same, GPRS technology, providing coverage anywhere in the world where there is phone signal.

It also offers an emergency service as added value when rapid and accurate card location is required, which activates GPS system to provide more precise location in case of emergency.

The justification provided to use this technology and not directly GPS as the previous systems do is explained by the Company itself:

Is GPS-level accuracy really needed for these applications? We believe it is not. iTraq allows enough precision to let you know if your child is in school or on a football field, or if your car is at home or in the parking lot. ***iTraq does not use GPS****, but it does use a technology that scans cellular towers that are in proximity to determine its location. The more towers it sees, the more precisely iTraq can determine its location.*

Avoiding the use of satellite technology in the device means a huge reduction in power consumption, which brings closer to one of the thesis objectives: designing a small-sized device that will imply using a small battery and thus optimizing its usage.

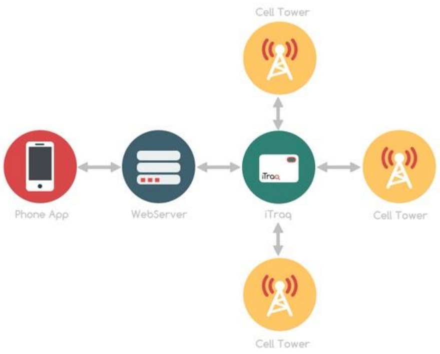


Figure 39: How works the iTraq system

Another point of the service to highlight, which is related to mobile network usage, is that there is no need to contract a specific data plan for the tracking system, it will be enough to have a preinstalled SIM card to perform tracking tasks. It remains as a system requiring a proprietary mobile application to perform device monitoring.

On the other hand, the service provided by iTraq card includes:

- Geo fencing: alarm system, activated when leaving delimited zone (configured by user).
- Wirelessly rechargeable battery
- Small size design (credit card size).

Taking into account the proposed prototype, the approach of iTraq device turns out to be very interesting since it offers the possibility of locating an element using a technology different from any other satellite technology.

Figure 40: iTraq main characteristics

4) Safe Link GPS:

The next range of products for people location has most of the described features so far including just one significant novelty in one of the models: the introduction of a system that activates an alarm in case of a possible fall detection.

The main features of the several devices provided are:

- Allow monitoring from computer or mobile device.
- Notifications system (Virtual Fence, SOS, low battery) via SMS.
- Real-time tracking of a user.

The three products offered in Safe-Link range are:

1) 2G Watch Tracker:

-Metallic watch with sleek design enabling location.

-Outdoor coverage by using GPS and complementary system for indoor coverage using wireless networks.

-Allows continuous tracking calculating the position every two minutes.

-Implements its own Geofencing system with alarm system.

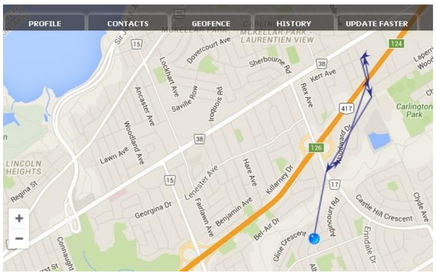


Figure 41: Safe Link monitoring system

2) 2G Personal Tracker: rectangular small-sized plastic device that offers the same features as the watch. It has a personal tracker that keeps the connection in case of failure of the other servers.
3) 3G Tracker: it is the most complete product in the range because it includes all services described by previous systems. It also includes:

- Implementation of a voice channel enabling the device to make calls to one or more mobile terminals in an emergency.
- Fall detection system, that allows when activated to send an alarm to the different pre-configured mobile numbers.

Regarding the design, no important new features are provided over previous solutions except related to the watch. Once again, there are proposed small size devices that can be placed on a belt, a shirt, or inside the pocket or any bag or suitcase.

The two additional features offered by the 3G Tracker are closer to a possible system of tele-assistance, although the alarm system is intended to be controlled by user's relatives or acquaintances and do not requires any specialized service that can offer assistance if required.

The fall detection plays an important role in any assistance system intended for elderly people since the possibility of an emergency voice channel greatly reduces the time for reaction.

5) Accuware products:

This tracking products range, even though it has no important novelties in comparison with the previous solutions, offers a well-suited location service using cellular technology (cell ID) and mobile networks (Wi-Fi), over mobile devices.

Unlike previous products, an external element is not required to perform the tracking and monitoring. Accuware allows the execution of all functions on the same user´s Smartphone without any other element.

Despite that, there is a range of recommended products that allows a more accurate location which are briefly described below:

a) Accuware Smart Tag:

- Designed for people and elements that require indoor coverage.
- Radio wifi, motion sensor and rechargeable battery.
- Wi-Fi signal continuous tracking, data storage service in the cloud.
- It allows indoor tracking with a tolerance of two meters.
- It has programmable button to define an alert system.

b) Combo Tags:

- Designed for people and elements that require global coverage (outdoor + indoor).
- Provided with wireless technology, GSM and GPS, motion sensor and rechargeable battery.
- Wi-Fi signal continuous tracking, data storage service in the cloud.
- Average accuracy:
  Indoor: 2 meters.
  Urban areas: 30 meters.
- Requires a mobile data plan for outdoor location.

These devices are not strictly necessary to access the different services since with user Smartphone or smart watch, the desired location can be obtained, due to the implementation of Accuware software.

The different services are divided into four parts:

- Tracking: location is allowed in both outdoor and inside a building, depending on the device used.

- Navigation: only indoor environment; specially designed to guide user in large buildings.
- Monitoring: provides recording and possible control of the motion and tracking of a user.
- Proximity: using wireless devices, different events will be handled when a user moves towards or away from a point of interest.
  Example: automatic check-in in a hotel when the user enters with his Accuware device.

It is observed that the presented range of products offers a complete solution that attends to new services such as indoor navigation or management of events according to user proximity.

6) Geo.Band

This system is defined as the smallest monitoring system in the market with a size of 40x41x13'5mm, waterproof. It provides outdoor coverage in about 133 different countries. The design is rectangular with a screen, and can be worn as a watch or key ring.

Figure 42: Geo band products

Geo.Band has all the features seen so far in a typical monitoring system:

- Notification/alarm system activated in case of:
  Falls or accidents
  Mobility overnight
  Prolonged immobility during the day.
  SOS button is pressed.

- It allows the creation of up to 5 security perimeters to know when a user enters or leaves one of them.
- Communication between Geo.band and a mobile terminal or computer via text messages. Its 1.3" screen displays messages, notifications and time.
- The monitoring can be performed on a map (as in the solutions seen so far) or with a smartphone camera and a proprietary application of Geo.band, by using the camera, the application displays a series of notifications with the navigation to find the person or desired element.

Figure 43:Geo band monitoring system

In the basic description of the product it is clearly informed that all communication between Geo.band and the user is done in an encrypted channel, making it unintelligible to unauthorized persons. By using its own APN, connection will only be granted to users that are configured.

Although the encryption of communication between a tracking device and a monitoring application is beyond the objectives of this thesis, it will be one aspect to consider in future lines for the implementation of more comprehensive and secure systems.

7) Smart-Track

To conclude this brief but comprehensive analysis about the most important and innovative systems, there will be presented personal tracking products of Smart-Track Company.

These products, apart from combining the features already seen in previous devices, offer new services that may be of interest either for the prototype of this thesis or for future designs.

a) STV 9 GPS watch tracker with software:

This product allows location using GPRS technology, monitoring via SMS or internet, and includes a button that is manually activated in case of emergency.

Monitoring via SMS is done by sending a link that the recipient Smartphone interprets using Google Maps platform.

Figure 44: STV 9 GPS design

The basic features of this device are:

FUNCTIONALITY

Get current location	GPS/GSM/Power LEDs
Tracking (by time interval, distance interval or smart mode)	GSM/GPRS simultaneously
Emergency alarm	Unit password setting
Waterproof design	Support mobile phone mapping (report comes with Google map links,
Geo-fencing control	Low Power notification
Battery power low alarm	Weight: 40G
Power management	Battery: 900mah
User report alarm	Optional dog collar

Figure 45: Functionality STV 9

b) STV 10 GPS watch tracker without software:

The next member of this series of products sets aside GPRS technology to implement a satellite tracking system.

It provides a more comprehensive service than STV 9, although if they are considered this project objectives, many of its functions are meaningless if they focus on a portable tele-assistance system.

FUNCTIONALITY

1. GPS location and tracking functions. Colorful display shows the current time, date, longitude, speed, direction, signal strength, power level etc. SMS & GPRS real-time tracking, support management platform.

- It can store phone numbers; you can press any one alarm number button to get help.

- Actively, when you call it, you will get a position. If you need location link function, it is also ok. As long as your cell phone supports GPRS function, then you can enter the link to check your position by Google map real-time.

- Searching for GPS signal after power on, then obtain your local time automatically

- Comply with your time zone on account of your location.

- A SOS button for emergency help.

- SMS comes with positioning link.
A cell phone, which supports GPRS, can access the link to check your exact location in Google map.
Listen-in automatically when you call the tracker.
Low power indication.

2. U-blox GPS ultra-low-power chips

3. GPS positioning function: Longitude and latitude altitude,

4. Location alarm

5. Compass function

6. Sports channels record

7. Network 850/1800/1900MHZ

9. MP3, MP4 player

10. Bluetooth 2.0

11. Standby: More than 120 hour

12. Language: English, Spanish, Russian, Turkish, Italian, Arabic, (English, Spanish, Vietnamese, Dutch, Turkish, Arabic, German)

13. Accessories: Mobile phone watch, stereo bluetooth headset, USB cable, battery, charger, user manual

Figure 46: Functionality STV10

Figure 47: STV 10 design

c) STV 11 Unit Portable Box – for kids, pets, parcels, hiking sports men

Basic tracking device that allows sending data through two different protocols:

1) SMS: oriented for personal monitoring (Smartphone)
2) GPRS: oriented for monitoring from a centre that receives data.

A very interesting point of this device is its power system. It is based on a solar recharge system so it ensures uninterrupted operation while there is sunlight. This concept of solar energy can be interesting for devices with continuous exposure to sunlight, such as the prototype proposed by this project, or for future designs where it can be combined a battery system with a solar recharge.

d) STV 12 Unit Kids Tracking Unit

This last model is a simplification of the previous models, oriented to children and which has all the basic functions already stated by previous location systems.

After analysing various tracking systems, they are identified their most common features, the usually used technologies and the extra features implemented by each one of the products.

The main features of the described elements are compared regarding the objectives for designing a prototype of this thesis are specified by the next table:

	Pocket-Finder	**GPS Smartsole**	**iTraq**	**Safe-Link (3G Tracker)**	**Accuware**	**Geo.Band**	**Smart-Track**
Design	Key ring, pendant	Shoes insole	Plastic card	Rectangular device (pager)	Smartphone, watch or pager	Watch, key ring	Watch, bracelet
Coverage	**Outdoor**	**Outdoor**	Indoor / Outdoor	**Outdoor**	Indoor/**Outdoor**	**Outdoor**	Indoor/**Outdoor**
Used technology	GPS	GPS	**GPRS** /GPS	GPS	**GPRS**/ GPS/ Wifi	GPS	GPRS
Additional software	Yes	Yes	Yes	Yes	Yes	Yes	No
Notifications& Alarms	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fall detection	No	No	No	Yes	No	Yes	No
Voice communication	No	No	No	Yes	No	No	No
Power efficiency	Only active in motion	No	No	No	No	No	Solar energy recharge in one of the device

The general insights obtained after analysing the previous table can be summarized as follows:

- Manufacturers opt for small size designs, and generally of easy usage on clothing.
- Outdoor coverage is generally provided via GPS technology, using cellular or wireless technology for indoor environments.
- Almost every tracking system has available a proprietary software to manage device monitoring.
- An alarm and notification system indicates the user of a series of events such as geofencing, low-level battery or SOS signal. However, not every tracking system has fall detection.
- Voice communication is present only in one of the analysed solutions.
- To manage power, different techniques are used but no device has an energy harvesting module.

The analysis of different tracking systems is not enough if we consider the extent of the objectives of this project.

It is observed that most of these devices perform constant individual location tracking to achieve some control. However, the little existence of a fall detection mechanism and the non-existence of a specialized centre to respond to alarms, moves away from the strict concept of tele-assistance.

Since the reaction time in an emergency is vital in terms of accidents in the elderly users, a more complete proposal must include a direct connection to a specialized centre dedicated to tele-assistance.

For this reason, it will be necessary to make a new analysis of devices and systems, strictly dedicated to tele-assistance, thus observing and contrasting the different techniques and algorithms used in relation to monitoring systems.

4.2.3) Tele-assistance products

Making a first contact with the state of the art of tele-assistance systems, there will be analysed different devices that allow notification and assistance in case of emergency and afterward moving to a brief description of some complete tele-assistance systems that are used nowadays.

The following devices differ from tracking systems in their main objective.

These systems are intended for people who may need help in certain circumstances.

1) i-Help CS299 (Aditech)

It is a tele-assistance device for fall detection.

Figure 48: i-Help CS299 product

The device is aimed to elderly, disabled people and in general for any individual who may require assistance, without sacrificing their autonomy and independence. The product design is shown in the attached image and its small size (73x53x18mm) makes it an easy-placement mobile device.

It combines three basic modules:

- GPS module: for the location of the device
- SIM module: to manage communication
- Hands-free module

It also has an electronic system that combined with a gyroscope and an accelerometer ensures the detection of accidental fall of a user.

In case of fall detection, some actions will be carried out:

- Alarm notification via SMS to previously configured numbers, communicating the GPS position, which can be viewed from a smartphone on Google Maps platform.

- - Emission of an audible alarm by the device, requesting help in proximity to the user.

The fall alarm will automatically be deactivated if the user is reinstated autonomously or deactivates the alarm manually.

In addition to fall detection, the person using the device i-help could make a phone call by pressing the button of the device to notify any emergency or need. The hands-free module facilitates communication in any call made via the device.

By using proprietary mobile application, the management and monitoring of the device is possible.

This first device offers a tele-assistance service, but again, there is no specialized service that can assist the patient in an emergency. The assistance shall come from family members or people owning programmed telephone numbers into the device, making it less effective depending on a case basis.

It has similar features to monitoring systems analysed, such as location using GPS technology or alarm notification via SMS.

However, while previous systems focus on a control and monitoring device, the main objective of i-help is the capability to offer assistance to a person in case of a fall or emergency.

2) Mindme:

The alarm devices "Mind Me" offer a simple and rapid solution to any type of emergency.

With small size design and easy placement -key ring, in a backpack, attached to the pants etc. - is a very interesting option for people who spend a lot of time alone, or can be found in risky situations without having nearby assistance.

The most important novelty compared to most of the analysed devices is the existence of a specialized centre that responds to the alarm signal.

So far, most solutions sent alarm signals to previously determined numbers although they did not need to know how to respond to an emergency.

The specialized centre is comprised of a team of people trained to manage and make decisions in cases of emergency, reducing waiting and response time when facing an adverse event.

In the image below, the most important features can be seen.

Features of Mindme Alarm

- Measures 60mm x 44mm (widest point) x 14mm and weighs 40 grams
- Uses a multi-network SIM chip (instead of a SIM card) - so long as a mobile network exists the device will remain connected
- Uses GPS to work out its location - accurate to about 10 metres
- Sends location to Mindme secure servers around every 3 minutes. 10 minutes when stationary
- Press the button and using GPRS the alarm connects quickly to Mindme's 24/7 Response Centre
- Two-way voice communication ensures the right help is available quickly
- Battery lasts up to 48 hours
- Simple to use charging unit with no fiddly connections
- System sends e-mail when battery is down to 10% capacity
- Ring fence option available – alarm will be tripped if user moves outside pre-set locations

Figure 49:Mindme Alarm features

Again, the device position is obtained by using GPS technology and it is available a voice connection in case of emergency, directly connected to the specialized centre.

It does not present a fall detection system, and there is no comprehensive monitoring of users in the specifications, so that in case of an emergency where the patient cannot trigger the alarm button, this solution can be inefficient.

Both tele-assistance devices seen so far show a clear difference from the classic services for elderly and disabled people: their outdoor capacity.

While most tele-assistance services implemented in different countries are limited to the user's home, using Mindme Alarm and i-help it is verified the existence of solutions capable to overcome the limitation of an indoor coverage.

Classic tele-assistance services, as already explained in the introduction consist of two key elements: the transmitter device, usually a watch or pendant, and the terminal connected to the telephone network.

The terminal is connected to a specialized service generally during twenty-four hours, that could track the patient or simply to act quickly in case of emergency.

For example, there are companies that make regular calls to patients in order to gain some control over them or study patients routines to detect any event that breaks the routine of the user and may originate some risk for them.

The transmitter device is usually small-sized and easy to use for avoiding being a burden to users.

There are a lot of companies offering tele-assistance solutions. Among them there are some companies that are located in Spain:

-SARquavitae: allows outdoor location using a mobile device and GPS technology.

-PROSEGUR alarms: with implementation of fall and warning system to medical services.

-Atenzia: with direct connection to emergency services and permanent connection.

After defining the basic structure of a complete system of tele-assisstance, the following device to analyse is the product Adamo, by Caretek Company, which is the basis or starting point for the research carried out in this project.

3) Adamo (CareTek):

It meets the requirement of providing autonomy and independence inside home to elderly people or people with certain disabilities.

Figure 50:Adamo logo

Adamo is shaped like a normal watch, light and practical. It accompanies the person without causing any discomfort. It is composed by waterproof materials that allow its uninterrupted use even under the shower.

It has a sensor that determines whether the watch is being used by the person and an individual monitoring is carried out if the pulse is detected, otherwise, the device only emits safe radio waves set by default. Apart from this sensor, different internal watch sensors are capable of detecting if the user is in motion or conversely remains motionless, besides it detects body temperature and battery status. Each of these sensors is capable to send alerts when abnormal parameters are detected.

Besides the watch, the system has a base station connected to the telephone line that is permanently active. This station allows instant connection between the user and the service centre or any user's relative in case any alarm or emergency is detected or the individual press the emergency button.

Figure 51:Adamo system

It has a fall detection system, if triggered and followed by a certain time of inactivity, sends automatically a fall alarm to the service centre. The base station allows hands-free communication with the service centre, users' relatives or any persons assigned by the user.

The monitoring carried out from the specialized centre is fully customized performing fine control according to the needs and routines of different users.

It does not implement any location system since the system is intended for home use, but it uses an algorithm that detects whether the user is away or near the base station.

The service centre is composed of specialists in managing emergency situations rapidly and effectively.

Figure 52: Adamo connectivity

Complementary to user monitoring, a service centre agent makes regular control calls to ensure proper use of the system and controls the situation of the individual.

Adamo system allows the additional capability of defining private numbers of users' relatives or acquaintances who can take care of emergencies without using the service centre.

The conclusions drawn after analysing the tele-assistance systems, and in particular Adamo system, allow us to know and estimate the strengths and shortcomings that such systems have at present.

On one hand, it is observed that on indoor coverage, services provided by different products cover almost all needs of a person requiring help or a daily control. However, one of the goals of the tele-assistance is based on providing the user with autonomy and independence in daily routine. Using these systems, this goal is partially fulfilled, because in outdoor areas, the user remains without full tele-assistance service.

This reason is one of the main motivations of this project. Starting from a classical system of tele-assistance such as Adamo provides research and development of a prototype guaranteeing assistance even in outdoor areas (solutions such as "Mindme Alarm" and "i-help" seem to mark a way to follow).

If it is intended to offer a practical outdoor coverage, the need to remove the base station arises, obtaining a compact device that can be introduced into daily routines in a simple and transparent manner.

For this reason, power saving becomes especially important since the use of batteries implies the device being bigger size. As the device is small size, there will be necessary the efficient use of energy in order to ensure proper and practical autonomy in real scenarios.

With the introduction of IOT (Internet of things) and in general, technology into ever smaller size devices, one of the most interesting fields under study, offering a possible improvement over the methodologies currently used, is called Energy Harvesting.

This concept is based on obtaining energy from different sources, so that a complementary source of energy is obtained, increasing autonomy without having to affect device small size.

To finish this section, a brief theoretical study is performed regarding the main techniques used in Energy Harvesting as well as checking development level of them. Besides, possible future lines are defined to exploit power efficiency in wearable devices. Besides, there will be mentioned in-market products which provide power saving to low consumption systems.

4.2.4) Introduction to Energy Harvesting

4.2.4.1) EH fundaments

The concept of Energy Harvesting starts from energy gathering originated in external sources, offering greater autonomy to different wireless systems.

Energy harvesters provide a very small amount of power for low-power electronics. While the fuel input to the large-scale generation is usually costly (oil, coal, etc.), the energy source for collectors is present as environmental fund and free. For example, in urban areas there are a lot of electromagnetic energy in the environment due to radio and television or the presence of large wind currents in certain areas etc.

By means of Energy Harvesting, efficiency is improved, in energy terms, as it offers the capability to capture small amounts of energy from environmental sources which would be lost by using other techniques.

It also enables the creation of new technologies and autonomous devices that can work without cables. (Example: Wireless Sensors).

EH has the potential to replace the conventional battery system for electronic low-power devices. By replacing the batteries, a more environment-friendly system is developed since batteries are often composed of hazardous materials to health and harmful to the environment and maintenance is cheapened as there is no need to replace the batteries so often.

These energy techniques are applicable in different areas:

- Large scale systems, where a lot of untapped energy is lost. Example: Industrial process where almost half the input energy is dissipated as heat. In this case, EH could be an energy increase by capturing that dissipated energy.

- Wearable systems, which have a constant source of energy from natural sources can provide great autonomy and economic maintenance without cables.

There is a lot of EH materials (ceramics, glass, polymers and composites) that are currently being developed. The purpose of these materials is to capture small amounts of energy that would otherwise be lost during industrial processes or simply processes performed day after day.

These small amounts of energy that can be captured by EH come from various natural sources. Depending from the source selected to obtain energy, it will be more appropriate the use of materials which have certain specific properties.

Following, there will be presented the most significant materials and their possible applications:

- **Piezoelectric Materials:**

Piezoelectricity is defined as the capability to obtain power from a specific pressure.

Piezoelectric materials accumulate electrical charge on a solid material as a result of mechanical tension.

The movement of the human body, low frequency vibrations or acoustic noise are some of the sources from which a piezoelectric material can collect energy.

Some examples are the following ones:

a) Remote control without the use of batteries: The force exerted when pressing a button is enough to generate a signal.

b) Generation of energy using the vibrations generated by the steps of people in a train station.

c) Maintenance of a wearable autonomous device intended for running, collecting energy through the vibration of the shoes of the device user.

d) Sensors on vehicle wheels, allowing its monitoring and been capable of making notifications on any screen or system.

Applications that use piezoelectricity techniques are at development state, although there are some commercial devices.

There is a lot of literature and scientific studies regarding the efficiency and performance waiting for piezoelectric materials.

Nowadays, it is difficult to make a comparison between piezoelectric devices since there is no international acknowledgment to characterize and compare the efficiency and performance of different devices. Each vendor offers its own features and studies, highlighting the product offering thus hindering an objective and simple comparison for interested users.

In wearable systems, where size and autonomy of the device is of vital importance, piezoelectric materials will be a cornerstone for their evolution without having to give up compact size.

- **Thermoelectric materials:**

The following materials exploit the temperature difference present in a thermoelectric crystal when a heat source is applied on it. When this happens, the different parts of the material are at different temperatures since a heat source has been applied to a part for increasing the temperature. This difference causes a voltage across the crystal.

The potential applications of these materials require a constant heat source. So there are different vehicles (cars, trucks) incorporating thermoelectric generators. When the engines of these vehicles are in operation, the heat dissipated by them is captured by the thermoelectric material, providing an additional source of energy.

Any heating system can incorporate thermoelectric materials. An example of it is a radiator that takes advantage of the heat dissipated to indicate in a display the temperature it is configured for.

Thermoelectric technology is considered one of the most promising technologies in terms of energy efficiency in industrial processes where a large amount of energy is lost as heat, for example the automotive or computer sector.

The behaviour of a thermoelectric material is defined by the thermoelectric merit factor. There is an international competition to improve this factor. However, this competition cannot be an absolute reference since there is no an undeniable thermoelectric material used by different vendors. Nevertheless, by using thermoelectric materials a fairly accurate comparison can be made among different products unlike what happened with piezoelectric materials.

Generally, applications of thermoelectric materials were limited due to the small conversion efficiency since very little energy captured. However, with the introduction of nanostructured thermoelectric materials, it has led to a remarkable improvement of thermoelectric properties.

Because of the need to improve energy efficiency through the recovery of residual heat present in the different processes, studies and progress on thermoelectric materials increase progressively.

- **Pyroelectric Materials**

The pyro-electrical effect converts a temperature change into an electrical current or voltage. If there is no temperature change on the material, no energy is generated, thus these materials require variable input sources over time causing different temperatures in the material.

Although pyro-electrical effect offers the advantage of allowing very high temperatures, regarding thermoelectric materials it is still at a remote stage far away of EH applications marketing. However, even at this early stage of development, the pyro-electrical effect appears to be more effective than other energy harvesting techniques, but only under specific conditions.

Power generation requires a temporary variation in temperature every few seconds, to find an input source that can provide such variation is an expensive task outside a laboratory.

It is important to mention that there are other sources available for the EH as obtaining energy through electromagnetic waves, sunlight or changes in atmospheric pressure, but they have been considered of lesser importance because of their state of development and potential applications offered.

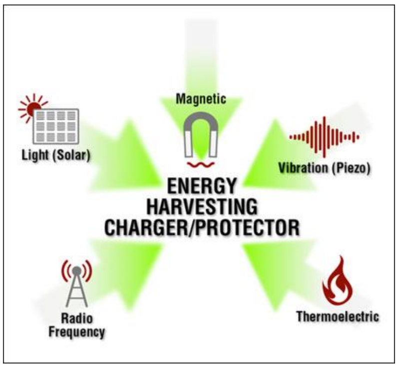


Figure 53:EH techniques

4.2.4.2) Future lines, Research and development

The European Commission (EC) has identified sustainable energy supply as one of the major goals of modern society.

In accordance with this goal, which is promoting a major European campaign funding for R & D (research and development on the generation, use and energy efficiency).

A section of this campaign focuses on research and development of technologies capable of capturing energy, which directly refers to EH.

The main obstacle to the development of EH technologies comes when characterizing and comparing different devices. Internationally and recognized measurement standards capable of ensuring a rigorous and accurate characterization of EH devices in terms of energy efficiency or consumption become especially needed.

The project named "The Metrology for Energy Harvesting", funded by the European Metrology Research Programme, has as one of its objectives to use a standardized approach that supports the different EH systems. The main areas addressed by the project are: efficiency, scalability, manufacturing and cost.

The Metrology for Energy Harvesting is a collaborative project of three years, which brings together experts from different countries and is aimed to different objectives:

- To address research gaps identified by the industry.
- To encourage increased collaboration between industry and the European research community.
- To reduce costs.
- To maximize energy efficiency.
- To improve sustainability in industrial processes and products.

The project provides the methodological framework, technical capacity and scientific knowledge necessary for the development of EH.

"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers… you have scarcely, in your thoughts, advanced it to the stage of science"(1)

Energy sources considered due to their interest for this project are largely unexploited sources of environmental energy, resulting from human activity and the environment in the form of residual heat, motion and vibration.

The project has the support of seven national measurement institutes in Europe:

1. NPL (UK)

2. PTB (Germany)

3. LNE (France)

4. INRIM (Italy)

5. MIKES (Finland)

6. CMI (Czech Republic)

7. SIQ (Slovenia)

After defining the framework within the main techniques of EH are included, the early stage of development can be considered. Currently, most of research focuses on analysing new techniques, materials, and the need for international standards that allow the marketing of different products.

Focusing again on the prototype developed in this project and its objectives, a possible implementation of pyro-electrical and thermoelectric materials can be considered meaningless.

On one hand, the device is placed on a user (watch) or hooked on a garment or placed in a pocket or purse. In either case, there is no a source of sufficient and constant heat to capture energy or a source generating a temperature that varies over time every few seconds providing a constant flow of energy. However, the inclusion of piezoelectric materials could make sense depending on the final design. For example, it could be taken advantage of the movement and vibration from a shoe to generate energy.

To conclude the study of the state of the art of EH techniques, a brief market survey can be developed starting with some EH modules available on the market, ending with the description of several products and energy solutions that are offered by different companies.

4.2.4.3) EH modules

There are several sensor vendors on the market, generally piezoelectric ones. Thus, it is observed how companies such as "Linear Technology" or " Midé " offer some variety of piezoelectric materials.

In the figures below different products offered by both companies can be seen:

In order to know the theoretical benefits of these devices, technical specifications of LTC3588 device, which vendor is "Linear Technology, are listed below ".

This small module (less than a coin) allows energy capture by adding a piezoelectric material and also using solar charging. The energy is stored in a capacitor that is integrated on the chip.

It offers four possible output voltages of 1.8, 2.5, 3.3 and 3.6 V with a maximum of 100 mA of output current.

Comparing technical specifications offered by different manufacturers, the problem discussed above for piezoelectric modules is checked. Each provider offers different features, a fact that causes some difficulty in comparing different devices.

Furthermore, there are different kits for studying EH, such as Energy Harvesting Solution To Go from Silicon Labs company. This kit has a microcontroller with a full EH module that includes piezoelectric capacity, solar charging and thermal charging through a peltier panel.

The goal of these kits is usually the study of different EH techniques and the analysis of results for future projects and applications.

4.2.4.4)Products and EH projects

Finally, in order to set a first view of EH concept and the different possibilities it offers, it will be describe several products that are part of the current market and which implement EH technologies that have been analysed previously.

1) Ampy

The Ampy portable device consists of a battery that is capable of storing energy collected directly through motion of the user.

It responds to the need to provide a power source for electronic devices of small size -Smartphone, smartwatch, Tablet-, when these cannot be recharged via cable connected to the current.

Ampy offers a complete solution for energy storage through wearer motion. Energy capture is performed by inductors.

The device has different accessories for placement in different parts of the body or clothing, so we can capture the greatest amount of motion in every situation, for instance if it is tied to the ankle when the user is walking or running around town.

The more motion, the more energy stored by Ampy.

In the product specifications, it is indicated the battery capacity, 1800 mAh, and the charge level achieved after one hour of standard activity:

- Up to one hour of battery in a Smartphone in normal use.
- Up to five hours of battery life, on a smartphone, in standby.

Up to 24 hours of use on a Smartwatch.

Thus, the device offers a solution in situations where a user requires battery for any of his mobile devices and does not have an electrical power system to connect to.

Ampy functions as a traditional powerbank, being able to be charged to the electric current. However, the ability to generate energy by performing routine activities is its fundamental property.

Complementing the device, user activities monitoring is allowed by using a proprietary mobile application. This way it is possible to analyse and check the energy generated each day or while doing any activity.

Using this product, an additional energy source is available for an electronic device taking advantage of EH techniques.

Figure 54:Ampy system

2) Sole Power

Next product is in a state of pre-marketing and is based on motion, the same principle as the Ampy battery.

In this case, energy comes determined by user´s steps. Sole Power system consists of a couple of shoe insoles, each connected to a rechargeable battery. These insoles exploit heels impact onto ground when walking to produce energy which is stored in aforementioned batteries.

When the user requires an additional source of energy or does not have a power supply to connect to, he can connect his device to one of system batteries using a USB cable.

The batteries have a storage capacity of 300mAh each, and as specified in the description, one hour walking with Sole Power insoles guarantee thirty minutes of conversation using a mobile terminal, although, the amount of energy depends on the speed, weight, activity and strength of the heels impact.

Figure 55:Sole power product

It also includes advice for people who need any power source at any time during their daily activities.

3) WaTTup:

The WaTTup system developed by the company Energous Corporation, offers a wireless solution for charging multiple electronic devices.

Its operation by using RF waves (radio frequency) allows electronic devices to store energy wirelessly.

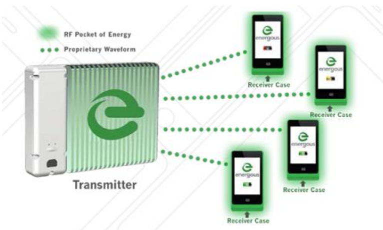


Figure 56:WaTTup charge system

A central module is the transmitter of these waves, allowing the charge a distance of up to five meters to the receiver. It allows connection of up to twelve simultaneous receivers and can be configured by using a proprietary mobile application. Example: Charging mobile overnight while in the morning can be automatically charged electronic appliances.

Possible uses of this technology are countless due to the incursion of technology in increasing modern society sectors. Undoubtedly, the wireless charging device will be one of the future lines to be adopted by any companies.

4) StickNcharge K3OPS:

The energy system aims to revolutionize the market for electric batteries. By means of a EH system that uses radio frequency waves, the system is designed to handle environmental radiation and convert it into electrical energy that can be used.

Figure 57:K3OPS principle

This process offers a new source of clean energy by removing electrochemical devices currently used to convert chemical energy into electrical power via toxic processes.

Existing batteries contain harmful and dangerous metals regarding humans and the environment. K3OPS prevents the exploitation of these natural sources such as nickel, mercury, zinc and lithium which extraction is toxic for the environment.

This company and its products have not yet reached the general public. Its founders are now beginning to show some of its main features in various international fairs.

EH technology certainly seems to be a strong line to follow in any field of low consumption electronics.

Making a close analysis to the prototype to be implemented by the project, the first two products may serve as reference for future designs where implementing a module for additional energy is desired or if it is decided to opt for a model of sustainable energy apart from traditional batteries.

Harnessing the motion of a user to produce energy may be interesting for the field of tele-assistance and even for any portable wireless device to be worn on the user's skin or clothing.

5) System Requirements

After concluding the review of the different technologies and available devices shown in the section of the state of the art, general vision of the current situation of the tracking and tele-assisstance available services.

It has been possible to extract the most interesting features from all of the different solutions, as well as some services available only in some of the products.

The first step in the development of the prototype of tele-assisstance of this project, consists on defining and justifying, the necessary functionalities with the intention of achieving the initially defined objectives.

In the context of tele-assisstance it exists a great quantity of data and events which could be measured and monitored offering a wide variety of services.

The main objective of this project seeks to improve different aspects of the service of tele-attendance ADAMO such as the covering, the autonomy and the design of a service through a wearable device.

The Adamo system allows to locate a user only if he is inside his home. Its capacity to locate the person is limited since it simply offers information if the patient is close or far from the terminal connected to the centre service.

Considering the objective as well as the mentioned limitation, the prototype should be able to improve the service of the localization and also to offer external covering to provide the user with more independence.

A system of tele-assisstance should provide the patient's location to be able to attend him in the event of necessity or emergency by means of the implementation of a localization service capable to offer covering inside and outside home to make it possible to improve the service offered by Adamo system.

On the other hand the World Health Organization defines the falls as one of the high risk factors among elderly:

"Falls are prominent among the external causes of unintentional injury. They are coded as E880-E888 in International Classification of Disease-9 (ICD-9), and as W00-W19 in ICD-10" “Approximately 28-35% of people aged of 65 and over fall each year (2-4) increasing to 32-42% for those over 70 years of age (5-7). The frequency of falls increases with age and frailty level” […].

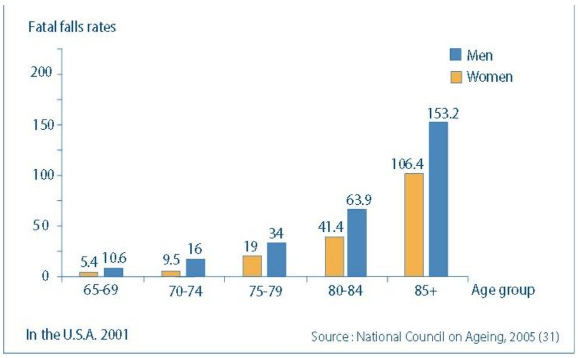


Figure 30 58:Fatal falls rate by age and sex group

This project is especially oriented to offer assistance to elderly or disabled people. Therefore, considering to the data and declarations carried out by the organism WHO, it was considered necessary to offer a service to detect the user's possible fall, identifying it as a possible emergency cause.

Another of the important risk factors for elderly is their exposition to temperature changes.

According the National Institute on Aging:

“Older people can face risks related to hot weather. As people age, their bodies lose some ability to adapt to heat. They may have medical conditions that are worsened by heat. And their medications could reduce their ability to respond to heat."

and U.S. Department of Health & Human Services:

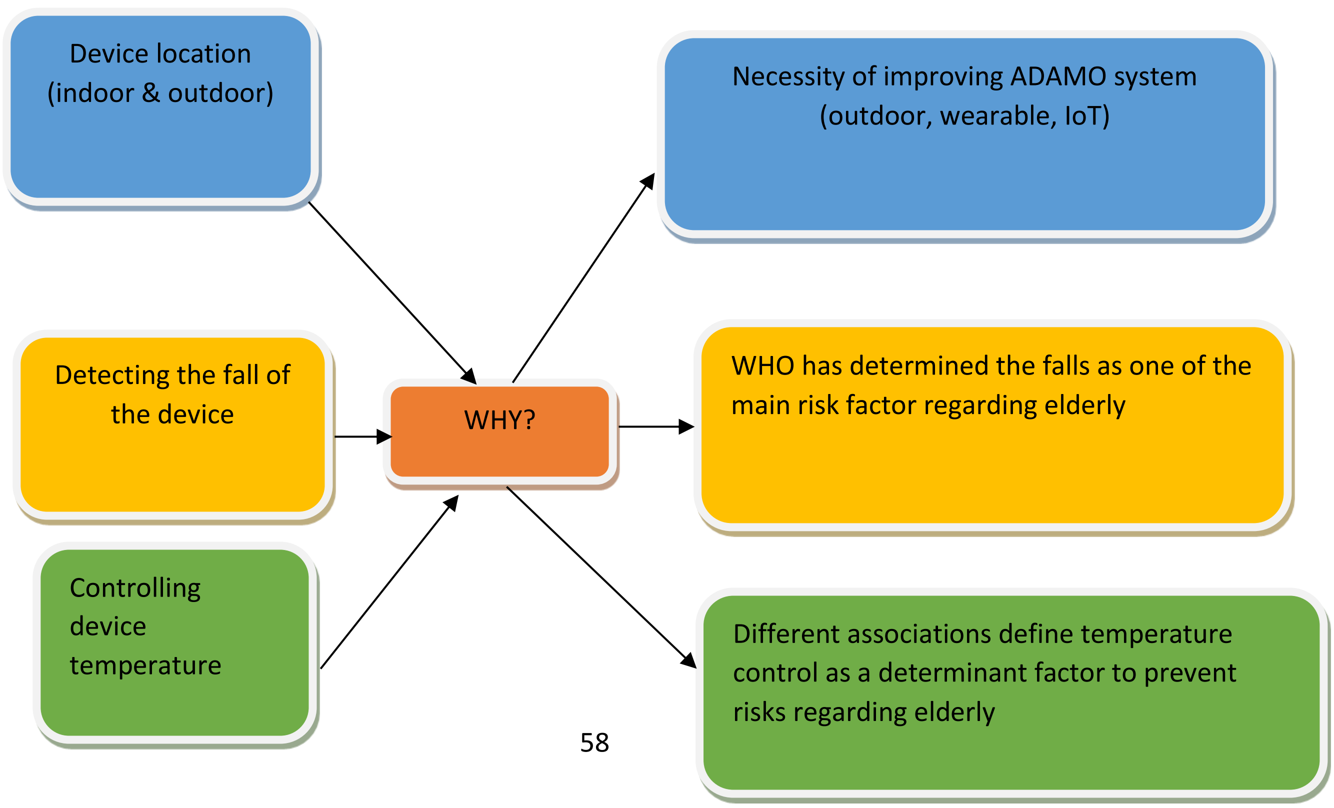
"Older adults do not adjust as well as young people to sudden changes in temperature." "Heat stroke is the most serious heat-related illness. It occurs when the body becomes unable to control its temperature: the body's temperature rises rapidly, the body loses its ability to sweat, and it is unable to cool down. Body temperatures rise to 106°F or higher within 10 to 15 minutes. Heat stroke can cause death or permanent disability if emergency treatment is not provided."

These institutions show the importance of controlling the body temperature of elderly with the purpose of preventing possible pathologies or emergencies.

Therefore, the mensuration and control of the user's temperature, would be part of the available functionalities of the prototype.

The process of development of the prototype will be based on the experimentation of the selected functionalities since they are considered of great interest and competition to implement a system of assistance for elderly.

The following graph synthesizes the information explained in the previous paragraphs:



These selected functionalities were considered enough to begin the process of experimentation of the device, since:

- It maintains similar characteristic to different products seen in the state of the art, thus offering other services in a different way.
- It fulfils the objective of being an improvement in some aspects regarding Adamo system
- It responds to the necessity of covering main factors of risk for elderly, as the falls or the temperature.

The architecture of the system will be defined starting from the selected functionalities. It constitutes the following step in the process of final development. The following chapter will be focused on the architecture of the prototype.

6) ARCHITECTURE AND TECHNOLOGIES

6.1) Introduction

This section describes the basic blocks scheme that will followed by the prototype to develop. Following, there will be presented possible technologies, both software and hardware, to be used for implementation of each of these blocks.

By analysing the state of the art developed, there were summarized the most interesting features in nowadays tracking devices.

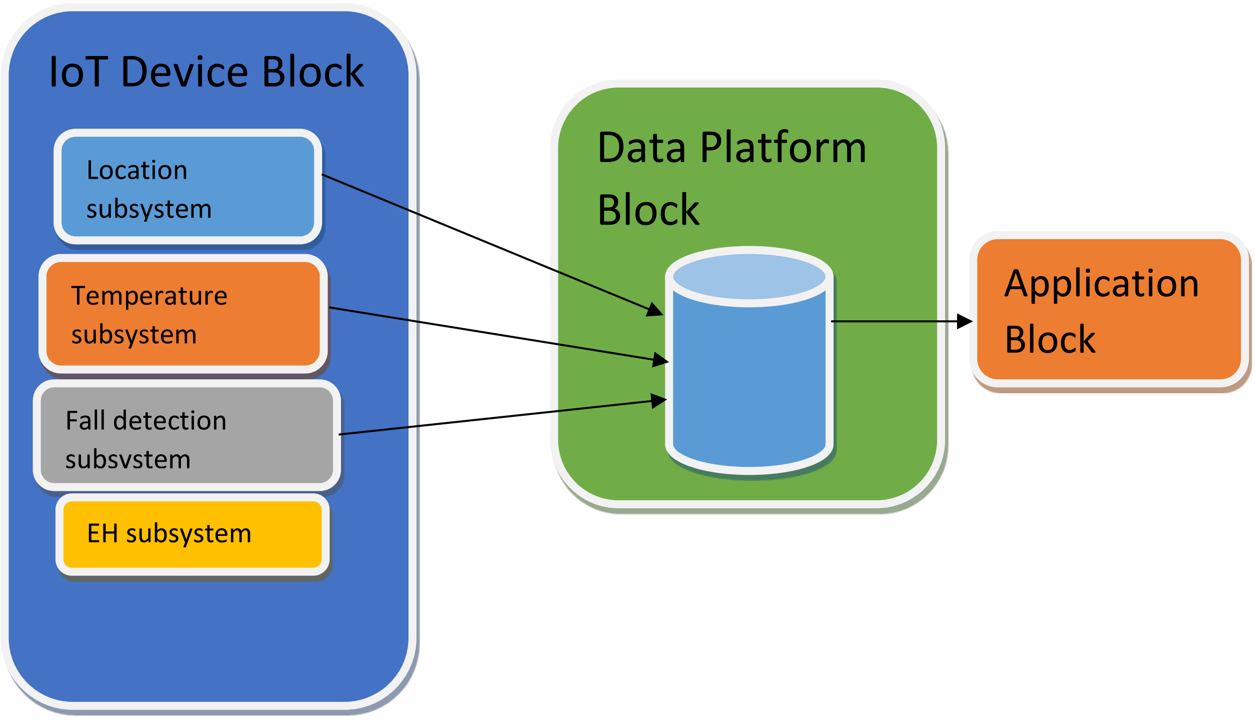
- **Tracking system.**
- Data monitoring.

Furthermore, it is important to recall one of the main objectives of this project: improving existing system (Adamo), offering an outdoor capability through a wearable device.

Features in Adamo:

- Indoor tracking.
- **Fall detection.**
- **Temperature sensor.**

The objectives as well as the analysis of the state of art defined the system requirements described in the previous chapter. From them, the architecture of the system is described as it can be seen in the following diagram:



The block IoT device constitutes the main element of the architecture since it takes charge of obtaining the data through different sensors. It is composed by four modules:

1) **Location subsystem:** responsible for providing the position of the device, ensuring its outdoor coverage.
2) **Temperature subsystem:** sensor measuring the temperature at which is the prototype.
3) **Fall detection subsystem.**

   These three subsystems are the consequence of each one of the functionalities elected from the system requirements.

   The following elements, although they do not constitute any functionality characteristic of the device, offer different services for the process of development it.

4) **Energy Harvesting subsystem:** system that implements some of the EH mechanisms previously seen by providing an energy solution for the device.

The following block is formed by a data platform in which the data collected by the block IoT device will be stored.

Finally the application block will be in charge of recovering the data from the platform and interpreting them in order to offer a specific service to the device users.

The architecture follows a logic sequence regarding the obtaining, the storage and the processing of the data of tele-assisstance. Great part of the development of this project, is centred in the design of the block IoT device, leaving the rest of elements as blocks to add and to improve in future designs.

Next it will exposed a brief presentation of all the elements present that are included in the architecture of the prototype:

6.2)IoT DEVICE BLOCK

The module of the device will provide the different data obtained by the sensors. Following the defined objectives and in accordance with the elected functionalities that will be offered by the prototype, there can be distinguished four different subsystems, considering that each one of them will offer the required service:

6.2.1) Location subsystem

As it has been explained throughout the project, the location of a user is a key feature to be able to offer assistance in the event of emergency. There have been also exposed the most important techniques that are used at the moment for the localization of a device such as satellite technology and the technology based on mobile networks.

The location subsystem will be implemented by means of a module that will be able to obtain the space coordinates by means of the employment of some of these techniques.

For the use of the mobile network, it will be needed an element able to be connected to the frequency bands used by GSM network by means of a SIM card in order to obtain all the services through the network.

If it is sought to locate the element by means of the satellite positioning, hardware with GPS integrated technology will be used.

For both technologies it will be needed an antenna and own hardware.

6.2.2) Temperature Subsystem

This subsystem should be capable to constantly measure the prototype temperature and guarantee an alarm system which is activated when abnormal temperature is detected.

The configuration of each alarm is defined in forthcoming sections where the subsystem is implemented. In tele-assistance field, it could be interesting to activate alarms when it is detected temperature that is higher than room temperature, or on the contrary, when the device receives a temperature value too small.

This subsystem implementation is done by using a temperature sensor.

In current market, there are quite a few sensors providing correct temperature readings.

The basic operation principle of these sensors is calculating temperature from generated tension.

These sensors are generally composed of a diode which voltage increases as temperature does. This increase is detected by the sensor and by amplifying the voltage properly, an analogue signal is created which is directly proportional to the temperature.

6.2.3) Fall detection subsystem

As in the previous subsystem, a user fall detection is a service to offer very interesting in the tele-assistance field.

An alarm system is in charge of notifying about a user possible fall detection.

Its implementation can be done by using some types of sensors, particularly for the prototype to develop, there have been analysed two possible elements: barometer and accelerometer.

- **Detection using a barometer**: a barometer is an instrument that provides the atmospheric pressure on a specific point. Following one of the atmospheric laws on Earth planet, it is a fact that as height increases pressure decreases. Thus, connecting heights and pressures an algorithm can be designed, that by calculating pressure difference on successive instants, detects height difference that could be a device fall. There are some commercial models of barometer designed for wearable elements and IoT.
- **Detection using an Accelerometer**: by using this instrument, it can be detected accelerations in any of the three spatial axes. If an acceleration threshold is defined as it could indicate a fall, then any movement exceeding the defined threshold can be detected by using an accelerometer.

6.2.4) Energy Harvesting subsystem

As discussed in previous sections, energy harvesting and its efficient use is one of the key points to research about wearable technology.

Because of the early stage in which all explained EH technologies are in the section of the state of the art, it deserves to be mentioned the possibility of introducing a piezoelectric EH block in later versions of the prototype.

This subsystem should be able to offer a superior autonomy or the possibility of dispensing with traditional batteries, by collecting energy by the motion of the user. A future device design should aim to maximize its usage detection.

6.3) Data platform block

The presence of this subsystem is justified as an answer to the next question:

Where is saved the data obtained by an IoT device?

The sensors found in the prototype allow to read different data in real-time, such as the position of the device or the temperature at which it is found.

A tele-assistance service must ensure some control and monitoring of patient activities. This implies the need for connection between the IoT device and a server, where data can be sent and stored.

Example: It is intended to track the activities of a patient to control the time slots in which he is at home. Monitoring patient activity is made possible by a database that stores the user's position at different moments of a day. Therefore, the data platform serves as support for the device, storing the data needed for subsequent interpretation.

In short, this block is a database obtained by the IoT device.

The most common architecture to perform client-server connections is shown in the following figure and makes use of a web server, acting as a proxy, in order to facilitate its use.

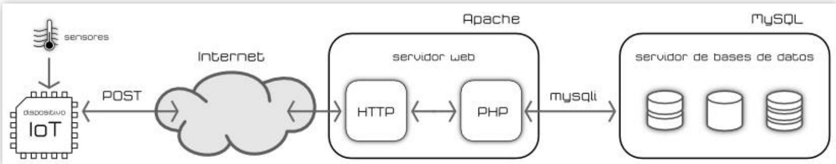


Figure 31: LAMP System

The web server, usually working on a Linux distribution, allows connection to the database server where the data of interest is actually stored.

The configuration described in the above figure is called LAMP (an acronym of its main components).

Finally, the web server assigns the data management to the database server, typically MySQL.

Therefore, there are two completely separate communications:

1) Device - Web Server: a connection is made by the client and configured using the HTTP protocol.
2) Web server – Database server: it is transparent to the device and uses the PHP language.

Communication between the device and the web server is performed by the following two instructions:

1) HTTP Post: The IoT device requests to store data in the database.
2) HTTP GET: The IoT device or another system application requires to retrieve data from the server.

Without describing technical details of how these actions are performed, since it will be described deeply in subsequent sections, there will be described the elements in the data platform and its basic operation.

6.4) Application

This last block of prototype scheme allows monitoring and interpretation of data stored.

If the data platform answered the question: Where is the data stored? Thus the application does to the following question: What to do with it?

If a database is available, it is necessary an application to interpret the data and provide the desired services.

Example:

- The positioning subsystem stores the latitude and longitude of the device every minute.
- The platform stores the data along a day.
- A user wants to watch, on a map or graphically, the journey performed.
- The application system would be responsible for, obtaining data from the platform, representing the position of the device on a map.

Without the existence of this block, only data of different types is available, stored on a server, the implementation of an application ensures monitoring and device control services.

As observed in the section of the state of the art, almost all tracking devices had its own proprietary application, from which the various services are offered.

The level of complexity of the application depends on the services to offer.

For the example of the location, there are applications that simply use the Google Maps application to locate a point on a map to applications that perform a complete real-time monitoring.

In the next section, it will be detailed the block by block prototype implementation of the project, describing technologies and devices used and justifying the choice of them.

7) IMPLEMENTATION

7.1) Introduction

Throughout this chapter, it will be described the process of development of the tele-assistance prototype. This process has been conducted by the student, and author of this project, at the headquarters of Caratek Company.

The implementation of the device starts from choosing a work environment to the development of a prototype model that meets the defined objectives.

In order to show a clear overview of all development, the structure followed in this section will describe comprehensively all the tools used and the different tasks carried out until the final prototype.

- First, it will be described the work environment offered to the student for the device implementation.
- Secondly, for each subsystem in the device architecture, the elements used will be detailed, its programming and experimentation.
- Finally, the subsystems will be combined to produce the prototype and following an explanation of the utilized techniques, setup phases and results.

In addition to this structure, the points of this chapter shall keep a chronological coherence and will mention at all times different problems or limitations that any of the elements involved may have caused.

In order to make more understandable the entire process, the introduction of the full source code of the prototype (it is attached as an annex) is obviated, thus including only the fragments considered as important which facilitate correct understanding of the functioning of the elements.

7.2) Work environment

It is defined as working environment, the initial set of tools available to the student which have allowed the development of the prototype.

The elements included are the following:

- Programming language and framework.
- Sensors.
- Breadboard (protoboard).
- Computer.

Programming language and framework

As any other electronic device, a programming language that indicates the processes to be performed at any time will be required.

Because of the features desired for the prototype, it makes no sense to use complex and heavy programming languages, generally aimed at large systems and machines.

At present, there are different systems specifically aimed at small, wearables devices belonging to the IoT.

Among all of them, it was decided to implement a system based on Arduino code platform.

Arduino

This platform is intended for creating flexible and easy to use prototypes, following there are some of the most important reasons for its choice.

1) Easy programming: The platform uses a high-level language based on C. It supports all C and C++ functions. In addition, it has an integrated development

environment (IDE) which is very intuitive and simple to any user familiar with programming languages.

2) The existence of a large amount of documentation and materials that greatly facilitate learning.
3) Open Source platform, with all the advantages this brings.
4) Use of libraries through which a large number of external components can be configured and programmed. As noted in the following points, for most peripherals used in the prototype, there were libraries for configuration and smooth operation.
5) Versatility: Arduino is different from other development platforms in terms of the variety of plates it offers on the market. Each offers individual and different features. Next, the plates used in the development process of the device will be mentioned.
6) Peripherals: Perhaps the most important benefit of all. An Arduino-based system offers a wide range of Shields and peripherals that can be incorporated simply by increasing the range of applications and services. For this project, in each subsystem, different peripherals have been used.

In the annex, all the detailed documentation will be attached since they allows a first contact with the Arduino platform and the steps to gain sufficient assurance for the preparation of a project.

The goal of this point is simply to inform about the programming language and platform used and the reasons for that choice.

The key element of a platform based on the Arduino system is constituted by the plate containing the microprocessor.

The microprocessor is responsible for executing programs and indicating the instructions to be followed by the different elements of the system.

As stated previously, there are a variety of plates available in the market. Each offers different benefits.

Below, those used throughout the implementation process are listed, by using a comparison chart which allows to observe each main features.

In the following sections, the plate used for experimentation will be detailed, and caused problems, if they ever happened.

Name	**Processor**	**Input Voltage**	**CPU Speed**	**Analog In/Out**	**Digital IO/PWM**	**EEPROM [kB]**	**SRAM [kB]**	**Flash [kB]**	**USB**	**UART**
101	Intel Curie	3.3V/7-12V	32MHz	6/0	14/4	-	24	196	Regular	-
Micro	ATmega32U4	5V/7-12	16MHz	12/0	20/7	1	2.5	32	Micro	1
Uno	ATmega328P	5V/7-12V	16MHz	6/0	14/6	1	2	32	Regular	1
Nano	ATmega328P	5V/7-9V	16MHz	8/0	14/6	1	2	32	Mini	1

Sensors

Recalling the architecture of the prototype, it has several subsystems that will make up the final model. The implementation of some of these subsystems is carried out by sensors and peripherals external to the Arduino board. Those are described in the following topics of the section and they are also part of the work environment.

Breadboard and Computer

Once one has a development platform, a microprocessor, and the necessary peripherals, the connection between them is necessary.

The peripherals are connected to the Arduino board using a breadboard, which offers the ability to assemble and disassemble circuits easily.

The computer will load the program to run on the processor, connecting to it via USB. Besides, thanks to the Arduino IDE loaded program results can be displayed directly on the computer screen thanks to the serial output.

All these elements are in the working environment in which the student has developed the prototype through the steps detailed in the following points.

7.3) Subsystems implementation:

As detailed in the architecture of the system, the prototype has three different blocks:

1) IoT Block, composed by the following subsystems:
   -Location subsystem.
   -Temperature Subsystem
   -Fall detection subsystem.
   -EH subsystem.
2) Data platform.
3) Application.

The development of the device is determined by the implementation of each of these blocks and the final combination, forming the complete model.

In this section, the implementation process of each subsystem will be detailed, following the algorithm "divide and conquer".

By implementing each block separately, to later combining them, a much simpler process is obtained which greatly facilitates the tasks of checking, error correction and testing the system.

Thus, the basic analysis structure for each block is as follows:

1) Presentation of the elements involved and the chosen technologies.
2) Software programming of different programs.
3) Experimentation and obtained results.

Besides, there are mentioned possible problems, difficulties or technological constraints encountered during the implementation process.

7.3.1) IOT DEVICE BLOCK

7.3.1.1) Location subsystem

This first subsystem is responsible for providing the location of the device in real time. As mentioned throughout the entire project, the service will cover both indoor and outdoor zones.

It was also observed, most common technologies for calculating the position: satellite systems (especially for outdoor coverage) and mobile-network-based systems.

Therefore, the module required for the implementation of this subsystem should support one or both of the aforementioned technologies.

7.3.1.1.1) Involved elements

SIM808 (SIMCOM)

The module SIM808 by SIMCOM Company offers as solution a Quad-Band (2G) for mobile systems, which also includes GPS technology to guarantee satellite navigation.

The module specifications are found in the annex section; the figure below summarizes the important features:

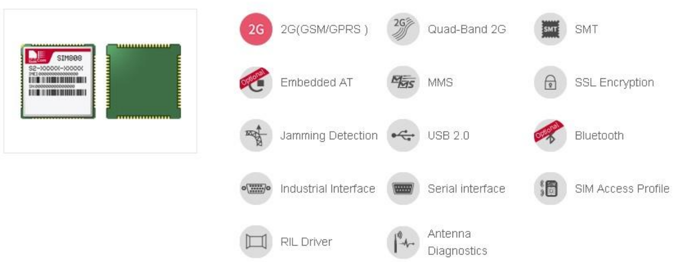


Figure 32: SIM 808 main characteristics

By using the SIM808, access is possible to all typical services of a 2G mobile network such as communications through voice calls, short text messages (SMS), multimedia messages (MMS), among others.

Assembly FONA808 (Adafruit)

Once the chip to provide the location of the device is decided, a mounting plate or board was sought, containing the SIM808, facilitates its use and implementation.

Adafruit electronic provider, offers in its assembly FONA 808, the module it was looking for.

Figure 33: Adafruit FONA 808 front view

Figure 34:Adafruit FONA808 back view

By this assembly, the user has all the elements perfectly configured for using the SIM808.

In the previous figures, it is observed the different output and input ports (USB port, jack 3.5 mm headphone audio output), the slot for inserting the SIM card on which the services will be performed, and also all module ports are indicated.

In addition, as will be detailed in subsequent sections, Adafruit also provides its own library for this assembly which implements a lot of easily combinable and programmable functions.

In the annexes to this project, can be found any additional information that may be of interest related to this assembly.

The following items are recommended by the vendor for proper operation of the FONA 808 module.

Passive GPS Antenna uFL

GPS antenna of very small dimensions (9 mm x 9 mm x 6.5mm), especially geared for small systems.

Compatibility is guaranteed with FONA 808 system.

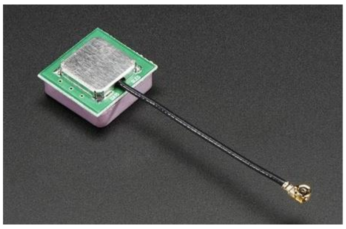


Figure 35: Antenna GPS

Lithium Ion Polymer Battery – 3.7v 1400mAh

Although the first implementations of this subsystem have used the FONA module connected to the computer, it is needed a scaled down size battery to provide autonomy to the system since in its final design it will not be connected to any computer or power source.

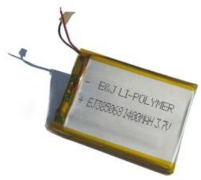


Figure 36: Lithium Ion Battery

Multi-band GSM Neris (EAD) Antenna

To provide a service with mobile network coverage, it is necessary to add an antenna to Fona 808 module. It was chosen the multi-band (900/1800/1900 MHz) Neris antenna, from the manufacturer EAD.

This antenna features a small size and the possibility of providing coverage in different frequency bands.

Figure 37: GSM antenna

Arduino Micro and Arduino Uno

Initially, the model Micro of Arduino boards was chosen due to its small size. The experiment was performed on a breadboard.

For the final design of the location subsystem, it was decided to change to the model Arduino Uno, with the aim of providing a compact and mobile model and to which external modules could added.

For both boards, the programs executed and results remained the same.

7.3.1.1.2) Assembly

The assembly of the subsystem is the combination of the different elements mentioned.

On the one hand, the full assembly of FONA808 module was performed, ie, the module assembly, the mobile antenna, the GPS antenna and battery:

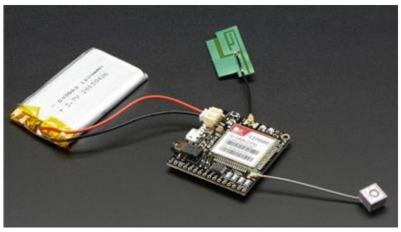


Figure 38: Assembly of FONA808, battery and antennas

As already mentioned, the first experiments were performed on a breadboard by connecting the Arduino micro.

However, in the following figures the final design of the location subsystem is shown, which will allow to add the other subsystems externally.

This design consists of the assembly interconnection of the previous figure, with the Arduino Uno. It has also been used the Arduino ProtoShield that facilitates the connection between the different elements.

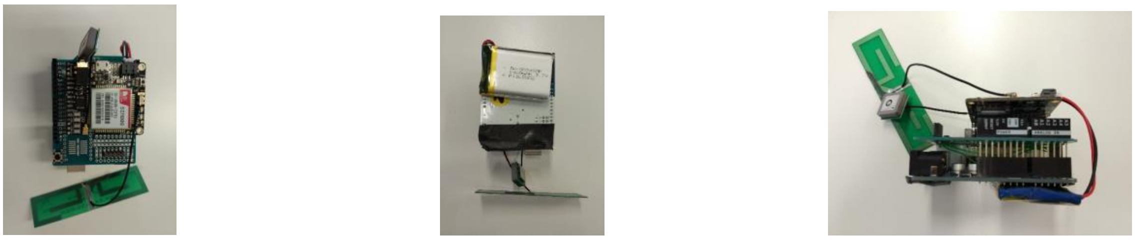


Figure 39: Views of final assembly

All the elements mentioned are distinguished and it is checked how it has a reduced design size and completely wearable, as it is a credit card size.

The final connection to the experimentation of the module is done by USB connection between a computer with Arduino development environment installed, and the Arduino board.

7.3.1.1.3) Implementation, experimentation and results

Throughout this point, the whole process of implementation of the location subsystem will be explained.

This process comprises the entire development of different programs used to understand, configure and design the system location.

The different programming codes have been implemented thanks to the Arduino IDE installed in a computer connected to the location system.

Adafruit_Fona Library

For the development of the different programs that are discussed below, it has been used the library provided by the vendor Adafruit. This library includes a lot of features that allow configuration and obtaining the various services offered by the FONA module.

In the annexes, all these functions can be found along with the documentation associated with this library.

Below, the functions used in programs that will be further elaborated are the following:

Due to the subsystem allows the location of the device and the module offers satellite and mobile network services, it will be of particular interest, all those methods that are related to positioning technologies.

```
// GPRS handling
boolean enableGPRS(boolean onoff);
uint8_t GPRSstate(void);
boolean getGSMLoc(uint16_t *replycode, char *buff, uint16_t maxlen);
boolean getGSMLoc(float *lat, float *lon);
void setGPRSNetworkSettings(const __FlashStringHelper *apn, const __FlashStringHelper *username=0, const __FlashStringHelper *password=0);
```

Figure 40: Adafruit library GPRS functions

First, it is observed the functions managing GPRS technology.

1) Enables and disables the GPRS service.
2) It allows to know the status of the GPRS service.
3) Getting the position in String format.
4) Getting the position in latitude and longitude format.
5) Defines the APN for the GPRS connection.

```
// GPS handling
boolean enableGPS(boolean onoff);
int8_t GPSstatus(void);
uint8_t getGPS(uint8_t arg, char *buffer, uint8_t maxbuff);
boolean getGPS(float *lat, float *lon, float *speed_kph=0, float *heading=0, float *altitude=0);
```

Figure 41: Adafruit library GPS functions

For the use of satellite positioning, it has functions to enable and disable the satellite system, to get the status of the service, and to get the positioning from the subsystem in two different formats.

The following methods, although not strictly related to positioning, will be useful in subsequent programs. They refer to the management and use of short text messages (SMS).

```
int8_t getNumSMS(void);
boolean readSMS(uint8_t i, char *smsbuff, uint16_t max, uint16_t *readsize);
boolean sendSMS(char *smsaddr, char *smsmsg);
boolean deleteSMS(uint8_t i);
```

Figure 42: Adafruit library SMS functions

Along with the library, the provider offers different example programs that serve to get used to the use of the different functions and know all the possibilities offered by the Fona 808 module.

So, the first step in the implementation of the positioning subsystem was to analyse and understand the program called ***FONAtest***.

This program shows on screen a menu with different actions that the device can perform.

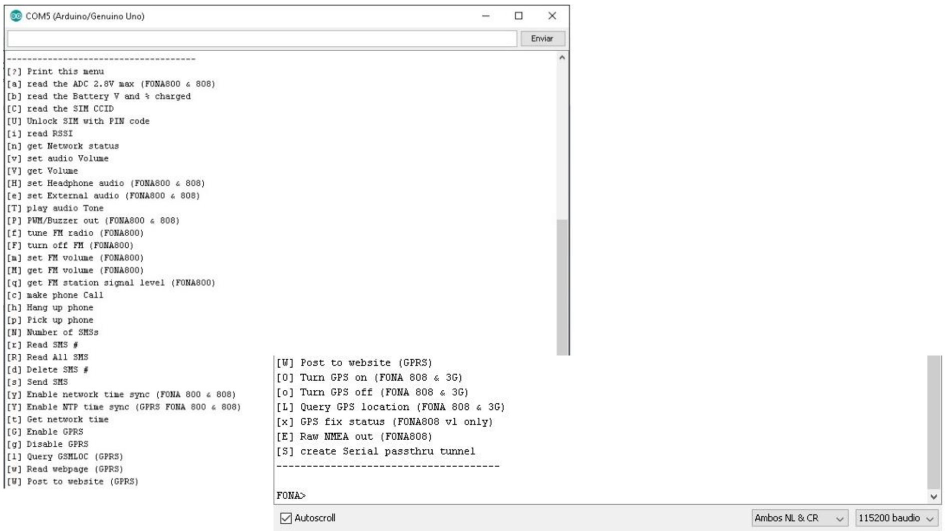


Figure 43: Fona test menu

If a user wants to perform any of the actions listed in this menu, it is just needed to type in the terminal, the character associated with each instruction.

Of all them, only the related to the positioning were considered of interest, i.e., those associated with the GPRS and GPS technologies.

Therefore, the next step was to identify these functions in the example code and understand its operation in order to implement similar algorithms in the program to be executed by the prototype:

GPRS

Using the library functions listed above, actions to enable, disable and get the position through the mobile network, are implemented in the example as:

```
case 'g': {
    // turn GPRS off
    if (!fona.enableGPRS(false))
      Serial.println(F("Failed to turn off"));
    break;
  }
case 'G': {
    // turn GPRS on
    if (!fona.enableGPRS(true))
      Serial.println(F("Failed to turn on"));
    break;
  }
case 'l': {
    // check for GSMLOC (requires GPRS)
    uint16_t returncode;

    if (!fona.getGSMLoc(&returncode, replybuffer, 250))
      Serial.println(F("Failed!"));
    if (returncode == 0) {
      Serial.println(replybuffer);
    } else {
      Serial.print(F("Fail code #")); Serial.println(returncode);
    }

    break;
  }
```

Figure 44: GPRS functions

In addition, in the head area of the example program, the following message appears:

```
// Optionally configure a GPRS APN, username, and password.
// You might need to do this to access your network's GPRS/data
// network.  Contact your provider for the exact APN, username,
// and password values.  Username and password are optional and
// can be removed, but APN is required.
//fona.setGPRSNetworkSettings(F("your APN"), F("your username"), F("your password"));
```

Figure 45: APN indication

It indicates how to set the APN to access the mobile network services. For programs of this subsystem the following command was used to start:

```
fona.setGPRSNetworkSettings(F("web.omnitel.it"),F(""),F(""));
```

Figure 46: APN definition

APN corresponding to the SIM card inserted in the FONA module.

GPS

Functions involving GPS configuration are implemented in the example as:

```
/********************************** GPS (SIM808 only) */

case 'o': {
    // turn GPS off
    if (!fona.enableGPS(false))
      Serial.println(F("Failed to turn off"));
    break;
  }
case 'O': {
    // turn GPS on
    if (!fona.enableGPS(true))
      Serial.println(F("Failed to turn on"));
    break;
  }
case 'x': {
    int8_t stat;
    // check GPS fix
    stat = fona.GPSstatus();
    if (stat < 0)
      Serial.println(F("Failed to query"));
    if (stat == 0) Serial.println(F("GPS off"));
    if (stat == 1) Serial.println(F("No fix"));
    if (stat == 2) Serial.println(F("2D fix"));
    if (stat == 3) Serial.println(F("3D fix"));
    break;
  }

case 'L': {
    // check for GPS location
    char gpsdata[120];
    fona.getGPS(0, gpsdata, 120);
    Serial.println(F("Reply in format: mode,longitude,latitude,altitude,utctime(yyyymmddHHMMSS),ttff,satellites,speed,course"));
    Serial.println(gpsdata);
    break;
  }
```

Figure 47: GPS functions

Having carefully analysed the sample program, the operation of the various functions that use GPS and GPRS systems was understood.

Experimentation

The next task, based on the knowledge obtained from by example, was to design a program that would provide the location of the device using both technologies.

Thus, the following figures represent the results obtained by using GPS technology and mobile network.

The basic structure of the program (found in the annexes of the project) is presented below, and will be repeated cyclically, offering the position every two seconds:

- GPRS Activation
- Getting mobile network location
- GPRS Deactivation
- GPS Activation
- Obtaining satellite location
- GPS Deactivation

All these instructions are implemented using the methods shown in the previous figures, with reference to the mentioned example program.

The first results of the program are shown in the following figure:

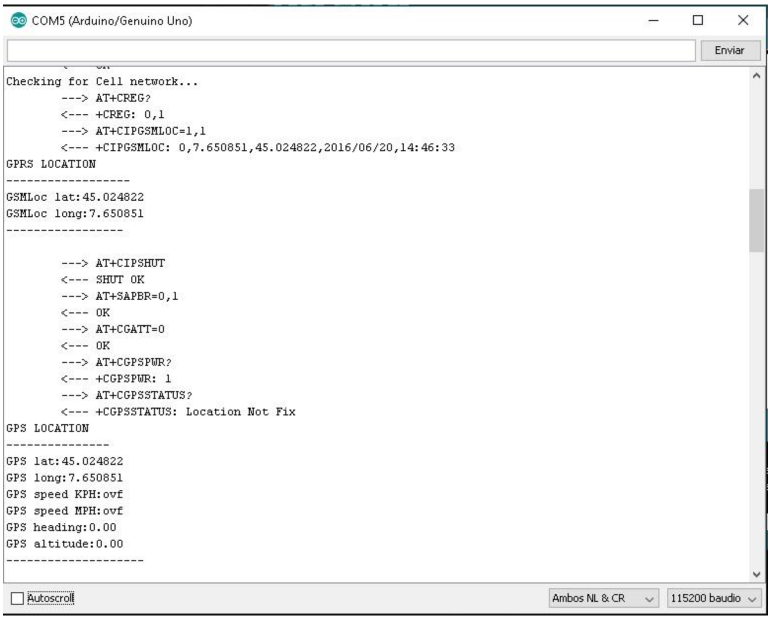


Figure 48: Results first program

The terminal's onscreen output, in addition to showing the FONA module's AT internal commands, shows the position obtained by the two technologies.

Using the mobile network, the program is able to calculate the latitude and longitude of the device.

The satellite location offers more data, however, do not show a valid value in the figure. The reason that GPS only get latitude and longitude, is in the message shown in the AT   GPSSTATUS command.

This command notifies that the device is not fully positioned by satellites. It is considered positioned when connected to at least three different satellites. Experimentation of this program was carried out inside a building, preventing satellite coverage.

The data obtained by the two technologies are identical, so that even knowing that in outdoors, the GPS system provides better accuracy, with this program we get the same location using the mobile network.

Such data were compared using the web application Google Maps, which locates a point on the world map, given the latitude and longitude.

After performing a great number of tests, changing the device position, it was concluded that the accuracy of the data obtained varies from 50 to 200 meters.

Using this first program, a system able to obtain the position using two different technologies was achieved.

In order to get a final design, it makes no sense the implementation of two different technologies (with the corresponding code, energy consumption, etc.) for the same result, in this case, the location of the device. Therefore, the decision to choose one of two possible technologies was taken. To justify the choice, it is necessary to remember two important points described throughout this project, such as energy consumption and coverage.

As described above, the GPS technology consumes a lot of energy, and as noted in the simulation result of the previous program, presents difficulties to provide coverage in areas of poor visibility such as the indoor areas.

The only clear point in favour of a satellite location, is accuracy. As shown throughout the program experimentation, using the mobile network, sufficient accuracy is obtained to meet the basic objectives of tele-assistance.

Therefore, it was decided that location subsystem would be based on the mobile network GPRS technology.

By exploiting the possibilities of the FONA module, and similar to the services offered by similar devices, a new program able to send the location of the device via a short text message (SMS) was implemented.

In the initial example (FONAtest), it was available various actions to manage SMS. In particular, the dispatch of a message by FONA is implemented using the following code:

```
case 's': {
    // send an SMS!
    char sendto[21], message[141];
    flushSerial();
    Serial.print(F("Send to #"));
    readline(sendto, 20);
    Serial.println(sendto);
    Serial.print(F("Type out one-line message (140 char): "));
    readline(message, 140);
    Serial.println(message);
    if (!fona.sendSMS(sendto, message)) {
      Serial.println(F("Failed"));
    } else {
      Serial.println(F("Sent!"));
    }

    break;
  }
```

Figure 49: SMS functions

Using the terminal, the recipient's phone number and the message content are indicated.

In the case of the implemented program, the number, would belong to a specialized institution in charge of the service or person interested in receiving the device location, and the content will be the location of the device.

The first step to design this program, after calculating the latitude and longitude, was to interpret the data so that the user could identify in a clear and simple way, the location of the module.

Example: If a user receives an SMS with two values (latitude and longitude), it can hardly know the location of the device.

Google Maps

The verifications of the previous program, were performed using the web platform Google Maps. The latitude and longitude obtained by the algorithm was inserted, and this platform represented on a world map, the point defined by the calculated coordinates.

In addition to the web platform, Google Maps has its own application designed for portable devices and Smartphones, therefore, if the program to be designed was able to create an SMS whose contents were directly interpretable by Google Maps, the user could view on a map quickly and clearly.

Therefore, the program will send an SMS with a valid link of the Google Maps application to the interested person's phone number.

Google maps allows visualization, been possible to insert the coordinates to represent or directly the address of interest.

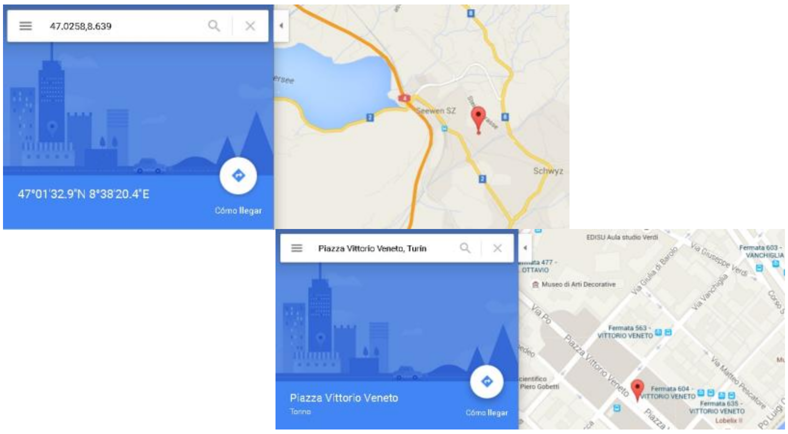


Figure 50: Google Maps

The goal of the module is to locate the device, so the address will be unknown at all time. Thus, a URL accepted by Google Maps platform was built so that from a latitude and longitude, coordinates could represent on the map.

The URL should always follow the following structure supported by the platform:

```
www.google.it/maps/place/LATITUDE,LONGITUDE
```

Being the latitude and longitude, the data that has been obtained by GPRS technology in the previous program.

Finally, the structure of this algorithm is:

- Enable GPRS.
- Get the position by mobile network (latitude, longitude).
- Build Google Maps link.

- Dispatch SMS to the set phone number.

To avoid sending bulk SMS, in experimentation was configured to send a message every thirty minutes.

The first two points were already implemented in the first program developed, and previously the method of the library responsible for sending short text messages was identified.

Therefore, the only significant addition to the code of this algorithm was manual link generation for the mapping platform, below the code snippet in charge of it is shown:

```
dtostrf(latitude, 0, 6, latBuffer);
dtostrf(longitude, 0, 6, longBuffer);
sprintf_P(message, PSTR("www.google.it/maps/place/%s,%s"), latBuffer, longBuffer);
Serial.println(message);
if (!fona.sendSMS(sendto, message)) {
  Serial.println(F("Failed"));
} else {
  Serial.println(F("Sent!"));
}
```

Figure 51:Google Maps Link generation

Where:

- Dtostrf: Converts data latitude and longitude (in numerical format) in two strings.
- Sprintf: Concatenates all strings that make up the Google Maps link.

For experimentation and checking of results, the generated SMS were sent to a known number.

The first figure shows the terminal's onscreen output, where coordinates calculated by the GPRS module and the content of the message sent are identified. And a message indicating the successful SMS dispatch.

```
Checking for Cell network...
        ---> AT+CREG?
        <--- +CREG: 0,1
        ---> AT+CIPGSMLOC=1,1
        <--- +CIPGSMLOC: 0,7.653975,45.021492,2016/06/21,08:47:07
GPRS LOCATION
------------------
GSMLoc lat:45.021488
GSMLoc long:7.653975
-----------------

www.google.it/maps/place/45.021488,7.653975
        ---> AT+CMGF=1
        <--- OK
        ---> AT+CMGS="3895060742"
        <--- >
> www.google.it/maps/place/45.021488,7.653975
^Z
Sent!
```

Figure 52: Program 2 Results

Next the received SMS is checked on the mobile device's screen and the representation of the message on the Google Maps application:

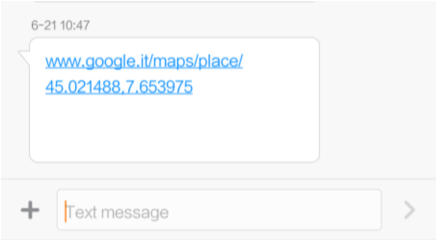


Figure 53: SMS with the location of the device

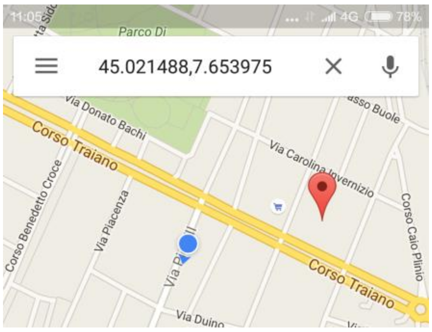


Figure 54: Location representation in Google Maps

As can be seen on the map, the location accuracy depends on the mobile network and generally provides an accuracy of 100-200 meters.

The implementation of this program involved the establishment of a full first design of the location subsystem. It is available the device location in real time as well as a tracking system thanks to the Google Maps platform.

7.3.1.2)Temperature Subsystem

The goal of the following subsystem is monitoring of device temperature. This way, it will be possible later on to implement a system of alarms, in case of detection of abnormal temperatures.

As described in previous points, the temperature is calculated by a sensor. Below the sensors and elements used in the development of this subsystem are listed:

7.3.1.2.1) Involved elements

BMP180 barometer

The BMP180 module implements a low consumption sensor able to calculate the temperature, atmospheric pressure and altitude (from the pressure). It is very small and fully compatible with the Arduino platform.

Particularly focused to GPS navigation and outdoor applications.

Figure 55: BMP180 front view

Figure 56: BMP180 front view

Arduino Uno

Just as in the location subsystem, an Arduino Uno board was used for the implementation of programs.

7.3.1.2.2) Assembly

To assemble this module, advantage on the available design was took, which also contained the location subsystem.

That is, the block consisting of the Arduino Uno board and the FONA module was exploited, connecting the barometer to the board through the protoshield.

Figure 57: Assembly of the BMP180

In spite of being two different subsystems, the final design should be able to combine them all in a compact and efficient way in terms of energy, so this assembly can provide solutions that combine the location and temperature subsystems.

7.3.1.2.3) Implementation, experimentation and results

The implementation of this subsystem was performed by the program that will be described below.

Just as for the module to get the location, a library specially developed for the BMP180 barometer was used, in a programming environment.

SFE_BMP180 Library

In the library, all the methods that the barometer is able to perform are declared and defined. To get the temperature from the sensor, the following ones were identified:

```
char begin();
    // call pressure.begin() to initialize BMP180 before use

char startTemperature(void);
    // command BMP180 to start a temperature measurement

char getTemperature(double &T);
    // return temperature measurement from previous startTemperature command
```

Figure 58: SFE_BMP180 Library Temperature

In addition to calculating the temperature, it is considered handy to use the functions related to pressure and altitude in order to explore the capabilities of the BMP180 Barometer.

The following figure shows different results when executing an initial program, while a slight heat source was applied over the device:

```
TEMPERATURE: 28.06 deg C
Absolute PRESSURE: 993.82 mb
Relative (sea-level) Pressure: 1022.46 mb
Computed ALTITUDE: 239 Meters

TEMPERATURE: 32.47 deg C
Absolute PRESSURE: 993.83 mb
Relative (sea-level) Pressure: 1022.46 mb
Computed ALTITUDE: 239 Meters

TEMPERATURE: 33.10 deg C
Absolute PRESSURE: 993.90 mb
Relative (sea-level) Pressure: 1022.54 mb
Computed ALTITUDE: 239 Meters
```

Figure 59: Executing initial program with slight heat source applied

The increase in detected temperature is checked, and the detection of the altitude corresponds to the altitude of Torino, a city where all tests have been performed and which is at an altitude of 239 meters above sea level.

Experimentation

After checking the operation of the sensor, in the subsequent program was implemented an alarm which would notify by using a string about the detection of a value above a threshold. To check its operation, it was defined as threshold a value easily attainable. In the final design, the choice of this value should be adjusted to a real and practical case.

It was observed, while reaching the threshold temperature, an alarm message displays and the program stops calculating data until the emergency is managed.

At this point of development of the first subsystems, a set of modules able to calculate the location and temperature of the device were available.

In order to get closer to an autonomous and practical system (without being connected to a computer), then it was proposed the combination of the first two subsystems to manage the temperature alarms system.

The program described below, uses the possibilities of the FONA module to send SMS to implement an algorithm which:

- Calculates in real time the temperature of the device.
- If a temperature higher than the threshold value is detected, activate the GPRS service.
- Gets the device location.
- Sends SMS notifying a temperature alarm and indicating the location of the device.

By this structure, the energy consumption of the continuous usage of the mobile network is avoided, only activating the location service in case of alarm.

The SMS would show a temperature alarm message, and a link for viewing the location on the map on the Google Maps platform, as explained before.

The receiver of the message, once the alarm has been identified, might contact the user wearing the device to check the situation in he is in, or request different services such as specialized assistance or a more comprehensive monitoring to see the behaviour of the device.

```
TEMPERATURE: 29.99 deg C
TEMPERATURE: 29.99 deg C
TEMPERATURE: 30.00 deg C
TEMPERATURE ALARM!!!!!!!! - Sending SMS

GPRS LOCATION
------------------
GSMLoc lat:45.024814
GSMLoc long:7.650836
-----------------

> TEMPERATURE ALARM!!! ; www.google.it/maps/place/45.024815,7.650836
^Z
Sent!
```

Figure 60: Temperature alarm results sms & google maps

On the one hand, the output is shown on the terminal's screen, where, once the threshold temperature is exceeded, the latitude and longitude of the device is obtained, to finally send a text message indicating that an abnormal temperature has been detected, and the coordinates the device is located at the time the alarm was generated.

From this first combination, a very basic tele-assistance service is obtained, in which a user can be monitored or assisted in case of a temperature above or below established normal values is detected.

7.3.1.3)Fall Detection Subsystem

Detection of falls, as observed throughout this project, offers a service of tele-assistance very important. Under normal conditions, the prototype will rarely detect abnormal temperatures. However, due to the intrinsic characteristics of users who require tele-assistance, falls in elderly or disable patients are more frequent than desired.

This module is intended to ensure rapid and efficient assistance in case of a fall is detected.

7.3.1.3.1) Involved elements:

As announced above, for the detection of falls, two different technologies were experimented: detecting by using: a barometer and an accelerometer.

A pressure difference implies a difference of height. Therefore, a height difference can be calculated from an increase or decrease in atmospheric pressure. Under this relation, a barometer may be able to detect a fall, as an abrupt change in height.

BMP280 Barometer

Absolute pressure barometric sensor, specially designed for mobile applications. Its small size and low power consumption allow implementation in navigation systems, mobile systems or watches.

It is the successor to the BMP180, offering high performance in different applications requiring accurate measurements of atmospheric pressure.

It supports services that require high accuracy, such as in-door navigation applications or medical applications, the BMP280 can be used, thanks to its accuracy of 0.12hPa, equivalent to a tolerance of 1 m height difference.

Figure 61: BMP280 front view

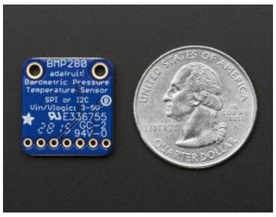


Figure 62:BMP280 size

An alternative method for detecting a fall is based on considering the fall as a very rapid variation in the spatial coordinates. This coordinate variation implies an acceleration, and currently there are different devices geared to measure acceleration in any of the three spatial dimensions, called accelerometers.

An accelerometer is defined as an instrument capable of measuring spatial accelerations, therefore, from these variations is capable to detect movements that could describe a fall motion.

EVAL-ADXL346Z (Analogue Devices)

The digital low-power-consumption accelerometer ADXL346. It calculates the spatial coordinates at any coordinate, in real time.

Designed for mobile devices applications thanks to its small size (3mmx3mmx0.95mm), allows measurement of the static acceleration (tilt-sensing application), and the dynamic acceleration caused by a movement or stroke.

The accuracy in high-resolution settings, allows measurements of inclination changes less than 1.0°.

It has different and special detection functions:

- Activity/Inactivity: detects the presence or absence of movement, comparing the acceleration in the three coordinate axes.

- Stroke detection (Tap): identifies the existence of a single or double stroke on the device, or the surface is on, in either axis.

- Free fall: detects if the device is falling.

Figure 63:ADXL346 front view

The management of these functions is performed individually by two interruptions (INT1, INT2).

Hardware interruptions are signals that interrupt the normal activity of a microprocessor to attend the event notified by the signal.

Arduino language allows the use of interruptions, enabling for each board, several (usually two) interruptions pin.

In this chapter, throughout the next session, it will be detailed in a synthetic way how interruptions are implemented in Arduino.

Arduino Micro

For experimentation with both modules, it was decided to work independently of the block formed by the location and temperature subsystem, implemented using the Arduino Uno board.

The tests, as will be shown in the next point’s figures, were performed on a breadboard and using Arduino Micro board.

7.3.1.3.2) Assembly

For the development of the fall system were carried out the different assembly tests on a badge of tests, connecting the pines of the barometer correctly and of the **Accelerometer** with the microcontroller

The Arduino board was connected through a cable usb with a computer that would act as terminal, to show the results obtained by the programs.

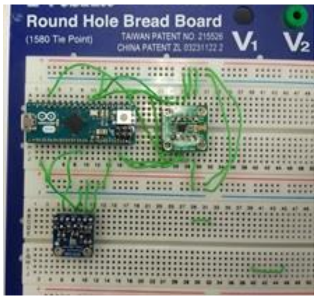


Figure 64: BMP280 and ADXL346 Assembly

7.3.1.3.3) Implementation, experimentation and results

In this section, the entire implementation process followed to implement the fall detection subsystem is detailed.

As observed in previous points, there are two different devices offering theoretically fall detection.

It was initially experimented with the BMP280 barometer, understanding its operation and exploiting its capabilities.

After checking the results and accuracy offered by the pressure gauge, it was decided to implement the subsystem using the ADXL346Z accelerometer.

All tasks performed will also be described as well as the concepts and code snippets to understand the process followed.

BMP280 Barometer

The barometer can calculate height differences through the measures of atmospheric pressure. A first design was done under this principle.

Similarly to the BMP180, the device offers the temperature, pressure and height, using just the different methods available in his library.

After a first program which calculated all this values, in the same way that was showed in the first example of the temperature subsystem, the next algorithm was developed:

- Measure the atmospheric pressure each second.
- From the second iteration, the difference between the pressure in the current second and the pressure measured in the past second is calculated.
- This pressure difference is converted into height difference, considering the equivalence showed in the datasheet of the device (an increment of 0.12hPa, is equivalent to a difference of one meter of height.

In order to establish a notification system in case of falling, it was decided to write an alert message through the screen terminal when the device had calculated a height difference bigger than a defined threshold value.

A fall is a loss of height therefore an increase in the pressure. For this fact the algorithm differentiates two cases:

- UP: When the current value of pressure was higher than the last value measured. (Which means that there was a pressure increase).
- DOWN: When the pressure has decrease with respect the previous measure.

The algorithm only showed the alarm message in the case that the threshold value was overcome and the pressure was increased (height decreased).

Once the results were interpreted, the inaccuracy of them was checked:

- The barometer in rest position, that is to say, with no height changes, showed height deviations with values up to 50 centimetres. In spite of an absence of increment or decrement of height, the measures showed the opposite, resulting in an incorrect implementation of the system.

Considering a threshold value of 40 centimetres (which is a value which can represent a true fall if the device is located around the waist or the knee for example). The alarm messages were generated despite the absence of movement in the device.

Observing the technical specifications of the barometer, it is indicated that the maximum precision of the device is 0.12hPa, which means one meter of height difference. For lower values the product offers incorrect measures as it was shown.

Due to this maximum precision, the fall detection system implemented by a barometer was considered insufficient to offer a good service of tele-assistance. (Examples: Generation of alarms in rest position, or falls not detected if they have a height difference less than 50 centimetres.

The precision of the BMP280 will be suitable for applications where the difference of pressures and height will be bigger than half meter.

Considering a tele-assistance service where an emergency can present a height differences of few centimetres, the precision of the barometer is not enough.

So that, after the experimentation with the barometer and his failed results, it was decided to implement a new system for the fall detection using in this case an accelerometer, which can detect the movement through the accelerations.

ADXL346Z Accelerometer

Before describing the programs and the process followed for fall detection by using the accelerometer, a small introduction to the use of interruptions in Arduino will be made, since in successive programs, interruptions will be used to manage events of interest such as free fall.

a) Interruptions

1) Sensor connected to the microprocessor generates an interruption signal.
2) The microprocessor identifies this signal.
3) The microprocessor stops its normal activity and carries out the instructions associated with the identified interruption.

To define an interruption in Arduino, it is necessary:

- An Arduino pin to receive the signal to manage (generated by the device, in this case the accelerometer).
- A condition under which the interruption is activated in the microprocessor.
- A function to be performed immediately after activation of the interruption.

1) Arduino pin

For this subsystem, an Arduino Micro board was used, which has five different pins that can manage interruptions. They are shown in the following figure:

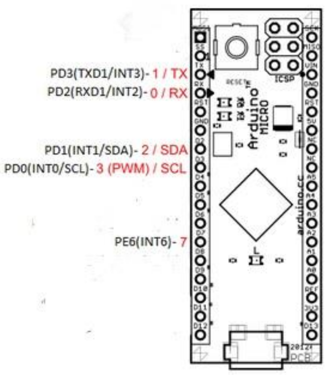


Figure 65: Arduino micro interrupt pins

There are five different pins that can be used for use interruptions, simply connect any of them with the pin of the device responsible for generating the signal.

2) Interruption condition:

An Arduino Micro, allows the following conditions, which activate the interruption of the microprocessor.

- Low: The interruption is triggered when the pin generating the signal is in low state.

- Change: It is triggered when the pin undergoes a change of state (High to Low or vice versa).

- Rising: When the device pin switches from low state to high state.

- Falling: opposite to the previous case.

3) Function to execute:

The set of instructions to be executed after identifying an interruption will depend on the interruption and the goal of the program.

In order to facilitate the understanding, the following figure shows an example program that generates a message notifying the existence of an interruption, when the pin detects a change of state.

The implementation of this program was fundamental for the subsequent use of interruptions.

```
int pin_int = 0;
int c;

void setup() {
  Serial.begin(9600);
  pinMode(pin_int, INPUT);
//  digitalWrite(pin_int, HIGH);
  c = 0;
  attachInterrupt(pin_int, interrupt, CHANGE);
}

void loop() {

  Serial.print("Working");
  Serial.println(c);
  c++;
}

void interrupt() {
  Serial.println("INTERRUPTION");
  c = 0;
}
```

Figure 66: Interruption Test

The statement to define an interruption management is **attachInterrupt**, whose fields:

- Pin_int: corresponds to the pin associated to the interruption, in this case the pin 0 corresponding to pin 2 of the Micro board (see figure above).
- Interrupt: is the name of the method that will be executed when the microprocessor receives the interruption signal.
- Change: condition under which the interruption is activated.

The program will display the message **“Working”** on screen as long as the pin2 of the microprocessor detects a change of state, at which point the screen will notify the existence of an interruption.

After becoming familiar with the use of interruptions, the next task was to use the accelerometer.

b)ADXL346 operation

Before showing the developed programs and the results obtained, it is considered interesting a brief explanation about the operation of the accelerometer.

The ADXL346, bases its operation through registers, as seen in its specifications manual. Each register has its allocated memory address, and fully configure the device based on the contents of each record.

In the following figure, the description of some of these registers are displayed:

0x2E	46	INT_ENABLE	R/$\overline{W}$	00000000	Interrupt enable control.
0x2F	47	INT_MAP	R/$\overline{W}$	00000000	Interrupt mapping control.
0x30	48	INT_SOURCE	R	00000010	Source of interrupts.
0x31	49	DATA_FORMAT	R/$\overline{W}$	00000000	Data format control.

Figure 67:ADXL346 registers

It is indicated, from left to right, the address in memory of the register (in hexadecimal and decimal), name, itype (read and/or write), the value to reset the register, and a brief description.

All possibilities offered by the accelerometer, can be exploited by writing to these registers.

As an example, the 8-bit register called INT_MAP has the following structure:

Register 0x2F—INT_MAP (Read/Write)

D7 DATA_READY	**D6** SINGLE_TAP	**D5** DOUBLE_TAP	**D4** Activity
D3 Inactivity	**D2** FREE_FALL	**D1** Watermark	**D0** Overrun/ orientation

Figure 68:ADXL346 INT_MAP register

This register performs the interruptions mapping. Each bit is associated with an event that can generate interruptions. Any bit set to zero in this register, sends its respective interruption signal to INT1 pin of the accelerometer, while a bit set to one, sends it to INT2 pin.

Therefore, for the development of the following programs, the different registers have been configured until the desired results were obtained.

The read and write operations on the registers were implemented by the writeRegister and readRegister functions. Which descriptions are available in the annexes section.

c)Implementation

The goal for the first program that was developed was the familiarization with the different registers and check the behaviour of the accelerometer.

This program provides coordinates reading from the accelerometer, for display on screen.

This algorithm uses no interruption system because it simply obtains the position measured by the sensor.

Once the proper operation of the accelerometer in providing the coordinates in any of the three axes is checked, a first program was implemented, capable of detecting a single or double tap on the surface that the accelerometer is on.

As shown in the previous figure, there are two related events with the Tap capable of generating an interruption signal, the simple and double Tap.

The program can provide the coordinates in the three axes as well as detect the presence of a single or double tap, generating an interruption.

The registers configuration is shown in the following figure, which includes in the comments, the description of each instruction:

```
//Create an interrupt that will trigger when a tap is detected.
attachInterrupt(0, tap, RISING);
//Put the ADXL345 into +/- 4G range by writing the value 0x01 to the DATA_FORMAT register.
writeRegister(DATA_FORMAT, 0x01);
//Put the ADXL345 into Measurement Mode by writing 0x08 to the POWER_CTL register.
writeRegister(POWER_CTL, 0x08);  //Measurement mode
//Send the Tap and Double Tap Interrupts to INT1 pin
writeRegister(INT_MAP, 0x9F);
//Look for taps on the Z axis only.
writeRegister(TAP_AXES, 0x01);
//Set the Tap Threshold to 3g
writeRegister(THRESH_TAP, 0x38);
//Set the Tap Duration that must be reached
writeRegister(DUR, 0x10);

//100ms Latency before the second tap can occur.
writeRegister(LATENT, 0x50);
writeRegister(WINDOW, 0xFF);

//Enable the Single and Double Taps.
writeRegister(INT_ENABLE, 0xE0);
```

Figure 69: Registers configuration

The **writeRegister** method writes in the register passed as the first parameter the value in the second field.

The method to be executed when the interruption signal is detected, it is called tap and it displays a message on screen, indicating the existence of an interruption per tap as well as indicates whether the event corresponds to a single or double tap.

The following screenshots shows screen output, throughout the following three situations:

1) Accelerometer at rest, without the presence of taps.
2) Simple tap.

```
6,11,109
7,11,113
8,10,113
8,10,113
TAP INTERRUPT
7,11,111
SINGLE
```

Figure 70: Single tap

3) Accelerometer at rest.
4) Double tap.

```
7,11,113
9,12,110
6,11,113
7,10,109
9,11,112
TAP INTERRUPT
9,13,113
DOUBLE
0.07g,0.10g,0.88g
```

Figure 71: Double tap

Interruptions are generated instantly after causing taps on the surface of the accelerometer.

Although detection of taps is not directly related to the fall detection, the development of this program was interesting because it offered a first contact with interruptions of the accelerometer.

Free fall

In order to detect the fall of the device and hence the user's, it was decided to use, first of all, a program using the accelerometer's free fall system.

The ADXL346Z is capable of generating an interruption signal when being in a free fall situation.

The detection of free fall, is defined by two accelerometer registers (Time_FF and Thresh_FF). When a value of greater acceleration than the registry Thresh_FF's, for a period of time less than the value of the register Time_FF, the interruption signal will be activated.

By the two aforementioned registers, the free fall signal will be generated depending on the acceleration and its duration.

The following figures show the configuration of the different registers:

1) General Settings of the accelerometer, where:

- Choose the resolution of the accelerometer
- Mapping of interruption signals
- Enables only free fall interruption
- Sets the accelerometer to measure mode

```
void ADXLinit() {
  writeRegister(DATA_FORMAT, 0x0B);    //+- 16g ,  FULL RESOLUTION , INTERRUPTS ACTIVE HIGH
  writeRegister(INT_MAP, 0xFB);   //FREFALL INTERRUPT -> INT1 , OTHERS -> INT2
  writeRegister(INT_ENABLE, 0x04); //ENABLE ONLY FREFALL INTERRUPTS
  writeRegister(POWER_CTL, 0x08);  //Measurement mode
  readRegister(INT_SOURCE, 1, values); //Clear the interrupts from the INT_SOURCE register.
}
```

Figure 72: ADXL configuration

2) Configuration of the free fall registers:

```
void ADXLfallinit(){
  writeRegister(THRESH_FF,0x05); //FREEFALL THRESHOLD min value recommended
  writeRegister(TIME_FF,0x25); // FREEFALL TIME value
}
```

Figure 73: Free fall configuration

The value of the register Thresh FF corresponds to 0.3125g and time for detection is 125ms.

These values are experimental and were adjusted to the tests conducted in the laboratory. Therefore, the program generates an interruption signal for free fall, by detecting an acceleration greater than 0.3125g over a period of time less than or equal to 125ms.

For the final design, the values of the free fall registers should be adjusted, taking the used ones as reference.

3) Statement of the interruption signal and instructions to execute:

```
attachInterrupt(0, fall, RISING);
```

Figure 74: Interrupt signal declaration

```
void fall(){
  Serial.println("FALL DETECTED WARNING");
  readRegister(INT_SOURCE, 1, values); //Clear the interrupts from the INT_SOURCE register.
  delay(2000);
}
```

Figure 75: Interrupt Function

At the time that the pin 0 of the microprocessor detects a change of state from low to high, it will interrupt its operation to execute the method called **fall**, to show a message on screen and clean up the registers.

Below the program output is displayed and the result is commented:

```
COM9 (Arduino/Genuino Micro)                                   Enviar
-17,19,-38
80,14,-71
19,6,-22
-51,20,-61
56,20,-33
81,48,-63
117,30,-73
FALL DETECTED WARNING
106,1,-20
3,44,301
69,50,-21
75,25,50
FALL DETECTED WARNING
12,-29,268
40,-13,272
94,59,-79
73,40,-53
18,4,-30
FALL DETECTED WARNING
-72,-13,-92
```

Figure 76: Free fall results

It is observed that the accelerometer displays on screen its coordinates in the three spatial axes until a free fall is detected. Then, the screen displays an alarm message.

With the values of this implementation, the fall is detected for differences in height of 20-30 centimetres. In a real case, for example, if the final design of the prototype was a clock, assuming a person of average height, a fall can make a difference in height of one meter or more.

The reason to have used these values in the laboratory lies in the system assembly. The system is connected to a computer via a cable of approximately 30 centimetres, so to simulate a fall of one meter was a complicated task.

However, as already mentioned, to adjust the detection for real practical cases, it is enough to configure the free fall registers.

Free fall + Immobility

While this first algorithm detects a free fall of the device. It turns out to be a mechanism quite far from reality, where any bodily movement can be considered as a free fall if the system accuracy is not high enough.

For this reason and taking as reference some algorithms for detection of complex falls, a new program was designed that would identify as a fall a free fall event followed by a period of immobility of the device.

A user needing tele-assistance might be disable or elder, so a fall of importance will be followed by a period of immobility of the patient.

This new algorithm already offers a closer solution to a service which could assist a person after receiving a notification of a fall followed by immobility.

Using the above program, fall detection was already available, so this new development implements the management of a new interruption caused by the immobility of the device.

Similar to the management of free fall, mobility and immobility of the accelerometer is configured with two registers, one to determine the threshold value for detecting immobility (TRESH_INACT) and another that defines the time that the device should remain below threshold to generate the interruption signal for inactivity.

To implement the algorithm, it has been used the two interruption pins of the accelerometer, one for free fall, and the other for immobility.

The goal of the program is the identification of two successive events, a fall followed by immobility.

Therefore, immobility should not be detected if there has been no fall previously, the code snippets, considered of greatest interest, are shown and explained below:

1) Declaration of interruptions signals: Using the two pins for accelerometer interruptions and two of the pins of the Micro board.

```
attachInterrupt(1, inact, RISING);
attachInterrupt(0,fall,RISING);
```

Figure 77: Interruption Signals

2) Initialization of the accelerometer:

-

```
void ADXLinit() {
  writeRegister(DATA_FORMAT, 0x0B);    //+- 16g ,  FULL RESOLUTION , INTERRUPTS ACTIVE HIGH
  writeRegister(INT_MAP, 0xFB);   //FREFALL INTERRUPT -> INT1 , OTHERS -> INT2
  //writeRegister(INT_ENABLE, 0x0C); //ENABLE ONLY FREFALL & INACT INTERRUPTS
  writeRegister(INT_ENABLE,0x04); // ENABLE ONLY FREEFALL INTERRUPT
  writeRegister(POWER_CTL, 0x08);  //Measurement mode
  readRegister(INT_SOURCE, 1, values); //Clear the interrupts from the INT_SOURCE register.
}
```

Figure 78: Accelerometer initialization

The accelerometer is configured so that only free fall detection can generate an interruption signal.

1) Setting the parameters of inactivity:

```
void ADXLinact(){
  writeRegister(THRESH_INACT,0x03);
  writeRegister(TIME_INACT,0x10);
}
```

Figure 79: Inact registers configuration

By writing the values shown in the registers of inactivity, a threshold value is obtained corresponding to 0.1875g and a downtime of 10 seconds.

These values are quite suitable for experimentation, since acceleration is small enough to only be activated in case of practically zero inactivity or mobility, and 10 seconds is a period of high enough time for the user to resume his activity, if the fall was mild and without assistance.

2) Management of interruptions:

```
void fall(){
  Serial.println("FALL DETECTED WARNING");
  readRegister(INT_SOURCE, 1, values); //Clear the interrupts from the INT_SOURCE register.
  writeRegister(INT_ENABLE, 0x0C); //ALLOW FREE FALL + INACTIVITY INTERRUPTS
}


void inact(){
  Serial.println("INACT DETECTED AFTER FALLING");
  Serial.println("ALARM!!!!!!!!!!!!!!!!!");
  readRegister(INT_SOURCE, 1, values); //Clear the interrupts from the INT_SOURCE register.
  writeRegister(INT_ENABLE,0x04);  //Allow only interrupts for FREE FALL
}
```

Figure 80: Interrupt functions

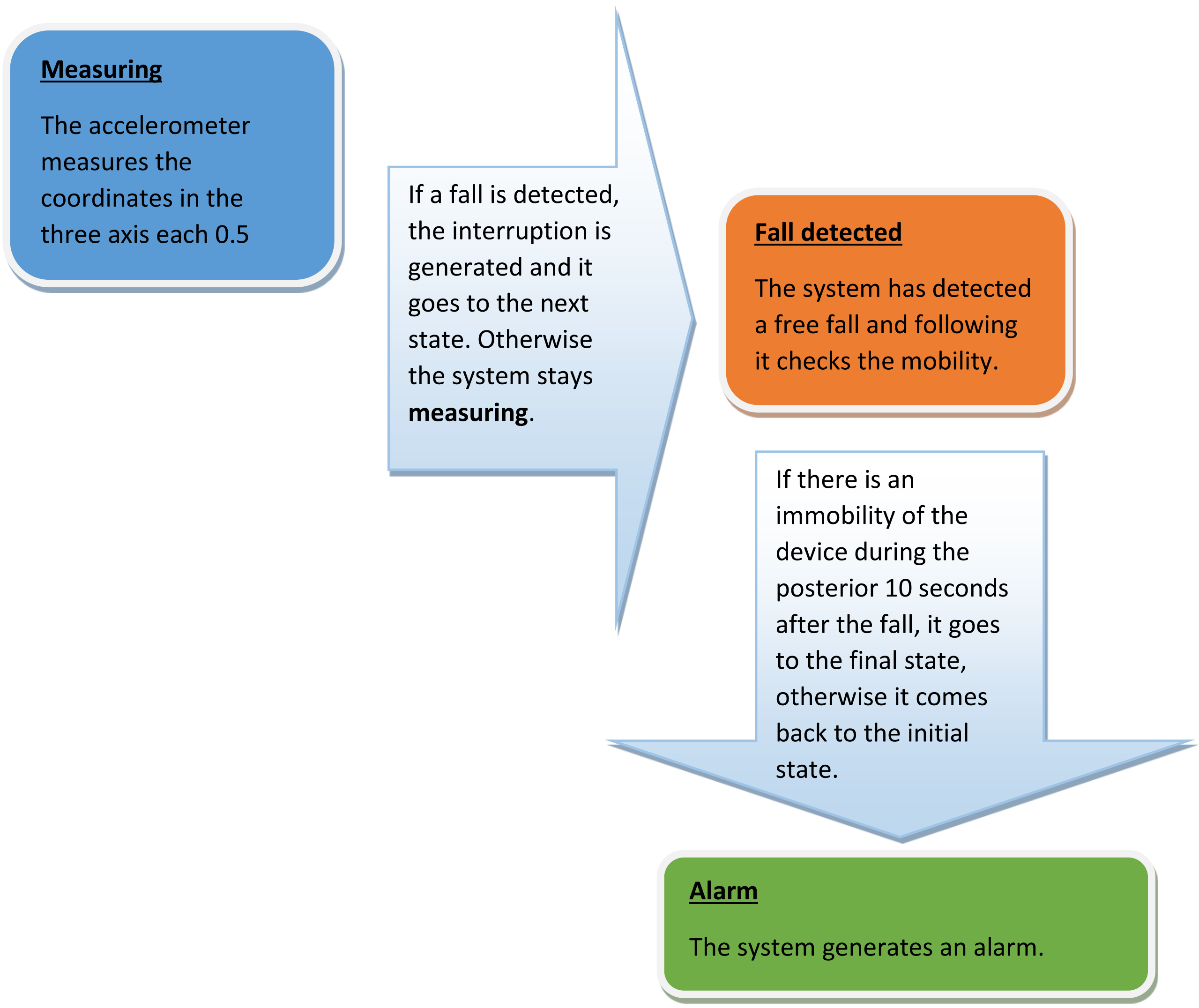
The first method is executed after a free fall is detected and:

- Displays a message on the screen.
- Cleans the registry of interruptions, to detect the following.
- Enables interruptions for inactivity detection.

The second one, related to the detection of inactivity on the device:

- Displays an alarm, since a fall has been detected followed by immobility.
- Cleans the registry of interruptions.
- Enables only the interruptions for free fall detection.

The algorithm followed by the program is described by the following figure:



Thus, the accelerometer continuously calculates the coordinates. Only if it detects a free fall, it will execute the instructions in the first method.

These enable detection of inactivity, and if it detects an inactivity of at least ten seconds, after the fall, a warning message will be shown.

The following figures show the results on screen for the following cases:

Note: In order to not have to show as many iterations of the program and wait for ten seconds, it has been set a time of immobility of five seconds.

The representation of the coordinates is performed every second.

a) Fall followed by mobility:

Figure 81: Free fall + inactivity result 1

The fall is detected, but not detect immobility, the accelerometer continues normal operation.

b) Immobility:

Figure 82: Free fall + inactivity result 2

As a fall has not been detected, no interruption is executed, and the coordinate values are displayed on the screen.

c) Fall followed by an immobility of five seconds:

Figure 83: Free fall + inactivity result 3

It is checked how the fall is initially detected, and after five seconds of immobility, the alarm message is generated.

Therefore, by developing this new algorithm, a fall detection system is obtained, and with the capability to generate alarms.

Just as in the temperature subsystem, alarms generated by the fall detection program might be managed by sending short text messages.

7.3.1.4) Energy Harvesting Subsystem

Throughout this Project, the main EH techniques have been described and analysed and also some devices and currently available products have been shown. However, the EH is still in an early stage of development, so it has been impossible to find sensors or elements that offer an interesting energy saving solution for the tele-assistance prototype.

For this reason, the possibility of implementing an EH module in the final system was discarded. However, it was considered interesting experimentation with the EH kit available in the market, to have a first contact with the different possible techniques, and analyse their behaviour.

Energy Harvesting Solution To Go (WURTH ELKTRONIK)

This section briefly describes the kit used and the results obtained after performing various basic experiments.

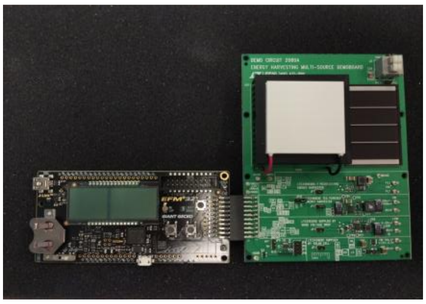


Figure 84: Energy Harvesting Kit

The system is composed by two different modules:

1) The EFM32 microcontroller, which manages the program instructions implemented in the system.

2) Multi-Source Energy Harvesting module by Linear technologies, which implements different EH techniques for generating energy.

The experimentation focused on getting familiar with the software working environment, Simplicity Studio, and then check the behaviour of the different techniques present in the EH sub-module.

Simplicity Studio provides different tools related to the design and testing of energy profiles. It allows to calculate the energy consumption of different configurations. The autonomy of different designs, it is checked how is increased at the time in which any EH technique is used.

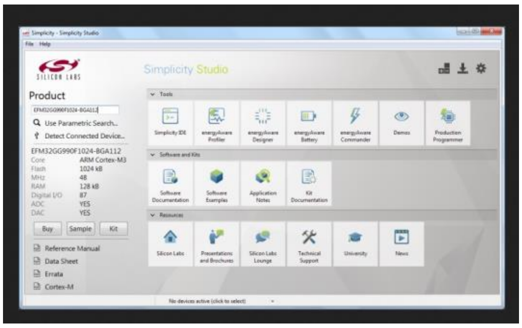


Figure 85: Simplicity studio

After exploring the software environment basically, it was proceeded to work with the EH submodule:

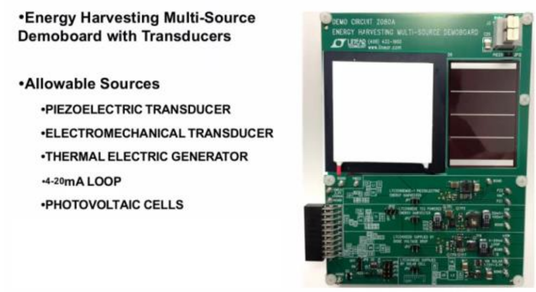


Figure 86: Energy Harvesting module

As it is shown in the previous figure, it allows to collect energy from four different sources:

- Piezoelectric transducer: stores energy from vibration of a piezoelectric fiber placed in the upper right board slot.
- Electromagnetic transducer: generates voltage from received electromagnetic waves.
- Thermoelectric Generator: by using Peltier technology offers the possibility of delivering power when it receives a heat source.

- Solar energy: from the light received by the photovoltaic panels, generates power to increase the autonomy of the device,

Each of these techniques is selectable by the correct positioning of the various Jumpers which connect the microcircuits.

For each of the cases except for the electromagnetic source, basic tests were performed to analyse the behaviour.

In the piezoelectric case, an additional variable-with-vibration energy source was obtained, providing a more irregular flow than in the case of using thermoelectric transducer or solar energy.

By placing the hand on the Peltier board or placing a source of constant light on the solar panel, constant energy flows in the order of millivolts are achieved.

After basic experimentation with the kit and its working environment, a first contact with the different EH techniques was made, defining various ideas and future lines that will be presented in the next chapter.

7.3.2) Data platform block

By implementing the above three subsystems, all the data required to offer a basic tele-assistance service is available:

- SMSs that indicate the user's location.
- Alarm message generated when the device has an anomalous temperature.
- Alarm message after detecting a fall event followed by a period of immobility of the device.

All these messages can be seen by a specialized centre or person responsible for assisting the user of the device. However, the most comprehensive tele-assistance services, also offer control and monitoring of patients.

The data obtained by the different sensors is monitored and based on it different services are offered. Such as, managing an alarm that is activated when a user leaves his usual geographical area overnight. (This area, would have been defined thanks to long time monitoring of the patient.)

In addition to the goal of providing a monitoring service, it is interesting that the IoT prototype may be able to connect to other devices or to store data collected over time in a database.

As explained throughout the chapter of Architecture and Technology, a platform capable of storing the parameters measured by the sensors would allow the implementation of new features and services for tele-assistance.

Once the data is stored, it would be possible to implement an application to interpret, represent or perform actions on it.

To address this point, a subsystem called Data platform is developed.

The implementation of this subsystem provides for the connection of different sensors, with an existing data platform, which will receive and store the different data that the prototype is capable of measuring.

It was decided to take advantage of an existing data platform called Flubber, which basic description is given in the following point:

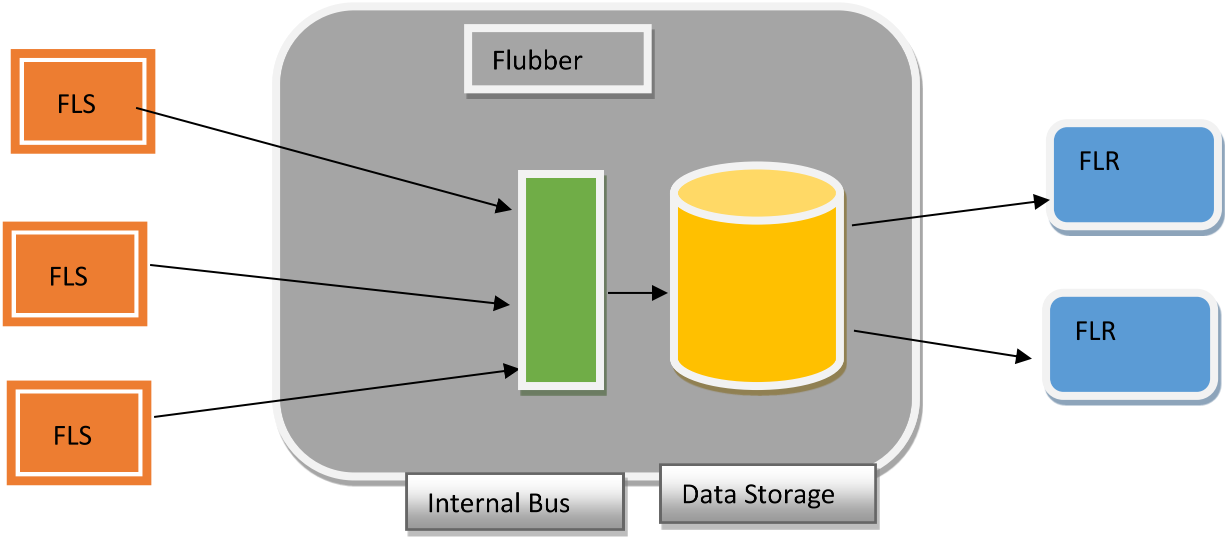
7.3.2.1) Flubber platform

7.3.2.1.1) Introduction

IoD platform (internet of data) that allows the interconnection of different components storing data sent by them. It supports connection of sensors, mobile applications and wearable devices, among others.

Figure 87:Flubber logo

The basic architecture of the platform for data storage, distinguishes the following elements:



Where:

- FLS (Flubber Sender): Representation of the elements that send data to the platform. After being created and enabled, an FLS can receive any valid data and save it to Fluber.
- Data Storage: NoSQL database that manages data sent by different FLSs.
- FLR (Flubber Receiver): Endpoint enabled to obtain data associated with one or more FLS, stored on the platform.

7.3.2.1.2) Communication protocol

Writing and reading on the Flubber platform is done by using REST instructions.

The term REST refers to a software architecture style for systems and describes any interface between systems that use the HTTP protocol to obtain and send data.

Therefore, communication between the IoT device and the platform will take place via HTTP POST instructions for write operations, and HTTP GET for reading data from the platform.

7.3.2.1.3)Data format

The data sent by the device to the platform is in the JSON format. This lightweight text format allows the use of numbers, strings, vectors and objects among others.

Each JSON object should contain the following fields:

- **senderUid:** Contains the identification of a FLS, which is automatically generated by the platform. It has a string format.
- **createdAt:** Field indicating the object creation time (UNIX timestamp format).
- **Value:** The JSON object with the parameters that will be sent. It will follow a scheme determined by the user, at the time of defining the FLS.

7.3.2.1.4) Security protocol

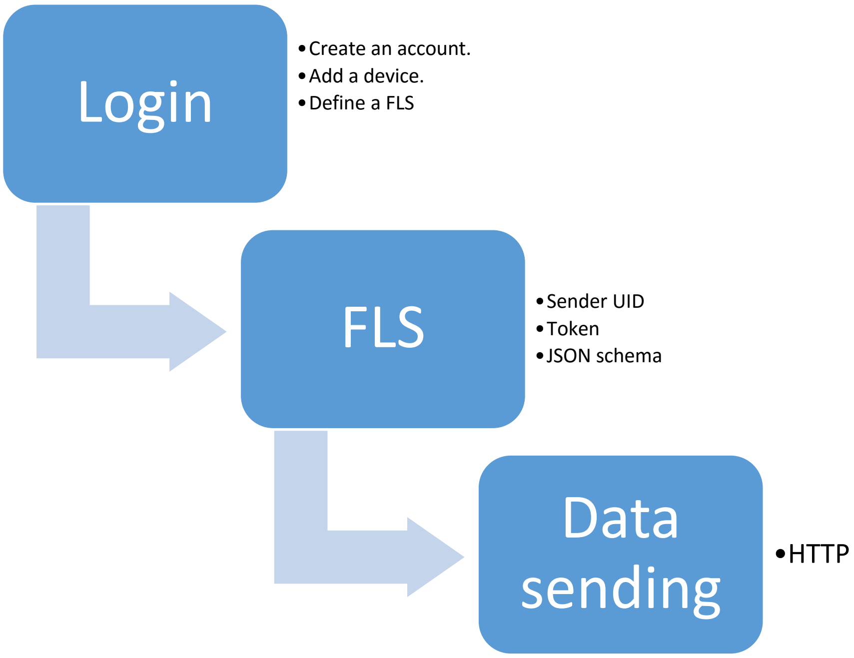
The platform ensures a secure connection by using the OAuth 2.0 token-based protocol.

When creating a FLS, in addition to automatically obtain an identification field to send the data, the platform provides a token, responsible for authorizing communication between the sensor and the platform.

This token must be included in the header of the data sent to the platform, in the way that will be explained in the implementation section.

Using the following schema, it is intended to summarize the steps for sending data correctly to the platform.

The part of creating an FLR and an application that can get the stored data from a FLS, has been discarded since the objective of experimenting with the FLUBBER platform was focused on sending data and its storage. The data retrieval was left for future experiments.



- Login: Includes registration tasks in the platform users' system and creating one or more FLS.
- FLS: Once a FLS is created, with a user-defined JSON schema, the platform provides fields for identification (ID) and authentication (Token) that allow sending data.
- Finally, using HTTP and the fields above, communication is performed with the platform, sending the desired data.

Having seen the basic operation of the platform, the entire implementation process followed in the laboratory will be analysed, following the steps described in the above scheme.

7.3.2.1.5) Implementation

1) Login:

After registration on the web portal of the platform using a user name and password, the FLS responsible for sending data was defined.

Such FLS was constituted by the device location subsystem, where the data to send is its own coordinates and Google Maps link representing that location.

The following figure shows the creation of the FLS:

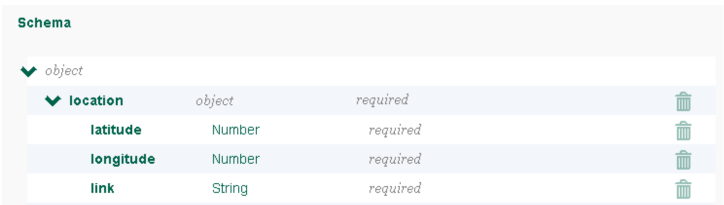
Figure 88: Basic GPRS FLS

The program that was used is described in the section of the subsystem implementation, where the latitude and longitude of the device was obtained using the FONA 808 module and GPRS technology.

2) FLS:

The next step, after the creation of the FLS was its setting, defining the JSON schema of the data to send (latitude, longitude, Google Maps link).

At the same time, it was made available the fields for identification and authentication for sending data:



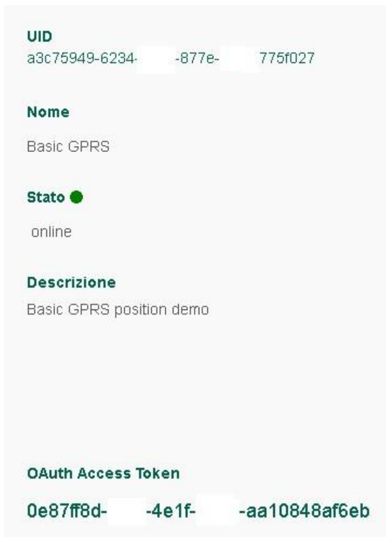


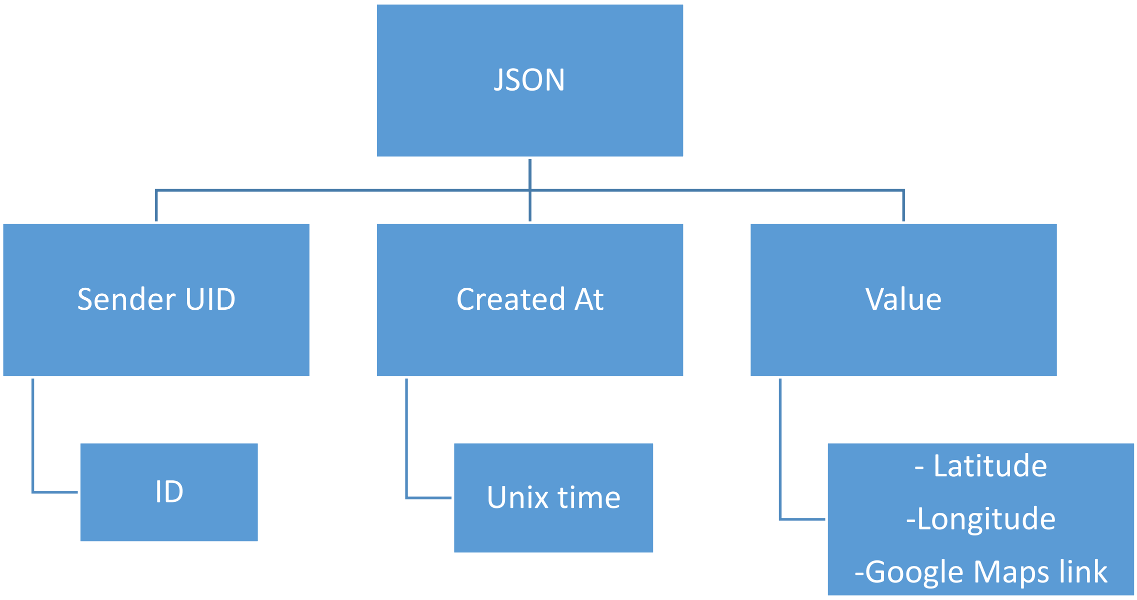
Figure 89: Data scheme for the FLS

Figure 90: FLS uid and Access Token

Therefore, the program that obtains the location of the prototype, was modified by adding the JSON objects in accordance with the previous figure.

It should be mentioned, as stated in the section **Data format**, in addition to the schema shown, the **senderUid** and **createdAt** fields must be added.

Therefore, the object to be sent by the device should have the following structure:



The identification of the FLS is automatically obtained from the platform, so it is a known field.

Obtaining the timestamp was implemented using the **fona.enableNTPTimeSync** function found in the library of FONA module that allows real-time synchronization using NTP network protocol. The format had to be transformed to unix timestamp format using the following piece of code:

```
/////////////////////UNIX TIME//////////////////////////////
if (!fona.enableNTPTimeSync(true, F("pool.ntp.org")))
  Serial.println(F("Failed to enable"));
char buftime[19];
String date;
fona.getTime(buftime, 19);
date = buftime;
date = date.substring(1);
Serial.println(date);
delay(5000);


String mes2 = date.substring(3, 5);
String dia2 = date.substring(6, 8);
String hr2 = date.substring(9, 11);
String mn2 = date.substring(12, 14);
String sec2 = date.substring(15, 17);

int mes = mes2.toInt();
int dia = dia2.toInt();
int hr = hr2.toInt();
int mn = mn2.toInt();
int sec = sec2.toInt();

setTime(hr, mn, sec, dia, mes, 2016);
time_t T = now();
unsigned long unix = (unsigned long) T;
```

Figure 91: UNIX timestamp code

So, all the data needed to create the different objects was available.

The creation of JSON objects in Arduino is detailed in the following figures, and is observed how it is required, to declare the object, reserving their space in memory, to instantiate it and finally fill the fields present in the object.

```
const int BUFFER_SIZE2 = JSON_OBJECT_SIZE(3);
const int BUFFER_SIZE = JSON_OBJECT_SIZE(1);

/////////////////////JSON//////////////////////////////////////////

  StaticJsonBuffer<BUFFER_SIZE2> Buffer_loc;
  JsonObject& location = Buffer_loc.createObject();
  location["latitude"].set(latitude, 8);
  location["longitude"].set(longitude, 8);
  location["link"] = link;

  StaticJsonBuffer<BUFFER_SIZE> Buffer_val;
  JsonObject& value = Buffer_val.createObject();
  value["location"] = location;


  StaticJsonBuffer<BUFFER_SIZE2> Buffer_json;
  JsonObject& json = Buffer_json.createObject();
  json["senderUid"] = "a3c75949-6234-457a-877e-b1bdf775f027";
  json["createdAt"] = unix;
  json["value"] =  value;

  String data = "";
  json.printTo(data);
```

Figure 92: JSON object definition

- First, two possible sizes for objects are defined, one or three parameters each.
- Then the object containing the location and link to Google Maps is created, and the fields are filled.
- Once the object is created, this must be included in the value object (according to the model required by the platform.
- Finally, the JSON object will contain the value object (with the location of the device and link), and senderUid and createdAt fields.

Once the data to send is prepared, the next step was to add the necessary HTTP instructions to send the data to the platform.

The data sending is done using the POST method, for that, a URL (a platform address) was defined to send the data, the headers required for correct delivery, and finally data payload was sent.

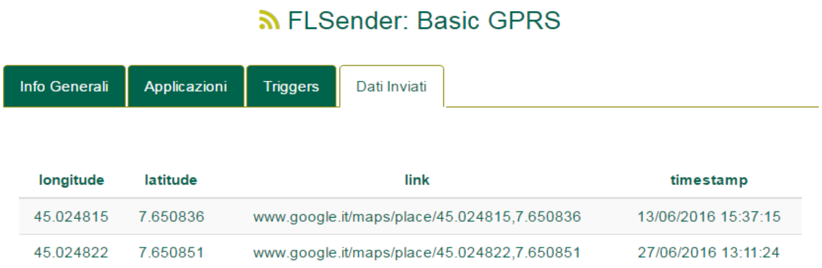
```
fona.println("Content-Type: application/json");
fona.println("Access-Control-Allow-Origin: *");
fona.println("Authorization: Bearer /TOKEN/");
fona.println("Accept: application/json");
```

Figure 93: HTTP headers

In the message HTTP headers, the token that enables communication between the IoT device and platform was included.

It was checked, how through the process described, the communication with the Flubber platform was achieved, so that the data sent on the data variable was stored in its database.

The following figure shows (from the control panel) the data set sent to the platform from the device:



longitude	latitude	link	timestamp
45.024815	7.650836	www.google.it/maps/place/45.024815,7.650836	13/06/2016 15:37:15
45.024822	7.650851	www.google.it/maps/place/45.024822,7.650851	27/06/2016 13:11:24

Figure 94: Data sent by the FLS

It can be observed that all fields are perfectly separated and also the time the data was sent.

Therefore, it is concluded successfully the communication between the platform and the prototype location subsystem.

7.3.2.1.6) Problems

Once a program was developed being capable of communicating with flubber sending the device location. It was tried to add successively the other subsystems to this communication.

Initially all code of the temperature subsystem was added to the program so it would be sent the location to the platform as well as the temperature.

When attempting to check the results of the new program, a memory problem on the Arduino board was found, in this case the Arduino Uno. When compiling the entire program, a message warning that the memory size reached could cause instability problems. These problems manifested after running the program showing meaningless messages and ultimately the incorrect execution of the implemented instructions.

For smaller boards, Arduino Micro and Nano, instability problems were not found, as execution was prevented since more than 100% of available memory was surpassed.

In an attempt to solve this memory problem, it was experimented using the Arduino board which has better memory capabilities than all mentioned boards.

Unfortunately, this new board has a different microprocessor and new technology, which results in incorrect interpretation of instructions implemented in the programs. These problems can be solved in the future, with the forthcoming software updates of the board 101. Therefore, it cannot be achieved a satisfactory communication including the temperature subsystem.

7.3.3) Application block

The last subsystem in the architecture of the tele-assistance prototype, it is intended to be able to obtain and interpret the data stored in a database.

By using the Flubber platform, it was possible to send all information related to the location and a Google Maps link.

During experimentation, it was decided to leave the implementation of a proper application for future designs. Seizing at the moment, the existence of any application that could interpret the offered data.

Throughout the whole process, the usefulness of Google Maps application is recognized, to display the device's location on a map, easily and clearly. Therefore it was decided to simply check, once the data is stored on the platform, how the link to the Google Maps application can be obtained through the HTTP GET method, and display the position of the device on a map, identically to the results obtained by sending the position via SMS.

Due to time constraints, one FLR associated with the previous FLS was created and defined, leaving for future designs the implementation of a program to get the google map link field from the data stored on the platform (using the HTTP GET method).

Just as for a FLS, the application presents the fields of identification and authentication to ensure secure and unambiguous connection between the platform and the application.

The implementation of the different subsystems of the prototype finished after performing the above experiments.

In the next chapter, an analysis of the results will be done to check whether this project's desired objectives were achieved.

Figure 95: FLR application

8) Evaluation

The objective of this section is to review and assess the results obtained, in addition to present the points to improve or could not be implemented in this first tele-assistance prototype.

To make that balance, firstly, the initial objectives of this project will be addressed:

- First contact and scouting of different EH techniques.
- Improvement of the Adamo tele-assistance system, offering outdoor capacity.
- Design of a small-size prototype to facilitate its insertion into the users' life.

8.1)EH

Throughout this paper, there have been several approaches to EH term and its current situation. Initially, there has been explained the meaning of that term and the main techniques in which it relies to obtain additional energy. Also an analysis was performed related to the current state of the different investigations and projects which manifested the initial development state that still have all EH techniques.

It was observed, as one of the main problems in finding products in the market, the lack of a standard regarding the technical specifications of the elements, thus preventing a rigorous comparison between them to choose the most suitable for the desired application.

Finally, some existing devices and solutions using some EH techniques were shown. In addition, a basic experimentation using a test kit was carried out, where it was observed and analysed practically the behaviour of different EH techniques.

Therefore, through this whole journey, a level of initial knowledge about the EH concept was achieved, which could be very important in future designs when the different EH projects, are not in such an early stage.

Throughout the study about EH, it has also been proven that this is especially interesting to IoT devices and wearable autonomous systems.

It is considered as achieved the goal of the research about energy collection since from the study done in this project, it has been reached a basic level of knowledge about the EH which can mark the inclusion of a EH subsystem, in future designs, to the tele-assistance prototype.

The following list summarizes the obtained data and the points considered as positive and negative and the problems encountered:

- Knowledge about the term and main techniques.
- Checking the importance of energy saving in wearable devices.

- Identification of different techniques that can be used in future designs (piezoelectricity, energy from light or heat).
- Information on the current status of the projects and some current devices.
- Initial phase of development.
- Lack of standardization of the technical specifications
- Few available and expensive products.

8.2) Tele-assistance system

To make an assessment of tele-assistance service offered by the prototype, it should be analysed the results obtained by each of the subsystems and as a whole.

The first three subsystems (location, temperature, falls system) offer the desired data and SMS alarm systems have been implemented for the first two.

Location is obtained by using network technology, based on the principle of energy saving, compared to satellite technology. The accuracy obtained using GPRS, is considered sufficient to provide an outdoor tele-assistance service. However, in emergency situations, or those where mobile network remains saturated (eg an accident in a football stadium), it might be insufficient to provide quick and effective assistance.

Since these situations are punctual, simply comment that could be interesting, as long as the battery permits and the design is not affected by increasing its size disproportionately, to include an additional GPS service which would be activated if the device is unable to connect to a mobile network. Otherwise, it would continue using GPRS technology.

The temperature subsystem also reaches a fairly good accuracy for the purposes of tele-assistance, under normal conditions, that is, the chances that the device is in extremely high or low temperatures are very small, and by using BMP180 barometer, both situations would be detected without problems.

In the subsystem temperature, it could also have implemented, by using a simple temperature sensor, since the other functions of the barometer are not used in this subsystem. The justification for the use of a barometer, it is behind the intention to use the barometer for detecting falls. In this way, two different subsystems could be implemented in the same device.

As observed during the implementation, it was not possible to use a barometer for detecting falls, due to insufficient accuracy. Finally, the use of another element, in this case an accelerometer, was necessary.

The algorithm for fall detection is considered sufficient for a basic tele- assistance prototype, but most real systems offer a much more complete and real solution to detect falls, as shown in the following project:

http://www.analog.com/library/analogdialogue/archives/43-07/fall_detector.html

Therefore, even though by using the programs implemented, it is possible to detect falls, simulated in the laboratory, it has been impossible to check their behaviour in real situations, with the device placed on a user, so it is unknown if it is sufficient to consider a fall followed by inactivity as sufficient to generate an alarm.

The developed implementation finished with the combination of the location subsystem with temperature subsystem, however, the fall detection system did not become interconnected with the rest.

The reasons were purely technological, because when combining the codes of the three devices, the memory capacity of the different Arduino boards available in the laboratory was exceeded. Since the Arduino language and its environment are optimal for application development and systems as the prototype of this thesis, the problem focuses on finding a board capable of supporting the code of the three subsystems.

The tests using the Arduino 101 board were performed, but as reported in the implementation, the instructions do not execute properly, due to the different architecture present on this board which has more memory.

Therefore, a negative point to mention is the lack of cohesion between the three subsystems responsible for obtaining the data. It has been possible to get a tele-assistance module offering the location and temperature of the device and also its system of alarms via SMS, however, the fall detection system is implemented in another block with another microprocessor, to check the results.

The problem is solved by finding an Arduino board capable of supporting the full code (already developed) and run properly. Simply connect the three elements to the microprocessor of the Arduino board, and thus a more complete tele-assistance service would be available.

The objective set by the tele-assistance service has been achieved, given that the prototype is able to offer (without fall detection subsystem, due to the problem presented) an outdoor assistance service and alarm system that works efficiently using SMSs.

Therefore, this prototype serves as a baseline for the exploration and development of Adamo system, for outdoor areas and implemented using an autonomous and wearable design.

Furthermore, it has been proven that the device is an open system able to communicate with a database easily. Using this communication with data platforms, new possibilities are opened to provide the service and alarm management. (Example: a specialized service that obtains data from a platform to carry out monitoring and control tasks).

8.3) Design

Although it was not an objective of this thesis to end the development with a final design that could be placed directly on the user, clear lines of design to be followed by the prototype and future designs were marked: the size and economic efficiency.

Therefore, most of the modules used (FONA 808, BMP180) are elements of low power consumption and small size.

Nowadays, the size of the prototype considering the accelerometer, barometer and locating device, has a similar size to a battery of a mobile phone or a wallet and a negligible weight, so it is considered as a wearable IoT device, which can be introduced transparently into a patient's life.

The size is mostly determined by the used Arduino board and the battery, by reducing both, even smaller dimensions can be achieved.

Again, the prototype defines the starting point after which evolution to obtain a completely wearable final design is possible.

After evaluating the whole process carried out in terms of the objectives set, in the next points the final conclusions are discussed and the possible future lines are also described.

9) CONCLUSION

By implementing the various existing modules, it is concluded that a basic tele-assistance system has been developed which is also managed by short text messages, without using a fixed terminal connected to the telephone line.

The autonomous prototype ensures indoor and outdoor coverage and a system of alarms generated by the various sensors. The service is offered via SMS, sending the location and the generated alarm. The SMSs are also sent to the configured phone number (s).

Enough knowledge has been obtained about the EH techniques to be able to implement a module for energy saving in future designs, which would ensure a higher autonomy of the device and even its use without batteries. It has also been carried out successful communication with a database that offers a variety of new services for future designs.

Therefore, there is a tele-assistance prototype defining the starting line, from which to develop a complete tele-assistance system offering coverage outdoor, and uses concepts such as EH, the monitoring and ultimately, an autonomous system able to provide assistance in real time.

10) FUTURE LINES

This prototype and the different modules of the system architecture allow us to define a series of future lines to be followed by similar designs or projects.

EH: Different EH techniques might be used in the near future. The inclusion of a piezoelectric module or using solar cells, seems really interesting in order to provide a source of natural and renewable energy for a wearable device. The choice of these depend on the design (if the design is constantly exposed to light sources, if the design can take advantage of the user's body motion or vibrations etc.).

Data platform: Using a data platform capable of storing and managing the data measured by the sensors. In future designs, new monitoring services, user or application control will be defined which would open the possibility of designing third party applications to display the data generated by the sensors.

Fall system and other data: As future tasks to improve the service already provided, it is proposed the improvement of the fall detection system, by developing more new and comprehensive algorithms. The insertion of new sensors that provide important parameters for tele-assistance, such as heartbeat, is also proposed.

To conclude, the future lines are marked with a view to progressively improve the service provided, adding services and making these more efficient in terms of energy consumption and size.

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13) ANNEX

Following, there are listed the links to access to the different datasheets of the devices used:

ADAFRUIT FONA MANUAL

https://cdn-learn.adafruit.com/downloads/pdf/adafruit-fona-mini-gsm-gprs-cellular-phone-module.pdf

Barometer BMP180 MANUAL

https://cdn-shop.adafruit.com/datasheets/BST-BMP180-DS000-09.pdf

Barometer BMP280 MANUAL

https://cdn-learn.adafruit.com/downloads/pdf/adafruit-bmp280-barometric-pressure-plus-temperature-sensor-breakout.pdf

Accelerometer ADXL346 MANUAL

http://pdf1.alldatasheet.com/datasheet-pdf/view/300957/AD/EVAL-ADXL346Z.html

The full code of the different programs implemented along the project are attached in the next section