UNIVERSITÀ DI PISA

MSc in Computer Engineering

Industrial Applications

Safety Driving Recognition

TEAM MEMBERS:

Francesco Bruno

Federico Cavedoni

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Content

1. Introduction

Driving is a cognitively complex task related to multiple functions, many of which can be diminished or altered by driver's medical conditions. Numerous studies have addressed the role of medical conditions in the causation of vehicle crashes. The aging population, cardiovascular disease, personalized medicine, and driver fatigue were significant motivations for developing a monitoring platform in cars to increase the safety in the cars since that people spent much time in cars.

So, our objective was to create an exhaustive monitoring system for the driver. The chosen crucial parameters in the health and drowsiness monitoring, was the Heart rate, from which we extracted the Heart-Rate-Variability (HRV).

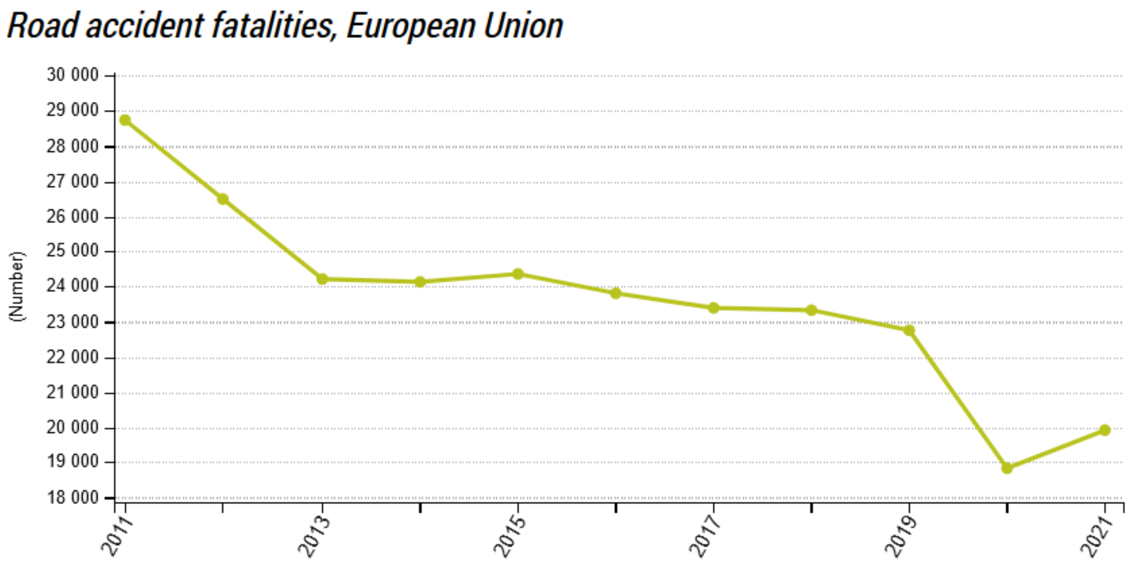


Figure 1: Road accident fatalities in European union

2. State of the Art

The state-of-the-art's study performed begins the most cutting-edge systems used by car manufacturers. In particular, the systems proposed by Toyota, Mercedes-Benz, Peugeot and Ford were analyzed to understand which functions were already in use on the market to help the driver and therefore limit the number of accidents.

From these studies, the main technologies used to implement these functions were then analyzed.

Furthermore, numerous research papers on the topic of 'driver detection' were analyzed to understand what stage the research is at and which technologies are in development.

2.1. T-Mate by Toyota

T-Mate is a set of systems designed to assist the user while driving and make it safer at all times: when parking, on the motorway or in the city.

Focusing on our objective, among all the systems within the T-Mate, we will report in detail only those related to the detection of tiredness and anomalies in the driver's health conditions.

2.1.1. Emergency Detection Stop System

It is responsible for keeping the driver under control and carrying out emergency braking if it realizes that the driver has had a problem and is no longer fit to drive due to a medical emergency.

Figure 2: Emergency Detection Stop System

2.1.2. Driver Monitor Camera

It is responsible for keeping the driver under control and checking that he is not distracted or asleep, promptly alerting him with a message.

Figure 3: Driver Monitor Camera

2.1.3. Rear Passenger Detection

It is responsible for checking that, when the driver leaves the car, there are no passengers left in the car involuntarily. This feature arises from the fact that a large number of children die every year because they are inadvertently forgotten in the back seats.

Figure 4: Rear Passenger Detection

2.2 Attention-Assist by Mercedes Benz

Mercedes-benz Attention-Assist is a device that analyzes the driver and tries to understand, through the way he drives, whether he is no longer in excellent condition for driving and therefore suggests a break to avoid unpleasant incidents.

This device - which in the car is intuitively indicated by a cup of coffee - can help avoid falling asleep, thus contributing to greater driving safety, especially on long journeys and at night. Thanks to optical and acoustic signals, the system warns when it recognizes typical symptoms of tiredness or inattention, urging you to stop.

To analyze driving behavior, steering movements are examined and an individual driver profile is compiled.

Figure 5: Attention-Assist by Mercedes Benz

2.3 Drive Assist by Peugeot

Peugeot drive assist is a device that monitors the driver and, using a video camera and his driving behavior, tries to understand whether the driver is capable of driving or whether he is not in an optimal state.

It therefore tries to avoid unpleasant accidents by promptly reporting the driver with a warning and advising a break when it suspects that the driver is driving distracted and drowsy.

Figure 6: Peugeot Drive Assist

2.4 Driver Alert by Ford

The Ford driver alert is a system that tries to understand whether the driver is able to continue driving and possibly invites the user to take a break if he is not.

This device is based on a sensor that is capable of "reading", any facial changes caused by tiredness, such as the drooping of the eyelids which prefigures the very dangerous falling asleep.

Figure 7: Driver Alert by Ford

This system is also equipped with a radar that allows the driver to be warned if there are passengers in the rear seats when leaving the car.

Figure 8: Rear passenger detection experiment

2.5 Results

To summarize the work carried out, we decided to build a table listing the car manufacturers and the features that are now implemented in their cars.

	Vital Signal Monitoring	Child Detection System	Driver Distraction Detection
T-MATE	✗	✓	✓
ATTENTION ASSIST	✗	✗	✓
DRIVER ALERT	✗	✓	✓
DRIVE ASSIST	✗	✗	✓

Figure 9: Summary of the state of art analysis of the car manufacturing

2.6 Research Papers

In addition to the car manufacturers, which represent the state of the art currently present on the roads, numerous research papers were analyzed to understand the direction in which the research is going and to have some ideas for the project realization. Among all those analyzed three papers were taken, carefully chosen because each of these reports one of the main techniques studied by researchers to implement features to help the driver.

- **Design of Smart Steering Wheel for Unobtrusive Health and Drowsiness Monitoring**

  This paper aims to study whether it would be possible to analyze the driver's health status using sensors placed on the steering wheel. The sensors used are PhotoPlethysmoGraphic (PPG) sensors which, using light, are able to obtain the driver's heartbeat.
  https://www.mdpi.com/1424-8220/21/16/5285

- **Driver Vital Signs Monitoring Using Millimeter Wave Radio**

  This paper aims to study whether rear passenger detection is possible using radio waves placed inside the car.
  https://ieeexplore.ieee.org/abstract/document/9615374?casa_token=M6LXft8mKGAAAAAA:6q_D-AZFErSj8-zDADY9Jr3E5jsF9uk2_-fL5LMsdKS0VvmRgMZl1-khlwde__6VOq2k_gxUew

- **Driver Distraction Detection on Edge Devices via Explainable Artificial Intelligence (UNIPI)**

  This paper aims to study whether using a video camera it is possible to understand whether the driver is distracted while driving or not.
  https://www.iiis.org/DOI2023/SA300MJ/

3. Project Specifications

From the analysis of the state of the art, the user specifications were first derived, i.e. the features that a user expects to find in a system of this type as they are successful on the market. The following have been identified:

- The system must be not invasive.
- The system must be user adaptable.
- The system periodically get data from sensors.
- The system classifies the obtained data.
- The system takes decisions based on classified data.

Once the user specifications were identified, the product specifications were derived from them, i.e. the set of features that the product must possess. The following specifications have been identified:

- The driver must not notice the sensor sampling, so he must be able to drive as if nothing had happened. The PPG parameters must be specific for each user.

- The System must have a degree of flexibility in analyzing the cardiac signals of different users. A main conditioning factor on heart rate is simply age.
  https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6147850/

- The classification must have a high precision (80%). We consider precision because by definition it is calculated as the total number of correct predictions divided by the total number of predictions. Therefore, False Negatives are also taken into account, which should not be underestimated at all as they are equivalent to the situation in which the user is not well and the system does not notice it.
  https://www.mdpi.com/2073-431X/10/12/158

4. Enabling Technologies

To implement the specifications, the enabling technologies were carefully analyzed and chosen:

• A photoplethysmographic (PPG) sensor was chosen to collect the data. Also analyzing the potential alternatives, this type of sensor was chosen because it is the least invasive and therefore most suitable for safe driving. From this sensor it is possible to extract the heart rate variability (HRV), used for the classification of driving status.

• To classify the data, a Recurrent Neural Network (RNN) made up of Long-Short Time Memory (LSTM) cells was chosen. This choice arises from the fact that, currently on the market, the LSTM neural network is the most optimal when working in long-duration timeseries.

• The classification parameters must be user-specific, i.e. they must perfectly adapt to the person who is driving. To perform this functionality, it was chosen to use the camera which, in modern cars, is already present as it has been possible to demonstrate in the state of the art. Using the video camera, it will be possible to recognize the driver and therefore adapt the system to his specific parameters.

5. Project Architecture

The system architecture is therefore composed of:

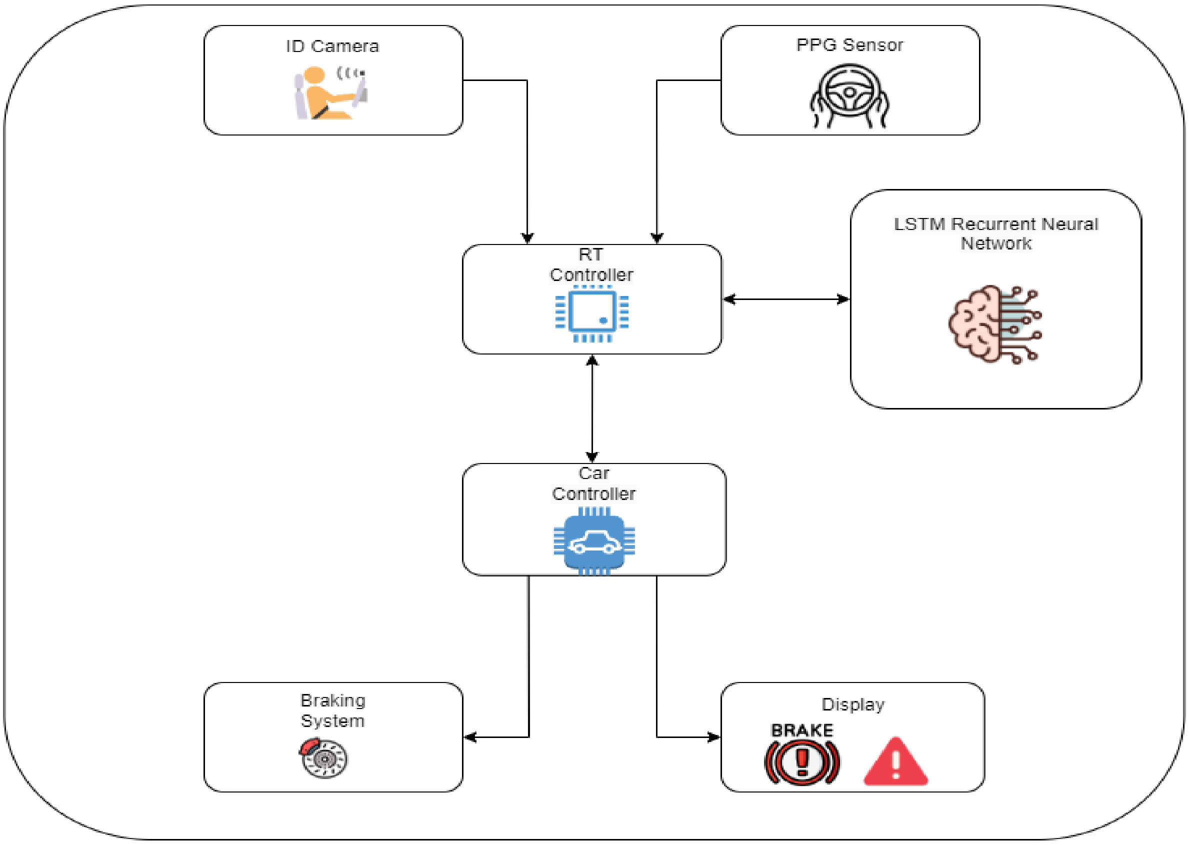
• A PPG sensor that collects data from the driver

• A video camera used for user recognition

• An LSTM neural network used for state classification

• An RT controller that coordinates the components and communicates with the car controller

• A car controller who is responsible for carrying out functions on the car, such as the error message or emergency braking



6. Work Packages Analysis

In this section, the work that will have to be done to create the prototype has been analyzed in full. The work was divided into four work packages to logically divide the work and organize timing and costs in a more modular way.

6.1 Profile Analysis

Profile analysis consists of understanding which profiles we need to create the prototype. The analysis had the following results:

• Researcher scientist in statistical science. To perform statistical analyzes used especially in the first phase of the project.

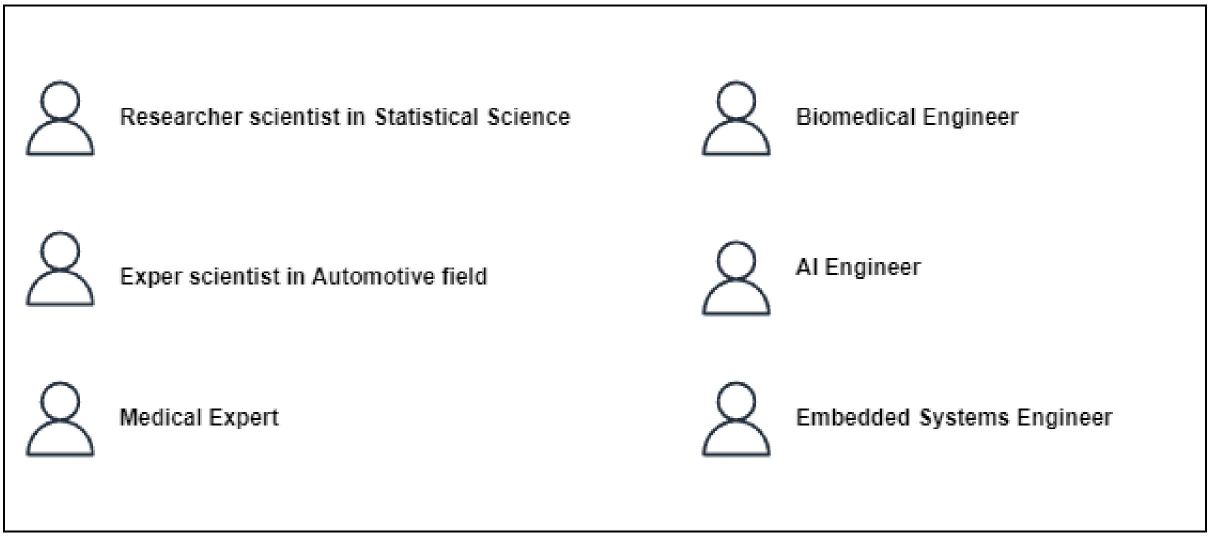
• Expert scientist in automotive field. To carry out a market analysis on the technologies present in cars on the market.

• Medical Expert. To obtain a medical opinion on the biological signals that have been collected by the driver via the ppg sensor.

• Biomedical Engineer. To operate the sensor correctly and understand the data collected by it.

• AI Engineer. To manage the deployment, training and execution aspect of the neural network used to classify the data collected by the sensor.

• Embedded Engineer. For both software and hardware development of the sensor and controller of the system.



6.2 Work Package 1

The first work package is the most introductory one, in which the analysis of the state of the art in the world of cars is carried out. In particular, the main causes of accidents were analyzed, the technologies currently used to improve driving safety and what the most common health problems for drivers are. These studies are essential to fully understand the market we want to enter and therefore exploit the winning technologies.

WP 1	**WP Title:** Analysis of factors that increase driving danger **WP Type:** R.I.	**Activity Start:** Month 1	**Activity End:** Month 2
Man/Month: 0.3 + 0.6 + 0.3 + 0.3 = 1.8 Man/Month			
Objectives: • Identification of the main causes of accidents • Understand what technologies exist to improve driving safety • Understand what are the most frequent causes related to driver health problems • Understand what technologies can detect the most frequent health problems that lead to accidents			

Activities:

- Analysis of the most common accidents causes
- Market analysis
    - Analysis of actual used technologies (State of Art study)
- Analysis of accident rates caused by sickness
- Study of key monitoring technologies on driver status

Roles hours per Task:

1) Analysis of the most common accidents causes (Month 1)
    - Researcher scientist of Statistical Science. Approx: 50 hours (0,3 man/month)
2) Market analysis (Month 1)
    - Expert scientist in Automotive field. Approx: 100 hours (0,6 man/month)
3) Analysis of accident rates caused by sickness (Month 2)
    - Researcher scientist of Statistical Science. Approx: 50 hours (0,3 man/month)
4) Study of key monitoring technologies on driver status (Month 2)
    - Medical Expert. Approx: 50 hours (0,3 man/month)
    - Embedded Systems Engineer. Approx: 50 hours (0,3 man/month)

Costs:

- Researcher scientist of Statistical Science. Approx: 100 hours (0,6 man/month)
  - €20 per hour x 50 hours = €1.000
  - €20 per hour x 50 hours = €1.000

- Expert scientist in Automotive field. Approx: 100 hours (0,6 man/month)
  - €20 per hour x 100 hours = €2.000

- Medical Expert. Approx: 50 hours (0,3 man/month)
  - €30 per hour x 50 hours = €1.500

- Embedded Systems Engineer. Approx: 50 hours (0,3 man/month)
  - €40 per hour x 50 hours = €2.000

Total Cost: €7.500

6.3 Work Package 2

The second work package is used to obtain the elements necessary to derive an initial architecture of the prototype. The package consists in the choice of the vital signal to analyze for the prototype, derived from the study of the sensor market and the most common health states. We then move on to the user specifications, which are the features that a user wants within the product and therefore successful on the market. We then move on to the product specifications, which are the features that the product must implement. Finally, the enabling technologies will be chosen, which are the technologies that allow us to achieve the specifications established in the product specifications, choosing the best technologies for the use case.

WP 2	**WP Title:** Preliminary product analysis **WP Type:** R.I.	**Activity Start:** Month 3	**Activity End:** Month 5
Man/Month: 0.6 + 0.6 + 0.6 + 0.6 + 0.6 = 3.0 Man/Month			
Objectives: • Choice of vital signs to be monitored • Deriving User Specifications • Deriving Product Specifications • Derive the enabling technologies for the product			

Activities:

- Analysis of the car application market and derivation of user specifications

- Development of product specifications
  - Vital sign detection study
  - Analysis of user specifications and derivation of product specifications
  - Analysis of product specifications and derivation of required enabling technologies

- Analysis of enabling technologies and derivation of the best for the use case

Roles hours per Task:

1. Analysis of the car application market and derivation of user specifications. (Month 3)
   - Expert scientist in Automotive field. Approx: 100 hours (0.6 man/month)

2. Development of product specifications (Month 3-4)
   - Medical Expert. Approx: 100 hours (0.6 man/month)
   - Embedded Systems Engineer. Approx: 100 hours (0.6 man/month)

3. Analysis of enabling technologies and derivation of the best for the use case (Month 4-5)
   - Researcher scientist in AI. Approx: 100 hours (0.6 man/month)
   - Researcher scientis in Embedded systems. Approx: 100 hours (0.6 man/month)

Costs:

- Researcher scientist in Automotive field. Approx: 100 hours (0.6 man/month)
  - €20 per hour x 100 hours = €2.000

- Medical Expert. Approx: 100 hours (0.6 man/month)
  - €20 per hour x 100 hours = €2.000

- Embedded Systems Engineer. Approx: 100 hours (0.6 man/month)
  - €40 per hour x 100 hours = €4.000

- Researcher scientist in AI. Approx: 100 hours (0.6 man/month)
  - €20 per hour x 100 hours = €2.000

- Researcher scientist in Embedded systems. Approx: 100 hours (0.6 man/month)
  - €20 per hour x 100 hours = €2.000

Total Cost: €12.000

6.4 Work Package 3

In this work package, a first draft of the project's architecture is initially developed, starting from the knowledge obtained in the previous work package. Subsequently, an accurate analysis was carried out on which type of neural network to use and which type of sensor to use for the system. Finally, a final architecture of the prototype was developed with the best enabling technologies chosen in the activities of this work package.

WP 3	**WP Title:** Development of product architecture **WP Type:** R.I.	**Activity Start:** Month 6	**Activity End:** Month 8
Man/Month: 0.25 + 0.25 + 0.25 + 0.6 + 0.3 + 0.3 + 0.25 + 0.25 + 0.25 = 2.7 Man/Month			
Objectives: • Product architecture development • Identify specific Neural Network • Identify Sensor Type			

Activities:

- Initial product architecture design
- Analysis and identification of the best neural network
- Analysis and identification of the best sensors for the use case
- Final product architecture design

Roles hours per Task:

1. Initial product architecture design (Month 6)
   - Embedded Systems Engineer. Approx: 40 hours (0.25 man/month)
   - AI Engineer. Approx: 40 hours (0.25 man/month)
   - Biomedical Engineer. Approx: 40 hours (0.25 man/month)

2. Analysis and identification of the best neural network (Month 6-7)
   - AI Engineer. Approx: 100 hours (0.6 man/month)

3. Analysis and identification of the best sensors for the use case (Month 7-8)
   - Embedded Systems Engineer. Approx: 50 hours (0.3 man/month)
   - Biomedical Engineer. Approx: 50 hours (0.3 man/month)

4. Final product architecture design (Month 8)
   - Embedded Systems Engineer. Approx: 40 hours (0.25 man/month)
   - AI Engineer. Approx: 40 hours (0.25 man/month)
   - Biomedical Engineer. Approx: 40 hours (0.25 man/month)

Costs:

- Embedded Systems Engineer. Approx: 120 hours (0.75 man/month)
  - €40 per hour x 40 hours = €1.600
  - €40 per hour x 50 hours = €2.000
  - €40 per hour x 40 hours = €1.600

- AI Engineer. Approx: 120 hours (0.75 man/month)
  - €40 per hour x 40 hours = €1.600
  - €40 per hour x 100 hours = €4.000
  - €40 per hour x 40 hours = €1.600

- Biomedical Engineer. Approx: 80 hours (0.5 man/month)
  - €40 per hour x 40 hours = €1.600
  - €40 per hour x 50 hours = €2.000
  - €40 per hour x 40 hours = €1.600

Total Cost: €17.600

6.5 Work Package 4

In this work package the actual development of the prototype takes place, and it is in fact an R.I. type work package. In this work package both the neural network for classification by the AI Engineer and the embedded software for the sensor and the controller by the Embedded software engineer are developed. Finally, a testing phase is performed to ensure that the system operates optimally.

WP 3	**WP Title:** Product development **WP Type:** S.S.	**Activity Start:** Month 9	**Activity End:** Month 12
Man/Month: 0.6 + 0.9 + 0.9 + 0.9 = 3.3 Man/Month			
Objectives: • Neural network development • Embedded software development • Prototype development and testing			

Activities:

- Development of the neural network that classifies the data collected by the sensor
  - Development and Training of the network
  - Testing and evaluation of the network
- Development of embedded software
  - Development of the controller firmware
  - Development of the sensor driver
  - Driver testing
- Development of the prototype
  - Testing and evaluation of the prototype

Roles hours per Task:

1. Development of the neural network that classifies the data collected by the sensor (Month 9)
   - AI Engineer. Approx: 100 hours (0.6 man/month)
2. Development of embedded software (Month 9-10)
   - Embedded Systems engineer. Approx: 150 hours (0.9 man/month)
3. Development of the prototype (Month 11-12)
   - AI Engineer. Approx: 150 hours (0.9 man/month)
   - Embedded Systems engineer. Approx: 150 hours (0.9 man/month)

Costs:

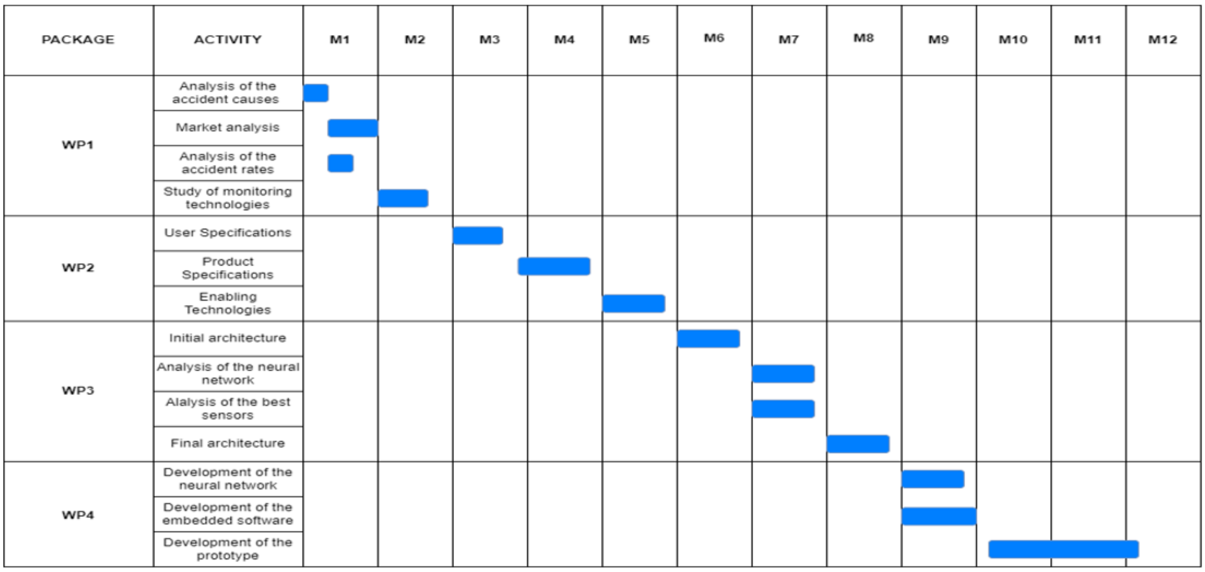
- AI Engineer. Approx: 250 hours (1.5 man/month)
    - €40 per hour x 100 hours = €4.000
    - €40 per hour x 150 hours = €6.000

- Embedded Systems Engineer. Approx: 300 hours (1.8 man/month)
    - €40 per hour x 150 hours = €6000
    - €40 per hour x 150 hours = €6000

Total Cost: €22.000

6.6 GAANT Chart

The GAANT chart is a graph that analyzes the development of the prototype in actual development time. Timings have been assigned to each activity of the project and, through this graph, we can clearly visualize their duration and the total development time of the prototype, from the beginning of the analyzes to the end in the final testing.



6.7 Risks Analysis

Risk analysis is based on analyzing the possible risks that the development of the prototype may encounter during the works. This analysis divided the risks into internal risks, i.e. linked to actions within the project, and external risks, linked to activities external to the project.

6.7.1 Internal Risks

- **Errors and Delays during project development**
  Errors and possible delays can result in increased project costs.

  Delays were minimized by trying to allocate a congruous number of hours for each task.

  Errors are minimized by using the **AGILE** methodology, which allows efficient error correction due to its multiple iterations.

- **Enabling Technologies not found**
  If the chosen enabling technologies cannot be found, it will be sufficient to replace them with similar technologies due to the modularity of the system.

  For example, in the absence of suitable ppg sensors we could choose another sensor from which can be extracted hearth rate variability (HVR).

6.7.2 External Risks

- **PPG Sensor**
  The data collected is used to extract the Herath rate variability (HRV), which can be extracted from many other types of sensors.

  Therefore, if the PPG sensor fails in the market, it would not be a problem since another sensor would be fine to extract this feature.

- **LSTM Neural Network**
  We chose the LSTM neural network because it is currently the best solution in long time-series classifications.

  If, in the future, a better solution will be discovered, the network can be replaced, since the system depends on the classification and not on the type of network chosen.

7. References

Here are the links that allowed us to draw conclusions that were used during the development of the prototype:

- **Syncope via PPG and ECG:** https://pubmed.ncbi.nlm.nih.gov/25769176/
- **Seizure via PPG and ECG:** https://www.mdpi.com/1424-8220/21/18/6017
- **Hypoglycemia via PPG:** https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10057625/
- **Hearth attack via PPG:** https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9371833/
- **Stroke via PPG and ECG:** https://ieeexplore.ieee.org/document/9761215
- **Hypoglicemia via ECG:** https://journals.sagepub.com/doi/10.1177/19322968221116393
- **Heart attack via ECG:** https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6632021/
- **Seizure from IR Camera:** https://www.seizsafe.com/en/
- **Man/Month info:** 160 (40 hours per week-full time job)
- **Cost Researcher:** https://www.unipi.it/index.php/phoca-prova/category/84-docenti-tabelle-retributive?download=6462:2022-costo-annuo-lordo-personale-dei-professori-e-ricercatori-universitari-secondo-il-nuovo-regime-art-3-comma-2-e-6-del-d-p-r-15-12-2011-n-232-adeguamento-stipendiale-aumento-0-45-dpcm-25-luglio-2022
- **Cost Embedded Systems Engingeer:** https://www.upwork.com/hire/embedded-systems-engineers/cost/
- **Cost Medical Expert**: https://www.becomeopedia.com/medical-researcher/