Deliverable 1 – Requirements and specifications

Index

I. Abstract

This document provides a description for the work done in Task 1 of the TIREBOT (a TIRE workshop roBOTic assistant) Experiment. In particular, a summary of the cooperation between the partners CORGHI and UNIMORE for the definition and formalization of requirements and specifics is presented. This document also presents the definition for the concept of "*safe behaviour*" and an analysis of the European Regulations concerning the safety of the machines and the user-machine interface. Furthermore, the choice of the data structure that will be used for TIREBOT is presented.

II. Introduction

This document presents the activities of the Task 1 of the TIREBOT Experiment. The goal is to summarize the requirements and the specifications that TIREBOT must satisfy.

During Task 1 UNIMORE and CORGHI have cooperated for formalizing the requirements and the specifications for TIREBOT and for establishing a common structure of the exchanged data. CORGHI has transferred to UNIMORE a significant amount of know-how about wheel processing and the working procedures in the tire workshop. On the other hand, UNIMORE has exploited its expertise for providing a sound and formal description of the wheel working process and of the tasks TIREBOT is expected to do. Furthermore, since TIREBOT will have to closely work with the tire workshop operator, CORGHI and UNIMORE have defined a task dependent concept of safety in order to guarantee a safe human-robot cooperation with an eye on the efficiency of the specific task human and robot are cooperating on. After the requirements for TIREBOT have been formalized, specifications have been detailed in order to quantitatively assess what the robot will have to do. This phase ends up with a collection of user-safe requirements for the TIREBOT.

In order to validate TIREBOT with its full capabilities, we have decided to disregard some aspects of the EU regulations that would have constrained the robot too much. In this way, it is possible to understand what are the most useful features of TIREBOT and to properly fully adequate it to the EU regulations after the experiment.

III. European Union Regulation

In order for the TIREBOT to be marketable in the EU, the final product must be compliant with the Machinery Directive (2006_42_CE), the Low Voltage Directive (2006_95_CE) and the Electromagnetic Compatibility Directive (2004_108_CE). Furthermore, an analysis of the European Regulation concerning machine safety and human/machine interface usability has been made.

The goal of this analysis is to shape the requirements and the specifications in order to make them as compliant as possible with the EU regulations and, as a consequence, to reduce as much as possible the time to market for TIREBOT. Nevertheless, in order to avoid to over constrain the design of the robot and to reduce its capabilities, some aspects of the EU regulations have been disregarded. In this way, it will be possible to design and evaluate the fully capable robot and, after a performance assessment, to adequate it properly to the EU regulations.

In the following, the list of the most important European Regulations concerning TIREBOT and how these regulations can influence the design specifications is reported. A more exhaustive list can be found in Appendix A – EU Regulation Analysis.

Human/Machine interface design

UNI CEN ISO/TR 9241-100:2011 - Ergonomics of human-system interaction - Part 100: Introduction to standards related to software ergonomics

ISO 9241-100:2010 enables users of standards related to software ergonomics to identify ergonomics standards particularly relevant to software development, gain an overview on the content of software-ergonomics standards, understand the role of software-ergonomics standards in specifying user requirements as well as designing and evaluating user interfaces and understand the relationship between the various standards.

UNI EN ISO 9241-129:2011 - Ergonomics of human-system interaction - Part 129: Guidance on software individualization

This part of UNI EN ISO 9241 provides ergonomics guidance on individualization within interactive systems, including recommendations on:

- Where individualization might be appropriate or inappropriate;
- How to apply individualization.

It focuses on individualization of the software user interface to support the needs of users as individuals or as members of a defined group. It does not recommend specific implementations of individualization mechanisms. It provides guidance on how the various aspects of individualization are made usable and accessible, but it does not specify which individualizations are to be included within a system.

Affected specifications:

These standards affect the design process in order to improve the ergonomics of the designed product. TIREBOT will be designed with an intuitive and easy-to-use user’s interface. In order to facilitate the use of the robot and improve its ergonomics, the user will be able to personalize the commands for the robot.

Ergonomics

UNI EN ISO 9241-410:2012 – Ergonomics of human-system interaction - Part 410: Design criteria for physical input devices

This part of UNI EN ISO 9241 specifies criteria based on ergonomics factors for the design of physical input devices for interactive systems including keyboards, mice, pucks, joysticks, trackballs, tablets and overlays, touch-sensitive screens, styli and light pens, and voice- and gesture-controlled devices. It gives guidance on generic design criteria for physical input devices, as well as specific criteria for each type of device. Requirements for the design of products are given either because of context-free considerations, or else can be determined based on the specified design criteria for the intended use; such specified criteria generally having been subdivided into task-oriented categories, wherever applicable.

UNI EN ISO 9241-910:2011 - Ergonomics of human-system interaction - Part 910: Framework for tactile and haptic interaction

This part of UNI EN ISO 9241 provides a framework for understanding and communicating various aspects of tactile/haptic interaction. It defines terms, describes structures and models, and gives explanations related to the other parts of the UNI EN ISO 9241 "900" subseries. It also provides guidance on how various forms of interaction can be applied to a variety of user tasks. It is applicable to all types of interactive systems making use of tactile/haptic devices and interactions. It does not address purely kinaesthetic interactions, such as gestures, although it might be useful for understanding such interactions.

UNI EN ISO 9241-210:2010 - Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems

This part of UNI EN ISO 9241 provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems. It is intended to be used by those managing design processes, and is concerned with ways in which both hardware and software components of interactive systems can enhance human-system interaction.

UNI EN 1005-2:2009 - Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery

This European Standard specifies ergonomic recommendations for the design of machinery involving manual handling of machinery and component parts of machinery, including tools linked to the machine, in professional and domestic applications.

UNI EN 1005-3:2009 - Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation

This European Standard presents guidance to the manufacturer of machinery or its component parts and the writer of C-standards in controlling health risks due to machine- related muscular force exertion.

UNI EN 1005-4:2009 - Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery

This European Standard presents guidance when designing machinery or its component parts in assessing and affecting health risks due only to machine-related postures and movements, i.e. during assembly, installation, operation, adjustment, maintenance, cleaning, repair, transport, and dismantlement. This European Standard specifies requirements for postures and movements without any or with only minimal external force exertion. The requirements are intended to reduce the health risks for nearly all healthy adults.

Affected specifications:

In order to avoid to manually move TIREBOT, it will be possible to move the robot by an external user's interface (e.g. a haptic device). Furthermore, the product will be designed limiting its weight and dimensions, in order for the user to easily move it manually in case of robot's malfunctioning and faults. The design process will follow a "user-centred-design" methodology, in order to obtain an ergonomic and easy-to-use product.

The user's interface will be designed taking into account the user's biomechanical compatibility. Furthermore, in order to increase safety, the interface will be thermally and electrically insulated. The software of the interface will be designed in order to avoid instability and with a proper resolution for facilitate the use. The machine will be designed for letting the user to operate it while in natural postures. The user will also be able to interact with TIREBOT with limited movements. The user interface of the robot will be designed taking into account the end user's physical limits and it will provide to the user a force feedback without limiting the controllability of the device. The interface will be designed in such a way that the controlled device will be responsive with a proper resolution and sensibility of the interface.

Stability of the vehicle

UNI ISO 24134:2012 - Industrial trucks - Additional requirements for automated functions on trucks

This regulation specifies the safety requirements for controls and control systems for the following automated functions of industrial trucks: steering (excluding direct mechanical guidance); travel; lifting and lowering operations; load manipulations, e.g. rotation, reach, slewing, tilting, clamping; combination and/or sequence of these movements.

UNI EN 1175-1:2010 - Safety of industrial trucks - Electrical requirements - Part 1: General requirements for battery powered trucks

This standard specifies electrical and related mechanical safety requirements for design and construction of the electrical installation in battery powered industrial trucks hereinafter referred to as trucks, with nominal voltage of the truck system up to 240 V. The Annex A is normative and gives requirements for "Connectors for traction batteries". Annex B is normative and contains "Electric motors- Output and test rules" and Annex C is normative and contains "Electromagnetic contactors".

UNI EN ISO 12100:2010 - Safety of machinery - General principles for design - Risk assessment and risk reduction (UNI EN ISO 12100:2010)

UNI EN ISO 12100:2010 specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. Procedures are described for identifying hazards, estimating, and evaluating risks during relevant phases of the machine life cycle, and for the elimination of hazards or sufficient risk reduction. Guidance is given on the documentation and verification of the risk assessment and risk reduction process. UNI EN ISO 12100:2010 is also intended to be used as a basis for the preparation of type-B or type-C safety standards. It does not deal with risk and/or damage to domestic animals, property or the environment

Affected specifications:

Risks concerning the use of TIREBOT will be evaluated following risk assessment and risk reduction guidelines. The robot will be designed by following strategies for making it electrically safe. The nominal voltage will also be limited.

Stability and verification of stability

UNI ISO 22915-7:2012 - Industrial trucks - Verification of stability - Part 7: Bidirectional and multidirectional trucks

This regulation specifies the tests for verifying the stability of bidirectional and multidirectional trucks with tilting or non-tilting mast or fork arms. It is also applicable to trucks operating under the same conditions when equipped with load-handling attachments.

UNI ISO 22915-1:2009 - Industrial trucks - Verification of stability - Part 1: General

UNI ISO 22915 deal with the safety of industrial trucks, as defined in ISO 5053, relative to their stability and the verification of that stability. For the purpose of UNI ISO 22915, industrial trucks are wheeled, self-propelled or pedestrian-propelled vehicles, excepting those running on rails. They are either operator-controlled or driverless and designed to carry, tow, push, lift, stack or tier in racks. This part of UNI ISO 22915 specifies basic test criteria and requirements to verify stability for industrial trucks. It applies to the following truck types and special conditions:

a) counterbalanced trucks with mast, as specified in UNI ISO 22915-2;
b) reach and straddle trucks, as specified in UNI ISO 22195-3;
c) pallet stackers, double stackers and order-picking trucks up to and including 1200mm lift height, as specified in UNI ISO 22915-4;
d) single side loading trucks;
e) bidirectional and multidirectional trucks, as specified in UNI ISO 22915-7;
f) additional stability test for trucks operating in special conditions of stacking with the mast tilted forward, as specified in UNI ISO 22915-8;
g) counterbalanced trucks with mast handling freight containers of 6m length and longer;
h) additional stability test for trucks operating in special conditions with the load substantially laterally displaced by powered devices, as specified in UNI ISO 22915-10;
i) industrial variable reach trucks;
j) industrial variable reach trucks handling freight containers of 6m length and longer;
k) rough-terrain variable reach trucks;
l) counterbalanced trucks with articulated steering;
m) pedestrian-propelled trucks;
n) burden and personnel carriers;
o) additional stability test for trucks operating in the special condition of offset load, offset determined by utilization, as specified in UNI ISO 22915-20;
p) order-picking trucks with operator position elevating above 1200mm, as specified in UNI ISO 22915-21

UNI EN 15000:2009 - Safety of industrial trucks - Self-propelled variable reach trucks - Specification, performance and test requirements for longitudinal load moment indicators and longitudinal load moment limiters

UNI EN 15000:2009 specifies the technical requirements, verification and test procedure for the longitudinal load moment indicator (LLMI) and longitudinal load moment control (LLMC) systems operating in the forward direction for self-propelled variable reach trucks covered by EN 1459. This European Standard covers LLMI and LLMC systems for stationary trucks performing loading or placing functions on consolidated, stable and level ground. This European Standard does not cover the risk due to lateral instability, or instability due to the travelling of the truck. The LLMI and LLMC are not intended for warning of the overturning risk whilst the truck is travelling.

Affected specifications:

TIREBOT will be designed taking into account the stability of the robot carrying a load. The stability will be also verified with tests provided by the Standard. The longitudinal reach of the robot will also be limited, in order to avoid overturning.

Safety guidelines for industrial vehicles

UNI ISO 15870:2006 - Powered industrial trucks - Safety signs and hazard pictorials - General principles

This international standard establishes general principles for the design and application of safety signs and hazard pictorials permanently affixed to all types of industrial trucks including those defined in ISO 5053. This International Standard outlines safety sign objectives, describes the basic safety sign format and colours, and provides guidance on developing the various panels that together constitutes a safety sign.

UNI ISO 3287:2006 - Powered industrial trucks - Symbols for operator controls and other displays

This International Standard establishes symbols for use on operator controls and other displays on powered industrial trucks.

UNI EN 1525:1999 - Safety of industrial trucks - Driverless trucks and their systems

This International Standard is applied to all the trucks and their systems but those trucks guided by means of mechanical devices and those trucks moving in open access areas with people unaware of driverless trucks associated dangers.

UNI EN ISO 13850:2008 - Safety of machinery - Emergency stop - Principles for design (ISO 13850:2006)

UNI EN ISO 13850:2008 specifies functional requirements and design principles for the emergency stop function on machinery, independent of the type of energy used to control the function. It is applicable to all machinery except for machines in which the provision of emergency stop would not lessen the risk, and hand-held portable machines and hand-guided machines. It does not deal with functions such as reversal or limitation of motion, deflection, shielding, braking or disconnecting, which can be part of the emergency stop function.

UNI EN ISO 13855:2010 - Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body

This International Standard establishes the positioning of safeguards with respect to the approach speeds of parts of the human body. It specifies parameters based on values for approach speeds of parts of the human body and provides a methodology to determine the minimum distances to a hazard zone from the detection zone or from actuating devices of safeguards. The values for approach speeds (walking speed and upper limb movement) in this International Standard are time tested and proven in practical experience. This International Standard gives guidance for typical approaches. Other types of approach, for example running, jumping or falling, are not considered in this International Standard.

UNI EN ISO 10218-1:2012 - Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots

This part of UNI EN ISO 10218 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

UNI EN ISO 10218-2:2011 - Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration

This part of UNI EN ISO 10218 specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in UNI EN ISO 10218-1, and industrial robot cell(s). The integration includes the following:

a) the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
b) necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
c) component devices of the industrial robot system or cell.

This part of UNI EN ISO 10218 describes the basic hazards and hazardous situations identified with these systems, and provides requirements to eliminate or adequately reduce the risks associated with these hazards. Although noise has been identified to be a significant hazard with industrial robot systems, it is not considered in this part of UNI EN ISO 10218. This part of UNI EN ISO 10218 also specifies requirements for the industrial robot system as part of an integrated manufacturing system. This part of UNI EN ISO 10218 does not deal specifically with hazards associated with processes (e.g. laser radiation, ejected chips, welding smoke). Other standards can be applicable to these process hazards.

Affected specifications:

In order to increase safety, emergency stop will be actuated through safety buttons that will start a safe-stop procedure. The robot will be also endowed with sensors that detect the presence of extraneous objects in the nearing of the robot, preventing it from bumping them. The maximum speed of the robot will be also limited, in particular during operations that require a human/robot cooperation. The final product will be endowed with devices that increase the visibility of the robot, like warning signs and hazard pictorials, as well as with blinking lights and buzzers that can alert near users when the robot is moving.

General guidelines for safety of machineries

UNI EN ISO 13857:2008 - Safety of machinery - Safety distances to prevent hazard zones being reached by upper and lower limbs (ISO 13857:2008)

UNI EN ISO 13857:2008 establishes values for safety distances in both industrial and non-industrial environments to prevent machinery hazard zones being reached. The safety distances are appropriate for protective structures. It also gives information about distances to impede free access by the lower limbs. It covers people of 14 years and older (the fifth percentile stature of 14 year olds is approximately 1 400 mm). In addition, for upper limbs only, it provides information for children older than 3 years (5th percentile stature of 3 year olds is approximately 900 mm) where reaching through openings needs to be addressed.

UNI EN ISO 13849-1:2008 - Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design (ISO 13849-1:2006)

UNI EN ISO 13849-1:2006 provides safety requirements and guidance on the principles for the design and integration of safety-related parts of control systems (SRP/CS), including the design of software. For these parts of SRP/CS, it specifies characteristics that include the performance level required for carrying out safety functions. It applies to SRP/CS, regardless of the type of technology and energy used (electrical, hydraulic, pneumatic, mechanical, etc.), for all kinds of machinery. It does not specify the safety functions or performance levels that are to be used in a particular case. UNI EN ISO 13849-1:2006 provides specific requirements for SRP/CS using programmable electronic system(s). It does not give specific requirements for the design of products which are parts of SRP/CS. Nevertheless, the principles given, such as categories or performance levels, can be used.

UNI EN 349:2008 - Safety of machinery - Minimum gaps to avoid crushing of parts of the human body

The object of this European Standard is to enable the user to avoid hazards from crushing zones. It specifies minimum gaps relative to parts of the human body and is applicable when adequate safety can be achieved by this method. This European Standard is applicable to risks from crushing hazards only and is not applicable to other possible hazards, e.g. impact, shearing, drawing-in.

UNI EN 12053:2008 - Safety of industrial trucks - Test methods for measuring noise emissions

This standard gives methods for determining the sound pressure level at the operator's position and the sound power level of industrial and rough terrain trucks.

Affected specifications:

TIREBOT will be designed in order to avoid for the user to reach with upper or lower limbs dangerous areas of the robot. Furthermore the Software and Hardware of the robot will be designed in order to avoid misuse and to implement fail-safe strategies. The speed of the robot will be limited during cooperation with human operator. The noise emission of TIREBOT will be reduced.

IV. Requirements

TIREBOT can be used in three different working modalities: an autonomous mode, a teleoperation mode and the gesture interaction mode. In order to provide a clear description of the requirements and of the behaviour of TIREBOT, we exploit the UML formalism[1]. Figure 1 represents the Finite State Machine of TIREBOT: it describes schematically the states that compose the three different working modalities of the robot and how the transition between them can happen.

[1] "Unified Modelling Language (UML)," [Online]. Available: http://www.uml.org/.

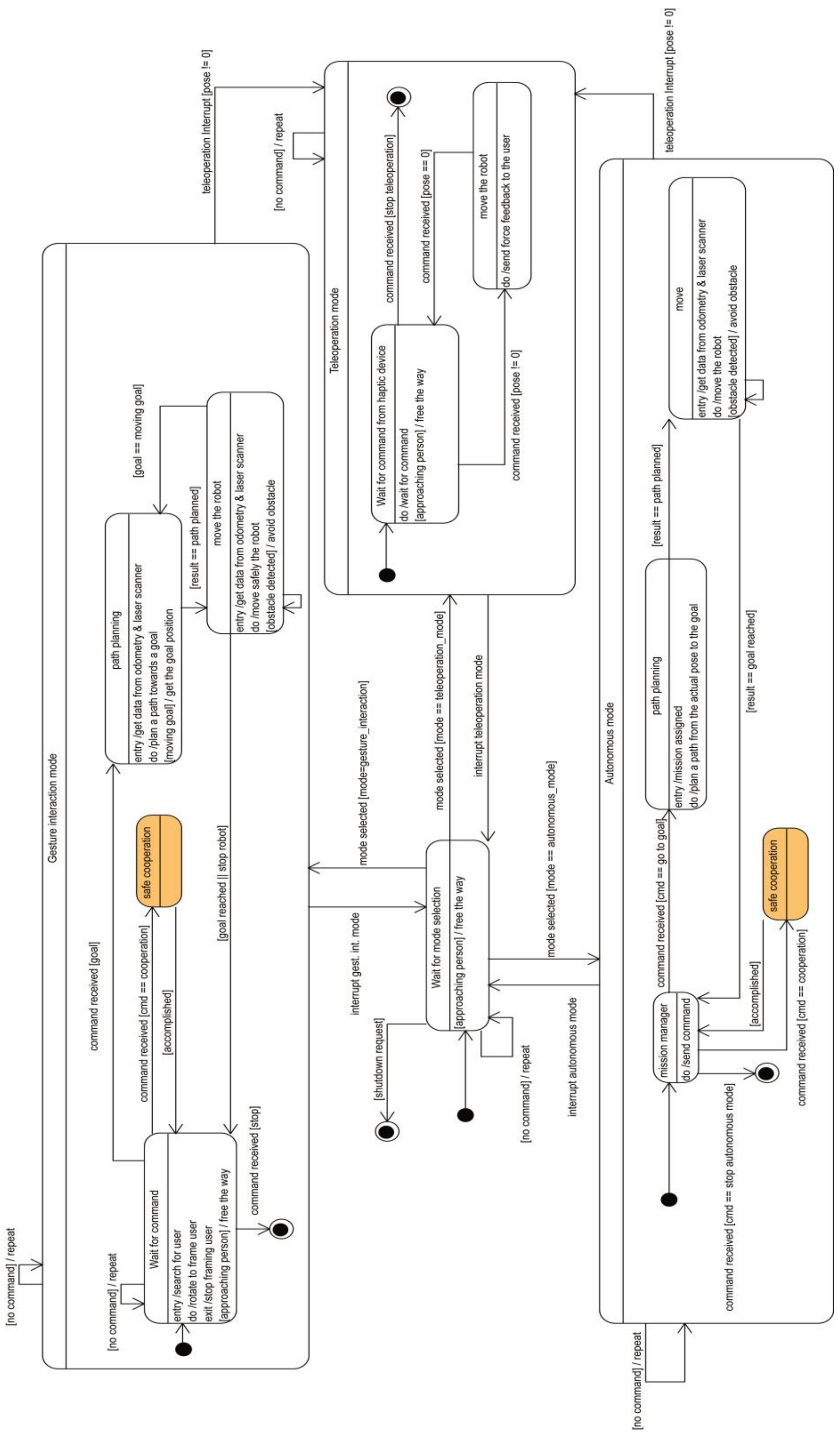

Figure 1: TIREBOT Finite State Machine

Once the robot is switched on, the user can choose a working modality. It is always possible for the user to change the working mode of the robot.

In "Teleoperation Mode", the user can interact with the robot and move it by moving a haptic device. This particular kind of interface can also return to the user a force feedback according to the obstacles "sensed" by the robot. The user can also check the robot's surroundings thanks to the video stream on a monitor near the haptic device. Furthermore, in this modality, while the robot is idle waiting for a user's command, if a moving obstacle (typically a person) approaches to the robot, TIREBOT moves in order to free the way. In order to improve safety, the user can always switch to this working mode from all the others modes, by simply moving the haptic interface.

In "Autonomous Mode", a mission manager chooses goals for the robot. Then a path-planning algorithm computes the best route for the robot, in order to move from the actual robot's pose (obtained by a localization algorithm) to the assigned goal by also avoiding the obstacles. Once the robot has reached the goal it is possible for it to enter in "*safe-cooperation*" state. A full description for the behaviour of the robot in this state is provided further in this document.

In "Gesture Interaction Mode" the user can send commands to the robot by moving his arms. Once the robot enters in this state, it starts rotating on itself in order to frame and recognize the master-user from whom will take orders. Once the master has been identified, the robot rotates on itself framing the master and waiting for a command recognizable by the robot. Then the user can choose to make the robot follow him, to send the robot to some predefined poses or to cooperate with it in "*safe-cooperation*" mode.

The "*safe-cooperation*" state mentioned earlier is a super-state that represents the behaviour of the robot when it works close to the human operator. We can distinguish this state according to the working phase the wheel is in: for example, Figure 2 is the Finite State Machine representing the behaviour of TIREBOT operator has to load the wheel on it. When TIREBOT has approached the area where the operator is, it changes the parameters for the navigation. These parameters are the safe distance the robot stays from obstacles and how the position and the speed of obstacles can influence the behaviour of the obstacle avoidance algorithm of the robot. In this phase, the robot also decreases the speed of its movements, in order for the robot to be more accurate in its movements. Once these parameters are set, the safe cooperation starts: the robot approaches to the user that is dismounting the wheel from the car and waits until the operator is ready to load the wheel on the robot. If the operator gets too close to the robot or if a moving obstacle (which can be the operator itself) approaches the robot too fast, the robot moves away. Once the robot has grabbed the wheel, TIREBOT is ready to leave the "*safe-cooperation*" state, it changes back the navigation parameters and enters into the "*free-navigation*" mode.

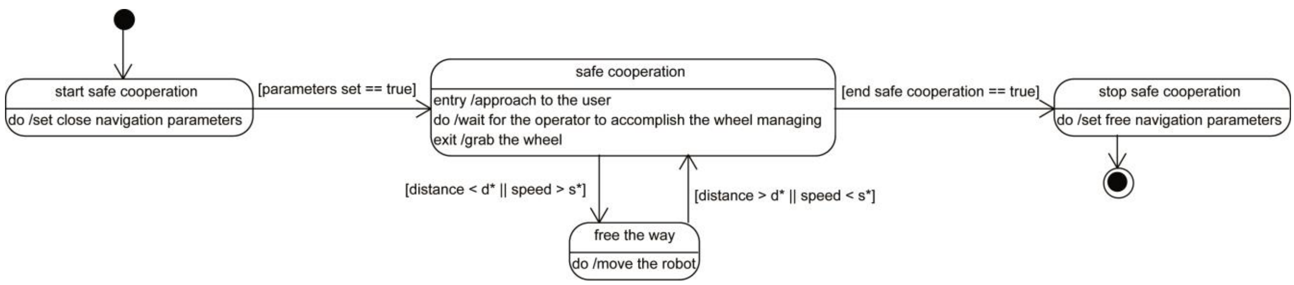

Figure 2: Finite State Machine: safe cooperation during the grabbing of the wheel

Similarly, Figure 3 represents another kind of "*safe-cooperation*". In this case, the release of the wheel is analysed. Once the robot, which is carrying a wheel, gets in the area near the machine the tire has to be put on, TIREBOT changes the navigation parameters in the same way explained earlier in this section. The robot, then, approaches the operator that unloads the tire from TIREBOT. As in the previous case, the "*safe-cooperation*" expects the robot to move away if an obstacle gets too near or approaches too fast to the robot. Once the tire has been unloaded from the robot, TIREBOT changes back the navigation parameters and leaves the "*safe-cooperation*" state.

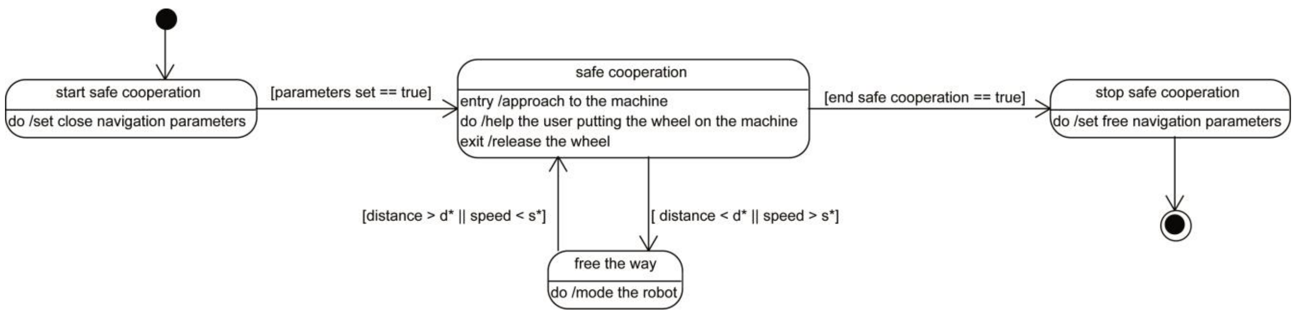

Figure 3: Finite State Machine: safe cooperation during the positioning of the wheel on a machine

Each working mode was analysed, in order to build a robust Software Architecture with two main tools of UML: the Use Case Diagrams and the Sequence Diagrams. For brevity, in this section only the Teleoperation Mode Use Case will be analysed. All the other produced diagrams are reported and explained in Appendix B – Software Architecture.

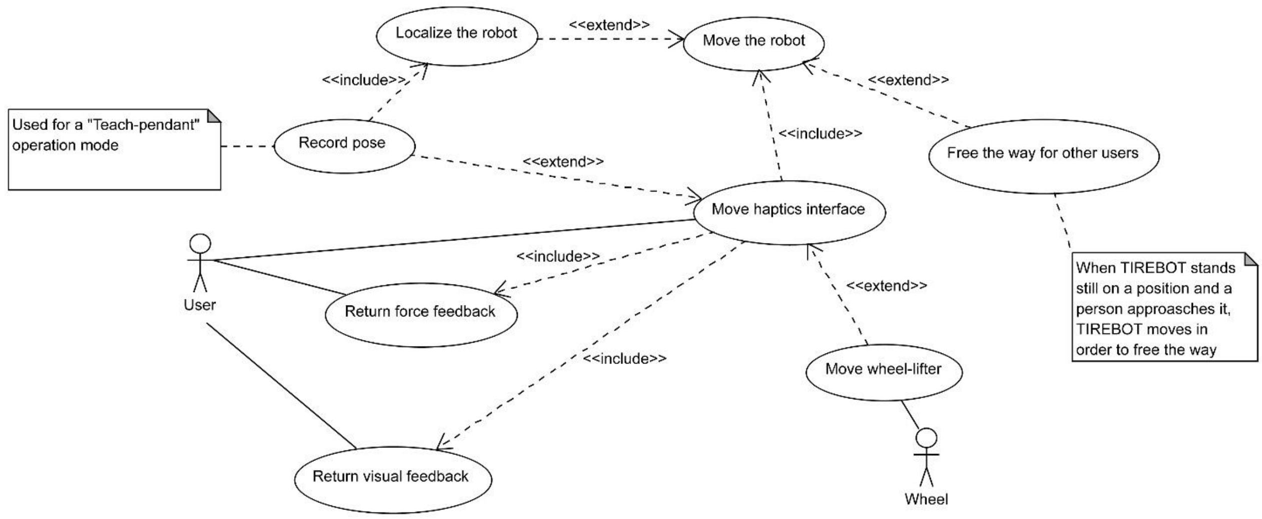

Figure 4: Teleoperation Use Case Diagram

Figure 4 represents the Teleoperation Mode Use Case Diagram. The actors, in this scenario, are the operator (the tire workshop worker) and the wheel.

The operator can interface with the TIREBOT by moving the haptic device. The robot moves with a speed proportional to the pose of the haptic device. The user has two different kind of feedbacks: a visual feedback collected by the robot thanks to its camera, and returned to the operator through a screen near the haptic device, and a force feedback proportional to the measurements of the laser scanners mounted on the robot. If the user wishes to move the robot in a direction where also an obstacle is present, then the haptic device returns a force proportional to the distance of the object and to its approaching speed. Through the haptic interface, the user can also actuate the wheel-lifter.

When the robot stands still, waiting for the user’s commands, if a moving obstacle approaches (typically a person) the robot moves in order to free the way.

Furthermore, the robot keeps on localizing itself in the working environment thanks to its sensors, and the user can record some critical poses of the TIREBOT (i.e. the position of a particular machine in the tire workshop). This could be useful if the user wants the robot to autonomously return in that particular pose.

In order to better understand the time-dependant message flow, a Sequence Diagram was developed (Figure 5).

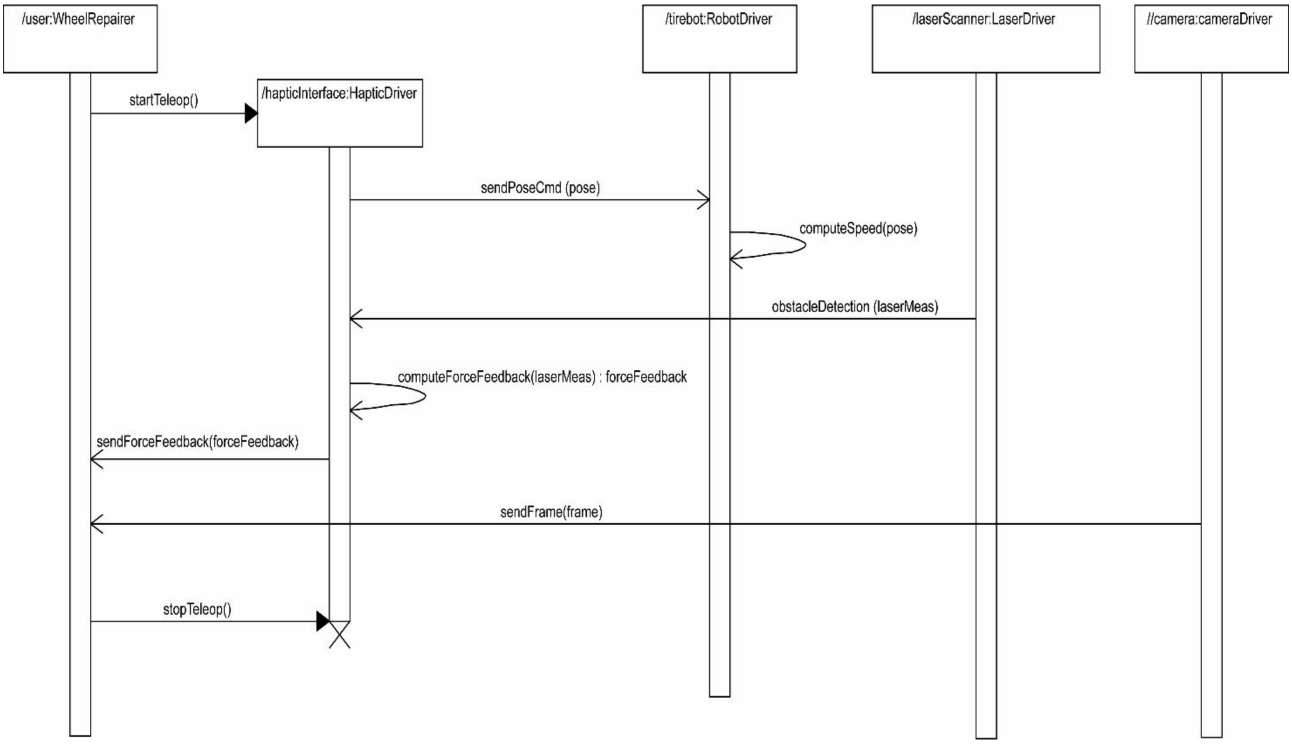

Figure 5: Teleoperation Sequence Diagram

When the user wishes to start the teleoperation mode, the haptic driver is started: the user moves the haptic device, and then the pose is sent to the driver of the robot. Here, an algorithm commutes the pose information into a speed message, which moves the robot on the desired direction at a speed proportional to the pose. If the laser scanner driver detects an obstacle, a message is sent to the haptic driver. Then the force feedback, which is proportional to the position and the speed of the obstacle, is computed and sent to the user. Furthermore, the camera keeps on sending frames to the operator. Once the user has completed the task, the haptic driver terminates.

V. Definition of Safe Cooperation

This section provides a more formal definition for “safe-cooperation”. The job of TIREBOT involves the cooperation of the robot with human operators. This leads to the need of defining how the robot will cooperate with the users and, above all, to the need of safety procedure for the robot, in order to prevent the robot from harming its human co-workers.

In order for a robot to be used in industrial environments, some safety procedures must be considered. For example, the access to the working area of robotics arms used for industrial purposes is forbidden to human operators. Similarly, the path AGVs (Automated Guided Vehicles) employed in the logistics of automated warehouses is travelled in corridors the access is forbidden to humans and manually guided forklifts. Furthermore, AGVs are endowed with safety sensors, like safety laser scanners and bumpers, which can avoid obstacles or stop the vehicle in case of impact with objects. The dominant logic for safety is to stop the robot’s movements when a person approaches it or if the robot moves too near to an object.

In the TIREBOT case, the robot should work with a tire workshop operator that, in some phases of his job, must work close to the robot; for example when the operator, once the tire is removed from the car, has to load the tire on TIREBOT. In this case, the robot should assist the operator without hindering him, moving away if the user has to work in positions occupied by the robot and actuating the wheel lifter without harming the human operator.

We will define a **safe cooperative behaviour** for TIREBOT as a behaviour such that:

1. It avoids obstacles (both objects and people)

2. It enables the cooperation when necessary (e.g. when helping the operator to mount/dismount a wheel)

When working autonomously, TIREBOT can work in two modalities: navigation and cooperation. During each modality a safe behaviour must be ensured. In free navigation a standard collision avoidance method (e.g. potential fields) can be exploited since the robot has just to reach a desired goal while avoiding obstacles and no cooperation is required. When the robot reaches a location when some cooperation with the operator is necessary a new strategy for implementing a safe behaviour must be implemented. In fact, standard distance based collision avoidance techniques will always let the robot to move apart when the operator gets closer making therefore cooperation impossible. In order to implement a safe and cooperative behaviour a novel collision avoidance strategy that depends both on the distance and on the velocity of the detected obstacles will be implemented. In this way, if the operator is very close but it moves slowly, TIREBOT will detect cooperation and it will not move. On the other hand, if the distance is small but the operator moves too fast, TIREBOT will detect something wrong (e.g. the operator can be escaping form some dangerous situations) and it will move apart to avoid collision with the human.

VI. Specifications

For brevity, requirements and specification are summarized in the following table:

Specification	Description	Target value
TIREBOT weight	The total weight of the robot (moving platform + wheel lifter device).	The robot (without the load) will weights: 150 kg
Pushing force	The maximum force needed by the user to push TIREBOT, in case of malfunctioning.	Conformity to UNI EN 1005-2:2009, UNI EN 1005-3:2009, UNI EN 1005-4:2009. Maximum pushing force for moving the robot: 200 N
TIREBOT dimension	The dimension of a prism containing the robot.	Conformity to UNI EN 1005-2:2009, UNI EN 1005-3:2009, UNI EN 1005-4:2009. Maximum dimensions of the robot (LxWxD): 1.5x1x2 m
Positioning accuracy	The accuracy of the robot in positioning reaching a certain goal and in positioning the wheel on machineries.	0.1 m
Safety distance	The distance the robot will respect to obstacles and people.	>50 m
TIREBOT payload	The maximum weight of the tires TIREBOT will lift.	>40 Kg
TIREBOT speed	The speed TIREBOT will travel inside its working area.	2-3 Km/h
Mechanical stability	The Centre of Gravity (CG) of the robot carrying a tire will be designed in order to avoid overturning.	Conformity to UNI ISO 220915-1:2009, UNI ISO 220915-20:2009, UNI EN 15000:2009, UNI EN 15000:2009.
Ergonomics and usability	TIREBOT will be designed with a User-centred methodology in order for the user to easy interact with the robot.	Conformity to UNI EN ISO 9241-129:2011, UNI EN ISO 241-410:2012, UNI EN ISO 9241-910:2011, UNI EN ISO 9241-210:2011
Electrical safety	TIREBOT will be designed in order to respect directives and European regulations concerning the safety of the electrical equipment.	Conformity to Low Voltage Directive, UNI ISO 20898:2009, UNI EN 1175-1:2010
Mechanical safety	TIREBOT will be designed in order to avoid mechanical features that could harm users.	Conformity to Machineries Directive, UNI EN ISO 12100:2010, UNI EN ISO 13849-1:2008, UNI EN ISO 13850:2008, UNI EN ISO 3857:2008, UNI EN ISO 13855:2010, UNI EN 349:2008, UNI EN ISO 10218-1:2012, UNI EN ISO 10218-2:2011, UNI EN ISO 14539:2002.
Low noise emission	TIREBOT will not be noisy while working.	Conformity to UNI EN 1203:2008
Safety navigation	TIREBOT will be endue with sensors that can avoid collisions.	Conformity to UNI EN 1525:1999, UNI ISO 22915-7:2012, UNI ISO 24134:2012

VII. Data Structure

A crucial step in the software design is to decide the communication protocol between processes and the data structure. In order to facilitate the development of software and, in particular, algorithms we decided to use ROS.

"*ROS is an open-source, meta-operating system for your robot. It provides the services you would expect from an operating system, including hardware abstraction, low-level device control, implementation of commonly-used functionality, message-passing between processes, and package management. It also provides tools and libraries for obtaining, building, writing, and running code across multiple computers.[…]The ROS runtime "graph" is a peer-to-peer network of processes (potentially distributed across machines) that are loosely coupled using the ROS communication infrastructure. ROS implements several different styles of communication, including synchronous RPC-style communication over services, asynchronous streaming of data over topics, and storage of data on a Parameter Server.*"[2]

In the last years, ROS became "*viral*" in the robotic developers community. The main reason of its success is the reusability of the code. This is possible thanks to the peer-to-peer network that can couple processes (a.k.a. *nodes*) that can be easily replaced by other processes.

ROS provides a vast choice between message types and the possibility to build ad-hoc messages. These messages have a structure similar to the "*struct*" datatype of the C/C++ programming language. Furthermore, worldwide ROS users contribute to the ROS package repository with code implementing algorithms of various nature.

All this features pushed the choice of the development environment and of the data structure towards ROS. Thus all data regarding TIREBOT, drivers for the hardware, processes and data structures, will be implemented in a format compliant to the ROS formalism.

[2] «ROS - Robot Operating System,» [Online]. Available: wiki.ros.org.

VIII. Conclusions

In this document presents all the activities done in the scope of “Task 1 – Requirements and Specifications” of TIREBOT (a TIRE workshop roBOTic assistant) experiment proposal for ECHORD++.

This document is a milestone that represents the starting point for all other tasks of the project. It summarizes the requirements and the specifications the final prototype must satisfy, with a deep analysis of the European Regulation in matter of user interface, safety of machinery and robots. Furthermore, it presents the software architecture that will implement all the working modalities of TIREBOT and how the processes will communicate between themselves.

IX. Appendix A – EU Regulation Analysis

The following table summarizes the European Regulation Analysis. The table also highlights the criticalities of each regulation as well as its impact on the requirements. In the “Criticalities” column, the green colour means the standard is not critical, the yellow colour means the standard is critical with some minor risks for the user’s health, while the red colour means the standard is very critical with major risks for the user’s health. Furthermore, in the last column, we report if we whether decide to follow the regulation during the development of the prototype. In this last column, the green colour means that the standard will be taken into account during the design of TIREBOT, the yellow colour means that the standard will be partially satisfied during the design of TIREBOT and the final product will be slightly modified before market. The red colour means that the standard is ignored during the development of the prototype, but will be taken into account during the design of the final product.

Standard/regulation name	Scope	Title	Summary	Criticalities	Feasibility
UNI CEN ISO/TR 9241-100:2011	Human/Machine Interface	Ergonomics of human-system interaction - Part 100: Introduction to standards related to software ergonomics	ISO 9241-100:2010 enables users of standards related to software ergonomics to identify ergonomics standards particularly relevant to software development.	This standard does not influence critical aspect of the application	The software and the User's Interface of the final product will be modified in order to satisfy Standards requirements
UNI EN ISO 9241-129:2011		Ergonomics of human-system interaction - Part 129: Guidance on software individualization	This part of ISO 9241 provides ergonomics guidance on individualization.	This standard does not influence critical aspect of the application	The prototype will be designed in order to satisfy this standard
UNI EN ISO 9241-410:2012		Ergonomics of human-system interaction - Part 410: Design criteria for physical input devices	This part of ISO 9241 specifies criteria based on ergonomics factors for the design of physical input devices for interactive systems. It gives guidance on generic design criteria for physical input devices, as well as specific criteria for each type of device.	This standard is partially critical because of the stability of the interface. Controllability and the user's biomechanical compatibility should be considered	The prototype will be designed in order to satisfy this standard
UNI EN ISO 9241-910:2011		Ergonomics of human-system interaction - Part 910: Framework for tactile and haptic interaction	This part of ISO 9241 provides a framework for understanding and communicating various aspects of tactile/haptic interaction. It is applicable to all types of interactive systems making use of tactile/haptic devices and interactions. It does not address purely kinaesthetic interactions, such as gestures, although it might be useful for understanding such interactions.	The Standard specifies criteria for stability for the interface. Furthermore, the interface will be safe (electrical insulation, thermic insulation, etc.)	The prototype will be designed in order to satisfy this standard
UNI EN ISO 9241-210:2010		Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems	This part of ISO 9241 provides requirements and recommendations for human-centred design principles and activities throughout the life cycle of computer-based interactive systems.	The Standard suggests a "user cantered" design methodology.	Once the prototype is realized with the proposed method, no big changes should be taken.

UNI EN 1005-2:2009	Human/Machine Interface	Safety of machinery - Human physical performance - Part 2: Manual handling of machinery and component parts of machinery	This European Standard specifies ergonomic recommendations for the design of machinery involving manual handling of machinery and component parts of machinery, including tools linked to the machine, in professional and domestic applications.	Risks for the operator's health.	The prototype will be designed in order to satisfy this standard
UNI EN 1005-3:2009	Human/Machine Interface	Safety of machinery - Human physical performance - Part 3: Recommended force limits for machinery operation	This European Standard presents guidance to the manufacturer of machinery or its component parts and the writer of C-standards in controlling health risks due to machine- related muscular force exertion.	Risks for the operator's health.	The prototype will be designed in order to satisfy this standard
UNI EN 1005-4:2009	Human/Machine Interface	Safety of machinery - Human physical performance - Part 4: Evaluation of working postures and movements in relation to machinery	This European Standard presents guidance when designing machinery or its component parts in assessing and affecting health risks due only to machine-related postures and movements. The requirements are intended to reduce the health risks for nearly all healthy adults.	Risks for the operator's health.	The prototype will be designed in order to satisfy this standard
UNI ISO 22915-7:2012	Industrial trucks	Industrial trucks - Verification of stability - Part 7: Bidirectional and multidirectional trucks	ISO 22915-7:2009 specifies the tests for verifying the stability of bidirectional and multidirectional trucks with tilting or non-tilting mast or fork arms. It is also applicable to trucks operating under the same conditions when equipped with load- handling attachments.	The load should be balanced on the robot in order to avoid instability.	The prototype will be designed in order to satisfy this standard
UNI ISO 24134:2012	Industrial trucks	Industrial trucks - Additional requirements for automated functions on trucks	ISO 24134:2006 specifies the safety requirements for controls and control systems for the following automated functions of industrial trucks: steering (excluding direct mechanical guidance); travel; lifting and lowering operations; load manipulations, e.g. rotation, reach, slewing, tilting, clamping; combination and/or sequence of these movements.	Robust and safe control for risky operations.	The prototype will be designed in order to satisfy this standard
UNI EN 1175-1:2010	Industrial trucks	Safety of industrial trucks - Electrical requirements - Part 1: General requirements for battery powered trucks	This standard specifies electrical and related mechanical safety requirements for design and construction of the electrical installation in battery powered industrial trucks hereinafter referred to as trucks, with nominal voltage of the truck system up to 240 V.	Electrical equipment insulation and safety. The prototype will use only commercial electrical components.	The prototype will be designed in order to satisfy this standard
UNI EN ISO 12100:2010	Industrial trucks	Safety of machinery - General principles for design - Risk assessment and risk reduction (UNI EN ISO 12100:2010)	UNI EN ISO 12100:2010 specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. UNI EN ISO 12100:2010 is also intended to be used as a basis for the preparation of type-B or type-C safety standards.	Risks for the operator's health.	The prototype will be designed in order to partially satisfy this standard. Other changes will be taken during the commercialization of the product in order to increase safety.
UNI ISO 22915-1:2009	Industrial trucks	Industrial trucks - Verification of stability - Part 1: General	ISO 22915 deal with the safety of industrial trucks, as defined in ISO 5053, relative to their stability and the verification of that stability. This part of ISO 22915 specifies basic test criteria and requirements to verify stability for industrial trucks.	Risk of overturning of the robot.	The prototype will be designed in order to satisfy this standard

UNI ISO 22915-20:2009	Industrial trucks	Industrial trucks - Verification of stability - Part 20: Additional stability test for trucks operating in the special condition of offset load, offset by utilization	ISO 22915-20 deals with supplementary stability tests for trucks with special condition of decentred centre of gravity of the load with respect the longitudinal axis of the truck.	Risk of overturning of the robot.	The prototype will be designed in order to satisfy this standard
UNI ISO 20898:2009	Industrial trucks	Industrial trucks - Electrical requirements	The standard specifies the electrical requirements for the design and manufacture of self-propelled industrial trucks.	Electrical equipment insulation and safety. The prototype will use only commercial electrical components.	The prototype will be designed in order to satisfy this standard
UNI EN 15000:2009	Industrial trucks	Safety of industrial trucks - Self-propelled variable reach trucks - Specification, performance and test requirements for longitudinal load moment indicators and longitudinal load moment limiters	UNI EN 15000:2009 specifies the technical requirements, verification and test procedure for the longitudinal load moment indicator (LLMI) and longitudinal load moment control (LLMC) systems operating in the forward direction for self-propelled variable reach trucks.	Risk of overturning of the robot.	The prototype will be designed in order to satisfy this standard
UNI EN 12053:2008	Industrial trucks	Safety of industrial trucks - Test methods for measuring noise emissions	This standard gives methods for determining the sound pressure level at the operator's position and the sound power level of industrial and rough terrain trucks.	The prototype will have low noise emission	The prototype will be designed in order to satisfy this standard
UNI ISO 15870:2006	Industrial trucks	Powered industrial trucks - Safety signs and hazard pictorials - General principles	This international standard establishes general principles for the design and application of safety signs and hazard pictorials permanently affixed to all types of industrial trucks.	This Standard suggests pictograms and safety sign to put on the machine	Before the commercialization hazard signs, lights, etc. will be added on the product
UNI ISO 3287:2006	Industrial trucks	Powered industrial trucks - Symbols for operator controls and other displays	This International Standard establishes symbols for use on operator controls and other displays on powered industrial trucks.	This Standard suggests pictograms and safety sign to put on the machine	Before the commercialization hazard signs, lights, etc. will be added on the product
UNI EN 1525:1999	Industrial trucks	Safety of industrial trucks - Driverless trucks and their systems	This International Standard is applied to all the trucks and their systems but those trucks guided by means of mechanical devices and those trucks moving in open access areas with people unaware of driverless trucks associated dangers.	This standard regards safety for the machine and the operator.	The prototype will be designed in order to partially satisfy this standard. The safety of the final product will be certified and further safety devices will be added
UNI EN ISO 13849-1:2008	Machine safety - Generics	Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design (ISO 13849-1:2006)	ISO 13849-1:2006 provides safety requirements and guidance on the principles for the design and integration of safety-related parts of control systems (SRP/CS), including the design of software.	This standard regards safety for the machine. In particular HW/SW safety integration.	The safety HW should be certified before commercialization. SW safety procedure should be avoided, in order to make the certification easier.

UNI EN ISO 13850:2008	Machine safety - Generics	Safety of machinery - Emergency stop - Principles for design (ISO 13850:2006)	ISO 13850:2006 specifies functional requirements and design principles for the emergency stop function on machinery, independent of the type of energy used to control the function.	Safety stop caused by hazards	The prototype will partially satisfy this standard. More changes should be implemented on the final product (emergency buttons redundancy, safe-stop procedures, etc.)
UNI EN ISO 13857:2008	Machine safety - Generics	Safety of machinery - Safety distances to prevent hazard zones being reached by upper and lower limbs (ISO 13857:2008)	ISO 13857:2008 establishes values for safety distances in both industrial and non-industrial environments to prevent machinery hazard zones being reached. The safety distances are appropriate for protective structures. It also gives information about distances to impede free access by the lower limbs.	Safe machine design	The prototype will be designed in order to satisfy this standard
UNI EN ISO 13855:2010	Machine safety - Generics	Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body	This International Standard establishes the positioning of safeguards with respect to the approach speeds of parts of the human body. It specifies parameters based on values for approach speeds of parts of the human body and provides a methodology to determine the minimum distances to a hazard zone from the detection zone or from actuating devices of safeguards.	Safe machine design	More safety procedure should be implemented before commercialization.
UNI EN 349:2008	Machine safety - Generics	Safety of machinery - Minimum gaps to avoid crushing of parts of the human body	The objective of this European Standard is to enable the user to avoid hazards from crushing zones. It specifies minimum gaps relative to parts of the human body and is applicable when adequate safety can be achieved by this method.	Safe machine design	More safety procedure should be implemented before commercialization.
UNI EN ISO 10218-1:2012	Robots - Generics	Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots	This part of ISO 10218 specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots.	Safe machine design AND safe machine use.	The prototype will be designed in order to partially satisfy this standard. Other changes will be taken during the commercialization of the product in order to increase safety.
UNI EN ISO 10218-2:2011	Robots - Generics	Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration	This part of ISO 10218 specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s).	Safe machine design	The prototype will be designed in order to partially satisfy this standard. Other changes will be taken during the commercialization of the product in order to increase safety.

X. Appendix B – Software Architecture

In this Appendix, some UML Diagrams are presented. In particular, the Use Case and Sequence diagrams for the "Autonomous Mode" and "Gesture Interaction Mode" are presented.

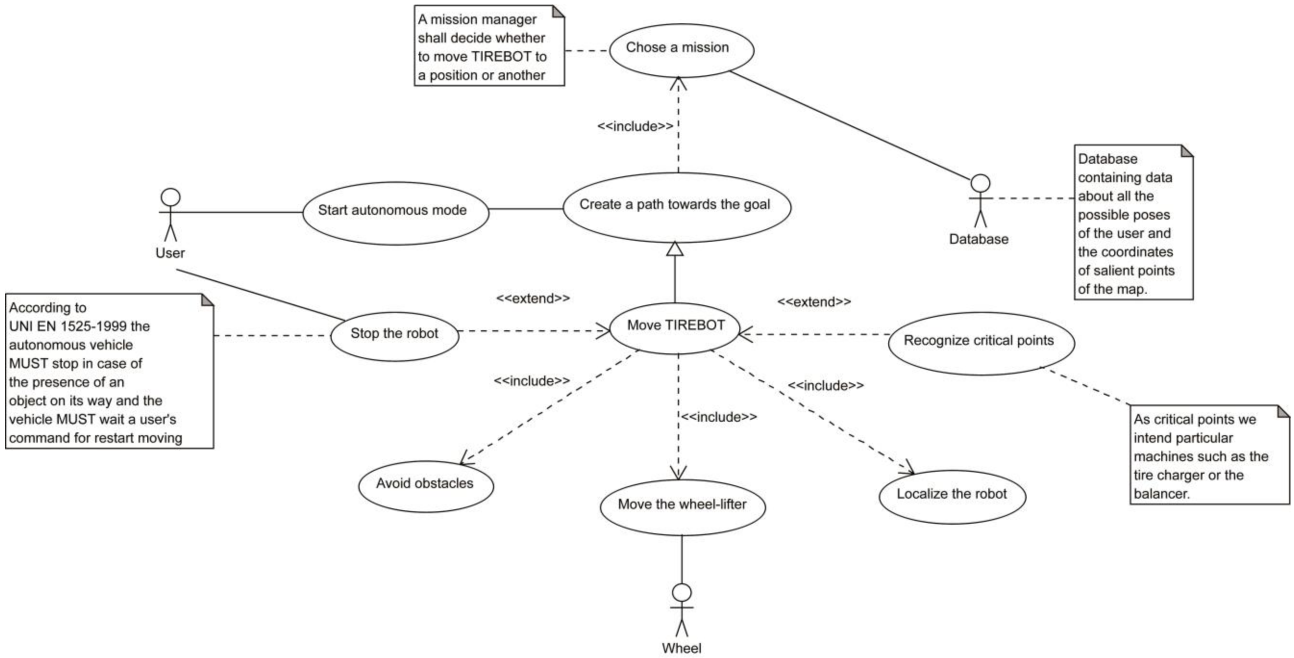

Figure 6: Autonomous mode Use Case diagram

Figure 6 represents the Autonomous mode Use Case diagram. Here, the user does not send direct command to TIREBOT, but a mission manager does.

Once the user starts the autonomous mode, the mission manager assigns a mission to the robot. A path is then created from the starting position of the robot to a goal and the robot starts moving on this path localizing itself and avoiding obstacles. The robot is capable of recognizing autonomously the machines used to work on the wheel. Once the robot has reached the goal, it can move the wheel lifter to manipulate the wheel.

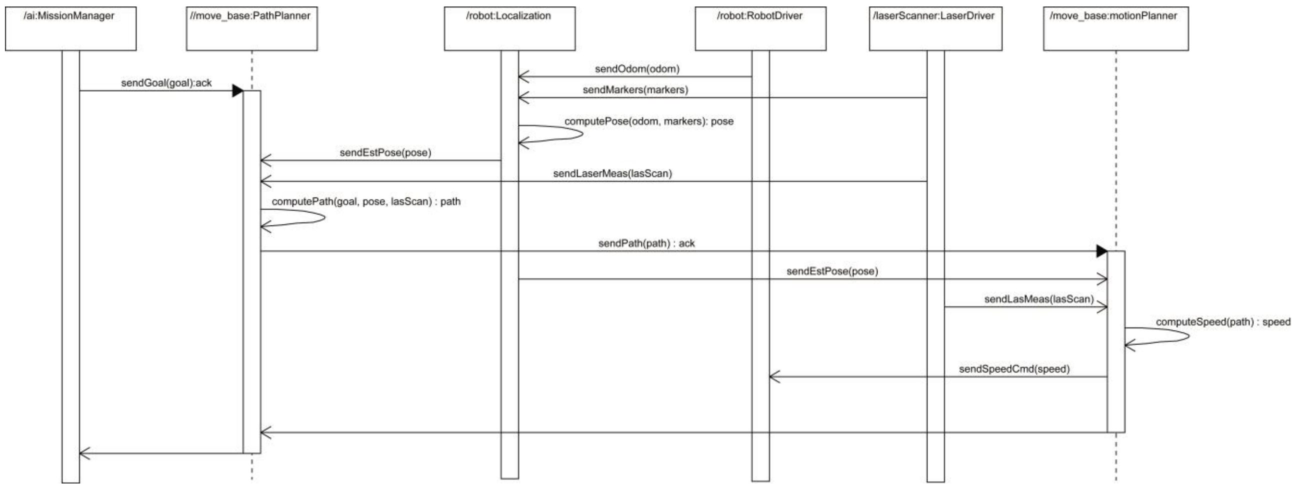

Figure 7: Sequence Diagram for the Autonomous mode

The behaviour of the robot working in autonomous mode is also described in Figure 7 through a Sequence Diagram. The modality starts with the mission manager sending a goal to the path planner. Meanwhile, the localization algorithm receives data from the odometry and from the laser scanner, estimates the pose of the robot and sends it to the path planner. The path planner also receives information about obstacles with raw laser measurements. Then the path planner computes the path and sends it to the motion planner that moves the robot avoiding obstacles exploiting the laser scanner measurements. Once the robot reaches the goal, the sequence terminates.

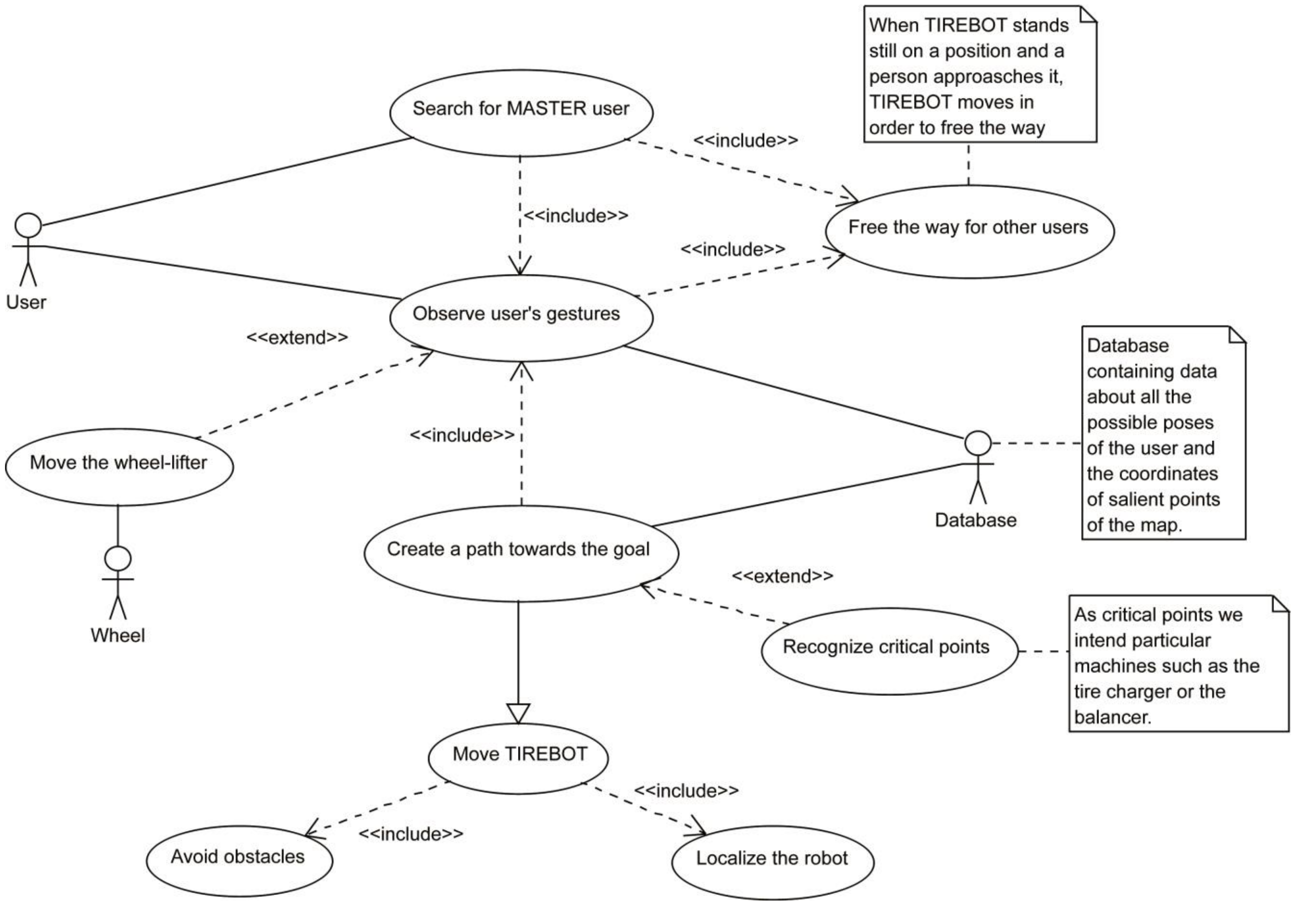

Figure 8: Gesture Interaction Use Case diagram

Figure 8 represents the Use Case diagram for the gesture interaction mode. In this mode, the robot search for a master-user and receives commands from him through his gestures. While the robot is waiting for a command, it can move in order to free the way for moving obstacles. Once the robot has received a goal from the user, it plans a path towards it, moves avoiding the obstacles and localizes itself. The robot is also capable of recognize "*critical points*" intended as poses near machines used for the tire processing.

In order to better understand the time-dependant message flow, a Sequence Diagram was developed in Figure 9: in particular, this Use Case diagram represents the behaviour of the robot that has already identified the master user.

The gesture recognizer process identifies the posture of the user and associates it to a goal to reach and then it is sent to the path planner. Meanwhile, the localization algorithm receives data from the odometry and from the laser scanner, estimates the pose of the robot and sends it to the path planner. The path planner also receives information about obstacles with raw laser measurements. Then the path planner computes the path and sends it to the motion planner that moves the robot avoiding obstacles thank to the laser scanner measurements. Once the robot has reached the goal, it stops and starts rotating on itself, searching for the user and waiting for another assignment.

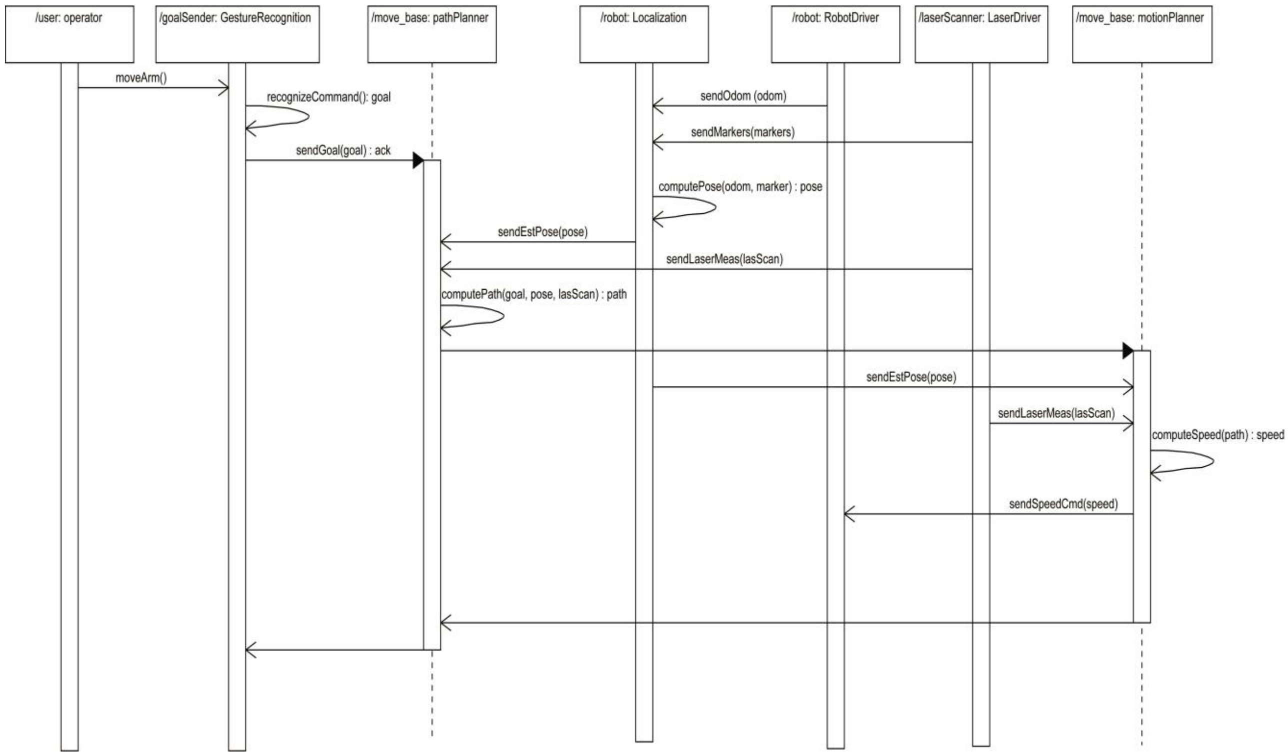

Figure 9: Sequence Diagram for the Gesture Interaction mode