Deliverable 2 – Mechatronics of TIREBOT

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I. Abstract

This document provides a description for the work done in Task 2 of the TIREBOT (a TIRE workshop roBOTic assistant) Experiment. In particular, the full description of the robot and the description of the mechanical design of the "wheel grabber", are presented. This document also provides a summary of the basic capabilities of the robot and the reader is invited to watch the videos provided with this manuscript, which prove the compliance of the robot with the specifics and the requirements defined in Deliverable 1.

II. Introduction

This deliverable presents the activities of the Task 2 of the TIREBOT experiment, namely the structure of the TIREBOT robot and its basic capabilities.

In Task 2, CORGHI has designed and developed a mechanical structure capable to load a wheel on the TIREBOT robot while UNIMORE has developed the low level and high-level control software for the robot and for the wheel grabber device.

During the construction of the robot, UNIMORE and CORGHI have cooperated in order to make TIREBOT as efficient as possible, compliant with the requirements, specifications and regulations identified in Deliverable 1, and, in order to properly place the sensors, considering the advanced capabilities being developed in Task 3. UNIMORE has also designed and implemented the low-level control for the motors actuating the wheel-handling platform and the software for collecting data from all the sensorial equipment available on TIREBOT.

A user interface has also been developed: this allows the user to give commands to the TIREBOT through gestures recognized by a RGB-D camera. Once the robot has received the command it can go autonomously, thanks to a laser scanner that detects obstacles, towards a predefined goal by avoiding obstacles and by recognizing, using a camera, the workshop tools (wheel balancer, tire changer, etc.…) to take the wheel to.

Finally, an off-board Control Station has been set up. The Control Station is made up of a PC and a haptic device for teleoperation purposes. The Control Station is connected wirelessly to the on board control unit of TIREBOT. The output of a laser scanner is used for building a geometric map of the environment surrounding the robot, while a visual stream captured by an on board camera is visualized on the PC at the control station in order to provide the user with further information about the environment the robot is moving in. This can be helpful both for monitoring and for teleoperation purposes.

This deliverable is organized as follows: Section III describes the Neobotix MPO-500, that is the mobile base chosen for the TIREBOT's realization, and the motivations that led us to choose an omnidirectional robot. In Sec. IV the wheel gripper is described from a mechanical point of view, while in Sec. V a description of the electronics is reported. Section VI explains in detail the motor control board and the devices connected to it, while Sec. VII reports a description of the control station. Sections VIII and IX report a summary of the basic capabilities of TIREBOT and the conclusions of this deliverable respectively.

III. The Neobotix MPO-500 robot

The Neobotix MPO-500 (Figure 1) is a mecanum wheeled mobile robot and it has been used as the mobile base of TIREBOT. Its particular holonomic kinematic configuration allows it to move in every direction. In fact, the forward, the lateral and the rotation velocities are decoupled. Commonly, this kind of robot is also called “omnidirectional mobile robot”. This allows the robot to execute complicated manoeuvres in narrow spaces: this capability makes the omnidirectional robot very suitable for the TIREBOT experiment.

The particular kinematic structure of the Neobotix MPO-500 has also some drawbacks: the mecanum wheels, composed of cylindrical rollers inclined with respect to the axis of the wheel itself, owe their ability to slip in any direction to friction. This reduces the overall efficiency of the robot, and, in order to travel, the robot consumes much more energy with respect to other robots with a different kinematic structure (e.g. differential drive mobile robots, car-like robots, etc.). Another important drawback is the very noisy odometric information provided by the robot’s encoders; the fact the robot can slip in every possible direction makes inaccurate the speed measurements given by the encoders and, by computing the pose of the robot by integration of the robot’s velocities, could lead to big localization errors in very small times. This issue can be overcome by installing the proper exteroceptive sensors on the robot and by implementing the proper localization algorithm.

Figure 1: The Neobotix MPO-500 robot

The robot has four mecanum wheels a frontal laser scanner SICK S300 Advanced (which also works as safety stop system), two lateral safety stop buttons, and four aluminium profiles on the top, which can be used to fix on the robot tools, sensors, etc...

The robot weights about 150kg. Its length is 880mm, its width is 666mm and its height is 408mm (frontal laser scanner included, see Figure 2). It has a payload of 150kg.

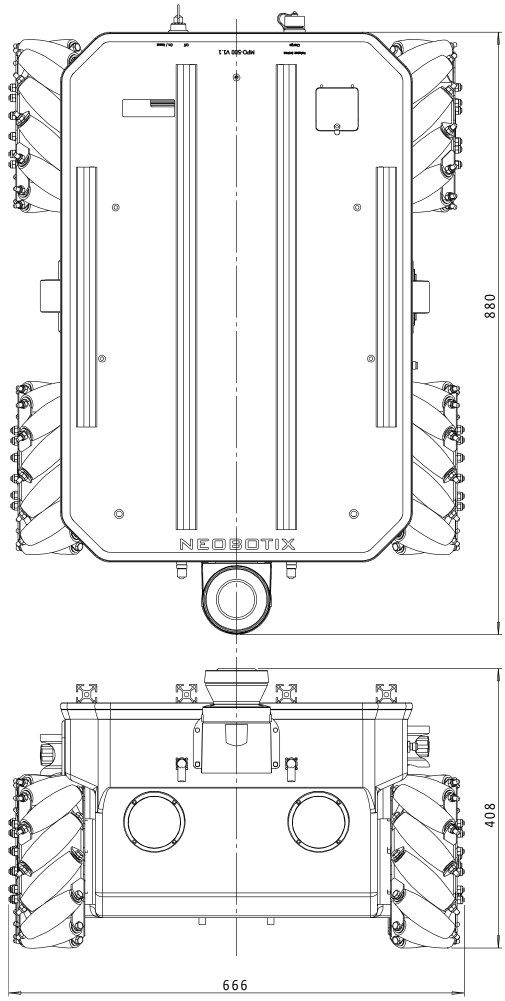

Figure 2: Neobotix MPO-500 technical drawing

The robot is already endowed with an internal computer with Ubuntu 14.04 (Trusty Tahr) and ROS (Robot Operating System) Indigo Igloo. The robot has already installed all the software needed (drivers and ROS nodes) for operating it remotely (with a joystick) or autonomously.

IV. The wheel gripper

In order to make the Neobotix MPO-500 capable of loading wheels and then move them in a tire workshop, CORGHI has developed a special tool capable of safely grabbing and lifting the wheel.

Figure 3: Some pictures of TIREBOT

The lifting system is composed by a linear guide, actuated by a motor, which carries two forks (the lower ones, see Figure 3) and a second and shorter linear guide, independently actuated by another motor, with a third fork. Four limit switches placed on the robot limit the stroke of the linear guide's carts.

The tire must be placed on the lower forks and held on by the operator until TIREBOT has grabbed it safely with the upper fork. All the forks have a load cell that can sense the presence of the wheel and check if it exceeds TIREBOT's payload (in the case of the lower forks) or if the tire has been grabbed properly (in the case of the upper cell).

This lifting device is fixed to a steel girder enforced by a thick steel plate, which avoids the torsion of the lifting device due to the robot's movements and vibrations. The whole lifting structure lays on the rear side of the chassis of the Neobotix MPO-500 and on the two middle aluminium profiles. The structure is further strengthened by adding an oblique aluminium profile, fixed both to the top of the lifting device and to the robot.

The lifting device, realized by CORGHI, is actuated by two motors that are connected to a control board. The control board is powered by both 12V and 24V that are provided by two batteries. The forks of the lifting device are endowed with load cells connected to an amplifier board, that is powered by the motor's control board (with 12V and the reference ground) and with -12V provided by a third battery.

We chose to place the wheel grabber on the rear of the robot for safety reason: if the forks were on the front of the robot (the same direction of the straight movement of the robot) they could possibly harm people. Furthermore, on the rear side of the robot it was possible to exploit the Neobotix's frame to support the whole structure of the wheel gripper.

The lifting device structure also carries other important components (see Figure 4):

- The RGB-D camera Xtion Pro-Live

- The SICK TIM-310 localization laser scanner
- A buzzer
- A safety flashing light
- A camera

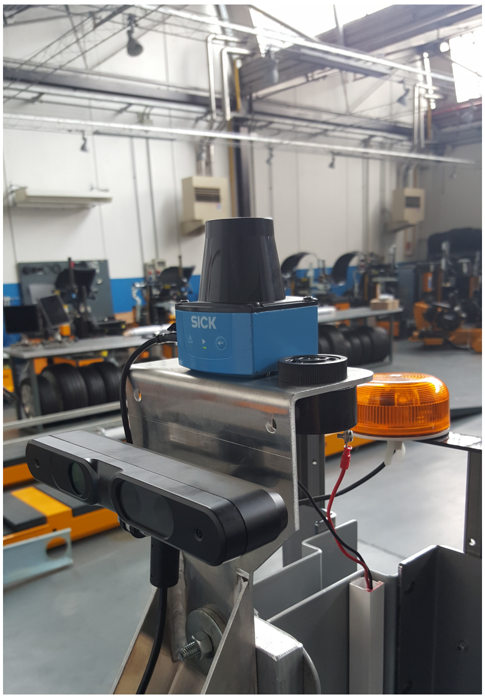

Figure 4: Particular of TIREBOT with the laser scanner, the RGB-D camera, the buzzer and the flashing light

In order to avoid overturning when the robot is lifting a wheel, two oblique aluminium profiles are fixed on the lower part of the robot. These profiles have also two spherical wheels to avoid creeping and jamming if the robot flips when it is moving. Furthermore, on the front of the robot a thick steel plate is mounted. It weights 40kg and, with the help of the three batteries, acts as a counterbalance. A full technical drawing of TIREBOT is in Figure 5.

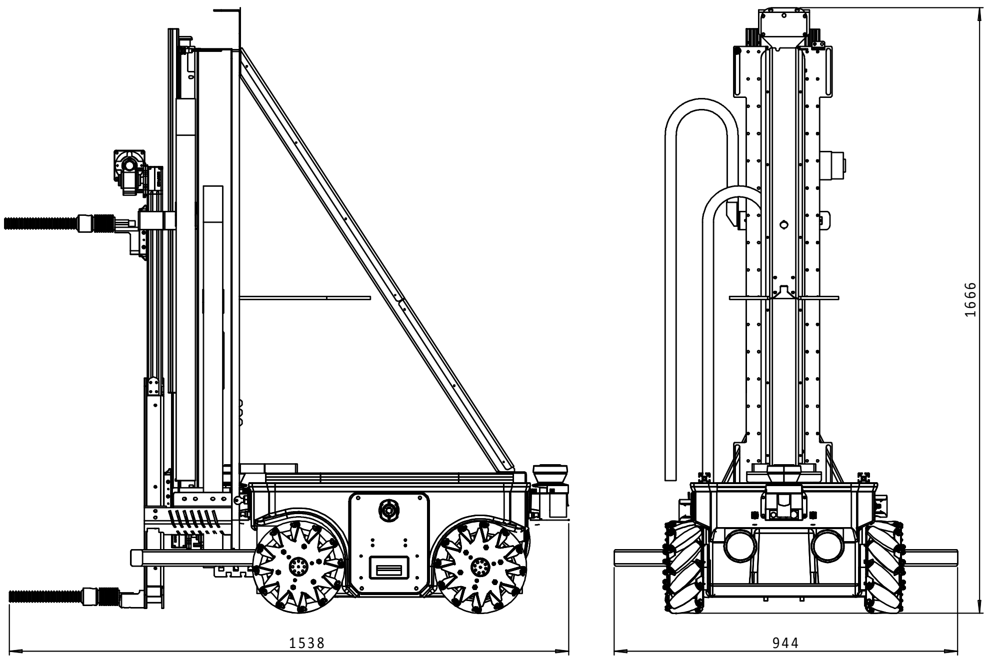

Figure 5: Technical drawing of TIREBOT

V. TIREBOT electronics

In order to avoid the Neobotix MPO-500 to be damaged by parasite currents the electrics of the wheel gripper and the sensor are physically separated by the one of the robot.

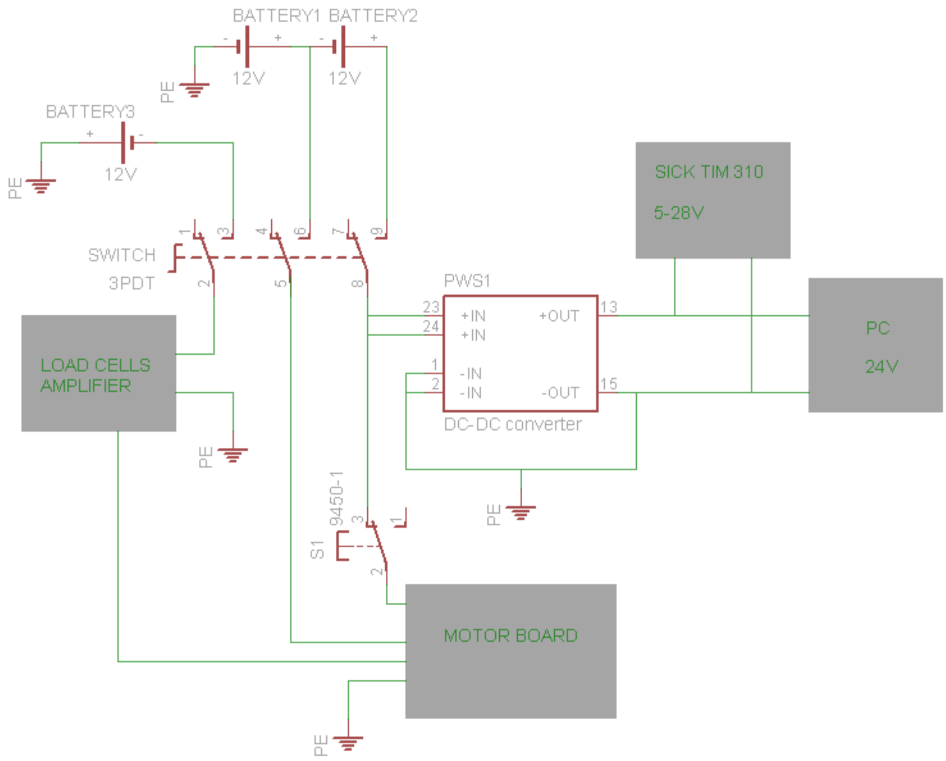

Figure 6: TIREBOT Schematics

Three batteries power the system: two 12V batteries in series give power to all the devices but the load cells amplifier, which is powered with -12V by the third battery and with 12V by the motor board. A three way switch powers on all the devices, while a safety switch interrupts power only for the motors (Figure 7).

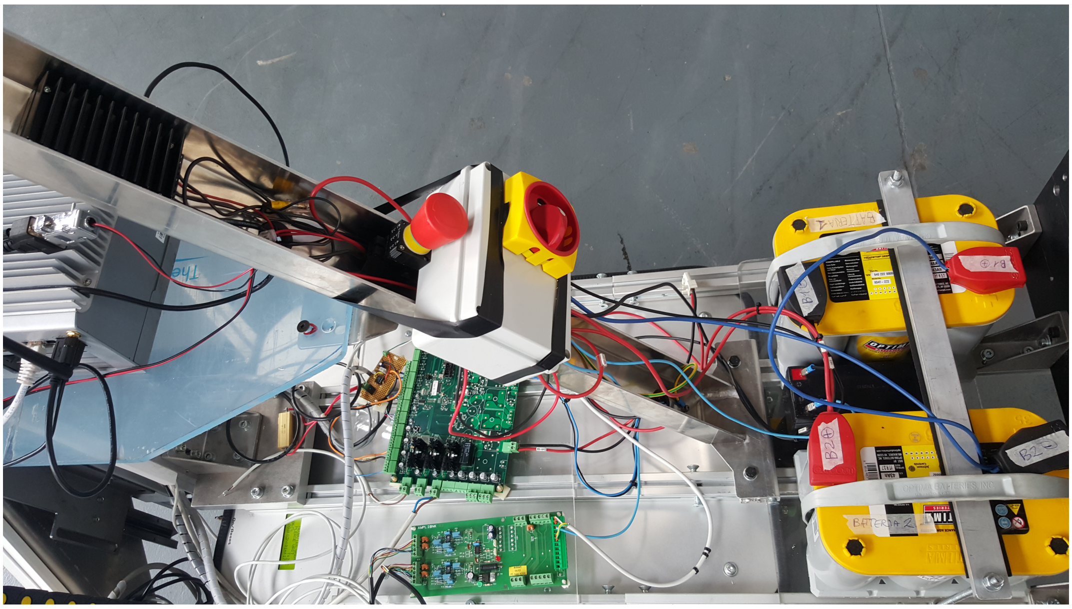

Figure 7: The power switches and the batteries

The batteries power on the motor board and a DC/DC converter, which works as a current stabilizer that, in turn, powers on an industrial PC and the SICK TIM 310 localization laser scanner. The industrial PC is placed on a Plexiglas sheet fixed on both the column carrying the gripper and to the oblique aluminium profile. The industrial PC runs most of the algorithms that make TIREBOT work correctly.

In order to avoid current laps, which could create noise and disturbances for the sensors, all the devices have a common ground, which is connected to the robot's frame, which discharges current to earth.

The robot is equipped with other devices, which are not powered directly by the batteries but by the motor board. In particular, the robot is endowed with:

- Four limit switches (Figure 8) placed on the linear guides; each linear guide has a lower and an upper limit switches that sense if the linear guide's cart runs out of the lower and upper limits

Figure 8: The limit switches

respectively;

- A buzzer that, when the robot is moving, sends acoustic signals to warn people who are in the neighbourhood of the robot;
- A flashing yellow light that, when the robot is moving, blinks for warning people in the robot's surroundings of its presence.

Furthermore, the robot is equipped with a RGB-D camera, the Xtion Pro Live, which is powered by the industrial PC through USB. The industrial PC is also connected to the motor board through a RS-422 serial communication cable (Figure 9).

A further RGB camera is mounted on the rear part of the robot, in order to frame a user who is loading a wheel on TIREBOT.

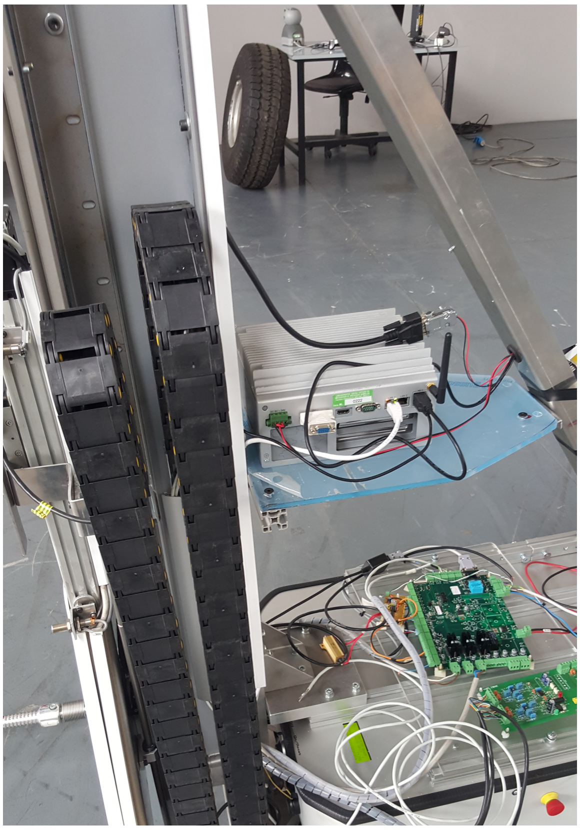

Figure 9: The industrial PC, the motor board and the load cells amplifier.

The load cells of the two lower forks are connected in parallel, while the load cell on the upper fork is connected singularly to the amplifier. The amplifier, then, is connected to the motor board's analogue input.

VI. The motor board

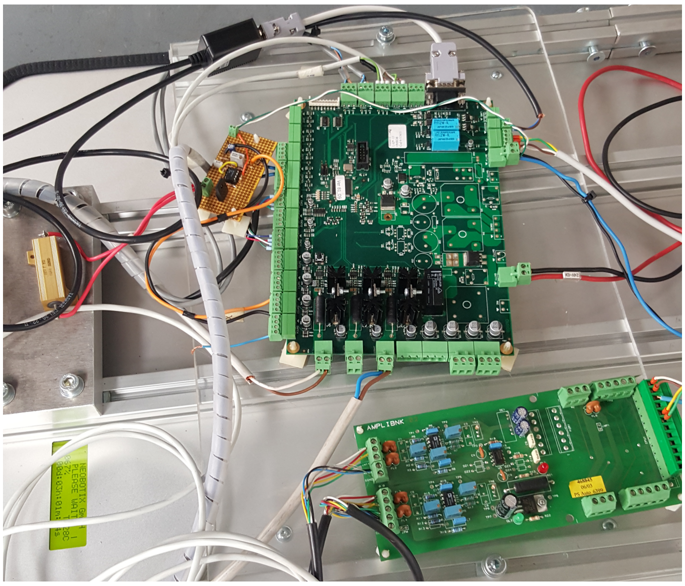

Figure 10: The motor board (up), the load cell's amplifier board (down)

The motor board mentioned in Sec. V does not only provide power to the connected devices, but it also acts as an interface to them. It is powered by both 12V and 24V and it is endowed with three H-bridges that can actuate up to three 24V DC brushless motors that communicate their speed to the board with absolute encoders. For the lifting device TIREBOT is endowed with, there are only two motors. The stroke of the motors is limited by the board's software thanks to the four limit switches.

The load cells amplifier is also connected to the motor board. It provides the 12V and the ground needed by the amplifier. The board also controls the safety flashing light and the buzzer.

In order to prevent damage to the board when the motor that moves the lower fork lowers a massive load and starts to produce energy instead of consuming, a further device was added. This device is a comparator that closes a switch that reroute the energy produced by the braking motor on a resistance when the voltage on the H-bridge is greater than 30V.

VII. The control station

A control station was set up in order to control the robot remotely. A laptop computer and the Geomagic Touch haptic device compose the control station.

The ASUS Xtion Pro Live broadcasts the captured video on an ad-hoc Wi-Fi network and the user can watch what the robot sees on the control station. The user can control the movement of the robot by interacting with the Geomagic Touch.

Figure 11: Communication architecture

The haptic device is connected through Ethernet to the laptop running its driver. Commands are then sent through the Wi-Fi network to the robot. The communication architecture is also described in Figure 11. The three computers (the Neobotix one, the industrial PC and the laptop) run Ubuntu 14.04 (Trusty Tahr) and ROS Indigo Igloo.

VIII. Basic capabilities

In this section, we want to summarize the basic capabilities of the built TIREBOT prototype.

- The robot is equipped with a wheel grabber that can lift tires weighting more than 40kg. Two lower forks and an upper fork compose the gripper. All the forks are equipped with load cells capable of sensing the presence of the load on the lower forks and if the third upper fork is properly holding the wheel.
- TIREBOT has a RGB-D camera capable of recognizing objects and users. Furthermore, the camera can send a visual stream to the user, who can control the robot from a control station through a haptic device.
- The robot can build a geometric map (Figure 12) of its surroundings thanks to a laser scanner. An occupancy grid map reports the position of the obstacles.

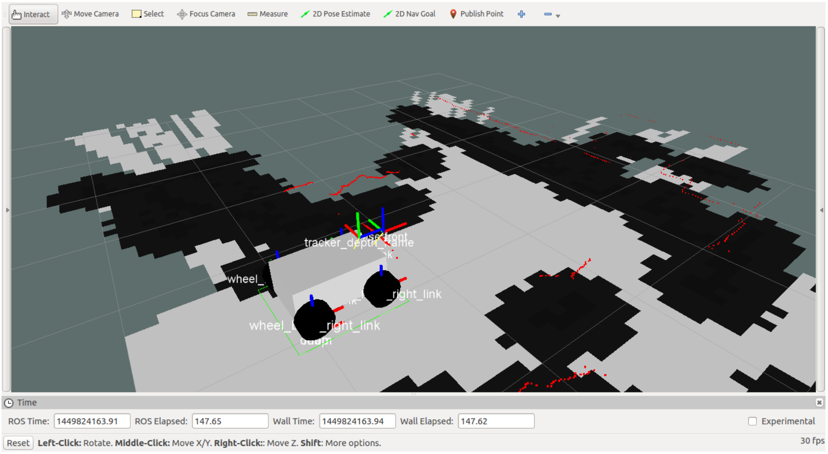

Figure 12: Geometric map of the robot's surroundings

- The RGB-D camera the robot is endowed with, is also used to recognize gestures from the user and "translates" them into commands TIREBOT will execute.

All these capabilities can be watched in the videos attached to this manuscript. Here it is a list of the available videos with a short description:

- Grabbing.avi: this video shows the robot tele-operated by a user while loading a wheel and moving to another location of the workshop.
- Teleoperation.avi: this video shows the moving robot while tele-operated. It is also shown the video stream and the user while he interacts with the haptic device, the Geomagic Touch.
- obj_recog.avi: this video shows the algorithm for recognizing objects in the scene.

IX. Conclusions

This manuscript reported the description of the realization of the prototype for the TIREBOT experiment. In particular, the document described the mobile base, the Neobotix MPO-500, and motivated the choice of an omnidirectional robot for a usage in a tire workshop.

The realization of both the mechanical and electrical part of the wheel grabber is minutely described, with a particular attention to the description of the sensor of the robot and the interconnection for the power supply for all the electrical equipment of the robot.

This manuscript reports, also, the components the user's control station is composed by and how the user can interact with the robot: by commanding it through gestures or by tele-operating it with a haptic device. The paper describes also how the computers, which compose the system, are interconnected.

Finally, a summary of the basic capabilities of the robot is reported. In particular, the reader is invited to watch the attached videos that demonstrate the many tasks the robot can accomplish.