A Tire Workshop Robotic Assistant (TIREBOT)

University of Modena and Reggio Emilia

Corghi s.p.a.

Table of contents

Section 1: Executive summary

- The goal of the project was to build a robotic assistant for helping the tire workshop operator in the wheel changing process.
- The wheel changing process consists of dismounting the wheel and taking it to a tire changer machine, where the tire is dismounted and the new tire is mounted, and then to a wheel balancer, where the wheel is balanced, and finally back to the vehicle, where the wheel is lifted and mounted.
- Currently the operator takes care both of high-level tasks for which her/his expertise is necessary and of low-level tasks, like transportation and lifting of the wheel, that are tiring and for which no specific expertise is required.
- Delegating to a robot the low level tasks allows to make the work of the operator less tiring and more efficient, since the operator needs to focus only on the parts of the job his expertise is due for.
- The proposed solution is a robotic assistant that can safely cooperate with the operator for wheel processing tasks. The robot can transport the wheel from one working station to the other and it can assist the user in the lifting process.
- Our solution aimed at significantly reducing the human effort associated to the wheel changing process and to provide the tire workshop operator with a safe robotic assistant it can very easily interact with. Furthermore, we aimed at exploring the effectiveness of TIREBOT as a “personal forklift” that can take care of heavy load transportation in tasks involving a human operator
- When using TIREBOT, the tire workshop operator has experienced a decrease of 57% of the effort with respect to the standard, all manual, wheel changing process. The usability of TIREBOT has been deemed sufficient. TIREBOT has been tested also in a RIF facility, where batteries for electric vehicles are selected by an operator and manually transported from a working point to the other. TIREBOT was exploited for safely approaching the operator in order to receive the load and to transport it from one point to another. The operators have experienced a 63% reduction of the effort with respect to the manual case and the usability of TIREBOT has been deemed sufficient.

Section 1.1: Milestone overview

#	Description	status
M1	Requirements	Timely achieved
M2	TIREBOT Prototype	Timely Achieved
M3	High Level Behaviors	Timely Achieved
M4	Complete TIREBOT	Timely Achieved
M5	Experimental Evaluation	Timely Achieved

Section 1.2: Deliverable overview

#	Description	status
D1.1	Requirements and specifications	Submitted
D2.1	Mechatronics of TIREBOT	Submitted
D4.1	The TIREBOT co-worker	Submitted
D4.2	Experimental Evaluation and RIF outcome	Submitted
SB	Storyboard	Submitted
MMR	Multimedia Report	Submitted

Section 1.3: Technical KPIs

#	Description	status
1	User-safe requirements and specifications	Achieved
2	The mechatronics of TIREBOT	Achieved
3	Advanced Motion Control and Robot Capabilities	Achieved
4	Comparative Evaluation	Achieved
5	Effectiveness in other industrial scenarios (RIF visit)	Achieved

Section 1.4: Impact KPIs

#	Description	status
1	Cost reduction in the wheel changing process	Achieved
2	Cost effect on healthcare system	Achieved

Section 1.5: Dissemination KPIs

#	Description	status
1	Social Media	Achieved
2	Website	Achieved
3	Press release	Achieved
4	Final press release	Under preparation
5	IROS Submission	Achieved
6	Video	Achieved
7	ICRA17 submission	Achieved
8	Specialized Journal submission	Under Preparation
9	Transactions on Mechatronics submission	Under preparation
10	AUTOPROMOTEC fair	Under preparation (next year)

Section 1.6: Additional (unplanned) achievements

- Collaboration with a major car manufacturer for inserting TIREBOT in their assembly line in order to implement cooperative wheel mounting.
- Collaboration with BPR group for developing cooperative robotic system based on TIREBOT strategies

Section 2: Detailed description

Section 2.1: Scientific and technological progress

- **Task 1: Requirements and Specifications**. CORGHI and UNIMORE have cooperated for formalizing the requirements and the specifications for TIREBOT. The use cases involving TIREBOT have been formalized using UML diagrams and ROS has been chosen for developing the software and for interfacing with the hardware of TIREBOT. A safe behavior concept and specification, based on the relative distance and relative velocity, has been defined.
- **Task 2: Tirebot Design and Basic Capabilities**
    - **Task2.1: Construction:** Starting from the requirements and the specifications provided by Task1, the lifter to be installed on the mobile base of TIREBOT has been designed and built by CORGHI. The actuation system of the lifter has been wrapped up in ROS in order to make it a ROS node easily integrable in the overall architecture. The lifter has been installed on the MPO-500 mobile base.
    - **Task2.2: Interaction:** The robot has been endowed with a RGBD camera for recognizing the machines it has to navigate among and with a laser scanner for

building a geometric map of the surrounding environment for navigation purposes. A gesture based interface for imparting commands to the robot has been developed.

- **Task2.3: Interface:** A control station where a visual stream coming from the RGBD camera mounted on TIREBOT and a simple interface the user can interact with the robot by has been setup and connected to the robot. Furthermore, a Geomagic Touch device has been connected to the control station for teleoperation purposes.
- **Task2.4: Test:** TIREBOT with its basic capabilities has been tested in the CORGHI facilities. TIREBOT has proven to be able to recognize and receive commands from the user, build a map of the environment, grab firmly a wheel and recognize the main objects it has to deal with. The control station has also been successfully tested.

- **Task 3: Navigation and Cooperation**
    - **Task3.1: Navigation:** A navigation strategy with obstacle avoidance based on a localization made with reflective markers has been developed. Furthermore, a visual servoing strategy for placing the robot in a desired pose with respect to the detected QR code has been implemented.
    - **Task3.2: Cooperation:** A novel safe interaction strategy, based on the concept of danger field, has been developed in order to allow the robot both to navigate and to avoid obstacles and to stay close to the operator for assisting him/her.
    - **Task3.3: Teleoperation:** A bilateral control strategy, based on the rate control paradigm, has been implemented using the Geomagic Touch. The force feedback is related to the distance of the robot from the obstacles. The switch between autonomous and teleoperation mode is determined by the activation/deactivation of the Geomagic Touch
    - **Task3.4: Test:** The advanced capabilities of the robot developed in Task 3 have been successfully tested in the UNIMORE labs using a PIONEER 3AT mobile based.
- **Task 4: Integration and Experimental Validation**
    - **Task 4.1: Integration:** The basic capabilities developed in Task 2 and the advanced behaviors developed in Task 3 have been integrated on the TIREBOT system. The integration has been quite seamless because of the successful choice of ROS as a common architecture of all the hardware that has been developed.
    - **Task 4.2: Tire Workshop Evaluation:** TIREBOT has been evaluated in Pegaso, a tire workshop. The experiments compared a fully manual wheel changing process with a cooperative one, with TIREBOT. Results have proven a significant decrease of the effort experienced by the operator when using TIREBOT and a sufficient usability of the robot
    - **Task 4.3: RIF Evaluation:** Using the Peccioli RIF facility, TIREBOT has been tested in Pretto, a company producing electric vehicles, for assisting the operators in the transport of the batteries. This has allowed to test TIREBOT as a personal forklifts. Results have shown a significant decrease of the effort when using TIREBOT and a sufficient usability of the robot.

Section 2.2: Scientific and technological achievements

- **User-Safe requirements:** TIREBOT is a cooperative robot and in order to achieve high-level performance in the cooperation it is necessary to specifically consider the scenario TIREBOT will be working in rather than designing a generic cooperative robot. This has been possible thanks to a direct cooperation between CORGHI, expert of the wheel changing process, and UNIMORE, expert in formalizing the requirements and the specifications for the design and control of a robot.

- **TIREBOT:** The first cooperative robot for helping a tire workshop operator in her/his tiring job. It has been designed by exploiting the from-the-field knowledge of CORGHI and the robotics expertise of UNIMORE.

- **Safe and Efficient cooperative behavior:** A novel switched navigation strategy, based on the concept of danger field, that allows to achieve fast navigation and obstacle avoidance while the robot is doing transportation and safe and accurate motions while the robot is assisting the operator.

- **Comparative evaluation:** TIREBOT has been proven to work as a prototype in a tire workshop cooperating with a real tire workshop operator, therefore reaching TRL 7. TIREBOT has proven to significantly reduce the effort experienced by the operator, showing that a safe and effective cooperation can lead to better working conditions.

- **Effectiveness in other industrial scenarios (RIF visit):** TIREBOT is more that a helper for a tire workshop operator, it is a personal forklift able to assist a worker in its heavy jobs. This hypothesis has been successfully tested in Pretto, at the Peccioli RIF, and this paves the way to a wide range of applications for TIREBOT.

Section 2.3: Socio-economic achievements

- **Cost Reduction in the Tire Workshop:** TIREBOT allows the operator to spare the time s/he actually spends for transporting the wheel. This leaves the operator a lot more time available for doing high-level wheel processing task by augmenting the number of wheels that can be processed per unit of time.

- **Possible improvement in the workshop organization:** since thanks to TIREBOT the wheel changing process can be pipelined, it is possible to re-organize the personnel in order to exploit this possibility. Since the transportation is handled by TIREBOT, by associating a unit of personnel to each processing machine, it is possible to process a wheel in a time much shorter that the one it would be required if the wheel had to be transported manually from one station to the other.

- **Cost effect on healthcare system**: Since effort due to wheels lifting and transportation is significantly reduced thanks to the use of TIREBOT, the working conditions of the operator are significantly improved. This implies a longer active time of manual work and fewer injuries related to the fatigue and, consequently, lower costs for the healthcare system.

- **New product:** TIREBOT has shown how cooperative robotics can be used for transferring tiring and low level activities to the robot, leaving the operator to focus on more challenging high-level activities. As shown in the project, this paradigm applies to a wide range of application scenarios (e.g. tire workshops, battery transportation). This makes TIREBOT a prototype product for a wide set of markets.

Section 2.4: Dissemination activities

Press Release

- Presentation of TIREBOT to local companies, September 25th 2015, Press Conference, Reggio Emilia.
  - The event was very well attended by the local industries representatives. It had a good impact on the local corporate image of CORGHI and of UNIMORE and it was very useful for raising the local awareness. This event generated a lot of articles in the local press and in the specialized press.

Participation to Events and Fairs

- TIREBOT presented at "Cooperative Robotics in Factories", October 30th, 2015 Vicenza (I), organized by Veneto's industrial association
- TIREBOT Presented at "Robot Forum at the MECSPE International Fair" March 10th, 2016 Parma (I)
- TIREBOT presented at "Factory 4.0 – The relationship between human and machine" April 8th, 2016 Mantova (I), organized by BPR Group
- TIREBOT presented at "Echord++ booth at the Hannover Messe" April 27-29, 2016 Hannover (D)
- TIREBOT invited to be presented at "Echord ++ second kick-off meeting" May 4, 2016 Palma De Mallorca
- TIREBOT presented at "Human-robot Interaction" September 28, 2016 Forlì (I), organized by the Forlì-Cesena Industrial Association.

These participation helped to have an impact on the global industrial awareness. Furthermore, during these events, we could have a direct contact with people interested in TIREBOT. In particular, during these events, we met the major car manufacturer that got interested in developing TIREBOT for inserting it in their assembly line and a company by BPR group that got interested in the sharing principles developed in TIREBOT for building novel cooperative applications.

Scientific Publications

- A. Levratti, A. De Vuono, C. Fantuzzi, C. Secchi, "TIREBOT: a Novel Tire Workshop Assistant Robot", IEEE International Conference on Advanced Intelligent Mechatronics, July 12-15, Banff, Canada
- A. Levratti, G. Riggio, A. De Vuono, C. Fantuzzi, C. Secchi, "Safe Navigation and Experimental Evaluation of a Novel Tire Workshop Assistant Robot ", IEEE International Conference on Robotics and Automation, May 29 – June 3, Singapore.
- Submission to the IEEE Transactions on Mechatronics (under preparation)
- Specialized Journal Submission (under preparation)

Social Media

- Social media pages (Facebook,Twitter, LinkedIn)
- Website on the ARSControl page

Social media have been very useful for reaching many people even if we posted few messages (more or less one message per week).

Section 3: Resource usage summary

	UNIMORE	CORGHI	TOTAL
Personnel Cost	101716	155354	257070
Travel Expenses	2500	4000	6500
Consumables	37800	20000	57800
Indirect Costs	85210	94624	179834

UNIMORE exploited the budget for hiring a full time contract researched that has been dedicated to the project. Furthermore, 14 PM of associate and full professor time have been allocated to the project. The consumables costs are due to the purchase of the MPO-500 robot, which has been used as a mobile base for TIREBOT. The travel expenses are due to the RIF visits and for disseminating TIREBOT's results to international conferences.

CORGHI exploited the budget for allocating 24 PM of researchers and technicians to the project. The travel costs are due to the transportation of TIREBOT and for the promotion of TIREBOT's results. The consumables costs are due to the construction of the TIREBOT gripper and to the sensors TIREBOT has been equipped with.

Section 4: Deviations and mitigation

No deviations.

Section 5: Future work

In the near future, TIREBOT will be adapted to be inserted in the production line of the major car manufacturer that contacted us. The same cooperative behavior will be implemented but the navigation strategy as well as some mechanical details will need to be modified. Furthermore, we will work with BPR group for developing human-robot cooperation with abilities splitting, as done in TIREBOT. We will then explore the possibility of adapting TIREBOT to make it a personal forklift for heavy jobs that can are not very repetitive and, therefore, scarcely automatable. We will look for funding in EU measures for spinoffs.

Section 6: Lessons learned (optional)

The ECHORD++ project has been very interesting. It has allowed to establish a well funded cooperation between UNIMORE and CORGHI with a reasonable investment of time for writing the proposal. We liked the way ECHORD++ managed the experiments. We have two comments:

- For the ECHORD++ team: a two months period for monitoring is too short. We would suggest to take this period to three months.
- For the ECHORD++ Team and for EU: The funding takes too much time to be delivered to the partners. This may be a problem for companies, especially for SMEs that cannot afford to anticipate the money.