Deliverable 4.2 – Experimental Evaluation and RIF Visit Outcome

Index

I. Abstract

This document provides a description of the final experiments of the TIREBOT (a TIRE workshop roBOTic assistant) prototype. First, this manuscript introduces the experiments that took place in a real tire workshop with real tire workshop's operators as robot's co-workers. Then, a deep analysis of the robot's performance will be presented, as well as the final user's evaluation.

This document also presents the evaluation of the robot in a different environment. Experiments took place at the Gruppo Pretto's warehouse, as indicated by the Peccioli RIF, where the robot was used to load and transport lead batteries.

The reader is also invited to watch the multimedia video report, attached to this document, which shows a summary of the activities involved in the TIREBOT project, the final experiments and the RIF's evaluation.

II. Introduction

This document presents a description of the validation experiments and their analysis that took place during task 4.2 – “Tire Workshop Evaluation” and task 4.3 – “RIF Evaluation”.

The first part of the experiments took place in the Pegaso tire workshop, in Correggio (Italy). Tests consisted in evaluating the robot’s performance in the environment the robot was designed for. Furthermore, the experiment was done to evaluate the robot’s cooperation with real tire workshop’s operators, who are the final users of the product.

The second and final part of the experiments consisted in evaluating TIREBOT’s capabilities in a different scenario suggested by the Peccioli RIF. The identified scenario was the Gruppo Pretto’s warehouse, where operators could use TIREBOT for loading and moving heavy batteries (approximately 30 kg) among the warehouse to the workshop where the batteries are mounted on electrical vehicles.

This document is organized as follows: Section III introduces the experiment done in the tire workshop, the setup and the tasks the robot needs to accomplish. Sec. IV describes the analysis of the robot’s performance and it also proposes the final user’s evaluation of the prototype. Section V introduces and describes the experiments that took place at Pretto. Finally, in Sec. VI conclusions are drawn.

III. Experiment description

The first set of experiments took place into Pegaso tire workshop. Figure 1 shows the environment where experiments took place. In order to let the robot work in this environment, it is necessary to setup the working environment.

Figure 1: the workshop where TIREBOT experiments took place

It is first necessary to setup the control station, composed by the computer and by the haptic device (Geomagic Touch). In order to communicate with the robot, the control station exploits an ad-hoc wi-fi network generated by a router.

The robot's localization algorithm exploits reflective markers reading provided by the localization laser scanner top-mounted on the robot. Then, the setup requires the environment to be endowed with reflective markers. In particular, ten reflective markers have been positioned in fixed locations in the workshop and mapped by the robot.

The navigation algorithm used by the robot to move, exploits also visual markers (see Figure 2) to recognize particular places of the working environment.

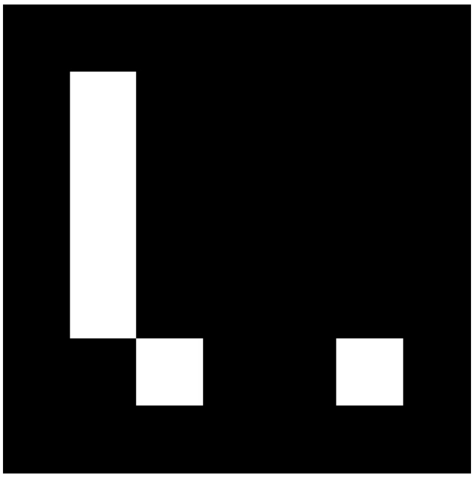

Figure 2: the visual marker that helps the robot during its navigation

Last, the robot has to memorize the positions where it has to move to. In particular, the robot has to memorize the location of the car lifter (left and right sides of it) and the wheel-processing workshop's machines (i.e. the wheel changer). Of course, in order to have the right locations, the localization algorithm of the robot must be activated during this process.

The experiment consists in the following operations:

1. The operator switches on the robot.
2. The operator is recognized by the robot as its master user by lifting his hands above his head.
3. The robot is ordered to move to a side of the car lifter bridge.
4. The robot navigates to the indicated position; meanwhile the operator unscrews a wheel from the car.
5. Once the robot has arrived to the selected position, the operator orders it to grab the wheel.
6. The robot rotates, grabs the wheel and lifts it. Then, the robot rotates again in order to frame the operator with its camera.
7. The operator, then, orders the robot to take the wheel to the wheel changer.
8. The robot navigates towards the wheel changer. As soon as it frames the visual marker, it corrects its trajectory and moves to a position with respect the visual marker's pose.
9. Once the robot has arrived near the wheel changer, the operator orders it to release the wheel.
10. The robot, then, rotates in place and releases the wheel that is grabbed by the operator. The robot, then, rotates again in order to frame the operator, waiting for other orders.
11. Once the maintenance operations have took place, the operator orders again the robot to grab the wheel.
12. The robot, rotates in place, grabs the wheels and rotates again to frame the operator.
13. The operator, then, orders the robot to take the wheel back to the car lifter.
14. The robot navigates towards the ordered goal pose.
15. Once arrived, the user orders the robot to release the wheel.

In order to evaluate the robot's performance, also the time required by doing this same operation manually was measured (see the attached multimedia report video from 0:11 to 0:32).

The experiment consisted also in evaluating the haptic interface. Operators were invited to move the robot from a starting location to the car lifter, to grab the wheel by only using the haptic interface and the control station, take it to the wheel changer and release the wheel by only using the haptic interface.

Finally, the operators involved in the experiments were asked to compile an evaluation questionnaire. This was done with the intent to evaluate both the appreciation and the usability of the robot. The questionnaire was composed by the following questions:

- q1. How much do you evaluate the difficulty in the use of TIREBOT? (1=very easy, 5=very difficult);
- q2. How much has TIREBOT facilitated your job with respect to the current practice? (1=for nothing, 5=a lot);
- q3. How comfortable do you evaluate TIREBOT's gesture interface? (1=very uncomfortable, 2=very comfortable);
- q4. How comfortable do you evaluate TIREBOT's teleoperation and haptic interface? (1=very uncomfortable, 2=very comfortable);
- q5. How difficult was to put the wheel on TIREBOT? (1=very easy, 5=very difficult).

IV. Performance analysis

Table 1 summarizes the performance evaluation and reports the results of the questionnaire. Columns' meaning is summarized as follows:

- Test: represents the experiment number;
- Age: age range of the operator who performed the test;
- Experience in car servicing: years the operator spent working in the car servicing field;
- Required time: indicates the time required by performing the task both manually and with the assistance of TIREBOT;
- Effort reduction: the effort reduction perceived by the operator while exploiting TIREBOT's help with respect to the manual operation;
- Usability: the evaluation of the usability of TIREBOT.

Test	Age	Experience in car servicing [ages]	Time required [s]		Question's score [0,1]					Perceived effort reduction $E \in [0,1]$	Perceived usability $U \in [0,1]$
			Manual	Assisted	q1	q2	q3	q4	q5		
1	30-40	18	35	128	3	3	3	3	3	0.50	0.50
2	18-30	1	41	174	3	2	4	3	2	0.50	0.63
3	30-40	1.5	43	153	4	4	2	4	1	0.83	0.36
4	50+	45	43	132	3	4	2	1	4	0.50	0.25
5	40-50	22	24	139	3	3	4	3	2	0.58	0.63
6	30-40	21	25	117	2	3	4	3	2	0.50	0.56
Average			40.50	146.75	3.00	3.17	3.17	2.83	2.33	0.57	0.54

Table 1: Table reporting questionnaire's results and the performance evaluation of TIREBOT during experiments into the Pegaso workshop

Some of the evaluated parameters, like robot's perceived usability and effort reduction, are neither objective nor countable. In particular, the perceived effort reduction required for accomplishing a particular task is subjective and it depends on many personal factors like health status, habit, musculature, age of the worker, etc.

We combined the results of the questionnaires for achieving two indicators: E, the perceived effort reduction with respect to the current manual practice, and U, the usability of TIREBOT. The indicators are defined as follows:

$$E = \frac{[(5 - q_1) + (q_2 - 1) + (5 - q_5)]}{12}$$

$$U = \frac{[(5 - q_1) + (q_3 - 1) + (q_4 - 1) + (5 - q_5)]}{16}$$

Both E and U take value in [0, 1]; the bigger the value the better is the experience. The experimental data are reported in Tab. I. Furthermore, the table reports the transportation time for taking the wheels from the vehicle to the machines and back, both manually and by using TIREBOT.

Several operators with different ages and experiences in the car servicing field have been involved in the experimental evaluation. Time required by TIREBOT to transport the wheel from the vehicle to the tire changer and on the way back to the vehicle is much bigger. Nevertheless, TIREBOT allows to pipeline the operations and while the robot is transporting the wheel the operator can start unscrewing the next wheel that is ready for transportation once TIREBOT is back. Furthermore, the transportation speed of TIREBOT can be easily improved by choosing a faster mobile base. In fact, the speed of the current mobile base is limited to 0.8 m/s, which is a very low value compared to the human velocity.

TIREBOT succeeded in significantly reducing the effort currently perceived by the operator. In fact, in average, the perceived effort is reduced to 57% and this means that the use of TIREBOT can lead to better working condition for the humans. The interface with TIREBOT has been evaluated as averagely usable and not very usable as we believed. Several operators pointed out that it is difficult to use a gesture based interface and they would have preferred a vocal interface (which would not be so easy to implement since the tire workshop is quite noisy). Furthermore, only some operators (mostly videogamers) could easily use the teleoperation system that resulted uncomfortable to the most of the older operators.

Thus, while TIREBOT has demonstrated its effectiveness in reducing the working effort, some further work needs to be done for improving the communication between the user and the robot in order to make TIREBOT usable by the average tire-workshop operator. From a mechatronic point of view, a faster mobile base needs to be adopted in order to augment the transportation speed.

The multimedia report attached to this document shows the experiment (from 3:30 to 5:43). The video shows first the operator moving manually the wheel from the car to the wheel changer and back. The video, then shows the operator repeating the sequence with TIREBOT's help. Finally, the video shows the operator controlling TIREBOT through the haptic interface: the operator moves the robot towards another operator to help him loading a wheel and taking it to the wheel changer.

V. RIF Experiments

The last part of the experiment consisted in testing TIREBOT's capabilities in a different scenario. In fact, TIREBOT is a "personal forklift" that could be used also in different contexts. The Peccioli RIF (Research Innovation Facility) identified the Gruppo Pretto's warehouse as a possible scenario for testing the robot prototype.

Gruppo Pretto is a producer of electrical garbage management vehicles. One of the most tiring activities in the Pretto's workshop is the batteries handling and transporting from a location to another. Batteries can weigh from 10 kg to 60 kg. For this experiment we chose a 30 kg battery.

In order to make the robot capable of loading the batteries a steel plate was fixed on the TIREBOT's lower forks (see Figure 3).

Figure 3: The steel plate mounted on the lower forks of the robot

The robot, for operating, requires the same setup described in the previous Section. For this experiment, only seven reflective markers were placed in the workshop.

Once the user has switched on the robot, the experiment consisted in the following activities:

1. The user gets recognized by the robot, which is standing still on its home position;
2. The user orders the robot to go to the batteries depot;
3. Once the robot has arrived, the user orders it to rotate in place, in order for him to be capable of loading the battery on the robot's loading platform;
4. The robot rotates in place and the operator loads the battery on the robot's loading platform;
5. The robot then, rotates again in place in order to frame the user, who orders him to take the battery near an under maintenance vehicle;
6. Once the robot has reached the assigned goal, the user orders him to rotate in order to unload the battery from TIREBOT;
7. Then, the user orders the robot to return to its home position and wait for other tasks.

The multimedia report video attached to this document also shows this experiment (from 5:45 to 7:22).

The operators at Pretto enjoyed using TIREBOT and those who tested the robot found the gesture interface quite comfortable and easy to use. Furthermore, unlike the experiments in Pegaso, the speed of TIREBOT has been deemed appropriate for the battery transportation task.

TIREBOT efficiently executed the battery transportation, by releasing the operator from such a tiring task and by allowing the personnel to work on more high-level tasks where their cognitive features are necessary.

People who tested the teleoperation modality found it, in some cases, even easier to use than the gesture interface. Such an enthusiasm can be due to the young age of the operators that tested TIREBOT. This may now bias some experiments but it is a good hope for the future, when all the operators will have the same or even more enthusiasm for the introduction of robots in their working environment.

From a quantitative point of view, the perceived usability index has been evaluated at 53%, which is similar to the one obtained during the experiments at Pegaso, and the perceived effort reduction has been evaluated at 63%. This means that the user interface of the TIREBOT system is evaluated as average also in the Pretto's setting and that, therefore, more work has to be done for improving it. On the other hand, the perceived effort reduction on the Pretto task is greater than the reduction perceived at Pegaso. This is due to the fact that the task executed at Pretto consists mostly of transportation, which has been completely automated by TIREBOT, and only the lifting of the batteries was left.

VI. Conclusions

This document reported the results of the final experiments on TIREBOT. In particular, this document described the project's final activities of subtask 4.2 – "The workshop evaluation" and subtask 4.3 – "RIF evaluation".

The manuscript reports the details of how experiments were executed in both the tire and the Gruppo Pretto's workshops. In order to do an objective evaluation, operators who tested the robot in the tire workshop were asked to compile an evaluation questionnaire. The collected data were then used to provide an analysis of the robot's performance, both concerning usability of the prototype and effort reduction in doing the task.

In summary, TIREBOT proved to be efficient in assisting the tire workshop operator in terms of cooperation and reduction of the effort both during wheel processing and during battery transportation. The user interface is deemed to be on average one and it can be improved by modifying the gesture interface and by introducing other interaction modalities (e.g. voice).

The experiments proved that the use of TIREBOT allows to decrease the effort in thee execution of the task of over 50% both in at Pegaso and at Pretto. This means that using TIREBOT has a very positive effect on the fatigue related to the tasks and, consequently, it allows to reduce the fatigue related injuries (e.g. back injuries) and, consequently, the related healthcare costs.

TIREBOT allows to pipeline the execution and, therefore, to reduce the operator time (and, consequently, the work cost) for the execution of the work. In the Pegaso this was not evident because, due to the low velocity of the TIREBOT platform and to the small size of the workshop, the operator was faster than the robot in the transportation. Nevertheless this is just a technological problem, that can be solved using a faster platform. On the other hand, the pipelining effect was evident at Pegaso, where the size of the workshop was bigger and the speed of TIREBOT was just good for the transportation.

Furthermore experiments have shown that, as we expected, TIREBOT is more that a wheel changing assistant but it can be exploited in all the tasks where a personal forklift is needed. Thus, the technology developed in TIREBOT is scalable and applicable to a wide range of scenarios.

The reader is also invited to watch the multimedia report video that shows both the experiments reported in this manuscript as well as the basic capabilities of TIREBOT.