TIAGo: the modular robot that adapts to different research needs

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***Abstract*— This paper describes TIAGo, the mobile manipulator created by PAL Robotics, which was conceived since its very begining as a modular robot. TIAGo inherits several modular components from its eldest brothers REEM, the service robot, and REEM-C, the biped humanoid robot, and incorporates new modular parts that can be used to build up other robots. The modularity techniques used to create TIAGo are introduced in this paper.**

I. INTRODUCTION

TIAGo is the mobile manipulator of PAL Robotics that has been designed in a modular way. Taking profit of mature technology of its predecesors REEM-C and REEM [1], see Fig. 1, TIAGo makes uses of existing components and proposes a new modular architecture allowing the robot to adapt to different applications and expand its capabilities. Modularity in TIAGo is addresses in two ways: with a modular hardware architecture and a modular software architecture.

The paper is structured as follows. In Section II an overview of TIAGo main components is presented. Then, the modular hardware architecture is presented in Section III. Following that, the modular software architecture is presented in Section IV. Afterwards, Section V presents some of the research fields and applications in which TIAGo fits in. Finally, conclusions are presented in Section VI.

II. OVERVIEW OF TIAGo

TIAGo main parts are depicted in Fig. 2. It is composed of a mobile base, a torso, an arm, a wrist, an end-effector and a head.

The mobile base has a differential drive mechanism. The base is provided with a laser plane for SLAM and safety purposes. On the rear part of the mobile base there are three ultrasounds to prevent collisions when moving backward.

The upper body of TIAGo is composed of a lifting torso with a stroke of 35 cm so that the robot height can be adjusted between 110 and 145 cm as shown in Fig. 3. On the upper lateral part of the torso there is a user panel providing some expansion ports. The top part of the torso is flat so that a laptop can be placed on top of it, this is the so called "laptop tray". The frontal part has a stereo microphone an a speaker, both aimed at Human-Robot Interaction.

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Fig. 1. REEM-C humanoid robot and REEM service robot

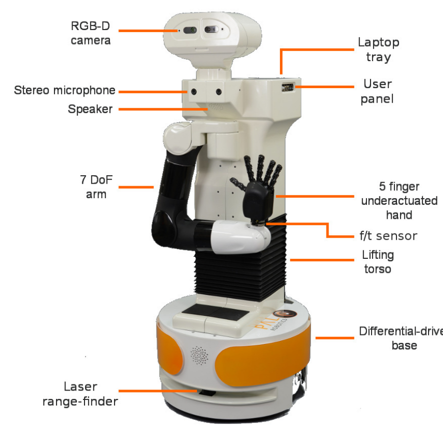

Fig. 2. TIAGo main specs

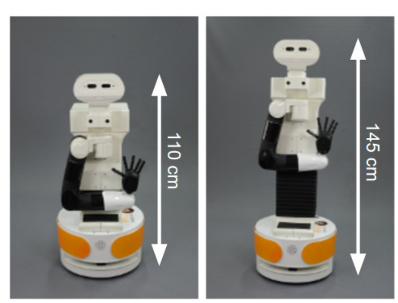

Fig. 3. TIAGo height range

The arm of TIAGo has 7 degrees of freedom (DoF). Then, a force/torque sensor can be attached at the end point of the wrist. Finally, different end-effectors can be used.

The head has 2 DoF, providing pan-tilt movements, and it is equipped with a RGBD camera.

III. MODULAR HARDWARE ARCHITECTURE

A. *Mobile base*

The mobile base of TIAGo, namely PMB-2, see Fig. 4, has been designed as a stand-alone robot. It is capable of doing SLAM and can be used to transport goods from one place to another.

Fig. 4. PMB2: the modular mobile base used in TIAGo

The metal plate on top of the mobile base can be removed and gain access to the expansion panel shown in Fig. 5. This panel provides a wide range of ports that can be used by the user to expand the mobile base or even mount another robot on top of it as done with TIAGo. The following ports are provided:

1) External lights: 4 LED driver outputs of 5 V with a maximum current of 0.5 A for each LED, which has to be connected using a series resistor.
2) Speaker: amplified audio output of right audio channel with an output power of 8 W and impedance of 8 Ohm.
3) USB 2.0
4) USB 2.0
5) USB 2.0
6) Power expansion: access to the battery and power supplies.
7) Communications expansion: access to 2 internal CAN buses of 1 Mbit/s.
8) Emergency Stop & GPIOs: input for an external emergency stop button and provides access to General Purpose Input (GPI) and Output (GPO) pins.
9) USB 2.0
10) USB 3.0
11) USB 3.0
12) GigE port
13) GigE port

Finally, the PMB2 has a payload of 50 Kg so that users can attach new equipment on top of it and expand its functionalities.

B. *Torso*

The torso has been designed to be modular as well. It has the option to attach an arm or not. Furthermore, the laptop

Fig. 5. Expansion panel of the PMB2

tray combined with the user panel ports allows to add new equipment to the torso like additional computers or sensors. The ports exposed by the user panel are shown in Fig. 6, which are:

1) CAN service port: for maintenance purposes.
2) Power supply: providing 12 V and 5 A max.
3) Fuse: to protect the internal power boards.
4) GigE port
5) GigE port
6) USB 3.0 port
7) USB 3.0 port

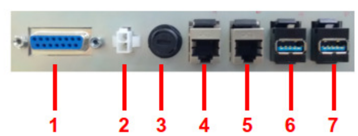

Fig. 6. Torso user panel

As shown in Fig. 7 one of the usages of the tray on top of the torso is to place a laptop that can be directly connected to one of the GigE ports of the user panel and gain access to the onboard computer.

Fig. 7. Example of use of the laptop tray

C. *Arm*

Modularity reaches its maximum expression in TIAGo's arm, see Fig. 8. The same components than in REEM and REEM-C's arms are re-used and the main difference lies in the links used between the first 4 DoF. These first DoF are made of M90L100 modules developed by PAL Robotics. The M90L100 is a compact and self-contained module that embedds a brushless motor with Harmonic Drive reductions and electronics managing power supply, current/velocity/position control and CAN bus communications. Then, the last 3 DoF are provided with the M3D wrist also developed by PAL Robotics. This is also a self-contained component including motors, reductions, a differential mechanism, electronics and communication.

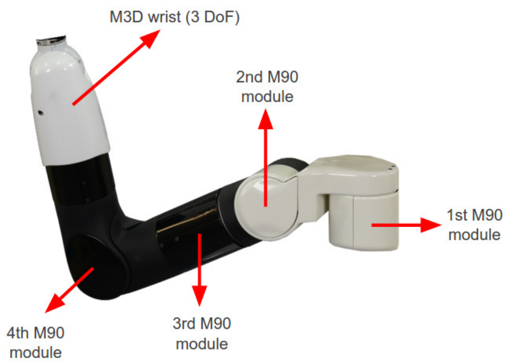

Fig. 8. TIAGo's modular arm

The ATI min45 force/torque sensor, see Fig. 9 can be added at the end point of the wrist in order to implement admittance control for instance.

Fig. 9. Force/torque sensor of TIAGo

D. End-effector

Currently TIAGo comes with two different end-effectors, the Hey5 hand[1] and a parallel gripper, see Fig. 10. The former is an underactuated passive compliant hand and the second is a typical gripper with parallel plates. Both end-effectors are compatible with the CAN bus exposed at the tip of the wrist and are self-contained, so that the user can inter-change them easily.

Furthermore, thanks to the power supply and communication ports exposesd in the user panel other end-effectors can be easily integrated with external cabling like shown in Fig. 11, where a Schunk gripper WSG 25 with ethernet interface was integrated to TIAGo.

[1]The Hey5 hand has been developed by PAL Robotics SL with contributions from QBrobotics srl. The Hey5 hand is a derivative of the "Pisa/IIT SoftHand" open source project by M. G. Catalano, G. Grioli, E. Farnioli, A. Serio, C. Piazaa and A. Bicchi.

Fig. 11. Integration of a third party end-effector

E. Head

The head of TIAGo contains two motors providing pan-tilt movements to the RGBD camera included. Furthermore, the top of the head is a flat surface with mounting points so that additional devices or sensors can be added making use again of the user panel of the torso. In Fig. 12 an example of integration of a tablet is shown.

Fig. 12. Tablet added on top of the head

IV. MODULAR SOFTWARE ARCHITECTURE

Last but not least, the software architecture of TIAGo is also modular. In our opinion, modularity not only applies for the harware architecutre of a robot but also to its software architecture. TIAGo uses different software middlewares in order to take the best from each one and provide a powerful software architecture. Built on top of the Ubuntu Operating System, the following software components are used:

- Xenomai: this framework is to handle the real-time part of the system.
- Orocos: the driver of the robot is written all as Orocos components.
- ROS: this de facto standard robotics middleware provides well known interfaces to roboticists in order to develop applications for TIAGo.
- ros_control: this specific layer of ROS provides access to the hardware through Orocos exposing ROS interfaces. All the controllers of TIAGo are implemented as plugins of ros_control so that the users can develop their own plugins and replace the default controllers.ayer provides access to the hardware through Orocos exposing ROS interfaces.
- MoveIt!: the motion planning library comes off-the-shelf integrated with TIAGo, so that users can easily

a) b)

Fig. 10. End-effectors currently supported: a) The Hey5 hand. b) PAL parallel gripper.

develop applications requiring complex upper body motions preventing self-collisions and collisions with the environment.
- user software deployment area: TIAGo defines an area of the hard disk where the user can deploy his/her own software with higher priority that software already provided off-the-shelf. This strategy allows the user to have full control of the robot but also protects the original software stack included in the robot.

V. Research areas for TIAGo

TIAGo was designed to be a standard research platform in different fields:

- Low level control: those who want to develop new algorithms to control the 7 DoF arm can do that thanks to ROS and the different low level control modes embedded by the modules of the arm.
- Autonomous navigation: the robot is equipped with typical sensors for mapping the environment, localization and navigation. The laser and sonars on the base and the RGBD camera on the head can be used to test existing navigation algorithms and to research new techniques.
- Human Robot Interaction: the RGBD camera, stereo microphones, speakers and the hey5 hand, able to shake hands, along with the off-the-shelf integration of voice synthesis provides TIAGo of powerful skills to interact with humans. Furthermore, the possibility to automatically switch the arm control mode to gravity compensation when a collision occurs makes it a suitable platform to be used in human environments.
- Pick & place applications: the 7 DoF arm along with the lifting torso provides TIAGo of a large manipulation workspace, allowing the robot to reach objects on floor level, on tables and even shelves.
- Industry 4.0: TIAGo is suited for research of applications in Industri 4.0 thanks to its mobility, manipulation skills, perception of the environment and safety features like the sensor-less current control of the arm or the admittance control that is implemented using the force/torque sensor of the wrist.

VI. Conclusions

This paper has presented an overview of the modularity of TIAGo, the mobile manipulator by PAL Robotics. The robot has been designed in a modular way so that it can be customized to fit properly in different research areas. TIAGo can be just a mobile base, targeting research in autonomous navigation and applications in the logistics field; a mobile lifting torso with head for HRI in applications like healthcare and assistive robotics; or a full mobile robot equipped with a 7 DoF arm able to do all the previous tasks plus manipulation tasks.

TIAGo has benefited also of the modular design of its predecesors, i.e. REEM and REEM-C, so that several of its parts have been exploited like the arm modules, the wrist and the end-effectors. Furthermore, TIAGo brings a modular software architecture to ease the development of new components or the replacement of existing ones. Future work will focus in exploiting the modularity of TIAGo in order to fit applications not only in service robotics but also in industry.

References

[1] L. Marchionni, J. Pags, J. Adell, J. R. Capriles, and H. Tome, "Reem service robot: how may i help you?" in *Proc. of the Int. Work-Conference on the Interplay between Natural and Artificial Computation, IWINAC*, Palma de Mallorca, Spain, June 2013, pp. 121–130.