Development of an Industrial Mobile Cobot

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***Abstract*— By associating an intelligent assistive device (IAD) and an automated guided vehicle (AGV), an industrial mobile cobot was developped that enables an operator to easily and intuitively manipulate and transport a load up to 100kg.**

I. Introduction

For the very last few years, collaborative robotics —also known as cobotics [4], has been a growing field for industrial robotic manipulators, mainly because it allows them to share space with operators and to remove safety fences, but also because it offers the possibility to safely perform physical human-robot interaction (pHRI) —or co-manipulation, i.e. it allows to enjoy the best of the machine (force, accuracy, connectivity, etc.) and of the man (perception, capacity of adaptation, high level understanding, etc.). A human operators remains essential to fulfill a task, but can do it better, more easily and in a safer way with the help of the cobot. Mobile robotics, on the other hand, has been widely used in industry for decades, de facto sharing space with human operators but without any pHRI. Thus, the term cobotics is generally not used for mobile robotics.

The present work relates the development of an industrial mobile cobot resulting of the association of an IAD and an AGV (fig. 1) that has the ability to safely perform co-manipulation of heavy loads (up to 100kgs) in an industrial environment.

Fig. 1: Industrial mobile cobot

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II. The IAD and the AGV

The IAD used is a Cobomanip [5], a passive and statically balanced force generator designed by Sarrazin Technologies. Its patented mechanical design [6] cleverly makes that the torque due to the load is always equal to the torque due to some counterbalancing force. Some particular attention has also been paid to produce a mechanism with very low friction in the joints, resulting in a very confortable feeling of weightless when manipulating a load in "zero-gravity" mode. This IAD has 4 degrees of freedom: three translations and a rotation around the end-effector vertical axis. It is moved only by direct manipulation from the operator and has no actuator. This latter point greatly improves the safety of such a system. Nevertheless to ensure a minimal risk, two deadman buttons are placed on the end-effector, that have to be pressed by the operator to release the safety break and allow the motion of the Cobomanip. Of a course, several emergency stop push buttons are also present.

On its side, the AGV is made by BA Systèmes. It is designed so that it can safely carry a weight such as the Cobomanip and its loads. The choosen AGV is a mono-turret and thus has only two actuators: one for steering and one (powerful) for traction. This kinematics can only follow non-holonomic trajectories but in most pratical use-cases, this is not a limitation and on the opposite, it reduces the cost and increases the reliability of the machine. With its embedded software, the AGV has the ability to autonomously transport heavy loads everywhere in the workshop by following virtual tracks previously or dynamically computed by *AGV Manager*®, the BA Systèmes software suit. Regarding the safety devices, the AGV has several emergency stop push buttons, two laser scanners (on the front and rear sides[1]) and safety bumpers on the lateral and rear sides.

III. The mobile cobot

Both systems taken individually already satisfy the industrial requirements in terms of safety and reliability, nevertheless their integration and combined use required some enhancements. Thereafter, two main technical aspects of the work are underlined: physical Human-Robot interaction and safety.

a) Physical Human-Robot Interaction: To perform pHRI, the Cobomanip serves as a low-impedance passive mechanism and the AGV as a high impedance active mechanism [3]: the operator interacts directly with the Cobomanip's end-effector and the motion is captured through the joint's

[1]By convention, for an AGV the rear side is where the load is situated. The front side corresponds to the main direction of motion.

encoders. Then the position of the end-effector is computed and used as an input for the AGV's motion control. Because the AGV offers an infinite workspace to the manipulator and because the static workspace of the Cobomanip is large enough to absorb the low reactivity of a starting AGV (fig. 2), both systems perfectly complement one another to offer very good characterics and performances to this mobile cobot.

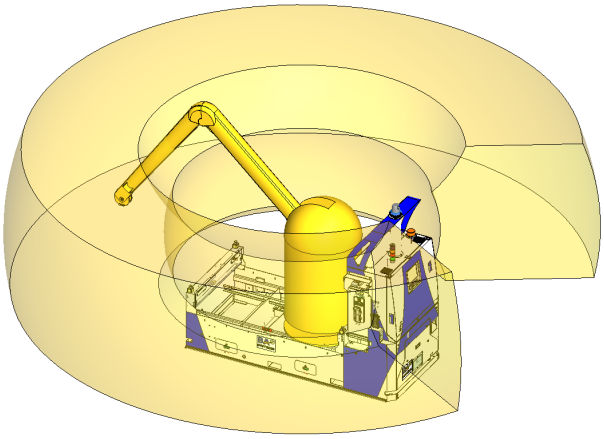

Fig. 2: Cobomanip workspace

In practice, when the operator is using the system in mobile cobot mode, the AGV is moving the Cobomanip such that the end-effector remains close to a reference position along the longitudinal axis, i.e. in the AGV reference frame, the end-effector doesn't move along this axis, while it has an "infinite" range of motion along the same axis with respect to the global frame. In the transverse axis however, the end-effector's motion is limited to the Cobomanip's workspace in both, the AGV frame and the global frame.

b) Safety: To comply with directive 2006/42/EC, the "machinery directive", some modifications have been made to the AGV's safety PLC (compared to a standard AGV): three safety modes have been configured: *AGV only*, *IAD only* and *combined motion*, and 3 safe I/Os have been added: *IAD move authorization*, *IAD in safe position* and *IAD deadman pressed*. The same I/Os have been added to he IAD safety PLC.

- In *AGV only* mode, the arm has no authorization to move (breaks are activated) and must be in safe position, i.e. folded and aligned with the AGV's longitudinal axis, otherwise the AGV cannot move neither.
- In *IAD only* mode, the AGV cannot move, but the IAD can, provided that the dead man button are pressed.
- In *combined motion*, both the AGV and the IAD can move, provided that the dead man buttons are pressed. The AGV speed is limited to 1 m/s and the fields of the safety laser scanners are configured as in *AGV only*, indeed the recommended position for an operator to manipulate the IAD is on the AGV's lateral sides. The IAD can be manipulated on the rear side of the AGV, only if the speed is below 0.3 m/s to avoid any risk of collision between the operator and the AGV.

Finally, the emergency buttons safety line has been integrated, and pushing any of the emergency stop buttons (on the AGV or on the IAD) will stop both of them.

IV. Industrial use-cases

For industrial applications, the developed machine offers three possible valuable use-cases. The most simple but nonetheless useful, is to automatically move the IAD between several stations in the workshop for the case where the IAD isn't intensively used at any of them. This solution might reduce the number of required IADs and improves the flexibility of the production lines. The second use-case is to use this mobile cobot as an usual AGV, i.e. to automatically transport items between two points in the workshop. The loading is done at one station and the unloading at another one by another operator. The main difference with the usual AGV use-case, is that these item's handlings are performed manually with the assistance of the Cobomanip. Therefore very complex and delicate handlings become accessible and safer.

The last use-case requires the *combined motion* mode to perform complex co-manipulation operations on a spot larger than the IAD workspace (for example, manufacturing tasks such as sanding or drilling on long objects). A demonstration of such a use-case can be seen in video [2]. The interest of such a mobile cobot will become even more obvious by taking advantage of the *virtual guidance* mode of the Cobomanip [5]. Indeed in this mode, the operator is assisted not only by a lift of the load but also by the setting of some counteracting efforts that constraint its motion and help him to flawlessly complete the task.

V. Conclusion

By taking advantage of both systems assets and enhancing them to work combinedly, Sarrazin Technologies and BA Systèmes developed a mobile cobot of industrial grade during the P-RC2 project. This new product already offers some valuable possibilities but also unlocks new ones that are still to endeavor. Presenting this work at the "Robotics for logistics in warehouses and environments shared with humans" workshop will be a good opportunity for BA Systèmes to discuss of other potential applications.

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