Design of Collaborative, Cross & Carry Mobile RoBots "C^{3}Bots"

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Abstract. This paper presents an introduction about C^3Bots project which aims to design collaborative, cross and carry mobile robots. In this project it is considered to design an innovative robotic system based on modular entities with a simple mechanical architecture able to collaborate to ensure object co-manipulation and transport. The resulting multi-robot system is called C^{3}Bots. In this paper we present the first version of this system using a parallelogram mechanism for co-manipulation and the realized prototypes which are going to be used for first experiments.

Introduction

Until now, robots have shown their effectiveness in different environments and different applications. In the industrial context, robotic manipulators are more and more involved in the assembly lines. They achieve various repetitive tasks with great speed and accuracy. In spite of this success, manipulators suffer from a lack of mobility, which means a limited workspace because of their fixed basis. Contrary to robot arms, mobile robots have the ability to move in industrial environment. In recent years, many researches were oriented to survey and design mobile robotic systems [1, 2, 3, 4], which is relatively a new young field, gathering different engineering and science disciplines. This blend between those disciplines allows the design of autonomous systems able to interact with the environment without human mediation .In order to choose an adequate locomotion for a mobile robot, its mechatronics structure should be studied. Three locomotion modes can be distinguished : Crawling robots which have the ability, by using structure deformation and multiple ground contact points, to move in irregular terrains and cross obstacles but the complexities of their control and the high energy consumption, even for moderate speeds, is a major drawback. Legged robots have the ability to cross obstacles and progress on rough terrains with one or several articulated legs that ensure intermittent contact with the ground. They are complex not only in terms of mechanical architecture but also in

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terms of control that has to maintain stability. Finally we can find wheeled systems can move efficiently on flat and regular surfaces while obstacle climbing is a challenge. In C^3Bots project it is been chosen the wheeled structure since crawling and legged systems require high degrees of freedom (DOF) which implies to set-up complex hardware and control architecture.
Autonomous mobile robots have the ability for sensing and reacting in the environment by acquiring additional abilities. Two main categories of robots may be distinguished according to ground nature : mobile robots for regular terrain which are robots designed for specific applications and tasks, mainly for material transport in an industrial structured environment such as Automated Guided Vehicle (AGV) which are mobile systems following a guided path and are controlled by a centralized or reactive control as explained in [5]. This technology is more detailed in [6] and includes different robot types. We can find also mobile gantry crane or Automatic Storage Retrieval Systems, which are more commonly used than AGVs but restricted to highly structured environment such as warehouses and libraries that have to be properly designed for this use. Mobile robots for regular terrain can also be used for research and development such as Alice robot used in [1, 5] which is one of the smallest fully autonomous mobile robots. Khepera which is also a small mobile robot used for research, with reduced dimensions (130 mm diameter) and which can handle additional modules such as cameras and grippers. It has infra-red proximity and ambient light sensors for environment interaction and obstacle avoidance. RobotCleaner and Pioneer robot [1] are also structured terrain robots used as service robot and research robot respectively. All these robots are efficient on regular terrains but have difficulties on rough terrains. Nowadays mobile autonomous systems are designed to all terrain exploration. This implies that the robot must have the ability to evolve and to move in different conditions of ground surface, so they can progress in rough terrain and avoid or climb obstacles by using different modes of locomotion [7, 8, 9, 10, 11, 12].

If The task needs more than one robot, such as co-manipulation or heavy objects transport, collaborative behaviour is required for mobile robots and many robotic examples can be mentioned such as Swarmanoid with its three different robots (Foot-Bot, Hand-Bot and Eye-Bot) which is used for collaborative transport tasks [13]. Another example of cooperative transport task is demonstrated in [14] were two coupled modules are used to transport an object. In [5], a fully distributed strategy inspired by a society of insects to perform reactive box pushing task is applied. Arnold [15, 16] is a differentially driven wheeled mobile robot that can team-up to cooperatively transport a large common object. In [17], authors present the example of a group of two to six Khepera robots equipped with gripper turrets to cooperate and pull a stick out of the ground. Mobile robots can also use tools for objects manipulation in a cooperative way as it was described in [18, 19] where the robots are using tools such as stick or string for object manipulation. Another interesting mobile robotic system was developed and described in [20] for Army Ant cooperative lifting robots using a frontal wedge with adjustable angle. Our goal in the C^3Bots project is to design several Collaborative Cross and Carry mobile roBots (C^3Bots) with a simple mechanical architecture that will be capable to co-manipulate and transport objects of any shape by connecting together. The resulting robot will be called a C^3Bots and will be capable to solve the so-called removal-man-task to transport any object. Reconfiguring the C^3Bots by adjusting the number of simple robots allows to manipulate heavy objects and to grip objects with any shape, particularly if they are wider than a single elementary robot. The remaining of this paper is organized as follow. Next section will present the methodology for object prehension, lifting, transport and the parallelogram mechanism used for manipulation. It will be also presented the 3D CAD for the developed system and the realized prototype. Finally we will give some conclusions and an overview of our future works.

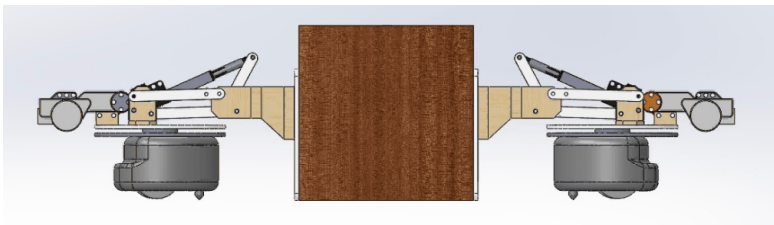
Collaborative Cross and Carry Mobile Robots

Specification. The aim of the C^{3}Bots project is to design an innovative modular multi-robot system composed by elementary robots able to interconnect and form a more complex structure (a poly-robot) that will be able to evolve in all terrain, manipulate and transport objects of any shape. The poly-robot structure is reconfigurable according to the object shape, load and position which should guarantee a good efficiency for task achievement.
In the next subsection we will present the first idea adopted to the design of C^{3}Bots and an analysis of the proposed kinematic structure.

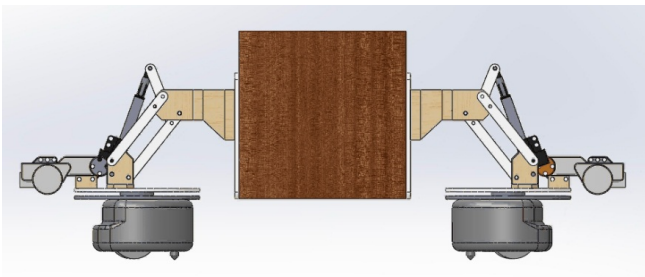
Kinematic structure. The first version of C^{3}Bots consists of a mobile robotic platform (Khepera robot) on which we have fixed a rotative mechanism for object manipulation. This mechanism is composed of a basis, a four bars linkage, a forklift and an actuator for object lifting. This architecture allows the multi-robot system to manoeuvre in all direction. This first version aims to validate the co-manipulation behaviour but the all terrain evolving will not be considered.

Co-manipulation methodology. In this part the co-manipulation strategy of two robots is going to be described.
The robots are going to detect the object position using Khepera robot sensors and they will be oriented toward it. In a second phase the two robots will tighten the object between their end effectors using wheels propulsion. The manipulation mechanism will lift the object using only one actuator and the robots continue moving forward to avoid object slipping until positioning the object on the top of robot bodies. Fig. 1 presents the different phases previously described and illustrates each step concerning prehension, co-manipulation, lifting and transport.

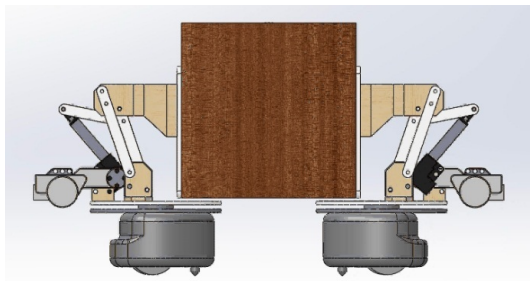
Maximal load. It is considered to calculate the maximal load that could be manipulated by one robot. To lift an object, the robots tighten it between their forklifts and then it is going to be lifted and put on the robots bodies. We consider a, b, c, l, s, θ and ϕ fixed parameters (cf. Fig. 2) defined during the design phase.As main result the total load that can be lifted and transported with our robots is expressed as follow



(a) Object prehension



(b) Object lifting



(c) Object ready for transport

FIGURE 1: C^{3}Bots co-manipulation and transport methodology

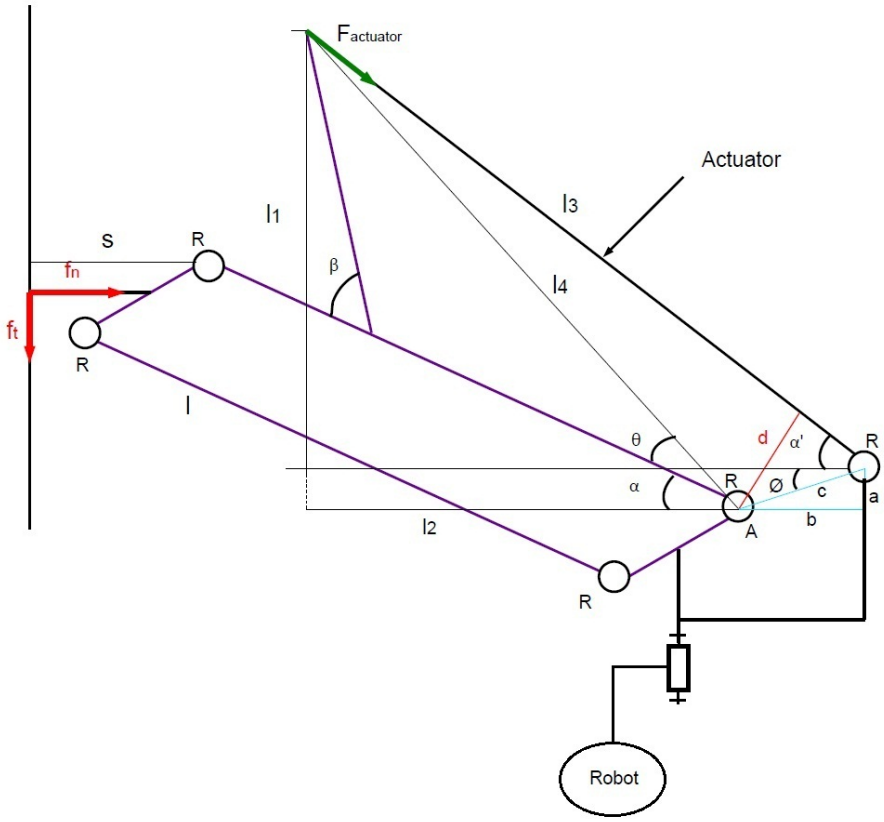


FIGURE 2: Proposed mechanism of co-manipulation

$$\vec{P}_{object} \leq 2.\frac{\mu' \vec{F}_n \sin(\alpha' + \phi)c}{s + l\cos\alpha} \tag{1}$$

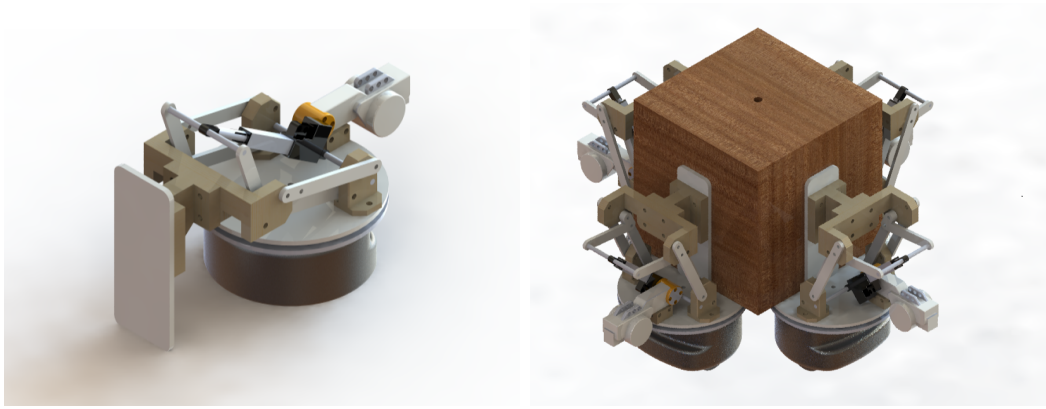
where μ' is the fork/object friction coefficient and $\vec{P}_{object}$ is the object weight that robots can lift.

Realized prototype

3D CAD. To make the design of our first prototype, we have used SolidWorks 2012 to develop a lifting mechanism and to make a model for a group of robots ensuring object manipulation and lifting. Fig. 3 illustrates the 3D model for a single and a group of four robots. During the design it has been considered to define the different parameters for the robot manipulator to ensure a successful object manipulation process. Fig. 3a presents the elementary-robot designed with the manipulation mechanism in a prehension position.

Used material. For an elementary-robot a mobile platform (Khepera III) is used which is able to move on structured and smooth ground. The robot base includes 9 Infrared Sensors for obstacle detection as well as 5 Ultrasonic Sensors for long range object detection. We also used one actuator for the manipulation and lifting mechanism which is a Lego Mindstorm compatible Linear Actuators L12 Linear motor 50mm which is controlled by a program developed under Bricx Command Center and uploaded on NXT Intelligent Brick which features a powerful 32-bit microprocessor and Flash memory. The used materials are presented in Fig. 4

Real prototypes. We have realized two prototypes to make experiments using two robots in the aim to validate the manipulation strategy. Fig. 5 presents two antagonist robots manipulating a box and lifting it on their bodies. The robots keep their forklifts down and tighten the object between forks and then they lift it up and put it on top of their bodies to be transported.

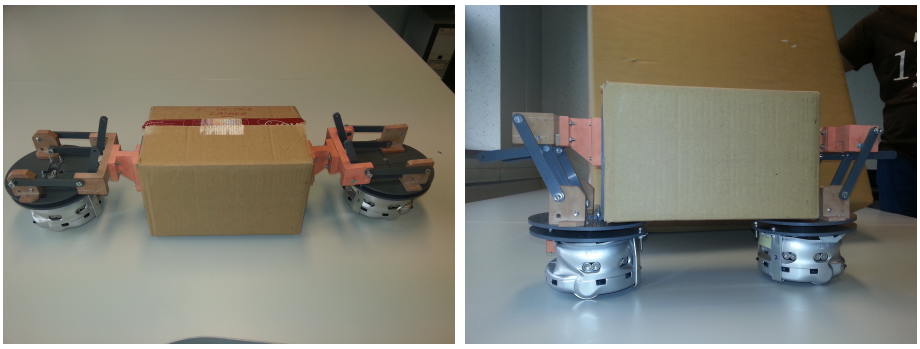


(a) First Prototype Design (b) Four Robots manipulating a Box

FIGURE 3: C^{3}Bots 3D design

(a) Khepera III (b) NXT (c) Linear actuator

FIGURE 4: Used materiel



(a) Object prehension by two robots (b) Object transport by two robots

FIGURE 5: Realized prototypes

Conclusion

In this paper we have introduced the context of C^3Bots project by giving a view about mobile robotic systems and collaborative aspect for tasks achievement. The aim was to design C^3Bots, an innovative system dedicated to object transport on various terrains. The paradigm of C^3Bots is to co-manipulate and transport a common object by collaboration between several similar elementary robots. Wheels will be selected for their versatility on various terrains and good efficiency on regular grounds compared to legs and tracks. However, classical robots such as AGV or Alice, etc lack of mobility on rough and irregular terrains, so advanced architecture such as OpenWHEEL [9] or Shrimp [7] will be considered in future works. One important function for C^3Bots is object transportation and may be achieved by robot collaboration. We will also inspire from Army Ants which transport objects by laying them on top of them [20] and Arnold [15], that has a rotative arm on top of it. We also keep the concept of modularity and propose to build our robots from two parts : a mobile platform and a manipulation mechanism. A preliminary 3D design for C^3Bots is presented in Fig. 3a. So our robots are modular and can gather in variable number to manipulate an object of a variable shape. It was realized in a first step using single-axle robots (Khepera) and a rotary manipulation arm attached to a vertical actuated and reversible revolute joint to let the robot turn freely on itself when the object to transport above the robot. The resulting multi-robot system is thus allowed to manoeuvre (translation is along any direction and rotation around any point in the ground plane). This preliminary design allows object manipulation without considering obstacle climbing which will be the goal of a second part of the project.

As future works, experiments with the actual developed version are going to be done to ensure object manipulation and transport. We will be interested to evaluate the stability during the different phases and with different object shapes and weights.

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