A Hybrid Primitive-Based Planner for Autonomous Navigation with CENTAURO Robot

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Abstract—**Wheeled-legged robots have the ability to navigate in cluttered and irregular environments adapting the locomotion mode to the terrain perceived. To achieve this functionality, a locomotion planner is needed. In this work we present a hybrid search-based planner, which considers a set of modifiable motion primitives and a 2.5D traversability map acquired from the environment to generate navigation plans for the hybrid mobility robot CENTAURO. Our approach was validated in simulation and on the real wheeled-legged robot CENTAURO, demonstrating traversing capabilities in cluttered environments with various obstacles.**

Index Terms—**Sensor-based Control, Motion and Path Planning, Legged Robots**

I. INTRODUCTION

Real world applications in the field of inspection, maintenance and search-and-rescue are still imposing high level challenges for robots requiring complex autonomous loco-manipulation skills. One of the needed features to face these challenges is the autonomous navigation in cluttered and unknown environments. The majority of the approaches use 2.5D elevation and traversability maps as in [1]. These methods have demonstrated good results and are suitable to perform search-based planning that is generally faster than sample-based methods like in [2], where an entire tree of whole-body actions has to be generated.

In addition, when dealing with irregular and cluttered scenarios, high mobility flexibility is requested to adapt to the diversity of the terrain. Hybrid mobility robots are the preferred solution for such environments since they merge the benefits of both wheeled and legged robots. Few examples are the CENTAURO robot [3], PHOLUS [4] or MOMARO [5]. The last one participated in the DARPA Robotics Challenge (DRC) being remotely controlled by a human operator to accomplish tasks. In the following years the team proposed also a semi-autonomous framework based on motion primitives [6], but still, there was the need for a human operator to control the robot. Later, also the team from ETH focused on hybrid robots, adding wheels to their quadrupedal robot ANYmal. They proposed a hierarchical whole-body controller (WBC) and a motion planner, obtaining autonomous capabilities [7]. This work was extended in [8] enabling the robot to perform stepping and driving simultaneously, decomposing the optimization problem in separate wheels and base Trajectory Optimization (TO). The results were shown in the DARPA Subterranean challenge, revealing the advantages of wheeled-legged robots in real-world applications.

In previous works carried out on the CENTAURO robot it was described a navigation planner for agile legged-wheeled reconfigurable robots [9] and we demonstrated autonomous capabilities with simple rectangular objects in series [10]. In this paper we extend the framework to accomplish autonomous navigation in irregular and unknown environments by employing a primitive-based planner built upon the Anytime Repairing A* [11]. We demonstrated our framework in the Gazebo simulation environment and on the real robot CENTAURO. In the following sections we are going to describe the approach considered and the results obtained.

II. FRAMEWORK OVERVIEW

The proposed framework can be divided into three main modules: traversability extractor, hybrid primitive-based planner and plan executor, as can be seen in Fig. 1.

The first module is the one in charge of building 2.5D elevation and traversability maps, starting from the point cloud acquired through the sensor and employing the work done in [12]. When starting the experiments, the map is built online moving the robot in the space to gain information about the environment. The result of the traversability map can be seen in the Traversability Extractor module in Fig. 1 where the blue depicts valid areas in which the end-effectors can be placed, while the red represents untraversable areas, which take into account defined safety thresholds. These two maps, together with a set of parametrized motion primitives are the input of the hybrid planner that has the objective to provide a feasible plan from the current location to the target one. The planning part is carried out in an offline way, without considering updates while the robot is moving. To find a solution, the planner evolves the state of the robot by concatenating the primitives available considering their costs and priorities. Finally, the resulting plan is acquired by the plan executor that

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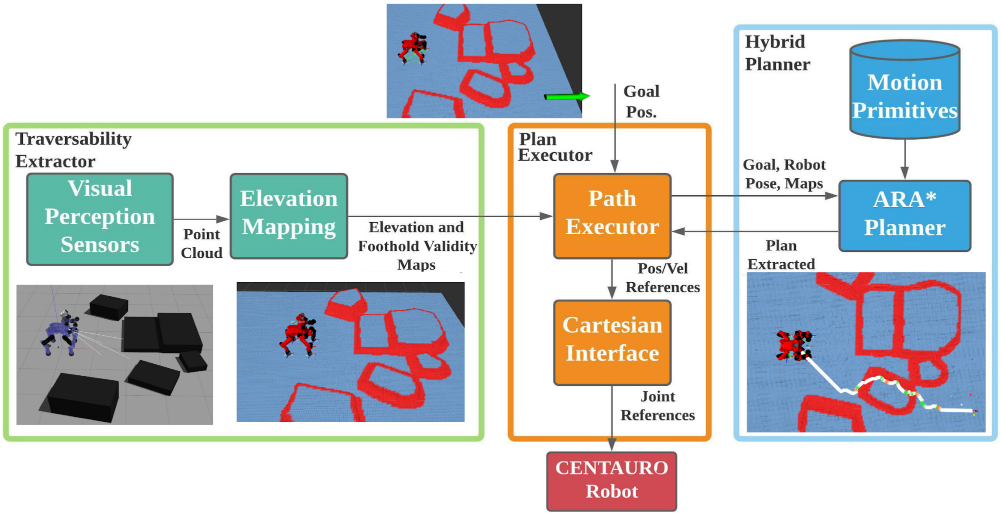

Fig. 1. Overview of the framework pipeline implemented. In green the perception component, in orange the motion execution module and in blue the hybrid planner component.

computes the position and velocity references and sends them to the robot via the cartesian controller CartesI/O [13] and the software middleware XBotCore [14].

III. HYBRID PLANNER

We implemented the hybrid planner employing a search-based method because of its lower time requirements, compared to sampling based methods. In particular we extended the ARA* to perform a search based on a set of motion primitives taken as input during the initialization. At each iteration of the main loop of the planner, the costs of the nodes are considered to expand the node with the smallest cost, minimizing:

$$f(n) = g(n) + \epsilon \, h(n) \tag{1}$$

where n is the node, $g(n)$ is the cost from the starting pose to the node n, obtained by adding the cost of the selected action to $g(n-1)$, $h(n)$ is the heuristic function, which estimates the cheapest path from n to the goal, evaluated as the sum of the distances along x and y. Finally ϵ is used to provide sub-optimal solutions and it is decreased in the following iterations. We start the search with $\epsilon = 4$, which offers, in our case, a good trade-off between planning time and optimality of the solution found. During the search, each node is expanded considering the reachable space of the selected primitive. The use of motion primitives provides great flexibility allowing to shape and extend the framework based on the robotic platform considered. In this work we targeted our robotic platform CENTAURO and the primitives considered are whole robot driving and single wheel motion. The first one allows to perform the driving action with the whole robot without changes in the legs configuration. We assigned a higher priority to this action due to its safety and time efficiency, selecting it only if none of the wheels is close to non traversable areas. In addition, the cost of this action is lower than the one of single wheel actions to strengthen the priority order and to prefer longer driving instead of a sequence of single wheel actions. In case of proximity to obstacles, the whole robot driving action is not contemplated and the second primitive is considered. The single wheel action is implemented in such a way that it can be decoupled into two sub-actions: single wheel driving and stepping, based on the elevation difference in the trajectory defined by the sampled movement. Based on the robotic platform we can also decide to activate just one of them. The importance of this primitive is that, in cluttered scenes, there are generally a lot of irregular obstacles and the robot cannot simply drive through them. With the single wheel action the robot gains the ability to move the wheels independently negotiating diverse obstacles. The sum of these primitives allows to fully exploit the potentiality of the robotic platform considered to accomplish autonomous navigation tasks in complex scenarios. All the primitives are embedded with a set of parameters that can be easily modified by a configuration file and were experimentally tuned to obtain a good trade-off between optimality of the solution and computational time.

IV. RESULTS

To validate the proposed framework we carried out experiments of increasing complexity in simulation and on the real robot CENTAURO. In particular, thanks to the possibility to easily enable/disable primitives we started considering only whole robot driving, then we added the single wheel driving and in the end, we introduced the stepping to climb on an elevated platform. We run 10 experiments for each of the first two cases, being able to complete all of them without failures. The goal position was specified at approximately 5.1 m in front of the robot and the plans were found in 5-5.8 sec. Finally we added a platform for the stepping on and we run 15 tests. The plan was found in 9.8 sec and we experienced only 2 failures due to wrong estimates of the position of the obstacles in the

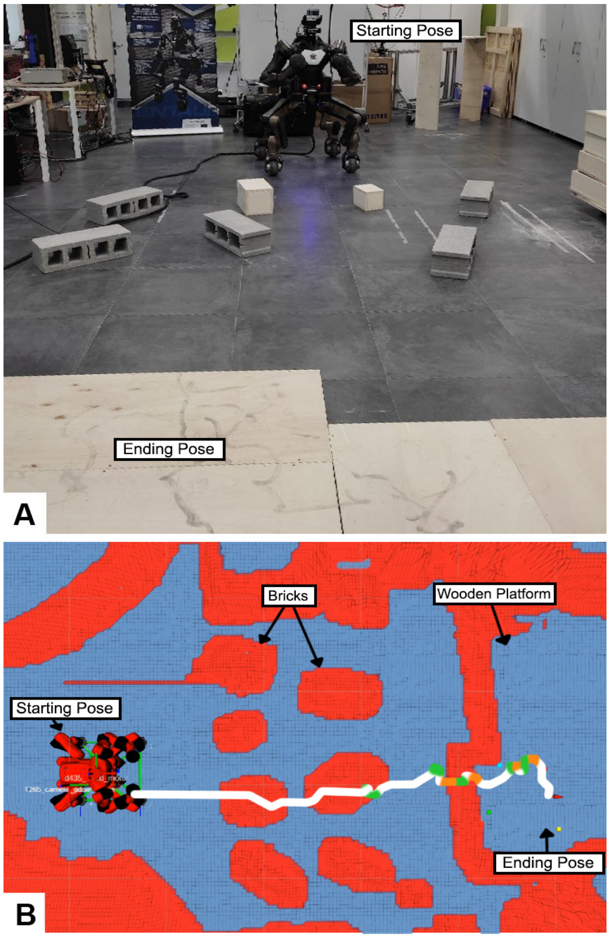

Fig. 2. (A) Real scenario considered to test the implemented framework. (B) Corresponding foothold validity map and plan found by the primitive-based planner.

map that brought the robot to fall, moving the wheels on the edges of the obstacles. Similar experiments were carried out on the real robot CENTAURO. In Fig. 2 is shown the scenario considered for the final experiment. Here the robot is asked to autonomously navigate through the bricks and then step on the wooden platform, having as only input from the operator the target position on top of the wooden element. In this case the plan was found in approximately 8.1 sec providing always a feasible solution. The only problem encountered during the execution was related to a wrong localization of the robot that sometimes made the robot slightly collide with the obstacles. We managed to handle this by adding a correction based on the distance traveled.

V. CONCLUSIONS

In this work we briefly presented a hybrid search-based planner to deal with irregular and cluttered scenarios with complex robots like CENTAURO. It employs a set of motion primitives that are easily extendable and can be customized based on the platform and environment considered. The planner demonstrated good efficacy in both simulation and real world allowing the robot to reach the target position without colliding with the objects placed in the scene. Future works intend to include online execution to deal with dynamic obstacles and to be more robust to small changes in scenario and localization errors. In addition, we are planning to introduce recovery methods and manipulation primitives to push obstacles that block the way to clear or simplify the environment.

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