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Autonomous Construction of a Roofed Structure: Synthesizing Planning and Stigmergy on a Mobile Robot

Stefan Wismer[1], Gregory Hitz[1], Michael Bonani[2], Alexey Gribovskiy[3], and Stéphane Magnenat[1,4]

***Abstract*— We demonstrate a scenario in which a mobile robot, according to a plan, builds a structure that it can then enter. The robot interacts with the construction using local sensing. This synthesis of planning and stigmergy opens the way to new construction techniques using mobile robots.**

I. INTRODUCTION

Autonomous mobile robots have the potential of supporting construction workers in tedious and dangerous tasks. Current work in this field can be classified into several approaches. A first one is inspired by the actions of eusocial insects like ants and aims at building approximate structures in a scalable way through stigmergy [1], [2]. This method requires only simple robots and a small set of local rules, but the resulting structures are approximate. The second approach focuses on multi-robot algorithms, but still exploits local rules and interactions [3]. The last approach focuses on constructing precise structures according to pre-defined plans, with few sensing of the environment and limited autonomy [4], [5]. Our work aims at a synthesis of these approaches.

This video submission shows a scenario in which a mobile robot builds a roofed structure autonomously. Because the robot must manipulate elements of different sizes into various positions, this setup exhibits many of the challenges a truly autonomous construction robot shall face.

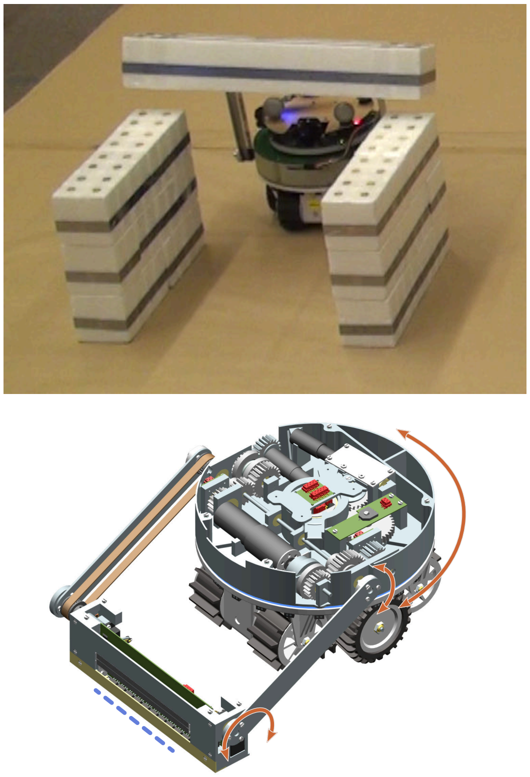

Fig. 1. The experimental setup (top) and the gripper module (bottom).

II. SYSTEM DESCRIPTION

A. Experimental setup

This experiment aims at assembling a roofed structure (Fig. 1, top). This structure is composed of polystyrene blocks equipped with small magnets to bind them together. The blocks are of three sizes, each a multiple of a basic unit of $6 \times 6 \times 6$ cm. The walls consist of layers of small (size 1) and medium (size 2) blocks, while the roof consists of large blocks (size 6). The walls have a height of 3 layers and are 4 units long. At the beginning of the experiment, the 18 blocks are available as 4 lines at pre-defined locations. A VICON tracking system informs the robot of its absolute position.

B. Platform

Our construction robot is based on the modular marXbot platform [6]. This miniature platform (17 cm in diameter) consists of a base, some intermediate layers, and a top module. The base provides mobility and energy, and short-range sensing via a ring of infrared distance sensors. The top module is a Linux-based computer and provides a camera and a Wi-Fi link. Between these modules, we have added a custom-built magnetic-gripper module.

One or more microcontrollers (MCU) drive each module and communicate through a CAN bus. They use ASEBA, an event-based control architecture for microcontrollers [7]. Our gripper module has two micrcocontrollers: one in the body of the robot and the other on the gripper.

C. Gripper Module

The magnetic gripper features three degrees of freedom: yaw, elevation, and tilt (Fig. 1, bottom). The resulting work space is large enough so that the robot can access places that are higher than its height and access blocks on its sides.

All axes are compliant and equipped with force sensors. Additionally, two arrays of infrared sensors in the gripper measure the distance to the construction blocks. The gripper can grasp these blocks using a magnetic switchable device [8].

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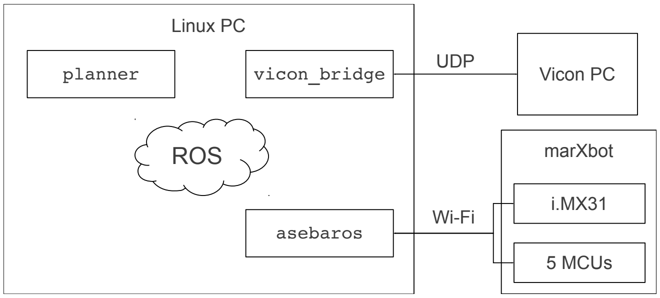

Fig. 2. The software architecture.

D. Software Architecture

The software architecture is divided in two layers. A PC with ROS runs the high-level executive. The latter contains a planner that generates a list of actions, such as *go to*, *fetch block*, and *depose block*. This executive receives the pose of the robot from the VICON computer through UDP and communicates with the robot using ASEBA. It orders the execution of the actions and implements the differential-drive control law that moves the robot to requested locations. The low-level layer runs in the microcontrollers and implements the block-manipulation actions such as fetching and deposing.

E. Low-level Actions

The fetching action aims at grasping a block in its center. A potential misalignment is measured using the difference between the left and the right infrared sensors in the gripper. For the small block, the robot rotates its gripper around the yaw axis, while for the medium and large block the whole robot rotates and scans laterally.

The robot builds walls layer by layer. The behavior differs between the first block of a layer and all subsequent blocks of the same layer. The first block is adjusted with the left edge of the wall using the gripper's infrared sensors. Each subsequent block is then added to the preceding block's right edge. The robot senses the contact between the blocks by measuring the current consumption of the yaw motor.

To construct the roof, the robot centers itself between the two walls using the ring of infrared sensors of its base. The robot then deposes the first block after a certain distance measured by dead reckoning. Each subsequent block is then added adjoining the previous block. The robot senses the contact between the blocks by measuring the force on the elevation axis.

III. RESULTS AND DISCUSSION

All actions are implemented and work most of the times (Table I). Based on these, our robot successfully constructed a wall and a roof. However, out of 10 trials, it did not manage to build two walls and a roof in a single run. Because we execute the actions sequentially, the overall probability of success depends on the successful execution of every action. Yet, the structure consists of 18 blocks, and every block requires 6 actions (one *fetch*, one *depose* and 4 *go to*), therefore building the whole structures demands 108 actions. Assuming that we want a success rate of 10 % for the whole construction, every action must have a success rate of 98 %, which is larger than our current rates. Thus, the structure presented in the video was built in multiple single runs.

Building

build type	**success rate**
wall: first block of layer	16 / 18
wall: other blocks of layer	11 / 16
roof: first block	6 / 11
roof: other blocks	8 / 11

Fetching

block type	**success rate**	**average offset**	**std. dev.**
Small	10 / 10	-3.6 mm	1.2 mm
Medium	10 / 10	0.2 mm	9.4 mm
Large	8 / 10	3.8 mm	5.4 mm

TABLE I
SUCCESS RATES OF THE LOW-LEVEL ACTIONS

This analysis shows that for long and complex tasks such as building a structure, error detection and recovery is inevitable. This is a non-trivial problem, because errors are of diverse types: they might be misalignments but also ill-placed blocks or lost blocks. Therefore an error-correction mechanism would lead to complex interactions, such as removing a block and replacing it correctly. Moreover, it might also require to do re-planning. We will approach these questions in future work.

IV. CONCLUSION

In this experiment, a robot manipulated blocks of different sizes into various positions, to build a structure it could then enter. This synthesis of planning and stigmergy opens the way to new construction techniques using mobile robots.

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