Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-1 (2017) 5654–5659

A Stochastic Learning Approach for Construction of Brick Structures with a Ground Robot

Sérgio R. Barros dos Santos * Diego O. Dantas * Sidney N. Givigi, Jr. ** Luciano Buonocore * Areolino A. Neto * Cairo L. Nascimento, Jr. ***

* *Federal University of Maranhão, São Luis, MA, Brazil (e-mail: sergio.ronaldo@ufma.br, diego.dantas@mecnet.org, areolino@ufma.br)*
** *Department of Electrical and Computer Engineering, Royal Military College of Canada, Kingston, ON, Canada (email: Sidney.Givigi@rmc.ca)*
*** *Division of Electronic Engineering, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brazil (email: cairo@ita.br)*

Abstract: In this paper, we describe an architectural framework by which a mobile robot can learn how to autonomously assemble solid 3D brick structures according to user-specified designs. The policies of actions to perform the construction task are obtained from a simulation environment using Reinforcement Learning (RL) and Particle Swarm Optimization (PSO) approaches. The proposed planning architecture is used to simultaneously solve three problems: 1) to generate feasible construction policies, 2) to define the set of maneuvers for the vehicle to carry out the assembly task, and 3) to obtain the set of trajectories for handling and mounting parts while avoiding fixed obstacles. During the learning process the power limitation of the ground robot is taken into account. Simulation results show that the set of learned actions may efficiently perform the construction procedures without resulting in conditions which prevent the fulfillment of the assembly procedures. The synthesis of this system opens the way to the development of intelligent construction approaches using ground robots.

Keywords: Robotic Construction, Reinforcement Learning, Nonholonomic robots

1. INTRODUCTION

Construction is the most important activity of civilizations; however, even today, it still lacks the use of intelligent and autonomous systems. Intelligent robotic vehicles may be very useful in building any 3D structure in either structured or unstructured environments. An intelligent construction system may be particularly applied to harsh environments where human presence is dangerous or in places where the traditional approaches of construction are problematic. Furthermore, the use of intelligent systems can improve efficiency and reduce accident rates (Wawerla et al., 2002), (Heger, 2010) and (Lindsey et al., 2012).

Current research in this particular area of study can be classified into different approaches. The first one is inspired by the building activities of termites and other social insects like ants, bees, and wasps in which the main goal is to build similar structures in a scalable fashion (Werfel et al., 2014) and (Stewart and Russell, 2006). The second one focuses on multi-agent systems (Lindsey et al., 2012) and (Bolger et al., 2010) with limited autonomy for assembling parts using few sensors (Stroupe et al., 2005) and (Knepper et al., 2013). The last approach focuses on autonomous construction systems of structures in which sets of actions for the robot are generated by artificial intelligence methods (Barros Dos Santos et al., 2015) and (Magnenat et al., 2012).

This paper describes an architecture framework based on Reinforcement Learning (RL) and Particle Swarm Optimization (PSO) to find the policy of actions that enables a ground robot to build several types of structures with different physical dimensions and number of pieces. Given the target structures, initial position of the robot and the location of the parts (bricks), the learning approach must take into account the capabilities and limitations of the target robot, as well as the constraints imposed by the structures and environment, to learn a feasible set of actions that is capable of mounting parts without resulting in a deadlock condition.

We present an adaptation and application of the problem described in (Barros Dos Santos et al., 2015) to ground robots and construction of specific structures. In (Barros Dos Santos et al., 2015), we describe a learning approach to generate feasible plans to build truss structures with a quadrotor. However, due to the use of another types of mobile robots and also of 3D structures with different mounting features, the following changes in the algorithm were accomplished: 1) the algorithm arrangement to enable the correct construction of the distinct levels of assembly of the proposed structures; 2) the manner in which the

2405-8963 © 2017, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.08.1114

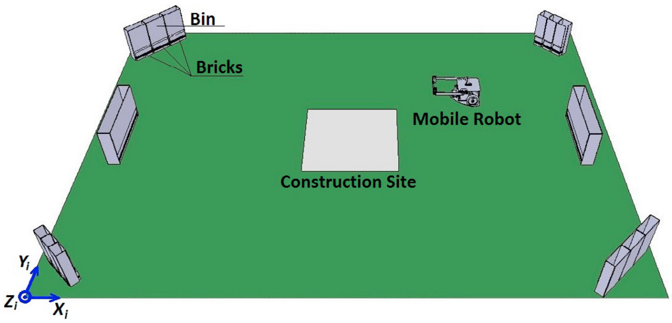

Fig. 1. Autonomous Mobile Robot Construction Setup.

set of trajectories are planned to execute the maneuvers (i.e. the handling and mounting procedures); and 3) the modification of the cost function used to evaluate the performed task. The aforementioned differences between the algorithms will be better clarified in sections 3 and 4.

This paper is organized as follows. In Section 2, we describe the proposed autonomous construction system. Section 3 presents the strategy for the planning of the trajectories. Section 4 describes the proposed learning approach. The obtained simulation results are discussed in sections 5 and 6. Our conclusions are presented in section 7.

2. AUTONOMOUS CONSTRUCTION SYSTEM

Fig. 1 displays the suggested environment setup used for the planning of the construction task with a ground robot. The X_i, Y_i and Z_i axes are defined as the global reference frame. The pose estimation of the robotic vehicle is done with respect to these axes. The useful workspace available for the construction of the target structures is $400 \times 300 \times 400$ cm. Parts are stored horizontally in six different storage bins randomly distributed in the environment.

We propose a method for the planning of the policy of actions and set of trajectories for a ground robot to build 3D structures. Using the generated plan, the robot must be able to efficiently perform the handling and mounting procedures (i.e., sequence of maneuvers) to pick up and assemble the parts, and also navigate through the environment and avoid collision with fixed obstacles. This approach is also used to define the sequence of assembly of the bricks that compose the structure.

Handling procedures are defined as the translational and rotational movements accomplished by the mobile robot to pick up a brick. Mounting procedures are defined as the translational and rotational movements executed by the agent to transport and build a part.

Fig. 2 shows the developed model of the nonholonomic ground robot based on the actual vehicle WOR-R1 manufactured by Manu Systems. This type of wheel robot was chosen for construction task due to its low power consumption compared with holonomic robots. The model of the robot was designed for the Virtual Robot Experimentation Platform (V-REP) using Solidworks packages. All kinematic and dynamic features and also the physical dimensions of the actual nonholonomic robot were considered during the design of the model. The motors characteristics (like angular speed and torque) and the translational and rotacional velocities of the vehicle were obtained empirically.

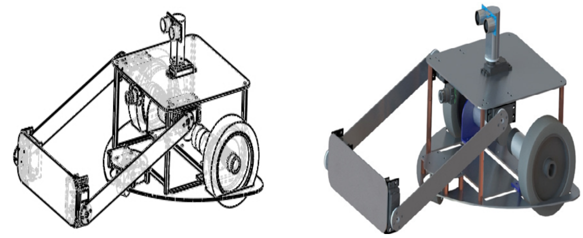

Fig. 2. Model of the nonholonomic ground robot

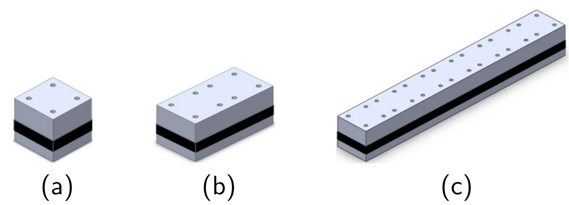

Fig. 3. Bricks: (a) Small; (b) Medium; and (c) Large.

The proposed magnetic gripper was designed to perform two distinct movements: elevation (to lift parts), and tilt (to turn part). The robot arm was designed to allow to assemble parts at higher places than its own height.

2.1 Parts of the Structures

A typical assembly scenario requires that a set of parts of different types be properly connected to one another to form desired structures. In this work, we define that the 3D structures are constituted by small, medium and larger bricks. The bricks must be attached to one another through magnets mounted on their upper and lower surfaces. Fig. 3 shows the parts equipped with magnets.

2.2 Brick Structures

In the current work, we explore the construction of 3D structures compatible with those commonly used in lighthouses, underground tunnels, bridges and retaining walls using a single robotic vehicle. Fig. 4 shows the brick structures composed by different types and of bricks.

Each one of the proposed structures is composed by four layers. The layers can be built with different types of bricks except for the upper layer of the tunnel in which only large bricks can be used. In these structures, bricks are placed in an interlocking configuration to provide greater stability for the structures. This condition is given by the target structure blueprint provided by the user.

3. TRAJECTORY PLANNING ALGORITHM

The trajectory is planned using the proposed Particle Swarm Optimization (PSO) algorithms (Arana-Daniel et al., 2014) for each one of the maneuvers so that the vehicle is able to execute the desired task and avoid collisions with mobile obstacles.

Although the trajectory generation can be done with many algorithms, like for example the A* algorithm (Barros