Automation in Construction 87 (2018) 248–262

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Mapping and localization module in a mobile robot for insulating building crawl spaces

Sergio Cebollada[a,*], Luis Payá[a], Miguel Juliá[b], Mathew Holloway[c], Oscar Reinoso[a]

[a] *Departamento de Ingeniería de Sistemas y Automática, Miguel Hernández University, Avda. de la Universidad s/n, 03202 Elche, Alicante, Spain*
[b] *Q-Bot Limited, Block G, Riverside Business Centre, Bendon Valley, SW18 4UQ London, United Kingdom*
[c] *Dyson School of Design Engineering, Imperial College London, 10 Princes Gardens, South Kensington, London SW7 1NA, United Kingdom*

ARTICLE INFO

Keywords:
Autonomous mobile robot
Localization
Point cloud alignment

ABSTRACT

This paper presents a novel robotic system that applies spray foam insulation in underfloor voids in order to improve the energy efficiency of buildings. The work focuses on solving the mapping and localization problems in such environments, since they are a key factor in the autonomy of the robot. Solving these tasks in underfloor voids is especially challenging because the terrain is extremely uneven due to the presence of stones, bricks and sand. Within these environments, the robot should be able to localize itself and apply the insulation foam to the underside of the floor. The robot is equipped with a 2D laser sensor which permits building point clouds from several positions of the underfloor environment. The localization process is solved by estimating the position of the robot with respect to previously known positions. For this purpose, the alignment between point clouds is calculated. This paper describes two algorithms to robustly obtain the alignment between two positions. The proposed algorithms are tested with a set of point clouds captured with a laser scan in several environments under real working conditions. The results show that the localization problem can be solved in such challenging underfloor voids by using depth information.

1. Introduction

There are many buildings in Europe and around the world which have voids between floor and foundations due to building methods. This kind of uninsulated suspended timber floors can be a key factor in heat loss as some studies show [1,2]. This includes conductive heat loss to the ground and also infiltration of cold air through the underfloor environment and wooden flooring. Taking this fact into account, the energy efficiency of such existing buildings could be improved by means of under-floor insulation. The process to insulate under the floor usually consists in removing the carpet and floorboards, applying rigid panels or rolls of insulation and finally, putting everything back together. It causes a large amount of disturbance to the building occupants since often, they must vacate the premises during the installation. To make this process less disruptive and faster, a robotic vehicle can be used. This robotic vehicle should be able to access to voids, to move autonomously and to apply foam insulation. An autonomous mobile robot that could manoeuvre around the void and apply insulation where needed should be chosen. Within this group, we can distinguish three main types: wheeled, legged and aerial robots. When choosing one of these three types, two main requirements must be considered. First, an umbilical hose must be attached to the robot to transmit power and supply the robot with the foam insulation. To meet these requirements, the hose would weigh around 3.5 kg per linear meter [3]. Second, a spray nozzle must be mounted on the robot to eject the foam onto the underside of the floor. During this process, it will exert a pressure on the robot. Therefore, the robot must remain stable. For these reasons neither the legged nor the aerial robots (that also create too much dust and disturbance) would operate correctly. Thus, a wheeled or tracked platform is used in this work.

Q-bot has developed a novel robot to carry out the insulation task. The robot, shown in Fig. 1, is composed of 4 small wheels (each one is individually driven by a motor and a gearbox with a peak power of 65 W), a front horizontal laser and an actuated camera-laser system (3D scanner). Furthermore, it has a spray nozzle which ejects insulation foam. Further information about the robot specifications can be found in [3] and also on the vendor website (http://www.q-bot.co). Initially, the insulation task has been developed through teleoperated assistance, what means that the robot vehicle is driven by an expert human operator [4].

When a mobile robot is used to tackle this task, it is necessary that the robot move through the environment in order to apply the foam

---

[*] Corresponding author.

E-mail addresses: sergio.cebollada@umh.es (S. Cebollada), lpaya@umh.es (L. Payá), miguel.julia@q-bot.co (M. Juliá), mathew.holloway@imperial.ac.uk (M. Holloway), o.reinoso@umh.es (O. Reinoso).

https://doi.org/10.1016/j.autcon.2017.11.007
Received 28 July 2017; Received in revised form 10 October 2017; Accepted 8 November 2017

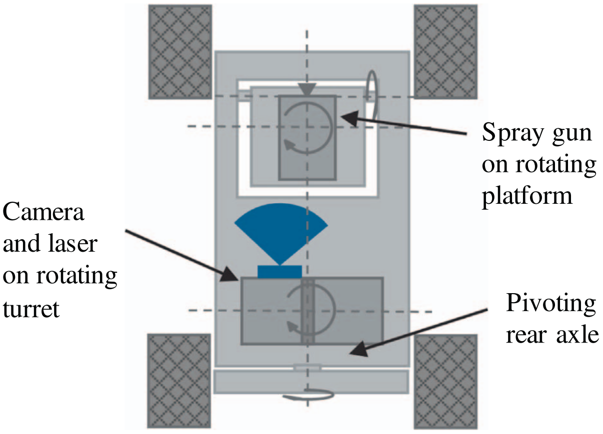

Fig. 1. Bird eye's view of the robot and main components.

insulation on the required areas. When teleoperated assistance is used, the human operator recognizes and interprets the environment and takes the decisions about the movement of the robot and the task. However, despite the successful use of teleoperated robots, the use of autonomous robots would improve performance and speed while reducing cost. They would be able to complete the task without the continuous supervision of specialized workers.

If an autonomous development is desired, many issues appear and they must be addressed accurately. First, accessing to the environment can be carried out by making an access hatch and putting the robot into the underfloor environment. Once the robot is inside, a number of challenges must be overcome. The main problems come up because the terrain tends to be extremely uneven, as stones, bricks fragments or sand are often present. This way, the robot has to move through irregular 3D paths, considering also the presence of unknown obstacles. Two sample images of such typical underfloor environments are presented in Fig. 2. The robot must tackle the insulation task in this type of challenging and previously unknown environments.

To address autonomously this task, firstly, the robot must be capable of mapping the environment with enough accuracy and reliability in order to recognize the zones where insulation is required and, at the same time, be able to estimate accurately its position within the map. This process is known as *Simultaneous Localization And Mapping* (SLAM). In order to tackle the mapping and localization, it is necessary to use one or more sensors to obtain some information from the environments. On the one hand, the SLAM task has been traditionally addressed using range sensors, such as laser, which measure the distance to the surroundings and usually lead to models that show occupied and non-occupied zones [5,6]. On the other hand, vision systems can also be used for this purpose and much research is being carried out on mapping and localization using cameras [7,8]. Visual approaches try to build a map of the environment using sets of features obtained from different points of view. Many researchers have addressed successfully the SLAM task in controlled environments through these vision systems such as Davison et al. [9] who use a single camera. Nevertheless, it is necessary to highlight the difficulty of the underfloor environments. The presence of elements such as dust, sand, poor illumination or shadows makes the mapping and localization process extremely complex.

Fig. 2. Images of typical underfloor environments where the registration is difficult due to their characteristics.

The extreme unevenness of the floor is an additional issue to be taken into account (see Fig. 2). Owing to it, the movement of the robot is not plane at all and it can be considered a 6 DoF (degrees of freedom) movement. Considering all these features and challenges, both a laser and a vision system are chosen to accurately build a map of the environment and installed on the robotic platform.

Using these sensors, the mapping and localization are carried out following the next process. First, from a specific pose (position and orientation) of the environment, a scanning process is performed. During it, the sensors capture information on 360 deg. around the robot. The result is a 3D local map which consists of a point cloud that combines both depth and color information. Once the local map has been built from a specific pose, the robot will move a relatively long distance to a new, unknown pose. To estimate this new pose, the environment will be scanned again and a new local map (point cloud) will be built. The translation and rotation from the first to the second pose can be estimated by comparing these two local maps. After repeating this process from several poses, the set of local maps will compose a complete description of the environment (global map). This global map can be used not only to estimate the position of the robot while it moves, but also to determine the physical properties of the underfloor environment in order to control the spray gun and, after the insulation step, in order to validate if all the areas are correctly covered with foam.

Taking these facts into account, obtaining a robust and exact global map is very important. With this objective, having an accurate knowledge of the pose where each local map was captured is crucial. This is why this work focuses on this problem: estimating the current pose of the robot with respect to the previous one. The problem will be solved by comparing the point clouds obtained from both poses using a registration approach, whose result is a transformation matrix that contains the rotation and translation experienced by the robot from the first to the second pose. No information on odometry will be used because the extreme unevenness of the floor introduces a severe error on it (owing to shifting, slipping and orientation changes). This way, the global map is expected to be robust against these phenomena.

Therefore, in this paper we present a procedure designed to solve the alignment between two consecutive locations and to build a global map of the environment so that the robot can autonomously develop the insulation task in this kind of environments. In this regard, the work is based on the autonomous surveying robot architecture introduced in [4]. In this previous work, a system was proposed for selecting the next best position for performing a 3D scan. Multiple scans were aligned using the Iterative Closest Point (ICP) algorithm and merged together into a global map model. However, this system depends on a correct functioning of the ICP algorithm which is prone to fail or converge to a local minimum due to the complexities of the underfloor environments. Consequently, we present an algorithm that solves the registration in such environments. Therefore, the two main contributions of this paper