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Terrain classification using ToF sensors for the enhancement of agricultural machinery traversability

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Abstract

Ground properties influence various aspects of mobile machinery navigation including localization, mobility status or task execution. Excessive slipping, skidding or trapping situations can compromise the vehicle itself or other elements in the workspace. Thus, detecting the soil surface characteristics is an important issue for performing different activities in an efficient, safe and satisfactory manner. In agricultural applications, this point is specially important since activities such as seeding, fertilizing, or ploughing are carried on within off-road landscapes which contain a diversity of terrains that modify the navigation behaviour of the vehicle. Thus, the machinery requires a cognitive capability to understand the surrounding terrain type or its characteristics in order to take the proper guidance or control actions. This work is focused on the soil surface classification by implementing a visual system capable to distinguish between five usual types of off-road terrains. Computer vision and machine learning techniques are applied to characterize the texture and color of images acquired with a Microsoft Kinect V2 sensor. In a first stage, development tests showed that only infra-red and RGB streams are useful to obtain satisfactory accuracy rates (above 90%). The second stage included field trials with the sensor mounted on a mobile robot driving through various agricultural landscapes. These scenarios did not present illumination restrictions nor ideal driving roads; hence, conditions can resemble real agricultural operations. In such circumstances, the proposed approach showed robustness and reliability, obtaining an average of 85.20% of successful classifications when tested along 17 trials within agricultural landscapes.
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Keywords: Agricultural robotics; Terrain classification; Pattern recognition

1. Introduction

Autonomous navigation within agricultural scenarios is a particularly challenging point since they are semi-structured environments composed of human workers, animals, obstacles and rough terrain that limit the machinery mobility and constraint its movement. In order to drive along a feasible, safe and efficient path, these vehicles must be capable of being aware of their surroundings for dealing with the constant changes of such elements within the workspace. In general, this capability is related with both object recognition (to interact with the environment or to extract information from it), and the vehicle-terrain interaction. The last point is specially challenging since the diversity of soil types present in the agricultural fields makes the scenes usually consisting in low-traction,

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deformable and steep-hill terrains, which can quickly degenerate the quality of the positioning and compromise the task execution. Therefore, control and path planning strategies can be executed based on the classification and characterization of the driving terrain or its surroundings (Iagnemma and Ward, 2009). In the same way, management of machinery resources (e.g., battery or fuel) can be improved, increasing the aggregated value of the agricultural activity (Michel, 2012; Xue et al., 2012). Furthermore, the integrity of the vehicle itself can be preserved by avoiding excessive slipping, skidding or even trapping conditions.

Interpretation and characterization of the terrain surface have been studied using dynamic and descriptive methodologies. Dynamic terramechanical approaches are performed on base of known wheel-soil models which provide information about the tractive forces involved during the navigation (Al-Milli et al., 2010; Taheri et al., 2015). In addition, longitudinal and lateral slip effects of such terramechanical interaction can be measured (Botha and Els, 2015b; Botha and Els, 2015a). This knowledge, along with the kinematic characteristics of the robot, have proven to enhance the traversability of wheeled mobile robots, specially in Mars rovers (Ishigami et al., 2009; Brooks and Iagnemma, 2012). In these cases, the unavoidable limitation regarding the lack of a priori in situ information about the terrain, requires the robot to drive through it first in order to obtain feedback (in relation to terrain interaction) from propioceptive sensors on board such as accelerometers or encoders (Brooks and Iagnemma, 2005; Ojeda et al., 2006). Thus, using additional sensors to explore the robot surroundings for predicting its navigation behaviour is not plausible, specially when the vehicle is driving through completely new scenes. Unlike these scenarios, agricultural landscapes do not present this drawbacks, since it is possible – and in some cases necessary – to use available a priori information in order to anticipate the upcoming navigation behaviour of the vehicle.

A descriptive characterization of the terrain consists in representing the most relevant properties of the soil surface as ground planes, elevation maps or terrain classification. The first two are plausible alternatives; however, the continuously changing characteristics of the farming lands make these methodologies impractical in some situations (e.g., when vegetation has grown or the soil have been ploughed). Terrain classification, on the other hand, can be performed during a normal operation and would allow to know beforehand the upcoming terrain and discern whether a region is traversable or not, based on the latest information acquired by the sensors (Ho et al., 2013; Ball et al., 2016).

Various challenging points arise when using exteroceptive and propioceptive information for these purposes. For example, the ambient conditions of field operations (e.g., weather conditions or vibration) can often limit the measurement capabilities. The computational cost and processing capabilities have to guarantee practical applications. Another important point of concern is the total cost of the solution since agricultural applications like autonomous wheeled machinery are aimed to be commercially adopted by farmers. From this point of view, a trade-off between robustness and cost should be achieved to develop applications that would impact in the agricultural industry.

Given the previous context, this research work is focused on the use of a low cost sensor to obtain a descriptive interpretation of the terrain. A study and application of a classification system capable of determining the type of soil surface in front of a vehicle navigating on agricultural landscapes is proposed. Infra-red, color and depth streams are acquired with the sensor and used in a supervised classification scheme. It is shown that only infra-red information complemented with color is required to obtain high accuracy classification rates in real-time during field operations. The proposed system is tested using a mobile robot driving through a variety of agricultural terrains. It is noteworthy that this research work is not intended to determine terramechanic variables of the terrain, but to provide a complementary system which used together with those that employ wheel-ground models (Ishigami et al., 2009; Gao et al., 2013) could enhance the traversability assessment capabilities of an autonomous mobile robot.

This brief is organized as follows: Section 2 presents a review of the state of the art regarding terrain classification for diverse applications. Section 3 describes the hardware employed, as well as the methodology developed in this work. In Section 4, the experimental results, consisting of a validation and real condition tests, are shown. In Section 5 we provide the analysis and discussion of the results obtained, specially for the real condition tests. Finally, in Section 6 we present the conclusions of our work.

2. Related work

Terrain characteristics influence directly the navigation performance of wheeled mobile robots, specially in off-road scenarios like the agricultural landscapes (Prado et al., 2016). In this sense, it is reported the use of a variety of sensors, models and processing algorithms to provide a descriptive interpretation of the soil surface. Propioceptive information obtained with inertial and vibration sensors have been used in various studies to distinguish between several types of terrain (Brooks and Iagnemma, 2012; Park et al., 2012). However, these approaches require the vehicle to drive through the terrain first to obtain a label, which make them impractical in various situations (e.g., driving over excessively muddy soil can result in a trapping situation). To overcome this drawback, exteroceptive sensors (or a combination with propioceptive sensors) have been employed with promising results. Specially, the robustness and working versatility in field conditions of light detection and ranging (LiDAR) or radar have made these devices commonly used (Reina et al., 2012; Fernandez, 2010). Furthermore, the first winner of the Defense Advanced Research Projects Agency (DARPA)

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