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Journal of Terramechanics 71 (2017) 15–24

Journal of Terramechanics

www.elsevier.com/locate/jterra

Terrain classification using intelligent tire

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Received 28 August 2016; received in revised form 13 January 2017; accepted 24 January 2017

Abstract

A wheeled ground robot was designed and built for better understanding of the challenges involved in utilization of accelerometer-based intelligent tires for mobility improvements. Since robot traction forces depend on the surface type and the friction associated with the tire-road interaction, the measured acceleration signals were used for terrain classification and surface characterization. To accomplish this, the robot was instrumented with appropriate sensors (a tri-axial accelerometer attached to the tire innerliner, a single axis accelerometer attached to the robot chassis and wheel speed sensors) and a data acquisition system. Wheel slip was measured accurately using encoders attached to driven and non-driven wheels. A fuzzy logic algorithm was developed and used for terrain classification. This algorithm uses the power of the acceleration signal and wheel slip ratio as inputs and classifies all different surfaces into four main categories; asphalt, concrete, grass, and sand. The performance of the algorithm was evaluated using experimental data and good agreements were observed between the surface types and estimated ones.

Keywords: Wheeled ground robot; Intelligent tire; Terrain classification; Fuzzy logic algorithm

1. Introduction

Terrain classification and characterization are the most challenging issues associated with vehicle mobility and more specifically with the mobility of small ground robots. Once the terrain is identified, the robot can adapt to this new surface condition through the onboard traction control system.

Terrain analysis can be classified into two major categories, first terrain classification, aims at associating terrain with well-defined categories, such as asphalt, concrete, gravel and sand. Second, terrain characterization which is determination of the terrain characteristics such as roughness, friction potential, etc. (Ojeda et al., 2006).

Different types of sensors are used in terrain classification. Based on the sensor types, all of the studies in this field are divided into two main categories; the uses of contact sensors and non-contact sensors. In the studies with the contact sensors, characteristics like signal vibration frequency are used to classify the surface. Park et al. (2012) designed a mobile robot and using the data from the tire sensors. They developed a method to extract the terrain features. Brooks et al. (2005) used a robot with an accelerometer on its chassis. They used the vibration measurement of the chassis to classify the surfaces. Weiss et al. (2006) attached an accelerometer to the vehicle body to measure the vibrations in the direction perpendicular to the ground. Then, they used fast furrier transform (FFT) and power spectral density (PSD) to train a Support Vector Machine (SVM) algorithm to classify the surfaces. They also compared different approaches in vibration based terrain classification (Weiss et al., 2007). DuPont et al. (2005, 2008b, 2008a) attached an accelerometer to the body of an unmanned ground vehicle (UGV). Using the dominant vibration frequency of the UGV's body, they trained a

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http://dx.doi.org/10.1016/j.jterra.2017.01.005
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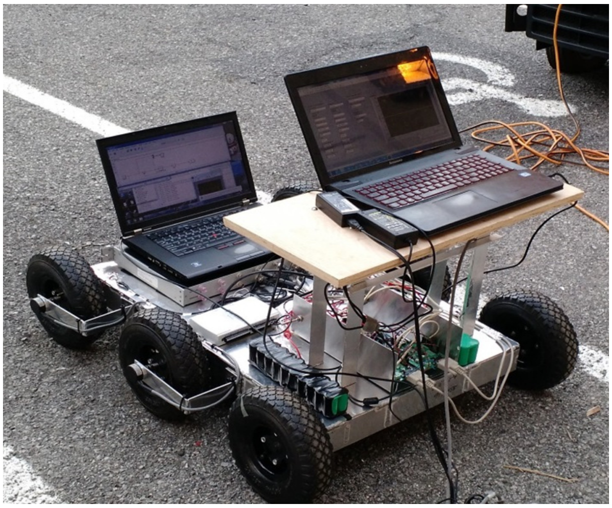

Fig. 1. The six-wheel robot.

Neural Network (NN) to identify the terrain. Collins et al. (2008) presented a vibration-based terrain classification algorithm for a UGV by mapping the vibration outputs to the terrain inputs using the Autonomous Guided Vehicle (AGV) vibration transfer function.

Non-contact sensors studies mostly used optical, sonar or acoustic sensors for terrain classification/characteriza tion purpose. Manduchi et al. (2005) used two sensor systems; a color stereo camera and a single axis Laser Detection and ranging (LADAR) that complement each other. Using stereo range measurements, they developed a color-based classification system to classify the detected terrains (Bellutta et al., 2000; Castano et al., 2001; Talukder et al., 2002). Larson et al. (2004) used a single camera and developed a new terrain classification technique. Vandapel et al. (2004) used a rover with a 3-D LADAR for terrain classification. Lee et al. (2011) used a Charge Coupled Device (CCD) camera; they extracted colors and textures from sensor data and classified the surfaces. Lu et al. (2011) used a laser stripe-based structured light sensor, which already has infrared camera component that allows sensing at night without external lightening, to sense the terrain directly. Their classification does not rely on color measurement, which can be distorted due to weather conditions and illumination. Their method was based on spatial frequency from range data and texture from camera data. Many studies have used a combination of contact and non-contact sensors for terrain classification. Ojeda et al. (2006) used a small robot for terrain classification purposes. Using a gyro with build in accelerometer attached to the robot's chassis, wheel encoder, microphone, infrared sensor and ultra-sonic range sensor, they developed an algorithm to classify different terrain to commonly known classes like gravel, sand and asphalt.

Also, much research has been conducted to characterize different terrains (Bekker, 1956, 1960; Bekker et al., 1969). Howard and Seraji (2001) used a mobile robot with a vision system and used an Artificial Neural Network (ANN) for real time terrain characterization. Cuong et al. (2014) designed a test rig and used it to measure the vertical damping ratio of tire-soil system using free-vibration logarithmic decay method.

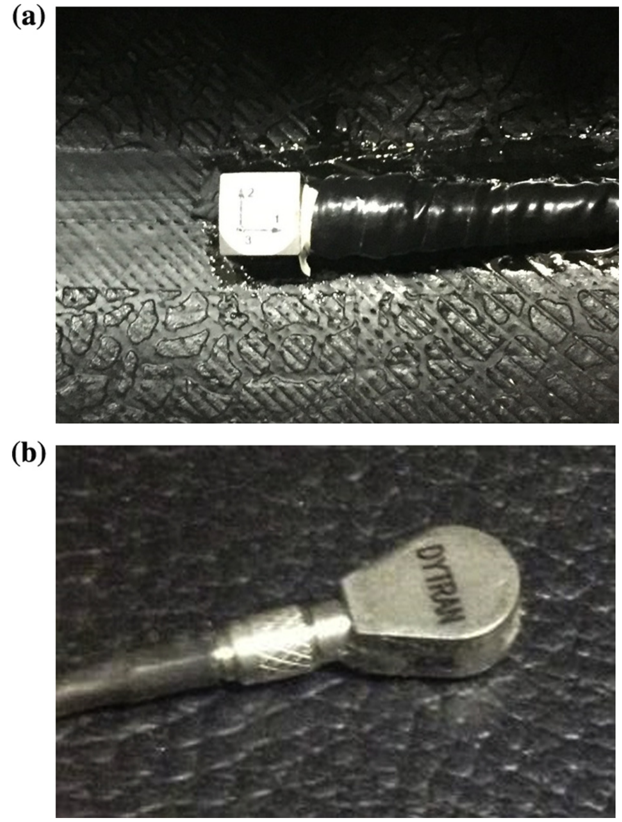

Fig. 2. Acceleration sensors used in the robot: (a) tri-axial accelerometer attached to the tire inner liner, (b) single axis accelerometer attached to the robot's chassis.

In this study, a six-wheel small ground robot was designed and built to classify different surfaces. The robot was equipped with intelligent tire to monitor the interaction between the tire and different terrains. Using accurate encoders, attached to the driven and non-driven wheels of the robot, wheel slip was calculated accurately. Analyzing the sensors data for different speeds on different surfaces, a Fuzzy Logic algorithm was developed to classify different terrains into four main categories; asphalt, sand, concrete, and grass. The rest of this paper is structured as follows. Different parts of the robot and its data collecting system and speed controller algorithm are introduced in Section 2. The fuzzy logic based terrain classification algorithm is explained -in Section 3. Results and discussion is presented in Section 4 follows by conclusions in Section 5.

2. Robot design

An all-terrain mobile robot platform (ATR) was designed and built in this study. The chassis base is 14.25″ wide × 17.25″ long, which are surrounded by 2.13″