INNOVATIVE MECHANICAL ENGINEERING **ISSN 2812-9229 (Online)**
University of Niš, Faculty of Mechanical Engineering
VOL. 1, NO 3, 2022, PP. 29 - 38

Original scientific paper *

PRECISE SPEED ESTIMATION OF PHYSICALLY CONNECTED OFF-ROAD ROBOTIZED VEHICLES

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Abstract. *Numerous types of robots can now be created thanks to modern technology, including industrial, humanoid, or soft robots, robotic vehicles, etc. A popular research field in robotics now covers groups of robots that are self-organized, autonomous, cooperative, and coordinated amongst themselves, known as swarm robots. There are numerous examples of swarm robots in industry and in scientific research. In most of these examples, each robotic unit is not physically linked to other robotic units. There are far fewer examples of a group of robots where there is a physical connection such as a rope or a towing link between two robots. Connecting a few autonomous robotic vehicles by wire or cable, where a wire is held to be tightened, can form a kind of a movable fence. One of the main challenges in keeping the wire tight is synchronizing the motion of the robots. In order to achieve that, precise measurement of the speed of every robotized vehicle is needed. Measuring the RPM of the wheels is insufficient when robotized vehicles are traveling on a non-flat, slick terrain where wheel slide of one or more wheels is anticipated. The information from various sensors is combined in this study to demonstrate the use of artificial intelligence methods for accurate speed prediction of physically connected off-road autonomous robotized vehicles.*

Key words: *robot, artificial intelligence, measurement, estimation.*

1. INTRODUCTION

In both daily life and the modern industrial environment, robots are becoming increasingly popular. Their applications range from health situations, assistance to the elderly or surgery, autonomous and driverless vehicles (on wheels or in flight) or assistance with driving. Recently, there has been an increasing interest in using robots in gardening and agriculture. Robots are being increasingly employed in groups rather than alone to do jobs as they become more commonplace in our daily lives. Swarm robots, or groupings of self-organized, autonomous, cooperative, and coordinated robots, are one of the rapidly expanding topics in robotics. Every robotic unit in most of these cases is not physically connected to other robotic units, which is common in both industrial and scientific swarm

***Received: December 10, 2022 / Accepted December 27, 2022.**
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robot examples. In [1], Dietz et al. presented a study aimed at understanding how different movement patterns impact human perception of groups of small tabletop robots. To understand this, they focused on the effects of changing the robots' speed, smoothness, and synchronization on perceived valence, arousal, and dominance, and found that speed had the strongest correlation to these factors. Paper [2] presented a method by which a swarm robot can catch a moving target and avoid multiple dynamic obstacles in an unknown environment. An imaginary map was built, including a highest mountain, some small hills, and a lowest lying land, respectively corresponding to the starting position of the robot, the detected obstacles, and the target. The robot was considered as a flow of water flowing from high to low. The flow of water was the robot trajectory that was divided into a set of points created by a Self-organizing migrating algorithm. Simulation results show that the obstacle-avoiding and target-catching task can be performed using this method. Many other authors have investigated different types of swarm robots [3-5].

There are much fewer examples of a group of robots where there is some physical connection in the form of a rope or tow link between two robots. In [6], the researchers studied how a group of physically assembled robots can display coherent behavior on the basis of a simple neural controller that had access only to local sensory information. This controller was synthesized through artificial evolution in a simulated environment in order to let the robots display coordinated-motion behaviors. Paper [7] addressed the problem of how a group of four assembled simulated robots forming a linear structure can coordinate and move as straight and as fast as possible. This problem was solved in a rather simple and effective way by providing the robots with a sensor that detects the direction and intensity of the traction that the turret exerts on the chassis of each robot and by evolving their neural controllers. The research presented in [8] examined the ability of a swarm robotic system to cooperatively transport objects of different shapes and sizes. The authors simulated a group of autonomous mobile robots that can physically connect to each other and to the transported object.

A moving fence can be created by joining a few autonomous robotized vehicles with wire or rope, where a wire is kept tight. One of the main challenges in keeping the wire tight is to precisely measure the speed of every robotized vehicle [9]. Measuring the RPM of the wheels is insufficient when robotized vehicles are traveling on a non-flat, slick terrain where wheel slide of one or more wheels is anticipated. The information from various sensors is combined in this study to demonstrate the use of artificial intelligence methods for accurate speed prediction of physically connected off-road autonomous robotized vehicles.

2. SYSTEM DESCRIPTION

A moving polygonal electric fence can be created via a swarm robotic system in which off-road autonomous robotized vehicles are physically connected by wire. The entire system is shown in Fig. 1. The system is made up of at least four robotic units, or four movable pillars connected by wires creating the fence.

Fig. 1 Movable polygonal electric fence

Every robotized vehicle can move in any direction, so the moving fence can take on many forms. One of the possible forms is shown in Fig. 2.

Fig. 2 One of numerous configurations for a mobile polygonal electric fence

The moving platform with four wheels, the vertical pillar, and the pillar wire tensioning system are the main components of every robotized vehicle. As it connects all nearby robotized vehicles, the electric fence wire forms a closed polygon.

The mobile platform can maneuver on land and in wet conditions and is, in fact, an all-terrain unmanned ground vehicle (UGV). With its strong construction, low ground pressure, weather-proofing, and excellent maneuvering capabilities, it is made to tackle all terrains and challenging conditions. This enables efficient mobility through moderately rocky fields, soft soils, sparse vegetation, mud, and steep slopes (Fig. 3).

Fig. 3 Robotic vehicle on steep slope

Electric wire which forms the movable fence must be tightened all the time. The movement of each robotized vehicle must be constantly synced with the wire tensioning system in order to complete this difficult task. The only way to correctly synchronize all robotized vehicles is to precisely know their individual speeds. Thus, accurate vehicle speed measurement is crucial.

3. PROBLEMS WITH SPEED MEASUREMENT OF ROBOTIZED OFF-ROAD VEHICLES

A robotic vehicle's speed can be measured in a variety of ways. Some of the most popular ones are described below.

3.1 Angular velocity measurement

The best method for measuring the speed of robotized four-wheeled vehicles is to measure the angular velocity of each wheel and then calculate the speed of the vehicle using the wheel diameter. Angular velocity can be measured by an encoder, or hall-effect sensors.

Wheel assembly of the described robotized vehicle is shown in Fig. 4. It is a wheel that is powered by a brushless DC motor via a chain reductor.

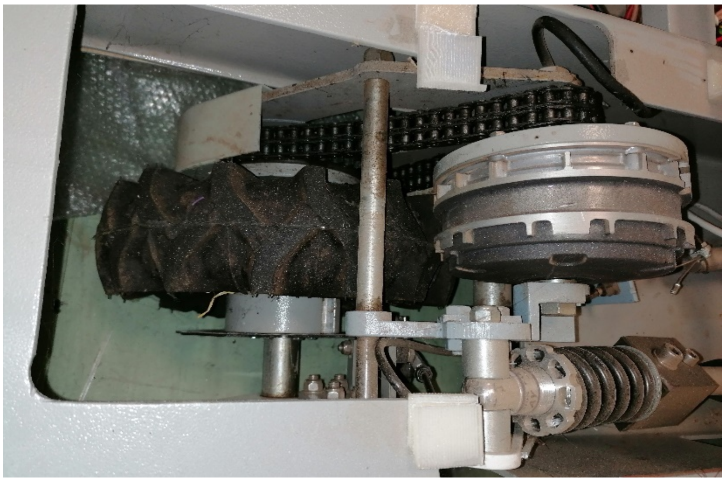

Fig. 4 Wheel assembly

The brushless direct current motor (BLDC) has built-in hall-effect sensors on the stator which can be used for angular velocity measurement. The motor has 30 magnets on the rotor (Fig. 5), and the hall-effect sensor can detect when a rotor magnet passes the nearest sensor, so that the 30th part of one rotation, or an angle of 12° can be detected by using only one hall-effect sensor. The chain reductor has 15 teeth on the motor side, and 50 teeth on the wheel side, and the reduction ratio of the chain reductor is 15/50. This means that the smallest angle on the wheel which can be detected is $12° \cdot 15/50 = 3.6°$, or 1% of a single wheel rotation. The wheel diameter is 27 cm, so that a move of less than one centimeter can be detected, since $27 \cdot \pi/100 \approx 0.84$ cm.

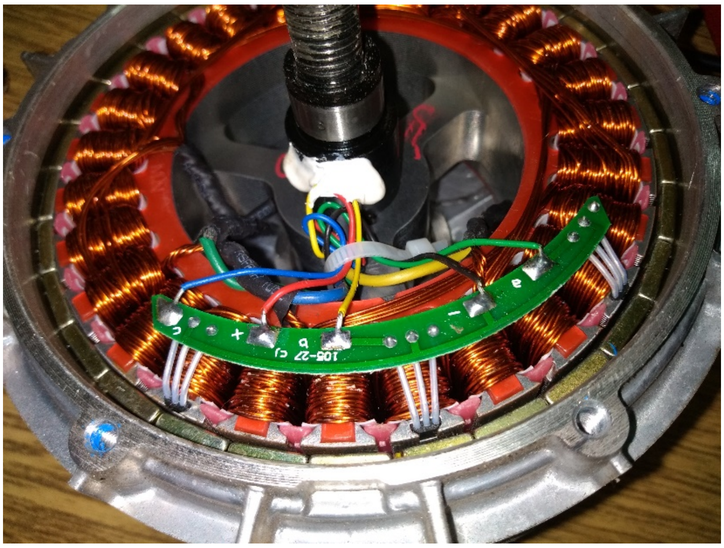

Fig. 5 Disassembled BLDC motor

Signals from the hall-effect sensors can have noise when the BLDC motor is in operation. For filtering this noise caused by electromagnets inside the BLDC motor, a Schmitt trigger filter was used. The schematics of a single Schmitt trigger filter and a built circuit with two filters are shown in Fig. 6. After filtering, the signal from the hall-effect sensor is a pure pulse signal and it can be detected by Arduino Mega 2560. With the pulsein() command the length of each pulse can be measured in microseconds.

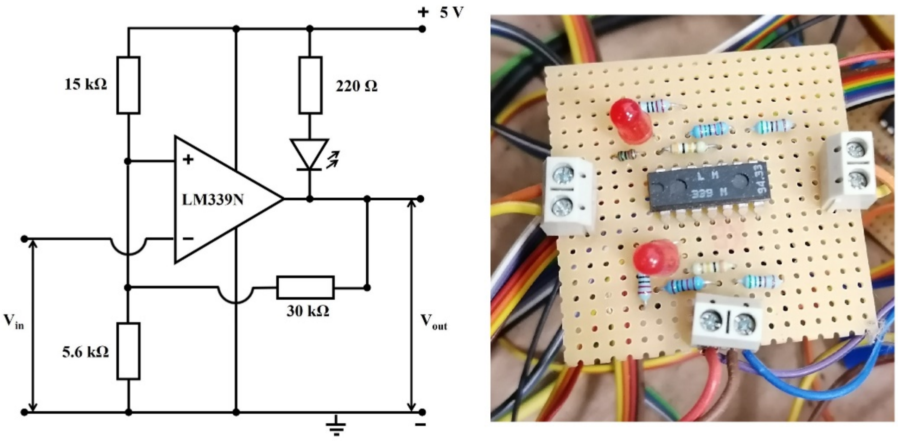

Fig. 6 Schmitt trigger filter

The described approach allows for a very precise angular velocity measurement on every wheel, but this can be used for the vehicle speed calculation only if there is no slip between the wheel tire and the ground. Since this entire system is designed to handle all terrains and tough environments, wheel slip is expected in a moderately rocky field, soft soils, low vegetation, mud and steep slopes [10]. The primary issue when utilizing this method is to determine the speed of robotized off-road vehicles.

3.2 Global Positioning System

GPS (Global Positioning System): A system that uses 24 orbiting satellites and covers the entire surface of the globe. An object must be equipped with a GPS receiver for its location on Earth to be determined. GPS receivers can attain an accuracy of a few meters, up to a centimeter. Real-time kinematic positioning (RTK) is the application of surveying to correct for common errors in the current satellite navigation. RTK GPS systems are high-precision systems that use a radio signal coming from a transmitter (satellite) to detect position. They are very accurate devices, with a lot of integrated hardware. RTK receivers use the differential correction method. Using a base station whose location is precisely known will make it simple to identify how the receiver's position should be corrected. It is possible to adjust the position of the receiver based on the determination of the station's position and the error discovered. Every robotized vehicle is equipped with an Emlid Reach M2 GPS receiver shown in Fig. 7 left, and corrections are received from an Emlid Reach RS2 base, shown in Fig. 7 right.

Fig. 7 Emlid Reach receiver and base for RTK GPS positioning

Using these GPS receivers and base, it is possible to obtain centimeter-level positioning in good weather conditions. The position is precisely determined with the frequency of 10 Hz, and it is shown in the form of latitude and longitude. If φ is the latitude, λ the longitude, R the Earth's radius, using the following set of formulas it is possible to calculate the distance d, traveled between two intervals.

$$a = sin^2\left(\frac{\Delta\varphi}{2}\right) + cos(\varphi_1) \cdot cos(\varphi_2) \cdot sin^2\left(\frac{\Delta\lambda}{2}\right) \quad (1)$$

$$c = 2 \cdot arctan\left(\frac{\sqrt{a}}{\sqrt{1-a}}\right) \quad (2)$$

$$d = R \cdot c \quad (3)$$

It is possible to use time differentiating of the calculated distance to obtain the speed of the robotized vehicle when its position is known. The low frequency of receiving positions is the main issue. For instance, when a robotized vehicle is traveling at 1 m/s, a movement of 0.1 m or less cannot be detected. This lack of accuracy is severe enough to affect the tightness of the electric wire fence. In bad weather conditions, positioning precision can be very low.

3.3 Inertial Measurement Units (IMUs)

Advanced inertial sensors measure a variety of parameters, such as: orientation (pitch, roll, yaw or azimuth), linear acceleration and angular rate, on either a single or dual axis inclination. With small size and weight, the system may be integrated into current unmanned platforms effectively without affecting the system performance. The system is controlled and stabilized with precision thanks to sophisticated data collection and estimation filtering techniques.

IMUs made by Lord Microstrain are quite capable of providing accurate data on the rover's orientation and/or acceleration/angular speed. Every robotized vehicle is equipped with 3DM-GX5-25 Lord Microstrain IMU shown in Fig. 8.

Fig. 8 3DM-GX5-25 Lord Microstrain IMU

Gravity compensation is the fundamental issue when utilizing IMUs to measure linear speed. Gravity always has an impact because IMUs measure acceleration. To compensate for the gravity, Euler's angles must be precisely obtained from a gyroscope. High sample rates are used to gather inertial sensor readings, which can later be integrated to determine the position and orientation. For small time periods, these estimations are accurate, but they suffer from integration drift for larger periods.

4. ARTIFICIAL INTELLIGENCE METHODS FOR PRECISE SPEED ESTIMATION

The development of the artificial intelligence technique applying machine learning, i.e. the artificial neural network (ANN), can solve the speed measuring issues for all-terrain vehicles. A standard feed-forward, back propagation ANN is used to determine the speed of the robotized vehicle. To provide an efficient solution, the artificial neural network has three layers: an input layer, a single hidden layer, and an output layer (Fig. 9). Driving a robotized vehicle on a flat asphalt surface where there is no tire-to-asphalt slippage or where this is negligible was the major goal. During this motion, the data obtained from the hall-effect sensors on the wheels were used to calculate the RPM of each wheel of the robotic vehicle, and to determine the precise speed of the entire vehicle, since there is no slip between the tire and the asphalt. The data were used as an output for the purpose of training the ANN. The data from the GPS receiver and the IMU sensor were used as inputs.

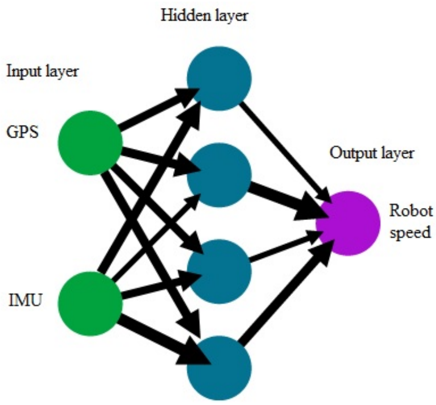

Fig. 9 Artificial neural network with 2 input variables, 1 hidden layer, and 1 output variable

For testing the ANN, the entire system of moving fence was driven on the field in Donja Vrežina, near Niš. Fig. 10 shows the GPS path of one robotic vehicle traveling during the testing procedure. The speed of the autonomous robotized off-road vehicle in cm/s obtained from the ANN while the vehicle was moving on a rough terrain is shown in Fig. 11. The vehicles' motion can be properly synchronized with the wire tensioning system using this speed estimation.

Fig. 10 GPS path of one robotic vehicle

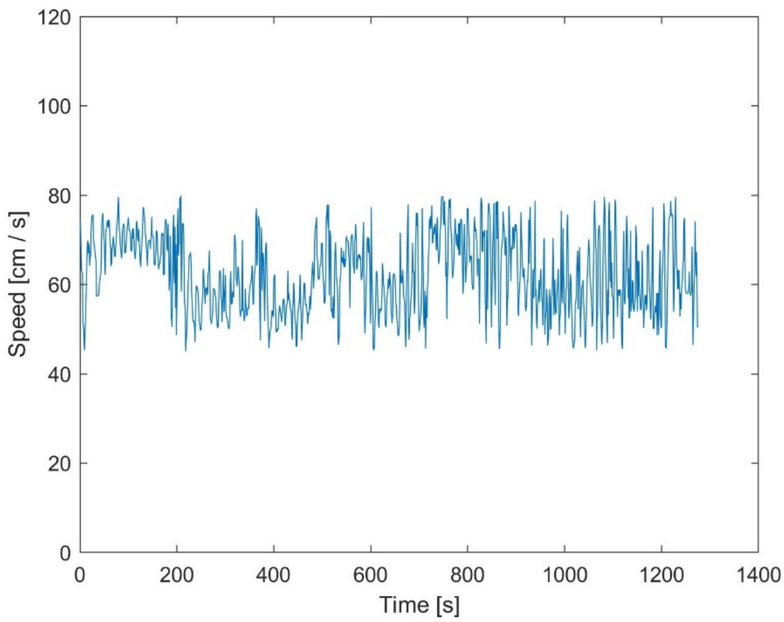

Fig. 11 Estimated speed of the autonomous robotized off-road vehicle in cm/s obtained from ANN

5. Conclusion

This study introduces an artificial intelligence method for precisely estimating the speed of autonomous robotized off-road vehicles connected by wire in order to create a moving electric fence. The wire for the moving fence should be tightened at all times during the motion of the entire system. To complete this task, the precise speed of each robotic vehicle is needed for every point in time. Measuring the RPM of the wheels is not enough because slip can occur between the wheel tire and the ground on off-road terrains. Thus, additional sensors like GPS and inertial sensor were implemented. The accuracy of these sensors can be unreliable. In order to overcome these difficulties, an artificial neural network was created. The vehicle was driven on a flat asphalt surface where slip between the tire and the asphalt can be neglected. Thus, the reliable data for the vehicle speed were obtained and used to train the artificial neural network.

The experimental test was performed on the field with grass where slip between the wheel tire and the ground is expected. The speed estimated by the artificial neural network was precise enough to achieve good synchronization between the motion of the vehicles and the wire tensioning system.

Acknowledgement: *This paper is a part of the research financially supported by the Innovation fund of the Republic of Serbia and Coming Computer Engineering through the project RoboShepherd, and the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract No. 451-03-9/2021-14/200109).*

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