Computers and Electrical Engineering xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

Design of a high-speed line following robot that smoothly follows tight curves ☆

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ARTICLE INFO

Article history:
Received 8 June 2014
Received in revised form 28 May 2015
Accepted 4 June 2015
Available online xxxx

Keywords:
Artificial neural networks
Reinforcement learning
Learning Vector Quantization
Low-cost line following robot
Non-linear control

ABSTRACT

In this paper the design of a novel high-speed, low-cost autonomous line following robot that combines human expert knowledge and experiential data extracted through neural network training has been proposed and implemented. The proposed autonomous robot overcomes the disadvantages of earlier designs like oscillations in motion, exception handling, high-cost and high-energy consumption. The robot uses a novel square-topology infrared sensor matrix that enables it to anticipate a turn by sensing the track ahead. Three different strategies to control high-speed line following robots are presented: a neural network based control strategy, a learning vector quantization based strategy and a reinforcement learning based strategy. The final design based on a hybrid neural network based control strategy smoothly followed the benchmark track with just 4 neurons and used a low-cost 8-bit microcontroller to implement the control system.

1. Introduction

Autonomous line following robot are increasingly being used to perform object transport tasks in industrial environments, in surveillance applications and in construction and mining industries [1–4]. However not much published work exists that discuss possible control strategies and implementations. Thus an investigation of possible control strategies, detailed design, implementation and performance of a line following robot is of interest. In this paper a novel neural network based low-cost line following robot that learns to smoothly follow a random curved path with minimal oscillations and overshoot is presented.

A line follower is an autonomous robot that detects and follows a line that is drawn on a flat surface. The path consists of a black line on a white surface or a white line on a black surface. The track is designed such that the absorption coefficient of the line being followed is significantly different from the background track. The control system must sense the line and maneuver the robot to stay on course while constantly correcting any deviation from the line being followed. Most line following robots that currently exist share a common system architecture which includes a chassis, locomotion system, sensing system and logic control unit.

Possible schemes for sensing the position of the robot with respect to the line include (i) Light Dependent Resistor (LDR) based luminous intensity detection system where the surfaces are differentiated from one another based on the amount of light reflected from the surface [4–6]. (ii) Infra-Red (IR) based detection system [6,7] which works on the principle of variable

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. Anand Bhojan.

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http://dx.doi.org/10.1016/j.compeleceng.2015.06.014
0045-7906/

absorption of IR rays by different surfaces. (iii) Camera feed based line imaging system [8–11] where a high-resolution track image is captured.

The locomotion systems of most robots comprise of standard Direct current (DC) geared motors with approximately 1 Nm torque and speed varying from 100 to 300 rpm. The control unit depends on the nature of the hardware implementation chosen. Possible implementation choices include (i) combinational logic structures using transistor level design or logic gates, (ii) microcontroller/microprocessor based implementations (8-bit, 16-bit, and 32-bit) and (iii) Field Programmable Gate Array (FPGA) based implementations.

Fig. 1 shows the operation of a conventional two sensor line following robot [6,7]. In this design the robot is initially placed such that the line lies between the two sensors. The simplest control strategy directs the robot to take control actions that result in neither of the two sensors detecting the line. For example in Fig. 1 since the bottom sensor detects the line at the start the control action must be to take a right turn to prevent the bottom sensor from detecting the line.

A major problem encountered with the two sensor scheme is the oscillatory nature of the robot motion even on simple tracks. If the lateral spacing between the two sensors is not properly chosen the robot might go into an oscillatory state where the average energy received by the motors is so low and that the robot comes to a stop.

The two sensor approach may be improved by using more sensors [4] as shown in Fig. 2. Here the control strategy is to direct the robot to take actions that will keep the central sensor on the track at all times. The state of the other two sensors determine wether a left or right turn is to be taken. However, it can be seen that this sensor topology is capable of taking action only based on the instantaneous input (presence of turns in the track ahead cannot be detected) which results in overshoot when turns are taken [5].

In this paper a 3×3 square-topology infrared sensor matrix (Fig. 3) is proposed to overcome the disadvantages of earlier linear sensor topologies. The strategy here is to try and maintain the central column of sensors in line with the track with the highest priority being to keep the sensor row closest to the robot on the line. If the sensor in the central column farthest from the robot does not detect the line then it is evident that a turn is approaching and logic control unit steers the robot such that it does not overshoot the turn.

A 3×3 square-topology infrared sensor matrix arrangement has 9 sensors, each of which gives a binary output which together represent the position of the robot (state) with respect to the line. The total number of possible combinations of

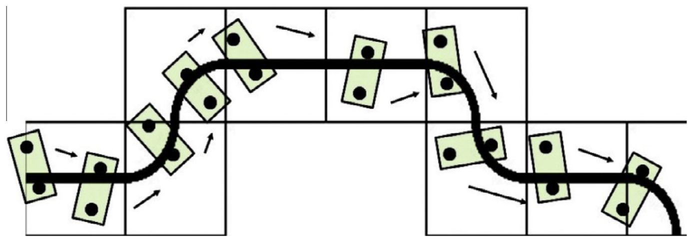

Fig. 1. Line follower with 2 sensors arranged linearly. In this approach curves cannot be anticipated and motion is oscillatory.

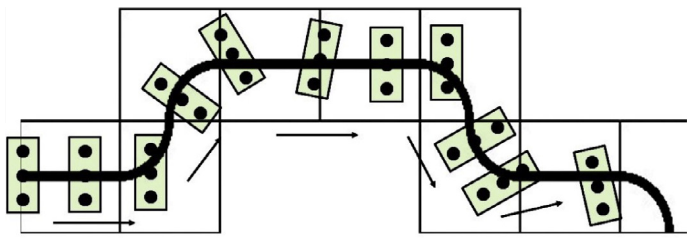

Fig. 2. Line follower with 3 sensors demonstrates less oscillation but curves cannot still be anticipated.

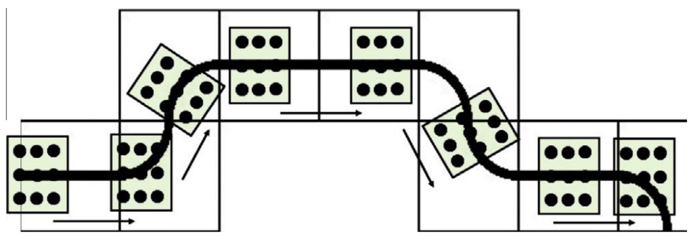

Fig. 3. A 3 by 3 square arrangement of sensors can detect the curvature of the track so line follower has reduced oscillations and overshoot.

Please cite this article in press as: Roy A, Noel MM. Design of a high-speed line following robot that smoothly follows tight curves. Comput Electr Eng (2015), http://dx.doi.org/10.1016/j.compeleceng.2015.06.014