Vision-Based Obstacle Avoidance Controller Design for Mobile Robot by Using Single Camera

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Abstract

By using the single VGA camera installed on mobile robot, a vision-based intelligent obstacle avoidance algorithm is developed in this paper. The image data are processed by edge detection method. By using the adaptive network based fuzzy inference system (ANFIS), the horizontal edge numbers (HEN) and vertical edge numbers (VEN) are feed into ANFIS to train the fuzzy rules such as to control the right and left wheels of mobile robot to avoid obstacles. The simulation results by using Matlab™ and Webots™ softwares reveal that the control performances and effectiveness are possessed.

Keywords: *Mobile robot; Webots; Vision-based control.*

1. Introduction

Mobile robots have the potential to become the ideal tool to teach a broad range of engineering disciplines. Indeed, mobile robots are getting increasingly complex and accessible. The elements from diverse fields such as mechanics, digital electronics, automatic control, signal processing, embedded programming, and energy management. Moreover, they are attractive for students which increase their motivation to learn. However, the requirements of an effective education tool bring new constraints to robotics. In this paper, the mobile robot design for obstacle avoidance is presented, which specifically targets engineering education at university level [1]. The mobile robot is developed on the base of the platform of Webots™. The extension board of mobile robot is based on a 32-bit ARM9 microprocessor and provides wireless blue-tooth network support. The ARM9 extension board runs in parallel with the dsPIC microprocessor on the mobile motherboard with communication between the two via an SPI bus. The extension board is designed to handle computationally intensive image processing, wireless communication and high-level intelligent robot control algorithms, while the dsPIC handles low-level sensor interfacing, data processing and motor control [2]. By using the Webots software, the dynamic image from VGA camera characteristics of the mobile robot model can be exploited for investigating the temporal aspects of multimodal integration. The temporal window for integration is shown to have an impact on the multisensory interaction, so the possibilities for its adaptation within the control field model and its impact on the computational outcomes are easily investigated [3]. Webots™ runs on Windows, Linux and Mac OS X and is intended for researchers and teachers interested in mobile robotics. It is commercially available from Cyberbotics Ltd. (http://www.cyberbotics.com). Although the final aim is real robotics, it is often very useful to perform simulations prior to investigations with real robots. This is because simulations are easier to setup, less expensive, faster and more convenient to use. A simulated robotics setup is less expensive than real robots and real world setups, thus allowing a better design exploration. The steps of Webots are first from modeling->programming->simulating, finally transferring the results of codes to real mobile robot [4].
The Adaptive Network-based Fuzzy Inference System (ANFIS) [5] has been embedded in toolbox of MATLAB™ [6-8]. In this paper, the ANFIS is used to train the fuzzy inference matrix for VGA image processing control algorithm which can be included in program of Webots to simulate the effectiveness such as the mobile robot can avoid obstacles.

2. The Preliminary of Mobile Robot

The mobile robot has already been used in a wide range of applications, including mobile robotics engineering, real-time programming, embedded systems, signal processing, image processing, sound and image feature extraction, human-machine interaction, inter-robot communication, collective systems, evolutionary robotics, bio-inspired robotics, etc. The mobile robot also features a large number of sensors, actuators and single camera [9]. Webots™ is a software for fast prototyping and simulation of mobile robots. It has been developed since 1996. Webots allows us to perform 4 basic stages in the development of a robotic project. The first stage is the modeling stage. It consists in designing the physical body of the robots, including their sensors and actuators and also the physical model of the environment of the robots. The second stage is the programming stage. We will have to program the behavior of each robot. In order to achieve this, different programming tools are available. The third stage is the simulation stage. It allows us to test if the developed program behaves correctly. By running the simulation, we will see the robot executing the developed program. Finally, the fourth stage is the transfer to a real robot. The control program will be transferred into the real robot running in the real world [9].

3. Model and Controller Design

The contact between the wheel and the ground satisfies both conditions of pure rolling and non-slipping during the motion; moreover, the robot is assumed to be rigid. The pixels of image from VGA camera can be processed to get edge detection data which then normalized from 0 to 1. Based on human knowledge, the $\dot{\theta}$ can be trained by ANFIS.

The ANFIS is a suitable off-line hybrid learning procedure to serve as a basis for constructing a set of fuzzy if-then rules with appropriate membership functions to generate the stipulated Fuzzy Associated Memory (FAM) input-output pairs. The principle of ANFIS is briefly described as follows [5].

$$R_i: If\ x\ is\ A_1\ \ldots and\ y\ is\ B_1$$
$$then\ h_1 = p_1 x + q_1 y + r_1 \quad (1)$$

where R_i denotes the ith fuzzy rules, i=1, 2,..,r; A_i is the fuzzy set in the antecedent associated with the kth input variable at the ith fuzzy rule, and $p_{i1},..., p_{in}$, r_i are the fuzzy consequent parameters.

Based on the *weighted averaged method* of defuzzification. The output u can be calculated as

$$h = \frac{w_1}{w_1 + w_2} h_1 + \frac{w_2}{w_1 + w_2} h_2$$
$$= \overline{w}_1 u_1 + .. + \overline{w}_2 u_n \quad (2)$$

where w_i is the ith node output firing strength of the ith rule, and $\overline{w}_1 = \frac{w_1}{w_1 + .. + w_n}$,.., $\overline{w}_n = \frac{w_n}{w_1 + .. + w_n}$.

Because the fuzzy inference system is a Takagi-Sugeno type, i.e., $h_i = p_i x + q_i y + r_i$, Eq. (2) can be rewritten as

$$h = \overline{w}_1 h_1 + \overline{w}_2 h_2$$
$$= (\overline{w}_1 x_1) p_{i1} + .. + (\overline{w}_1 x_n) p_{in} + (\overline{w}_1) r_1$$
$$+$$
$$\vdots$$
$$+ (\overline{w}_n x_1) p_{i1} + .. + (\overline{w}_n x_n) p_{in} + (\overline{w}_n) r_n . \quad (3)$$

The hybrid learning algorithm developed in [5] can be applied to Eq. (3) directly. A two-input one-output ANFIS is shown in Fig. 1. In the *forward pass* of the hybrid algorithm, functional signals go forward until layer 4 of Fig. 1 and the consequent parameters p_i, q_i, r_i are identified by the Least Squares Estimate (LSE) approach. In the *backward pass*, the error rates propagate backward and the premise parameters x, y are updated by the gradient descent approach. As the values of these parameters change, the membership functions vary accordingly; thus exhibits various forms of membership functions on linguistic labels A_{i1} and A_{i2} .

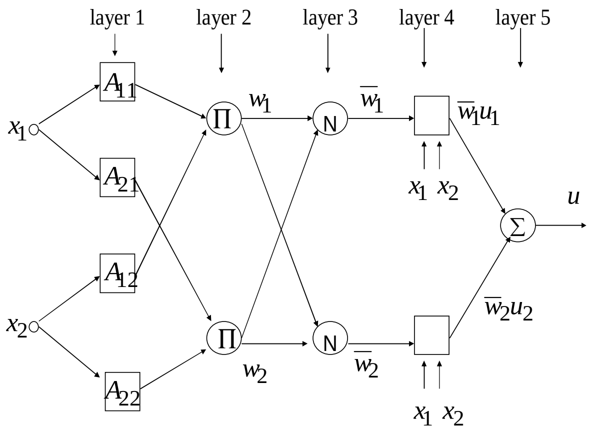

Fig. 1. A two-inputs one-output ANFIS architecture

4. Results of Simulations

In this section, the edge detection number (EN) is used for ANFIS. The fuzzy rules are constructed by using horizontal edge numbers (HEN) and vertical edges numbers (VEN). The concept diagram is shown in Fig. 2.

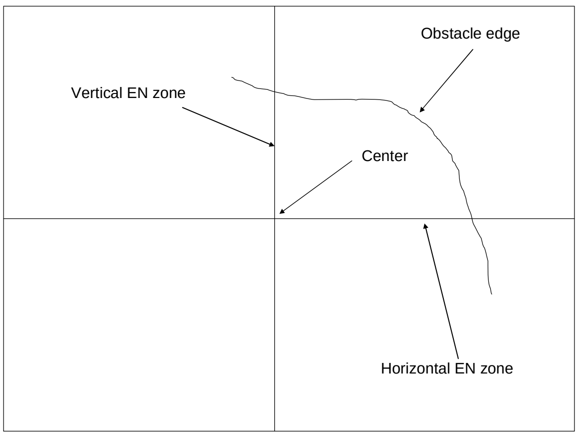

Fig. 2. Concept diagram of single VGA camera detection edge number

Based on Fig. 2, some reasonable fuzzy rules can be developed and trained by ANFIS by Matlab™. The trained result and simulation result are shown in Fig. 3. The result of Webots™ simulation is shown in Fig. 4. The results are revealed that the effectiveness of vision-based ANFIS control is possessed.

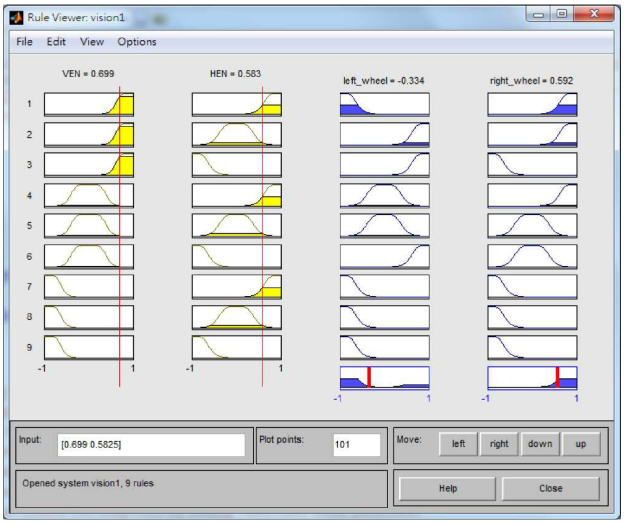

Fig. 3. The results of trained and simulation by ANFIS

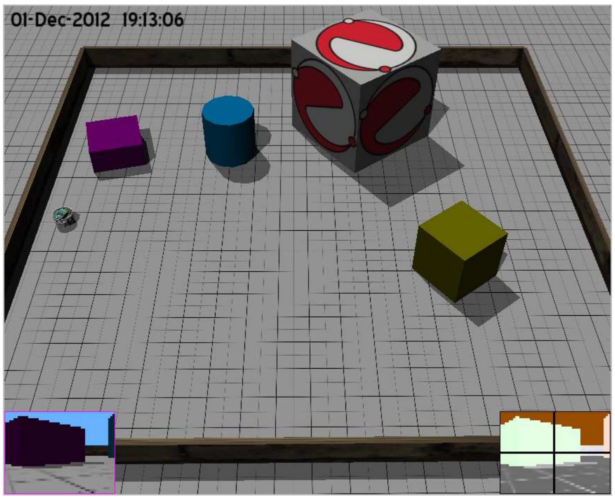

Fig. 4. The simulation result of vision based obstacle avoidance by using single camera

5. Conclusions

The single camera is used in this paper to develop a vision-based intelligent obstacle avoidance algorithm. The VGA camera is installed on mobile robot, then the image data are processed by edge detection method. From the horizontal edge numbers and vertical edge numbers, the adaptive network based fuzzy inference system (ANFIS) is used to train the fuzzy rules to control the right and left wheels such as the performance of obstacle avoidance can be possessed. From simulations by using Matlab^{TM} and Webots^{TM} softwares, the control law's effectiveness are verified.

Acknowledgments

This research is partially funded by the teachers' research and cooperation with company research project of the Taoyuan Innovation Institute of Technology and supported by the SOC project of the Ministry of Education, Taiwan, R. O. C.

References

[1]. F. Mondada1, M. Bonani, X. Raemy, J. Pugh, C. Cianci, A.Klaptocz, S. Magnenat, J. C. Zufferey, D. Floreano and A. Martinoli, "The e-puck, a Robot Designed for Education in Engineering," *Proceedings of the 9th conference on autonomous robot systems and competitions*, 2009, Vol. 1, No. 1, pp. 59-65.

[2] W. Liu and A. F. T. Winfield, "Open-hardware e-puck linux extension board for experimental swarm robotics research, "*Microprocessors and Microsystems*, Vol. 35, No. 1, February 2011, pp. 60-67.

[3]. E. Barakova and W. Chonnaparamutt, "Timing sensory integration," *Robotics Automation Magazine, IEEE*, Vol. 16, No. 3, 2009, pp. 51-58.

[4]. O. Michel, "Cyberbotics Ltd. WebotsTM: Professional Mobile Robot Simulation," *Inernational Journal of Advanced Robotic Systems*, Vol. 1 No. 1, 2004, pp. 39-42.

[5]. J. S. R. Jang, "ANFIS: adaptive-network-based fuzzy inference system," *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 23, 1993, pp. 665-685.

[6]. Y. J. Mon, "Supervisory Adaptive Network Based Fuzzy Inference System (SANFIS) Design for Empirical Test of Mobile Robot," *Inernational Journal of Advanced Robotic Systems*, Vol. 9, 2012, Article ID 158, 31th Oct. (DOI: 10.5772/53404).

[7]. R. Havangi, M. A. Nekoui and M. Teshnehlab, "Adaptive neuro-fuzzy extended kalman filtering for robot localization," *International Journal of Computer Science Issues*, Vol. 7, Issue 2, No 2, March 2010, pp. 15-23.

[8]. E. C. Pérez, I. A. Badillo, V. H. G. Rodríguez, "Performance Analysis of ANFIS in short term Wind Speed Prediction," *International Journal of Computer Science Issues*, Vol. 9, Issue 5, No 3, September 2012, pp. 94-102.

[9]. O. Michel, F. Rohrer and N. Heiniger, *Cyberbotics' Robot Curriculum*, 2010, Wikibooks, the open content textbooks collection.

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