Expert Controller for Road Tracking Mobile Robot

مسيطر خبير لروبوت متحرك يتبع خارطة طريق

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Abstract:

the road boundaries provide useful information for performing safe vehicle moving paths in intelligent or expert vehicles. Many previous researches have treated road boundary detection, using different types of sensors such as vision, ultrasonic, RADAR, LIDAR (Light Detection and Ranging), and LRF (Laser Range Finder). In spite of that these sensors show advantages for road boundary extraction including good resolution but IR sensor is the most famous device for measuring small distances since it has a high accuracy, fast response time, low cost and a wide field of view. However, none of the previous works examined the problem of detecting road boundaries when roads could be structured with narrow regions. In this paper, we developed road boundary detection and tracking algorithm using two IR sensing for structured roads with narrow regions distributed along the road. The algorithm extracts road dimensions and distances relative to Left and Right IR sensors keeping the robot vehicle in the center of the road. The measured distances are kept constant by controlling analog inputs of the sensors using an expert controller. ARM processor controller is used to control the navigation of the mobile robot in this environment. The speed and direction of the robot are controlled by Pulse Width Modulation (PWM) signals generated by the ARM controller. Emphasis has been attributed to the design of the motor driver switching module in order to achieve effective and energy saving driving using power transistor drivers. The system is tested using a road prototype made from wood prepared for that purpose. It proved a good working in environments with narrow regions yielding a safe movement for the robot.

Keywords - Expert controller, Center road tracking, IR sensor, ARM processor, Multimodal road

I. INTRODUCTION

The motion control of mobile robots such as wheeled and walking robots is a very important real-time task in industrial and home applications. Wheeled robots with track are suitable for complex environments such as terrains and not plane off-road lands besides the normal environments and roads. To improve road safety and driving comfort, intelligent vehicle technologies are introduced worldwide. In these intelligent vehicles, perception of roads surrounding the vehicle is important in generating safe paths. Generally, roads are divided into two types: structured and unstructured [1]. Structured refers to highways and city streets with clear markings using lanes or curbstone. Unstructured roads are those with no markings such as rural roads. The unstructured roads are difficult to detect leading to unknown road shape and boundaries. Linear floor wall robot tracks are highly useful in many applications. Common fixtures when it comes to painting or door opening. Robot track systems can also prove valuable applications such as: welding, cutting and material handling. In spite of using various kinds of sensory technologies such as: vision, RADAR, LIDAR, and ultrasonic to detect roads, but IR sensory method is the best for narrow structured roads [2]. Center road robots are important since they are used in many industrial-wise production lines [3]. The design of a center road estimator is the main goal of this paper. In order to keep the mobile robot in the center of a road while moving with a high speed, then an expert controller is designed. This expert controller depends on many rules that make it think as a real driver. Hence, the experience of a real driver is moved out to the controller so the name "expert". This controller has been used for motion navigation of the robot avoiding any collisions with walls and keeping it down a road. A number of studies have been done to detect the roads using various kinds of sensory technologies such as: vision, RADAR, LIDAR, ultrasonic, and IR. In 2012, C.K. Chang, et al, presented a monocular vision-based navigation system that incorporates two contrasting approaches: region segmentation that computes the road appearance, and road boundary detection that estimates the road shape. The algorithm operates in urban road settings and requires no training or camera calibration to maximize its adaptability to many environments. In 20 trial runs the robot was able to travel autonomously for 98.19% of the total route length of 316.60m [3]. In spite of that the vision-based methods have many advantages, but they are less effective under complex illumination, shadows, or bad weather [4]. In 2014, J. Han, et al, developed road boundary detection and tracking algorithm using LIDAR sensing for both structured and unstructured roads. The algorithm extracts road features as line segments in polar coordinates relative to the LIDAR sensor. The extracted road features are then tracked with respect to the vehicle local coordinates using a nearest neighbor filter. Unfortunately, road boundary cannot be accurately detected by LIDAR sensors especially in icy and wet roads [1]. The obstacle and road detection using RADAR method is relatively old technology [5] and may not yet being used. A localization method based on omni-directional ultrasonic sensing is proposed in [6], circumventing the detection-angle limitation of ultrasonic signals. Each ultrasonic sensor is integrated with a Zig-Bee module for communication. The coordinate of the robot is obtained based on the distance measurement. The ultrasonic sensor suffers from delay as compared to IR the matter that makes them unsuitable for applications of mobile robot with continuous speed changes especially in narrow multi model roads with obstacles. IR sensors are simple, commonly used, and low cost sensing modalities used to implement the road tracking task. IR sensors may be preferable to other types of sensing units due to their faster response time and narrower beam width. Hence, two IR sensors (Left and Right) will be adopted in this paper for center road keeping of a mobile robot. To satisfy motion navigation of wall or road tracking moving robot, a controller will be designed for that purpose. Many works adopt this topic recently; most of them depend on PD or PID controllers [7], or fuzzy control [8]. Far from complexity of PID and fuzzy systems for satisfying real-time requirements such as tuning, in this work we will build an expert controller that based on rules of the form:

If condition **Then** Action

This is similar to the rules of the inference engine of the fuzzy controllers except that the variables are not linguistics.

The rest of this paper is organized as follows: Section II concerns with the details of the proposed data acquisition and control system. Section III is dedicated for the software developed for the control system. Section IV displays some simulation results to prove the accuracy and operation of the developed system. Section V summarizes some conclusions.

II. THE ROBOT CONTROL SYSTEM

The measured quantity of this system is a real world signal, which represents "distance" from the road boundary. The data flow graph of the proposed data acquisition and control system is shown in Fig.1.

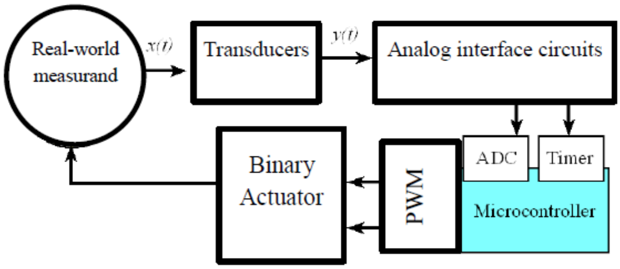


Fig.1: Signal flows of the proposed data acquisition and control system

The real-world measured variables block in Fig.1 represents the distances, while the transducers block refers to the two IR sensors. Finally, the binary actuator block is built from two power transistor drivers.

A. Infrared (IR) Sensor

The Sharp GP2Y0A21YK IR distance proximity sensor is used in this work. Fig.2 shows this sensor with its transfer function. From this figure, it is clear that if a 2V transducer voltage is read, then the object is 3cm or 12cm away. This confusion can be solved by assuming the distance is always greater than 10cm. Therefore, the right measurement is 12cm. The two IR sensors are positioned in the front of the mobile robot at 45^o as shown later in Fig.10, which will be used for keeping the mobile robot down to road.

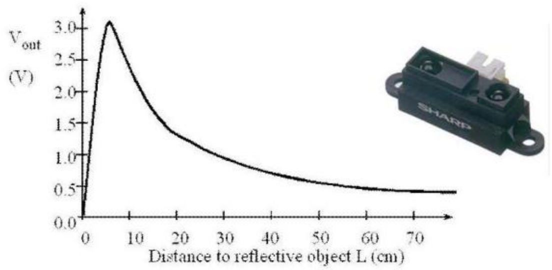


Fig.2: IR sensor with its transfer function

B. The Robot Vehiecle

The used vehicle is a new breed of tracked robot chassis designed specifically for mobile robot projects as shown in Fig.3. It has a track with two actuated wheels and two passive wheels. The clearance can be adjusted by rotating the gearboxes in 5-degrees to maintain tension as required. It has two DC motors that should be controlled with an expert PWM speed controller. It would be supplied with 7.5VDC rechargeable batteries. The maximum speed that can be obtained with this vehicle is 1km/h.

Fig.3: The mobile robot chassis

C. DC Motors Driver Circuit

Now, we need to extend the robot implementation by designing two motor drivers and connect them to the left and right motors as shown in Fig.4 [9]. The inputs to this driver circuit are two PWM signals coming from the ARM microcontroller to control speed and direction of the robot moving in the center road so that we can independently adjust power to each motor. If the friction is constant, motor resistance R is fixed, then the power can be calculated as [9]:

$$\text{Power} = \frac{8.4^2}{R} \times \frac{H}{H+L} \qquad ....(1)$$

Where H and L are the ON and OFF durations of the PWM signal. H/(H+L) is the duty cycle. The PWM signals should have fixed frequencies and variable duty cycles. Changing H leads to change delivered power since "H" is linearly proportional to the power. This technique is significant and valuable to slow down motors to control speed. Controlling the value of H will be by software as will be explained later.

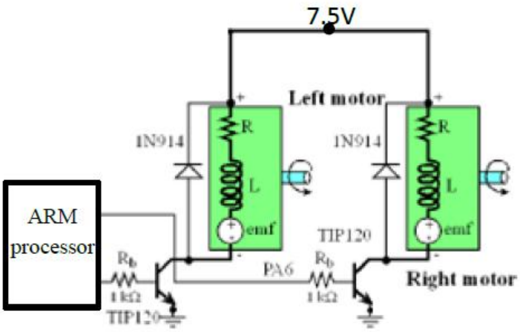


Fig.4: The driver circuit for the two motors

D. The Cortex M4 ARM Processor

The EK-TM4C123GXL board from Texas Instruments is a microcontroller-based kit that shows how to build solutions to real-world problems using embedded systems [10]. The microcontroller has a state of the art ARM Cortex M4 processor as shown in Fig.5.

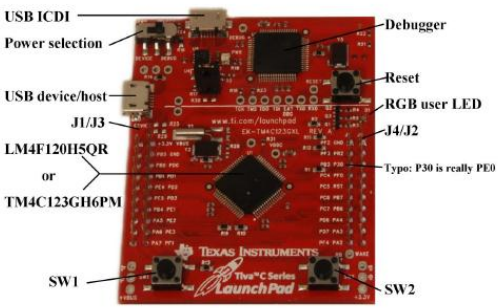


Fig.5: ARM processor kit

The design procedure uses a bottom-up approach to problem-solving producing software device drivers for the proposed expert controller. Building of the proposed device driver will be in C programming language. Designed software are first performed in simulation using *Keil uVision* Integrated Development Environment (IDE), and then built and debugged on the real microcontroller board. The programming of the kit is done by connecting it to a personal computer (with *Keil uVision* installed) via USB serial port. As mentioned before, the goal is to drive a robot car autonomously down a road. Autonomous driving is not simple. So, we have to simplify it towards satisfying the control problem. It is desired to drive down to the middle of the road, so the state variable for this problem is the distance to the left- and right-side of the road as shown in Fig.6.

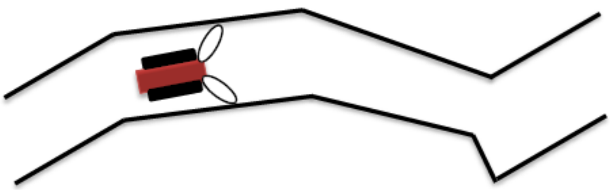


Fig.6: Movement of the robot in a structured road

If the robot is in the middle, the two distances are equal and the robot will be in the exact center of the road otherwise the controller will always try to re-adjust the position of the robot. In order to test the robustness of the proposed expert controller, the robot will be tested in a road with different width along the track as shown in Fig.6. Two analog-to-digital converters (ADCs) are used to convert the input analog distance measurements into digital numbers. If LEFT and RIGHT are ADC digital samples measured from the two IR sensors, and assuming that the distance is linearly related to *1/voltage*, then software functions is implemented to compute the distance as a function of the ADC sample (0~4095). The 241814 constant is found empirically meaning that we collected data comparing actual distance to measured ADC values. Therefore the following equations can be defined:

$$D_{left} = 241814/LEFT \quad \ldots(2)$$
$$D_{right} = 241814/RIGHT \quad \ldots(3)$$

The locomotion feedback control loop of the robot system is shown in Fig.7.

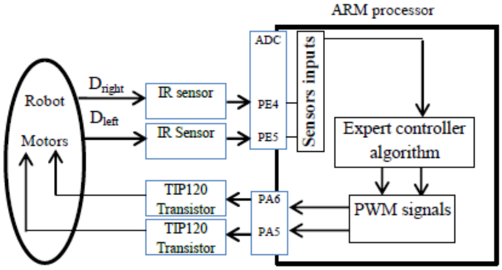


Fig.7: Closed-loop control system of the robot.

If the robot is closer to the left wall ($D_{left} < D_{right}$) one of the rules fires leading to more power will be applied to the left motor, turning robot right. Conversely, if the robot is closer to the right wall ($D_{left} > D_{right}$) another rule fires leading to less power will be applied to the left motor, turning robot left. Once the robot is in the middle of the road, power will not be changed (same duty cycle for both). The IR sensors are controlled so that their coverage distance lies within two different levels: L_1 and L_2 for left sensor and R_1 and R_2 for right sensor as shown in Fig.8. During robot movement, these distances are alternatively setup in an increasing order.

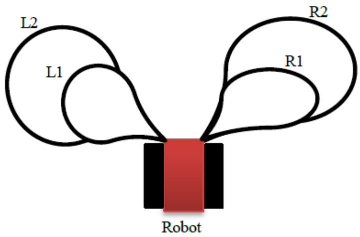


Fig.8: The coverage beams of left and right IR sensors

If no sensor detects a wall then the robot moving will be at maximum speed. When one (or both) IR sensor detects one (or two) wall, at level L2 and/or R2, then the robot moving will be at slow speed. When one (or both) sensor detects one (or two) wall, at level L1 and/or R1, then the robot will turn left, right, depending on the walls position relative to sensors. If a narrow region is detected (distance < (R_1=L_1)), then the controller must slow speed or stop. Depending on the wall position, the robot will set its speed to maximum, minimum, or zero (if the robot cannot pass the narrow region). This control algorithm can be written as a set of simple rules. The rules derived for the control algorithm are listed in Table I.

TABLE I Rules of the Expert Control Algorithm

R2	L2	R1	L1	Movement
0	0	0	0	Max. Speed
0	1	0	0	Slow Speed
0	1	0	1	Turn Right
1	0	0	0	Slow Speed
1	0	1	0	Turn Left
1	1	0	0	Slow Speed
1	1	0	1	Turn Right
1	1	1	0	Turn Left
1	1	1	1	Narrow Region (Stop if (R1 & L1)<10cm)

Logic 1=Walls in robot way.

Logic 0=No walls in robot way.

In the testing phase of the algorithm, the distance is taken with two levels: level_1=15cm and level_2=40cm. When facing a narrow region with IR sensory distances less than 10cm, the robot should be stopped to avoid insertion.

The controller on the robot is a Launchpad with ARM processor. This compact unit features universal capabilities for measuring, controlling and steering as well as PWM generation and data storage. The microprocessor allows programming in the well-known C programming language. Through a few lines of C source code the computer is able to handle a task like the "brain" of a small autonomous mobile robot. To communicate with its environment, the ARM processor receives two IR analog inputs and produces two

PWM outputs. The signals given by sensors are directed to microcontroller inputs and the signals commands are used for speed and direction control of the two DC motors. In the same time these signals can be used to turn the mobile robot with different turning radius. The developed C program, determining the actions and reactions of the robot, will be translated into a sequence of command bytes by the compiler. The commands and the related parameters may then be transferred to the microcontroller and stored into the EEPROM memory. When the robot is programmed (the program was transferred or uploaded into robot memory), it may be disconnected from the personal computer before starting the robot. The commands execution depends on data received from left sensor (L1, L2) and right sensor (R1, R2). Based on these data, the mobile robot activates one of the behaviors presented in Table I. The speeds for motors, in program, are between 0 and 255 as shown in Table II.

TABLE II Programming values for motors' speed

Speed	Speed_L	Speed_R
Max. speed	255	255
Min. speed	100	100
Turn left	50	100
Turn right	100	50

The algorithm is tested inside a road made with two wood walls with some regions narrower than others i.e. multimodal road.

III. Software for the Expert Control Algorithm

Controller rules are executed in the SysTick Interrupt Service Routine (ISR) of the ARM processor so that the controller runs at a periodic rate. The complete software of this robot is included in a project built with *Keil uVision* IDE as an interrupt-driven real-time sampling device driver. The analog inputs to the ADC are sampled at 40Hz using the SysTick interrupts. Inside the ISR, when a narrow region is detected by the IR sensors (when (R_1=L_1) < 10cm), then the robot should be stopped to avoid insertion. Hence, the developed software is an interrupt driven real-time system for mobile robot. The data flow graph of the overall software system is shown in Fig.9.

IV. The Simulation Results

In order to evaluate the road boundary detection and tracking algorithm, a prototype tracked vehicle is equipped with two IR sensors and ARM processor kit as shown in Fig.10. The two IR sensors are used with the expert controller to facilitate the center road satisfaction with road narrow regions. The accuracy of our data acquisition system, which is a relation between the estimated distance and the true distance, is measured and plotted as in Fig.11 [11]. The distances for left and right sensors are measured empirically in real time to get results displayed in Fig.11. The proper deployment of interrupt can be noticed in simulation using the logic analyzer tool available in the *Keil* IDE environment.

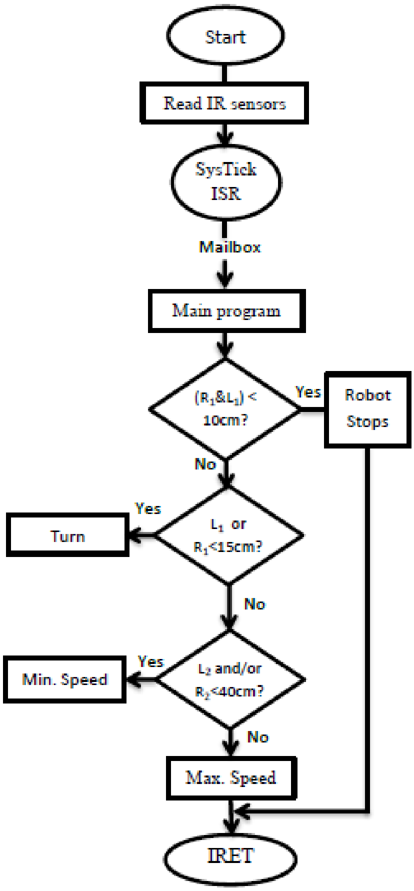


Fig.9: Data flow graph for the complete expert control system of the robot

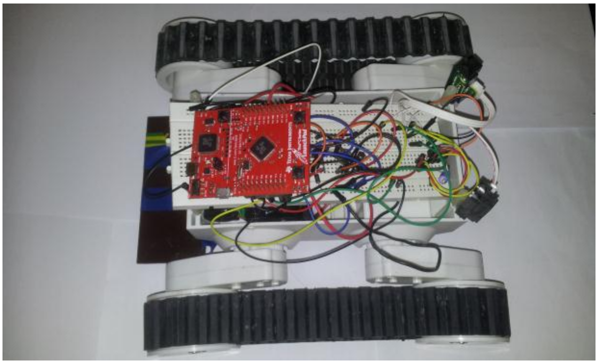


Fig.10: Real photo of the physically constructed robot prototype

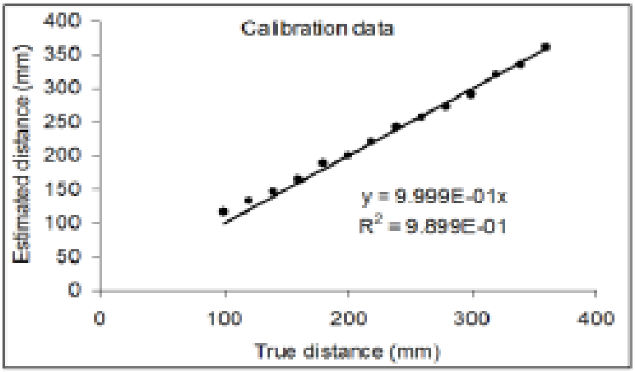
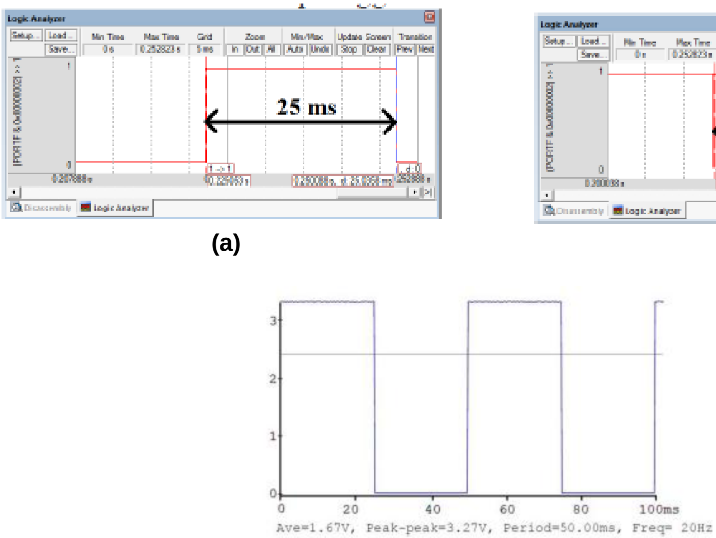


Fig.11: Accuracy measurement of the IR sensor

The ISR running at 40 Hz (25ms) is shown in Fig.12 (a). The ISR running at 0.111GHz (9µs) is shown in Fig.12 (b), which explains that the time to execute the ISR is small compared to time between interrupt triggers. The interrupt running at 25ms that measured on the real board by an oscilloscope is shown in Fig.12 (c). The C function that converts the ADC samples into distance is written with units of 0.001cm. That data stream is passed from the ISR into the main program using a mailbox inter-process communication, and the main program outputs data to the motors driver.



(a) (b) (c)

Fig.12: SysTick interrupting every: (a) 25ms; (b) 9 us; (c) 25ms on the real board

V. CONCLUSIONS

IR sensor is the most famous device since it has a high accuracy, fast response time, low cost and a wide field of view. The problem of detecting road boundaries when roads could be structured with narrow regions is discussed in this paper. We developed road boundary detection and tracking algorithm using two IR sensing devices for structured roads with narrow regions distributed along the road. The algorithm extracts road dimensions and distances relative to left and right IR sensors keeping the robot vehicle in the center of the road. ARM processor controller is used to control the navigation of the mobile robot in this environment. The speed and direction of the robot are controlled by PWM signals generated by the ARM controller. Emphasis has been attributed to the design of the motor driver switching module. The system is tested using a road prototype made from wood prepared for that purpose. It proved a good working in environments with safe movement for the robot.

الخلاصة:

إن حدود الطريق تعطي معلومات نافعة عن كيفية تحقيق مسار حركي آمن للمركبات الخبيرة والذكية. العديد من الابحاث تعاملت مع مسألة هيكل الشوارع وكشف حدودها باستخدام انواع مختلفة من المتحسسات مثل الكاميرات، المتحسسات فوق الصوتية، المتحسسات الرادارية الخ. على الرغم من ان هذه المتحسسات اثبتت مزايا جيدة في عملية كشف خرائط الطرق وبدقة مقبولة، الا ان متحسسات الاشعة تحت الحمراء هي الاشهر لدقتها العالية واستجابتها السريعة وكلفتها الواطئة. لم تتطرق البحوث السابقة الى مسألة ايجاد حدود الطرق عندما تكون الطرق غير منتظمة اي تحتوي على مناطق عريضة واخرى ضيقة. في هذا البحث تم تطوير خوارزمية كشف ومتابعة لحدود الطرق بالاعتماد على حساسين اشعة تحت الحمراء في شوارع تحتوي على مناطق ضيقة موزعة على طول الطريق. الخوارزمية تقوم بحساب ابعاد الطريق والمسافات نسبة لسينسورات اليمين واليسار وبذلك تحافظ على وجود الروبوت في مركز الطريق. تبقى هاتين المسافتين ثابتة بواسطة المسيطر الخبير. ان نوع المسيطر المستخدم هو معالج نوع ARM اعتمد بعد برمجته كمسيطر على ملاحة الروبوت في بيئة العمل. تم السيطرة على السرعة والاتجاه وذلك بالاعتماد على موجة PWM تم توليدها من قبل المسيطر. تم ايضا بناء سواقة محرك كفوءة وفعالة باستخدام احد ترانزستورات القدرة. تم اختبار النظام في بيئة شارع خشبي تم تصنيعه كنموذج لهذا الغرض. اثبت الروبوت المصمم عمل جيد في بيئة غير منتظمة وتم الحصول على حركة آمنة.

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