DRIVING CONTROL FOR UNMANNED DRIVING VEHICLE SYSTEM IN FACTORY

[1]YEN-HUI KUO, [2]SHU-HUI LIN, [3]ERIC HSIAO-KUANG WU

[1]Institute for Information Industry
[2]Dept. of Computer Science and Information Engineering,
National Central University, JhongLi, Taiwan
E-mail: [1]yenhui@iii.org.tw; [2]vickylin@iii.org.tw; [3]hsiao@csie.ncu.edu.tw

Abstract - The rapid progress of automation technologiesmerge, manufacturing processes will change dramatically.The use of smart machines will enable more flexible and autonomous manufacturing units.we know thatrelated technologies such as the Internet of Things and Artificial Intelligenceare applied everywhere, many industries will also be closely integrated with these technologies.A kind of unmanned driving vehicle for manufacturing and warehousing is popular. Generally, unmanned driving vehicle sensesa path through the built-in sensor which can be many kinds of sensors, such as magnetic type, light type etc., so that the unmanned vehiclecan operate in accordance with the pre-planned path. When the unmanned driving vehiclegets the path deviation information from the sensor,Unmanned driving vehiclebased on the deviation information to calibrate the unmanneddriving vehicledirection. The design of the path of unmanned driving vehicleis relate to environmental space and shape,there are straight path and bending path.There are the following problems based on colored tape and camera image guidance solution, the camera is set in front of thecar and lead to the driving wheel for a distance, the state of the camera image is inconsistent with the wheel state. The driving control has to take care of the inconsistenceprecisely.Furthermore, the turning mechanism of driving wheels are not tightly couple with the car's body, the turning angle of driving wheels is not align with thecar. Here, we present adriving control mechanism for colored tape guiding solutionforunmanned driving vehiclesystem. In thisstudy, we focus oncolor tapedriving control methodology based on Arduino control module interface.The implementation of the system architecture and thedriving control methodology of unmanned driving vehicle in the proposed system are described and validated in this paper.

Keywords - MACD, unmanned driving vehicle

I. INTRODUCTION

The most of the manufacturing or warehousing layout is chessboard like, the paths of an unmanned driving vehicleare formed as straight line, and the intersection of two lines is right angle normally. The jobs of driving control of an unmanned driving vehicle on chessboard like path are according to the path shape, direction deviation information and anchor (workstation mark). In this experiment, we get the path shapeandanchor from an image recognition module, driving control module generates thecorresponding instruction based on the result of image recognition process.If the directionof the car towardto the left side then system generates a rightward correction instruction, the direction of the car towardto right side then system gives a leftward correction instruction.If there were no direction bias of the car, system gives a forward instruction.When the car arrived the anchor point (where manufacturing equipment is set), system gives an arrival instruction.Otherwise, if the image recognition module got no guiding line information, it gives a stop instruction and waiting for next instruction.A camera is set in front of the car and lead to the wheel for a distance, the state of the camera image is inconsistent with the wheel,the driving control has to take care of the offset of that difference precisely. Further, the turning mechanism of driving wheels is not tightly couple with the car's body, when a turning operation happen the driving wheels is not align with car's body.Because of those issues we statedpreviously,in this paper we pay attention on (1). How to compensate the distance between camera and driving wheels? (2). How to do aright angle turn? And make theunmanned driving vehicle work smoothly.We implement aunmanneddriving vehicle system to verify this methodology.

II. THE ARCHITECTURE AND DRIVING CONTROL MECHANISM OF UNMANNED DRIVING VEHICLE SYSTEM

2.1 The architecture of unmanned driving vehicle system

Anunmanned driving vehicle systemarchitecture and mechanical of what we used in this experiment is shown as Figure 1. Some of the critical dimensionparameters are shown.The major components are described below:

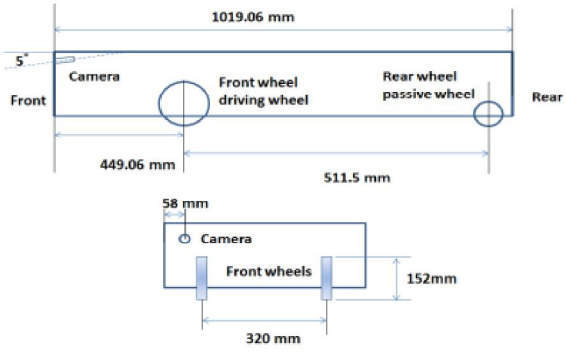


Figure1:The architecture and mechanical of unmanned driving vehicle system

(1). Driving wheels: there are two front wheels driven by electrical motor, each wheel with an electrical motor works independently.

(2). Passive wheels: the rear wheels without electrical motor they are passive wheel.

(3). Front end camera: a camera is set in the front end of the unmanned driving vehicle, the angle of depression of camera is 5°, the distance of a picture which camera takes is about 100cm in front of the unmanned driving vehicleas Figure 2 shown.

(4). Motor drive: there are two kinds of motor, one is stepper motor[1], the other is servo motor[2],electrical motoris driven bymotor drive.The states of the motor such as: run, stop, and speed is control by the signal which motor drive got.

(5). Arduino module[3]: an Arduino module as a microcontroller is connected between motor drive and computer through RS232. The control signal of motor is passed to motor drive through an Arduino module, whichcollects the signal from sensors and pass back to computer also.

2.2 The driving control mechanism of unmanned driving vehicle system

1. Image recognition module: there is an image recognition moduleimplemented in thecomputer, the hue,saturation, intensityattributes[4]of guiding line are gotten through image recognition module, computer generates an instruction to drive the unmanned driving vehiclebased on the position attributesof guiding line.

2. Computer site driving instructions: there are four majorgroup driving control instructions, which direct the unmanned driving vehicle walking along with guiding line.

A、Forward: forward with calibration, forward without calibration

B、Forward left turn: forward left turn with calibration, forward left turn without calibration

C、Forward right turn:forward right turn with calibration, forward right turn without calibration

D、Stop: stop

3. Vehicle site instructions:we use the Arduino module as connect point to link motor drive. There are two types of pins, digital and analog, the driving control instructions from computer site is charter string format, it has to transform to electronic signal and output to motor drive. In our experiment we implement a function to convert charter string to electronic signal, and the other function to convert the electronic signal which we got from sensor, to charter string and feedback to computer site.

4. Control mechanism: a control signal of motor generatedfrom the computer is passed to motor drive through Arduino module, it pass the signal from sensors back to computer also. We will descript more detail in next section.The components relation is shown asFigure 2.

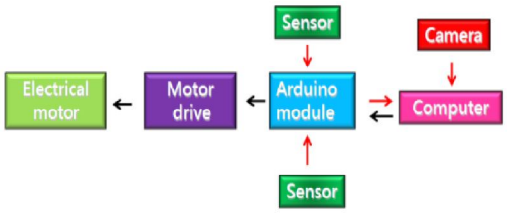


Figure2:unmanned driving vehicle system major components

In this paper, we propose somedriving control algorithmsfor the unmanned driving vehiclesystem,through the instructionsets to guide a unmanned driving vehicle working smoothly.

III. THE CHALLENGES

As we exploited in the section 2, unmanned driving vehicle system has combined many components work together, each component with differentcontrol format, we have to convert the control signal back and forth. The system should concern about the speed, accuracy, and security sort of things.

3.1 Challenges

Electrical machine is driven by Electricalpower, it works as high/low voltage or on/off state, it totally different from the computer digital charter or Booleanstate.There are some challengesinvolvedin this experiment.We have to deal with hardware and software communication interface, message conversion, analogy signal to digital data and versus,the characteristics of the motor will affect theunmanned driving vehicle systemmoving.The challenges are:

(1) Driving control message arrangement: How to arrange the human readable symbol in the shortest formatthen transport to hardware control unit?

(2) The pins of control modulearelimited: There are many hardware components connect with the computer, each of them linked by wire, thearrangement ofthepins of Arduino moduleis the second challenge.

(3) Alignment the direction of the front wheelwith car:When the unmanned driving vehicleis park, the front wheel should align with the car. How to align the direction of front wheel with the car is the third challenge.

(4) Directionestimation and compensation: The image caught by camera is about 100 cm beyond front wheels position,especiallywhile in the right angle turning operation,the guide lineis out ofpicture. How to estimate the guide line positionand give some

directioncompensationto the front wheels,while doing the right angle turn.

(5) Direction calibration: Car is running about 50 cm/sec, any direction calibration operationmust be done within 100 milliseconds.

IV. THE DRIVING CONTROL STRATEGYFOR THEUNMANNED DRIVING VEHICLE SYSTEM

The key issue of controlling the unmanned driving vehicle system is to control the speed ofmotor.The first thing we have to do is to collect motor attributes, such as motor pulse width modulation (PWM) [5] value vs. moving speed. We use PWM value to control motor rotation speed,we applied an programmable interface module to receive the control message from computer side,the interface module convertscontrol message to electrical signal then output to the motor drive, the capabilities of control unitis important. The controlmessages are send back and forth between computerand Arduino module, the message patternmust be interpreted easily. In order to drive the unmanned driving vehicle, we have to do the following things:

(1) Searchinga motor which can be controlled by program.

(2) Programming an interface module to receive the control messages from computer and transfers to the motor driverof wheel.

(3) Design acontrol message patternto control the motor run/stop, speed and rotation.

1.1 The characteristics of motor

PWM value against the speed of a unmanned driving vehicle system is shown as Figure3.

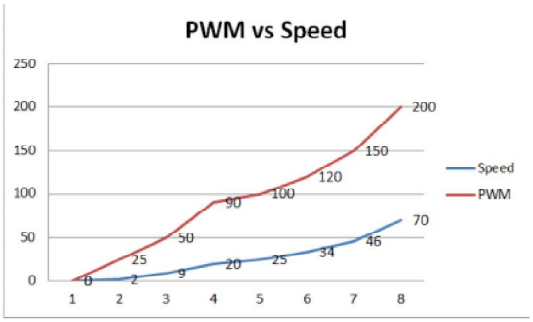


Figure3:electrical motor PWM vs. Speed

In the figure 3, we show the analog PWM value against speed value which our experiment used. When PWM at the value of 25 the car moves 2 cm per second, PWM at the value of 100 the carmoves 25 cm per second, the maximumPWM value is 255. In this experiment the highest speed is PWM at the value of 200, the speed is about 70 cm per second. As customerrequests, the speed of unmanned driving vehicle system is no more than 50 cm per second, we set the PWM value to 150 when unmanned driving vehicle run at high speed level.

4.1 Interface module

We apply a programmable Arduino module as an interface between computer and motor driver. An USB RS232 cable connectsArduino module with computer. There are 13 digital pins and 5 analogy pinson ArduinoUno module.The digital pin can be set as input or output pin,and can be set the pin at high or low state.The analogy pin can be set as input or output, the PWM value vary from 0 ~ 255.

There are two groups of code in Arduino site,groupedby matching curly braces, named setup() and loop(), we use setup() functionto configure thestate of input and output pins, that we only need to run once. Conversely, loop() function will perform actions are inside of it over and over again for an eternity.

Before we implementanalogWrite() function, we have to find out the rotation speed difference between left and right wheel. The rotation speed difference is caused by the characteristics of electrical motor, in this experiment theright wheel is lower than left wheel by 4.1 PWM value, that means, if you want to keep the car move straight forward,you have to give different parameter for analogWrite()function.

4.2 Control message pattern design

The requirements of the control message are readable and short enough.In this experiment theunmanned driving vehiclewithtwo motor driving wheels,each wheelruns independently. Each wheel has a drive control interface with four signal wiresRUN/STOP, CK/CCK, BRAKE,and SPEED, there are eight wires for two wheels.Additionally, there is amandrelwith two signal wiresCK, CCK to control the mandrel up and down.In this experiment, we design a ten characterscontrol message patternto control the unmanned driving vehicle system, as shown in the Table 1.

Table 1: message pattern

device	left wheel			right wheel			Left wheel	right wheel	Mandrel motor	
Control pin	RUN/ STOP	CK/ CCK	BRAKE	RUN/ STOP	CK/ CCK	BRAKE	SPEED	SPEED	CK	CCK
Pin pattern	H/L	H/L	H/L	H/L	H/L	H/L	H/M/L	H/M/L	H/L	H/L
Forward high speed without mandrel operation	L	L	L	L	H	L	H	H	H	H

CK: clockwise
CCK: counter clockwise

For example, the control message pattern of high speed forwardingwithout mandrel operation represents as “LLLLHLHHHH”. As the message patternrepresents in the above table, we can compose a control message patterneasily for any operation of the car.

V. APPLICATION OFTHEUNMANNED DRIVING VEHICLE SYSTEM

The application of theunmanned driving vehicle systemincludes two parts.One on PC side named Main_App, the other onArduino side named Driver_App.

(1) Main_App: Main application is running on PC side, it consists of four major modules, forward left turn module, forward module, forward right turn module, and stop module. When car is moving, it needsto calibratethe direction when car is not in the right position, so there are direction calibration [6] modules for four major modules.

(2) Dirver_App: Driver application is running on the Arduino side, it consists of two major modules, loop module and setup module.

Figure5depicts the structure ofunmanned driving vehicle system.

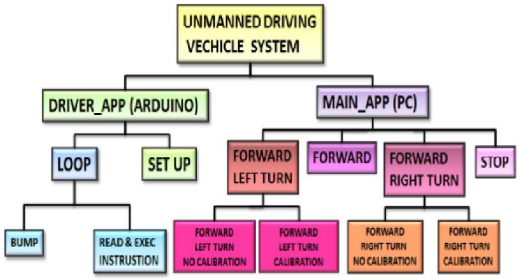


Figure5:structure of unmanned driving vehicle system

5.1 PC side driving control application

On the PC side, the driving control application named as Main_App in this experiment. The Main_App application follows the instructionsinthe job table that directs the car moving, FW: for forward moving, FW_L: for forward left turn moving, FW_R: forforward right turn moving, and STOP: for stopa car.The instruction style isshown as Table 2.

Table 2:job table

NO	DIRECTION	TO_NODE	MANDREL	WAIT
1	FW	21	0	5
2	FW_L	22	0	5
3	FW_R	23	0	5
4	STOP	24	1	5
5	STOP	24	2	5

The unmanned driving vehicle systemin this experiment is driven based on an image recognition module, the output of that modulewill pass a direction calibration message to driving control module, driving control module based on the direction calibration message to do the direction control job.Based on the direction type of Table2, we implement the driving control module respectively.

(1) Forward module:Forward module based on the parameters to construct a control message, part of the instruction is shown as follow:

```
ControlMessage = "LLLLHL";  //forward
 if (Speed == "HIGH")
          ControlMessage += "HH";
else if (Speed == "MEDIUM")
          ControlMessage += "MM";
else
          ControlMessage += "LL";
if (Mandrel == 1)  // up
           ControlMessage  += "LH
else if (Gear == 2)  //down
           ControlMessage += "HL";
else
          ControlMessage  += "HH";
ArduinoSerialPort.WriteLine (ControlMessage);
double x = 0;
while (x < Wait && ArrivedANode == false)
{
      PictureImage = null;
      Thread.Sleep(35);
      ArrivedANode = DirectionCalibration(Mandrel, Speed);
      x += 35;
}
```

In the forward control message “LLLLHL” the left side 3 charters“LLL”are for left wheel control instruction, the first “L” represents to set wheel at running state,the second “L” represents to set wheel at clockwise running state, the third “L” represents to release thebrake.The right side 3 charters “LHL”arefor right wheel control instruction, the first “L” represents to set wheel at running state, the second “H” represents to set wheel at counter clockwise runningstate, the third “L” represents to release thebrake. Speed control messagehas 2 charters “HH”, the left side “H” stand for left side wheel speed set to high speed, the right side “H”charter for right side wheel set to high speed. The control message is easy to read, that meets what we claimed “readable”.

A camera is set in the front side of the car, the image caught by camera in front of the carabout 100 centimeters, each direction calibration operation takes about 50 milliseconds, the car moves about 3.5 centimeter perimage recognition operation, there are about 28 chances to fix the direction before car totally deviate from the lane mark. It meets the challenge and keep the car moving stable.

(2) Forward left turn calibration module:

This module do the direction calibration job, when the car tends to right side against the lane mark, this module will calibrate the car direction to the left side and guide the car in the middle of the lane.Thespeed ofthe right wheel is set higher than the left wheel byPWM value 12, the turning time is depended on the deviation degree, it’s vary from 40 milliseconds to 100 milliseconds.When we do the forward left or right turn calibration, we have to do the forward

operation for a while that makes the car aligns with the wheel direction, in this experiment a forward left turn calibration doing 60 millisecond forward left turn for direction calibration operation follows astraight forward operation for 20 millisecond.Part of direction calibration operation log is shown as Figure 6.

```
Forward_LeftTurnCal ---GLineCenterpoint = 10, Wait = 60.00
ForwardNoCal ---GLineCenterpoint = 10, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 11, Wait = 60.00
ForwardNoCal ---GLineCenterpoint = 11, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 11, Wait = 60.00
ForwardNoCal ---GLineCenterpoint = 11, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 11, Wait = 60.00
ForwardNoCal ---GLineCenterpoint = 11, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 12, Wait = 60.00
ForwardNoCal ---GLineCenterpoint = 12, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 12, Wait = 60.00
ForwardNoCal ---GLineCenterpoint = 12, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 14, Wait = 40.00
ForwardNoCal ---GLineCenterpoint = 14, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 14, Wait = 40.00
ForwardNoCal ---GLineCenterpoint = 14, Wait = 20.00
Forward_LeftTurnCal ---GLineCenterpoint = 14, Wait = 40.00
```

Figure 6: Direction calibration log

An image caught by camera is resized to 20 pixels in horizontal, based on the log data in Figure 6 we have about 36 times to fix the direction before the car totally deviate from the lane mark.

(3) Forward left turn no calibration module:

This module just do the left turn operation,the speed ofthe right wheel is set higher than the left wheel by PWM value to 52.The car will doleft turn quicker, the duration is depended on the degree of turning.

(4) Forward right turn calibration module:

This module do the direction calibration job as forward left turn calibration module do, but it do the opposite side operation, when the car tends to left side against the lane mark, this module will calibrate the car direction to the right side to guide the car in the middle of the lane. The speed of the left wheel is set higher than the right wheel bythe PWM value to 12, the turning time is depended on the deviation degree, it's vary from 40 milliseconds to 100 milliseconds.

(5) Forward right turn no calibration module:

This module just do the right turn,the speed of the left wheel is set higher than the right wheel bythe PWM value to38, the duration is depended on the degree of turning.

(6) Forward left turn module:

The image caught by camera in front of the wheel about 145 centimeters, before the car operates the turning job, it should move forward some distance.The forward left turn module is much complicated, we apply forward left turn calibration module,forward left turn without calibration moduleand ForwardRightTurn without calibration module to do forward left turn. The unmanned driving vehicle is driven by the front wheels, each wheel is driven independently.We set each wheel with different speed while car is moving.Based on Figure 3 we set the front left wheel PWM value as 48 and set the front right wheel PWM value as 90.The left wheel is rolling at low speed and right wheel is rolling at high speed.Initially, we implement forward left turn without calibration for 3600 milliseconds, after that system checks the lane mark position either reach the lane mark or not.If system not got a lane mark, system is keep doing the left turn operation until the lane mark is gotten. if systemgot the lane mark, system calls forward right turnwithout calibration module to turn the wheel align with the car, that is the most tricky part of this system, because the camera is set in front the car, the image caught by camera is not at the same positionas the driving wheel, it leading about 145 centimeters, when camera caught the lane mark, the driving wheel actually over turn, shown as Figure 7.

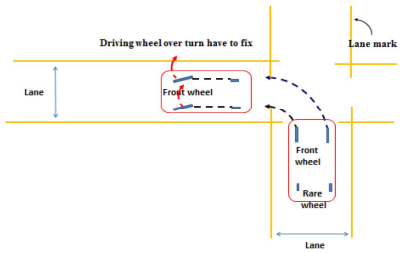


Figure7:driving wheel over turn to the left

The front wheels direction is not align with car that is why we have to do forward right turn without calibration about 1 secondto align the driving wheel with car.In this experimentapplies the forward right turn compensation mechanism for forward left turn. This forward left turnat a radiusless than 20 cm.It is much better than doing forward left turnoperation follow by forward operation in every turning operation that left turnat a radius more than 30cm.The difference of one time compensation mechanism against each forward left turn operation follow by forward operation is shown as Figure8.

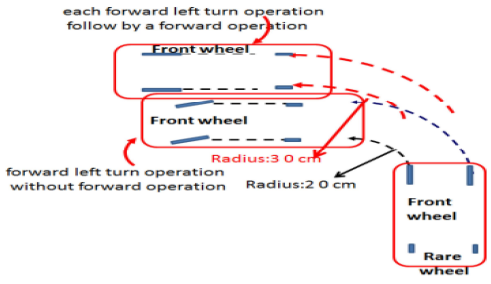


Figure8: The difference of turning mechanism

(7) Forward right turn module:

The forward right turn operation is opposite to the forward left turn. Initially, we do forward right turn without calibration for 3600 milliseconds, after that system checks the lane mark position either reach the lane mark or not, if system got the lane mark, system calls forward left turnwithout calibration module to turn the wheel align with the car. Otherwise, the system is keep doing the right turn operation until the lane mark is gotten. Due to the camera is set in front of the car, the image caught by camera is not at the same position as the driving wheel, when camera caught the lane mark, the driving wheel actually over turn to the right.In that case, we have to do forward left turn without calibration function to align the driving wheel with car body.

(8) Stop module:

This stop module sets the run/stop sate of both wheels to stopthe car. The control message looks like as "HLLHHL", from the left most charter 1 and charter 4 is set as “H”, that means the motor is at stop state.

(9) DirectionCalibration module:

When car is moving,system needs to check the car direction periodically, the checking cycle takes about 35 ~ 50 milliseconds, if the car deviates to some degree, it has to do direction calibration.In some cases the car move beyond the drive lane, we apply a similar moving average convergence/divergenceMACD[7] mechanism to direct the car back to the lane. When car is moving, we collect the lane mark position data then accumulate it. The formula is shown as below:

MACD = (MACD x (n-1) + new-lane-position)÷ n

For easy explain, we set n to 5.

When car move beyond the lane mark, the camera can’t catch the lane mark image, system use the MACD value to direct the car back to the lane. The lane position value vary from 0 to 20, when MACD value is at 18~19 before lane mark missing, the car will be directed to the right. If MACD value is at 0~1 before lane mark missing, the car will be directed to the left.

5.2 Arduino side driving control application

Arduino module is connected to motor drive module through wire. Arduino module also connect to PC by USB RS232 cable,the control signal of motor generated from the computer is passed to motor driver through Arduino module.Arduino pass the signal from some sensors back to computer also.Arduino side program is much lower level programming, it controls the device though pin with an electrical voltage at high or low state. Arduino receives a control message in string format like as“LLLLHLMMHL” from computer side, control message should be parsed and convert to control signal.

(1). Setup module: this module initials the hardware pin tocorresponding state. It sets the pin either at input state or out state.

(2). GetInstruction module: this function read the control message from computer side, and check every character is valid or not, if the input data were valid, it ready to parse and output to the pin of Arduino board to drive the motor.

(3). RunInstruction module: there are 2 kinds of the pin on Arduino board, one is digital pin, the other is analog pin, they use different function to do input or output operation:

(4). CheckObstaclemodule[8]: this function will feed back information to computer side, if the sensor connect to the pin detects anything is hit by the car, the hit message is send back to the computer. The feedback message is a string type as “STOP”, this message transfers to computer side, when computer get this message, it stop the car immediately.

CONCLUSIONS

In this experiment, we implement the above algorithmforunmanned driving vehicle system, it works smoothly. In this experiment we provide some solutions tomeet the system requirements, the problems we solved and the benefits we got as follows:

(1). Problems solved:

1). Driving control message is shortfor transmitting to the control unit, andalso shorten the transmitting time.

2). Driving control message is a character style, it is a readable style not in bit or machine code style.

3). Unmanned driving vehiclerunning smoothly.

4). When unmanned driving vehicle start from parking lot, system alignsthe front wheel with the car first.

5). When unmanned driving vehicledo the right angle turn operation, we compensate the wheel direction accurately to align the front wheel with the car.

6). There are more than30 chances to fix the directionbefore the car totally deviate from the lane mark.

(2). Benefits:

1). Shorten control message is good for quick response

2). Driving control message is readable, ease for system implementation and maintenance.

3). Left/Right turn at a small radius, good for spaceutilization.

4). There are more than 30 times to fix direction calibration, improve the safety of unmanned driving vehicle system.

REFERENCES

[1] The Stepper Motors Controller Practices by Arduino Technology,, 2014-02-25 ISBN/ISSN：9789869035606

[2] The Position Control of Servomechanism,2008-04-16,http://www.auto.fcu.edu.tw/wSite/publicfile/Attachment/f1254446642261.pdf

[3] arduino interactive design , 2014-08-12, ISBN : 9789863471004

[4] color image enhancement with exact HIS color model, international journal of innovative computing, information and control volume 7 number 12, december 2011

[5] Pulse-Width Modulation (PWM),http://wiki.csie.ncku.edu.tw/embedded/PWM

[6] Design and Implementation of Fuzzy Controlfor the Autonomous Vehicle, July 2007,National Chiao-Tung University

[7] Learning analyze technology without pain , ISBN 9789867283368

[8] Easy to play LEGO robot EV3-G programming,bar code : 9789864555116

★★★