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STEERING CONTROL METHOD BASED ON TSL1401 LINEAR SENSOR ARRAY

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ABSTRACT

The development of an automatic steering control system has been a major concern for most researchers towards the realization of a fully automated car in the near future. It is believed that such system could mitigate the effect of road accidents caused by human errors. Therefore, this project was carried out to develop a prototype of an intelligent car that has the capability to navigate automatically without human interference. A Freescale cup development kit was utilized in this project that consists of a development board, a servo motor, two DC drives, a driver circuit and a vision sensor. A special test track was developed using a white material with black lane along both edges of the track. A vision system, based on TSL1401 Linear Array Sensor, with 128pixels of detection resolution was developed to sense the track condition. The data captured by the sensor was sent to a Freescale FRDM-KL25Z processor and the steering angle of the car was determined. The programming code was written in C language using Freescale CodeWarrior software platform. A steering control method was introduced to navigate the prototype car autonomously. The method utilizes the linear sensor as it inputs parameters to identify current position of the car and determines the output parameters that dictate the car behavior. As a result, the car managed to steer automatically in various route conditions such as straight path, ramp, junction and also sharp turn.

Keywords: steering control; automated car; FRDM-KL25Z; ARM; TSL1401 sensor.

INTRODUCTION

Death tolls caused by road accidents are alarmingly reaching high levels in recent years. Thus, the development of a smarter car has been a major concern in most country. Steering control is one of the basic elements in an automated car. One of the common techniques used in the navigation systems for automated car are based on the line-tracking method. Many researchers have proposed the line-detection using vision system to navigate an autonomous car (Shubra Deb Das *et al*., 2013), (Guo-Zu *et al*., 2011). A vision sensor has much spatial and optical resolutions compared to the conventional method (Norhashim and Noorfadzli, 2012). With the rapid of microelectronics technology, an intelligent car motion control system described by Xi *et al.* (2011) based on single-chip AT89C52 microcontroller. They proposed a system that has multi-sensor fusion technology, high flexibility, equipped with automatic obstacle avoidance and route tracing.

Jian and Guangzhong (2009) and Qu *et al.* (2012) design a fuzzy-based steering controller by processing the route information using a miniature Charged-Coupled Device (CCD) camera. It helps the car model to run smoothly on a given raceway including 'S' curve and intersection at a speed of approximately 2m/s. Besides, route identification technique based on Infra-Red (IR) sensor array is implemented by Singh *et al.* (2010). Utilizing proportional-integral-derivative (PID) control method, the car captures and process information in real time, identifies track condition and optimizes the actual performance of the navigation (Singh *et al.* (2010) (Shuan Chen *et al.*, 2013). Median filtering algorithm with T-shaped window is proposed by Ning *et al.* (2011) to optimize the route identification capability and reduce unwanted noise from the camera sensor. This technique improves the edge detection by filtering noise and smoothing the whole image.

However, the use of CCD camera as part of the navigation approach requires complicated data processing and also very vulnerable to external light interference (Junhua *et al.,* 2010) (Zhang *et al.* 2014). This paper propose the use of TSL1401CL linear sensor as the smart car vision system and also discusses a method for steering angle and speed control calculation in order to perform autonomous navigation

VISION SYSTEM AND CONTROL APPROACH

Figure-1 shows the arrangement of the vision system used in this paper. A linear sensor array based on TSL1401CL was chosen in this project as it offers less pixel count than other types of sensor. Table-1 illustrates the pixel comparison between three different sensor modules.TSL1401CL linear sensor consist of 128x1 pixel array of linear image sensor with focusable 7.9mm lens. Each pixel contains a photodiode, charge amplifier circuitry, and an internal pixel data-hold function. Besides, the sensor also comes with a five way printed circuit board (PCB) connector for interfacing purposes including one analog pixel output. Compared to the sensor used by Jian and Guangzhong (2009) and Xi *et al*. (2011), this sensor is simpler and easy to use. Moreover,

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the frequency of capture can be manipulated by the user based on several considerations such as surrounding light exposure and sensor position. The allowable exposure time for this sensor is between 267 microseconds to 68 milliseconds. Other than that, it offers sufficient definition for line detection application while its lens can also be adjusted and changed for different resolution (Freescale, 2011).

Table-1. Pixel comparison between three different vision sensors.

Vision Sensor	Pixel count
CM-26N/P CMOS Color Camera Module	640 x 480
RMRC-520 520 Line CCD Camera (NTSC)	768 x 492
TSL1401CL Linear sensor array	128 x 1

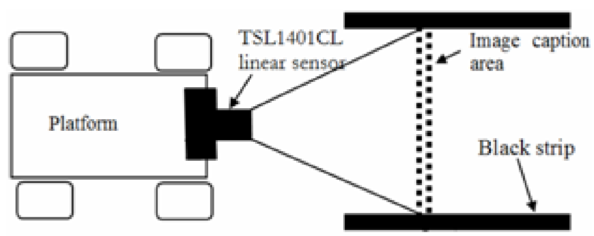

Figure-1. Vision system based on TSL1401CL linear sensor.

Installation

The smart car test bed used in this project was based on a Freescale cup smart car kit that consists of a 1/10th scaled car, a Freescale Freedom (FRDM) development board and a motor driver shield as shown in Figure-2. The linear camera sensor was mounted on top of the car kit to get the optimum field of view. The orientation angle was also determined to get the farthest possible detection distance for more efficient steering control.

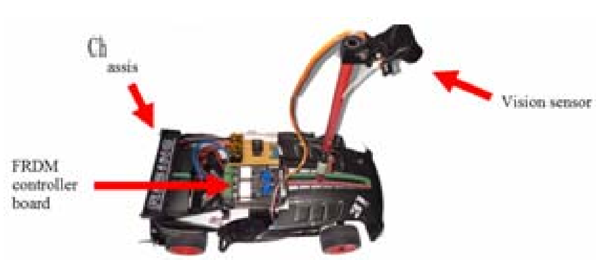

Figure-2. The smart car test bed.

Image detection

When the light bounces from the environment, it enters the camera through the lens and deflects light into the sensor. Each pixel will gain charge at the same time depending on light intensity. The amount of charge obtained at each pixel is directly proportional to the light intensity and integration time (TAOS, 2011). The sensor will later relay each pixel value to the analog output (AO) terminal, one by one until all pixel charges are released. Subsequently, the signal will be converted into a digital form using 12bit analog to digital conversion (ADC) function in the controller board. As a result, analog data in each pixel will be represented by digital value ranging from 0 to 4096. Figure-3 illustrates the analog output samples from the sensor. Since the camera employs a linear image sensor, it only captures one single strip of the full image.

In order to assist the line identification, a threshold value of 3500 was introduced in the source code. For every sample that exceeded the threshold value, a value of 1 was given indicating the white sample. Besides, if the reading was lower than threshold value, the camera was considered to detect a black surface and a value of 0 was given.

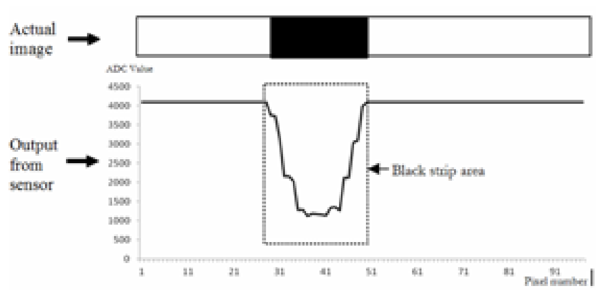

Figure-3. Analog output samples from the sensor.

Steering control method

The process of controlling the car position based on the black line location is described in Figure-4. The line scanning action was carried out from the center of the track to the right and left edges consequently. Two counter variables were introduced in the program code. If the sensor pixel detects a white surface, the counter value will increase; otherwise it will stop looping and proceed to the next process. Next, the quantity of white pixel from left (x) and the total number of white pixel on the right sides of the track (y) was calculated. Both parameter x and y are expected to indicate the location of the car as illustrated in Figure-5.

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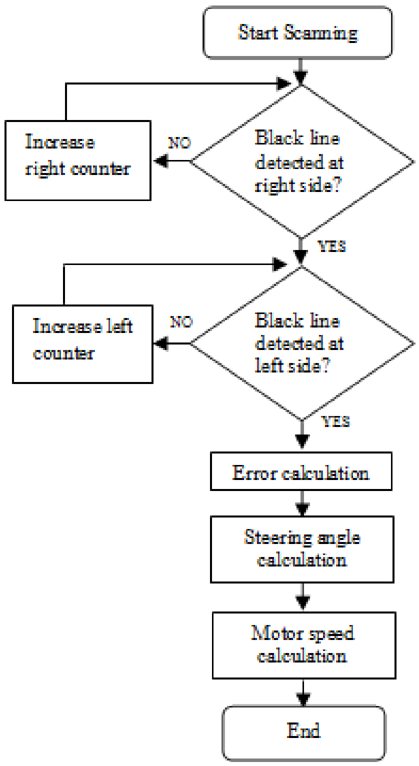

Figure-4. Control and line identification process.

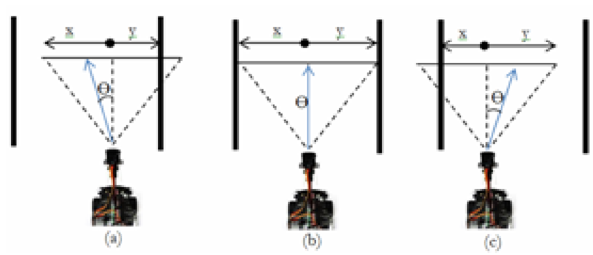

Figure-5. Position and steering angle estimation based on edge line location.

Once the number of pixels on both sides was obtained, the set point (SP) was determined by using equation (1). The error value can be calculated by simply subtracting summation of x with summation of y. If the car position was at the center, the error should be equal to zero. Besides, if the error value was not equal to zero, it indicates that the car position was not at the center and the system requires some readjustment. After that, the steering position parameter (Ø) was calculated by using equation (2) and the actual steering angle (Θ) can be estimated using equation (3), where β is equal to 42.857.

$$SP = \frac{\sum x + \sum y}{2} \tag{1}$$

$$\emptyset = \frac{\sum x}{-SP} + 1 \tag{2}$$

$$\theta = \emptyset\beta \tag{3}$$

The movement of the prototype car is based on two separately driven wheels. When the car deviated from the center of the track, the maximum speed, (m_speed) should be reduced to minimize the error. The speed parameter is ranged from 0(stop) to 1.0(full speed). This can be done by implementing equation (4) and (5) to control the speed of both right motor and left motor respectively. It helps to enable the differential drive mechanism use in the prototype car. For example, if the car diverges to the left side of the track, the speed of right motor is expected to be reduced while the left motor speed is expected to be increased. This will assist the steering action and also help to provide braking mechanism when the car deviates from the track.

$$R_{motor} = \sum x \times \frac{m\_speed}{SP} \tag{4}$$

$$L_{motor} = \sum y \times \frac{m\_speed}{SP} \tag{5}$$

Source Code

The proposed steering control method was embedded into the system by using C language. The code snippet to control both steering and speed of the prototype car is shown in Figure-6.

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```
void Linescan()
{
for(i=63;i>=0;i--){
if(LineScanImage0[i]>3500) countL++;
else break;}
for(j=64;j<128;j++){
if(LineScanImage0[j]>3500) countR++;
else break;}
}
if ((i==63 && j==64) || (i==0&&j==127))
if(poss>-5 && poss<5){
servoPos = sPos;
R_motor = R_m;
L_motor = L_m;
TFC_SetServo(0,-servoPos);
TFC_SetMotorPWM(L_motor,R_motor);
sPos =  servoPos;
R_m = R_motor;
L_m = L_motor;}
else{
if(poss<0){
TFC_SetServo(0,-1);
TFC_SetMotorPWM(0,0.4);
sPos =  -1;
R_m = 0.4;
L_m = 0;}
else{
TFC_SetServo(0,1);
TFC_SetMotorPWM(0.4,0);
sPos =  1;
R_m = 0;
L_m = 0.4;}
}
}
else{
SP = (float)((countR+countL)/2);
servoPos = (float)(countR/(-SP)) + 1;
R_motor = (float)countR*(m_speed/SP);
L_motor = (float)countL*(m_speed/SP);
if(R_motor>max_speed)R_motor=max_speed;
if(L_motor>max_speed)L_motor=max_speed;
if(R_motor<min_speed)R_motor=min_speed;
if(L_motor<min_speed)L_motor=min_speed;
TFC_SetServo(0,-servoPos);
TFC_SetMotorPWM(L_motor,R_motor);
}
```

Figure-6. Source code implementation.

EXPERIMENTAL RESULTS

Steering response

The car model used in this project utilizes a servo motor to steer and provide the maneuvering action. The proposed control algorithm was implemented in the system and the car steering responded differently according to the car position from the center of the test track as shown in Figure-7. Figure-7(a) depicts the responds of the front wheel when the car position was at the middle of the track. It shows that both wheels were heading straight while in Figure-7(b), both wheels turn towards the left side of the track as the car position was at a distance (p) from the center. From the test results the steering angle varied slightly different from the estimated angle based on the calculation. This was because; the alignment of the front wheels was not properly done due to the mechanical limitation of the prototype car. Table-2 provides the detail of a few samples taken during the test.

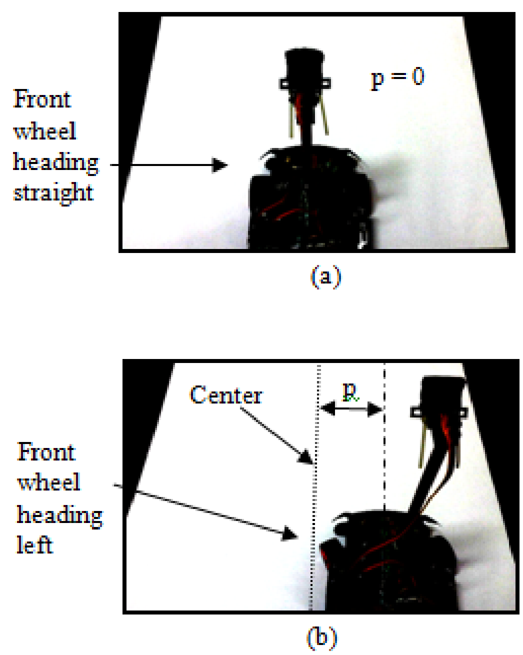

Figure-7. Steering response.

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Table-2. Steering Angle results.

Car position from center (p) (inch)	Left pixel (x)	Right pixel (y)	Set Point (SP)	Calculated angle (Ө)	Measured angle (Ө)
8.0	29.0	48.0	38.5	10.6	23.0
6.0	41.0	48.0	44.5	3.4	18.0
4.0	45.0	48.0	46.5	1.4	13.0
2.0	47.0	48.0	47.5	0.4	6.0
0.0	48.0	48.0	48.0	0	0.0
-2.0	48.0	47.0	47.5	-0.5	-5.0
-4.0	48.0	42.0	45.0	-2.9	-12.0
-6.0	48.0	38.0	43.0	-5.0	-17.0
-8.0	48.0	25.0	36.5	-13.5	-22.0

Car navigation

An autonomous navigation test was also conducted to study the feasibility of the proposed control algorithm. Figure-8 illustrates the capability of the car to navigate autonomously through various track conditions such as T-junction (Figures 8a and 8b), S-curve (Figures 8e and 8f), uphill and downhill and also sharp turns (Figures 8c and 8d). The car was able to capture and process the track condition efficiently and navigate smoothly. On the straight path, the car will accelerate at full speed and will automatically reduce its speed when it undertakes sharp turn.

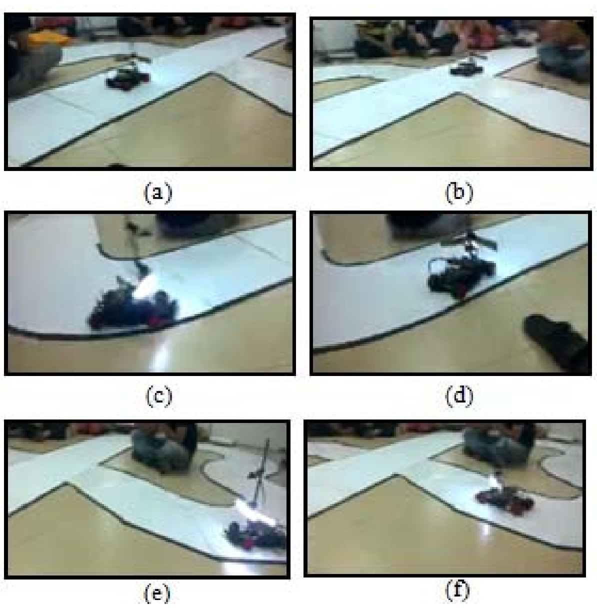

Figure-8. Navigation test.

CONCLUSIONS

In this paper, an autonomous navigation of the smart car test bed has been successfully achieved using TSL1401CL linear sensor as its vision system. A method for steering angle calculation has also been discussed and presented. Test results indicate smooth car maneuver and uphold ability to capture and follow the track guidelines without fail. Further improvement can be made by embedding sophisticated control scheme such as PID and Fuzzy to the existing system to achieve faster response, more effective and stable car.

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