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Improved Line Tracking System for Autonomous Navigation of High-Speed Vehicle

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ABSTRACT

Line tracking navigation is one of the most widely techniques used in the robot navigation. In this paper, a customized line tracking system is proposed for autonomous navigation of high speed vehicles. This system has been proposed an automatic car navigation system based on infrared sensors and intelligent line. By adding the status information of the road in the form of diagonal lines to the tracking line they're smart. The infrared sensors by read the tips that have been added to the tracking lines are aware of the vehicle of the road ahead. Therefore, car navigation act with more intelligence does. In the presented system, auxiliary information -in addition to the road path- is added to the tracking lines such as locations of turn and intersections in the real roads. Moreover, the geometric position of line sensors is re-designed enables the high rate sensing with higher reliability. Finally, a light-weight navigation algorithm is proposed allow the high-speed movement using a reasonable processing power. This system is implemented on a MIPS-based embedded processor and experimental results with this embedded system show more than 98% accuracy at 200km/h with a 1GHz processor is viable.

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1. INTRODUCTION

Movement is one of the most influential factors in daily life of people in modern societies. With growing of the cities and expansion of cars, guidance of the cars is getting quite harder and harder and driver distraction can also exacerbate these factors. In Europe, over 40000 people were killed through road accidents in the year 2000 with another 1.7 million injured [1]. The great majority of these accidents were due to human error while only 5% caused by defective vehicles. High speed requirements and growing congestion of the roads will tend to more and more accidents. In this situation, car automatic or even semi-automatic car navigation systems can plays very critical role.

Autonomous navigation broadly refers to any technique, approach or method which can be utilized to navigate a vehicle (terrestrial, marine, airborne or deep space)safely on its own in a static or dynamic environment without any intervention by a human controller. Autonomous navigation is a way to help achieve better route planning, path prediction, smoother maneuverability in dynamic environments and thereby achieving optimized fuel efficiency and enhanced human comfort [2].

Successful high-speed autonomous navigation requires integration of tools from robotics, control theory, computer vision and systems engineering. Many approaches are tried for autonomous car navigation (ACN) in last decades and bulks of them were promising with current technologies. Autonomous vehicles will in all probability dominate the roads in the near future and will provide the drivers with extreme safety and assistance features, such as computer vision, sensing abilities, accident warnings, safer lane changing, parking assistance, collision avoidance technologies, optimal routing, vehicle to vehicle communication, communication with ground infrastructures and others[3].

A burst of research and experiences are reported on positioning and navigating of autonomous cars and robots and various methods such as GPS-based method, inertial navigation system (INS), vision-based method, fusion of map and sensor data, line tracking method and soon are used. However, the situation and issues of car navigation are very different from robot control. For example, in car navigation, speed of movement is very higher than robots and delay of any navigating algorithm will be crucial. Therefore, regular line-tracking algorithms cannot be used directly in automatic car navigation.

In general, line followers are the mobile robots that automatically follow the lines drawn on the surface. The path normally is a black line that is drawn on a white background (or reverse). Line trackers systems can be used to guide the robots to follow a line with any guidance mechanism. Moreover, it can be used to control robot speed based on environmental conditions. Speed should be such that the robot does not deviate from the path when passing the turn. Therefore, we review the contributions related to autonomous car navigation and line tracking systems.

Authors of [4] focused on design of a line tracker and its implementation on Freescale S12X microcontroller it is able to detect predefined start and stop markers. They try to improve input signals as signal condition to use in car algorithm but this method does not consider line as active objects.

In [5], three control algorithms (gray scale, X-Y and binary) were implemented on smart car with new automatic steering control and adaptive cruise control. Authors of [5] analyzed result of this algorithm on the various parameter like speed, tracking time and tracking efficiency and show that binary algorithm have better speed accuracy and tracking accuracy and complete rather than other algorithms.

Vision-based car navigation is outgoing evolved but it seems that visual approaches are very hard to automated, especially for cars which must be routed in complicated roads [6], [7].

In [8] and [9], the wireless sensors have used as landmark. In this paper, wireless sensors are frequently published their position and when the vehicles are in the range of this sensor find their path. This method is expensive due to the use of wireless sensors. Moreover, the tolerability of this system in real road accidents is low too.

Most of navigation techniques have recently been proposed based on Global Positioning System. These systems have been improved to help car driver not to automate the navigation, moreover, this system has an error up to about 100m [10].

The landmarks that are used in car navigation are mainly cognitive and semantic but not structural [11]. Line is widely used as a Landmark in robot navigation [12], [13]. Guide lines are usually simple black lines that are drawn on a white background.

In recently research lines usingas guidance to determine whether agent follow the right path or not, this usage causes the agent not to be aware of road restrictions that result in reduced operation maneuverability and lower its performance. In this paper we use the lines as landmark; these lines provide information about road to vehicles (such as, the turn, intersections, places with high traffic, overtaking prohibited and etc.). Consequently, the algorithm used for vehicle navigation is more intelligent to navigate the path.

Field of the vehicle is field of a speed and real-time decisions. Therefore, it is necessary to provide methods and algorithms that are fast enough to be able to answer these needs. These requirements can be provided with prior techniques that make the car aware of road construction to be fast enough. For areas that need more control of the car, GPS with digital maps can be used to provide this information to [14], [15] or another example, like curve speed warning [16], [17]. The problem there is that in many cases we do not have road maps paths or GPS does not work well. But the lines as a factor in a smart environment that makes us aware of road construction has not been studied until now So, in this paper we are trying to make this case analysis.

In this paper, we customized an infrared line tracking system to be used in high speed vehicles. In the proposed system, an improved arrangement for the infrared sensors is suggested enabling the low error navigation in high speed movements. Moreover, the shape of the tracking lines are revised to represents some other information about the road in addition the absolute path. Finally, we proposed a light-weight navigation algorithm to execute the positioning and planning the movement at rational time. The proposed system is implemented on a MIPS-based embedded system and evaluated with different clock frequencies to reach a reasonable execution time/power tradeoff.

This manuscript is organized as follows. Section 2 describes the key features of state-of-the-art line tracking systems. In Section 3, the structure of the proposed system is explained and Section 4 is dedicated to the proposed vehicle motion algorithm. In section 5, experimental results and analyzes are reported and Finally, Section 6 concludes the paper.

2. LINE TRACKING SYSTEMS

Generally, a line follower robot is a self-operating mobile machine that follows a line drawn on the road. The path can be a visible black line on a white surface (reverse)or it can be invisible like a magnetic field.Sophisticated robots can distinguish between different colors, making it possible for them to follow one among several lines accurately. Such devices can be subjects of competitions in robots and computing, and they also have a number of real world applications. For example, robots in warehouses can follow lines to pick up and deliver products along a specific route [18]. Figure 1 shows a simple view of a line tracking robot and some of its internal components. This figure shows a robot consisting of power supply module, controller board, sensors and other electro-mechanical components navigated with a white line on black background.

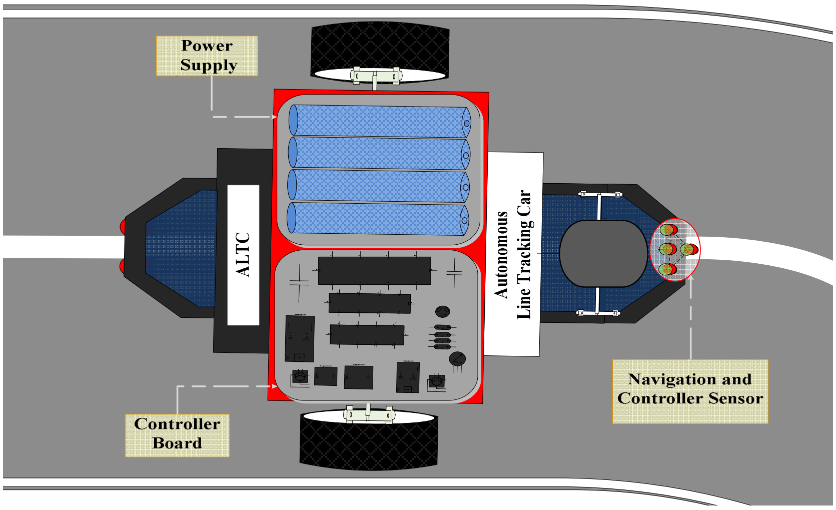


Figure 1. Basic components of a line-tracking robot

A line follower robot requires a chassis that can allow it to move, whether on wheels or via another mode of locomotion. It also needs detection devices to find lines, and on-board computing to process information. A simple camera may be used to provide an inexpensive method for spotting and following lines. A processor interprets the input from the camera and controls the movement of the robot [19].

In practical applications, considerable challenges are existed to determine how well a line follower robot works. One is a complex path with lots of sharp turns and overlapping lines, which can confuse a robot with limited programming. Technicians can also place lines of different colors to see how the robot responds, and may set up a course on an incline or with other obstacles to determine the degree of sophistication in the programming. An advanced robot can compensate, while others may not be prepared for rough terrain or other problemsas the following [18]:

- Taking the line position with optical sensors mounted at the front end of the robot. Most are using several numbers of photo-reflectors, and some leading contestants using an image sensor for image processing. Therefore, the line sensing process requires high resolution and high robustness.
- Steering the robot to track the line with any steering mechanism. This is just a servo operation; actually, any phase compensation will be required to stabilize tracking motion by applying digital PID filter or any other servo algorithm.
- Controlling the speed according to the lane condition. The speed is limited during passing a curve due to the friction of the tire and the floor. Better mechanisms, therefore, can improve the power of maneuver. The speed of the robot, hence, can be increased. Consequently, the robot's performance can be increased, too.

Line tracking system is relatively simple in design and implementation, it can distinguish with chip sensor such as photo diode, and photo transistor coupled whit light emitter device such as common LED or infrared Led [4]. The emitter and sensor pair forms a reflective light detector unit which could be used to sense line based on intensity of light reflected back from the color line.

Structured line can decrease cost of design and implementation mobile robot. In [13] proposed a latest idea of using only on discrete sensor for mobile vehicle to detect a line having two color shades on a white background surface. Result of this paper show that single sensor managed to allow the vehicle to maneuver as effectively on the line.

Authors of [20] focused on vision-based line tracking application. Result of this paper described a line detection algorithm; it can be implemented on an embedded vision system with limited resource.

In [21], an intelligent vehicle system is introduced based on infrared photoelectric sensor trace. The intelligent vehicle was tested on the road which middle was pasted black mark line. The result shows the intelligent vehicle can run at high speed and stability on the straight road. As long as the vehicle speed is controlled appropriately, the vehicle can run smoothly on the road bend.

3. PROPOSED NAVIGATION SYSTEM ARCHITECTURE

Figure 2 shows the block diagram of the presented line tracking system. In this system, microcontroller manages the motors of the wheels and steer based on the current state of the agent and sensors information.

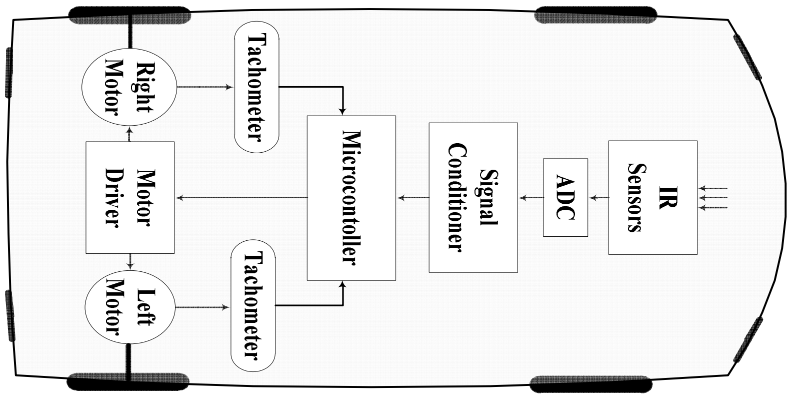


Figure 2. Block diagram of control system

As mentioned before, regular line tracking system cannot be used generally for high speed vehicles. Therefore, we suggested new configuration for the tracking lines corresponding with new tracking algorithm. In a line tracking system, position of the vehicle is determined based on the infrared sensors that are placed under the vehicle. Infrared sensors output are as analog signals that show the vehicle position relative to the original lines. Thus, it is necessary to signal that converted to digital form, this action is done by the analog to digital converter that is embedded in system. Vehicle's embedded system controls the speed and direction of the Vehicle's based on navigation algorithm loaded on it gives necessary instructions to the steering servo motor.

3-1. Suggested Tracking Lines

Traditionally, roads are equipped to white and clear lines to guide the drivers. These lines are drawn on black background (normally asphalt) that have very good contrast and acceptable visibility for the lines. Current roads may have multiple lines to partition the wide roads to some driving lines. Road lines may be solid or dashed that each of these states has a special meaning for the derivers. Figure 3 shows the lines on a regular road.

In regular roads, cars do not cross the lines in normal situations and driving is performed between the lines. Normally, the lines are drawn left and right sides of road to prevent vehicles out of the road. Conventional road's lines have some features:

- They are very low-cost.
- Lines are very robust in real world.
- Implementation of them is very simple whenever necessary.
- New information can be added into them by changing their shape.

We suggest that the conventional roads' lines changed as shown in Figure 4. In the suggested structure, two lines are added to existing lines that called Tracking lines. New lines are drawn on the center of driving paths such that cars moved along on top ofthem. Tracking lines are sensed by line tracking sensors.

Moreover, we suggest that the Tracking lines before some parts of the road such as the turns, intersections, places with high traffic and generally places that need more control of the vehicle have special shape that can be sensed by the sensors. We called these points of the road as *special regions*. Our analyses on features of the line tracking sensors show that dashed lines are suitable for this purpose as shown in Figure 5.

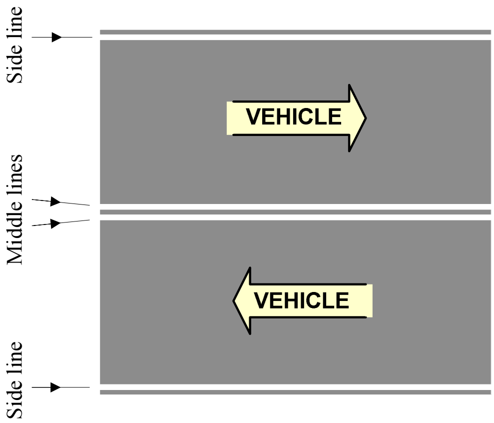


Figure 3. Road lines in a two-way road

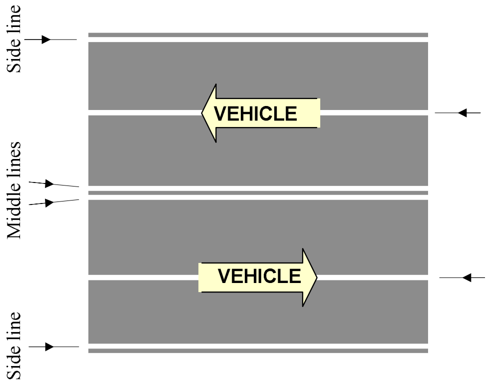


Fig. 4. Suggested structure for the road lines

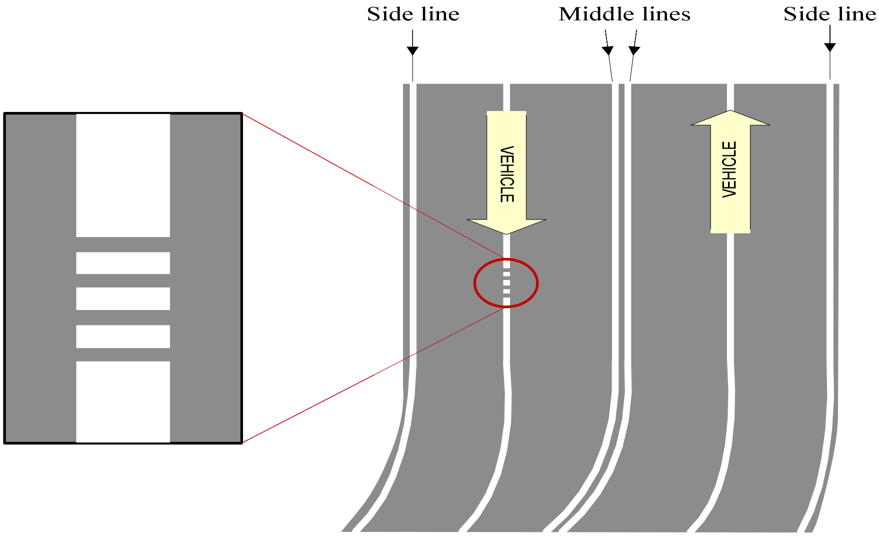


Fig. 5. Dashed lines to show the special regions of the roads

As shown in Figure 5, before any special region of the road, dashed pattern is drawn on the roads showing the type and strength of the road. For example, number of dashed lines can show the angle of the turn. This information aids the navigation system to make more accurate and consequently safes navigation.

We assumed that line width is 20mm in simulation that is scale base on real line that have 20cm width and 60m length. There are another sensors to read transverse lines on the original lines (guide line). Data read from these sensors and then converted to a pattern of zeros and one then based on these data, the algorithm that loaded on the vehicle's microcontroller performs the necessary operations.

3-2. Infrared Sensors

Sensors are basically electronic devices which are used to sense the changes that occur in their surroundings [22]. The change may be in color, temperature, moisture, sound, heat etc. They sense the change and work accordingly. In Infrared sensor there is emitter and detector. Emitter emits the IR rays and detector detects it.

We used two set of four infrared sensors in our vehicle. The first set of sensors is used to navigation the car and the second set are utilized for detecting the special regions. Each set of infrared sensors are located as cross shape which is widely used [23]. Configurations of the sensors are shown in Figure 6.

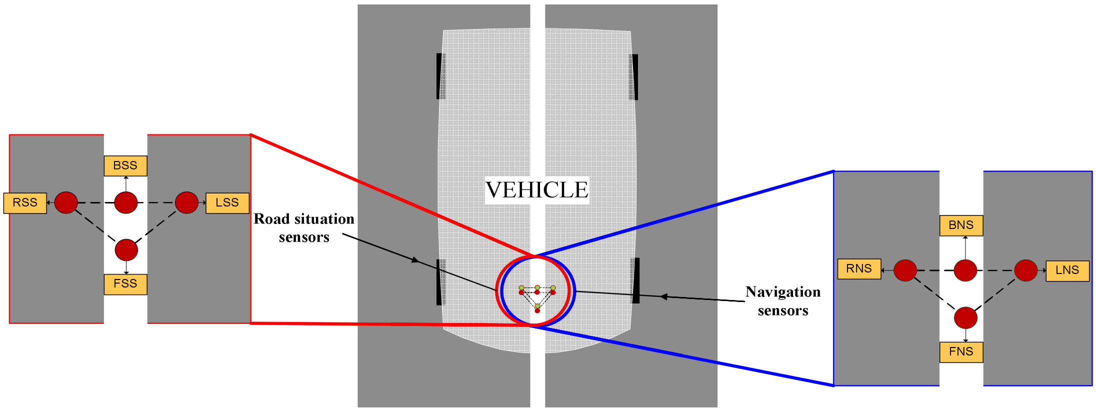


Figure 6. Configuration of infrared sensors

Robot must be aware of their status at any moment until be aware of its position relative to the line.Therefore, it is better to robots, the sensor is in the middle of the body. Ideally, sensor is always on the line but it’s impossible any time because robot my deviate from path in some places (for example turn). It is clear, if we used higher number of sensor vehicle movement will be smoother and reliable for sharp turn but using more sensors also require additional processing and complex programming and more time should be spent for data processing. Therefore, we must have a tradeoff between the number of sensors and the computational speed.

In cases where the robot is out of line it is necessary to know that have deviated from the left or right of line. Therefore, sensors are placed on the right (Right Navigation Sensor (RNS)) and left (Left Navigation Sensor (LNS)) of middle sensor. Thus, the initial state of the sensors can be made to the three sensors are placed in one direction. but this arrangement for the sensor when the robot is placed in the turns is not appropriate. In this case it is better instead of one sensor in the middle (Back Navigation Sensor (BNS)), use of two sensors that are located in the middle with appropriate distance (BNS and FNS) Therefore, even when in case the robot in a very sharp turn placed, at least one sensor is on the line and identify the status line is done the better. We use this model until never don't placed the line between the sensors.

The side sensors are used to prevent the exit vehicle of the road. When these sensors are activated (When these sensors are placed on the roadside line) this means that the car is running out of road as a result, reduce vehicle speed until be stopped.

The distance between each sensors depend on number of sensors used and width of straight line (distance between sensors should be less than width of line) although distance between sensors may not be constant it depends on the logic. Figure 7 shows the arrangements of the sensors in the proposed system.

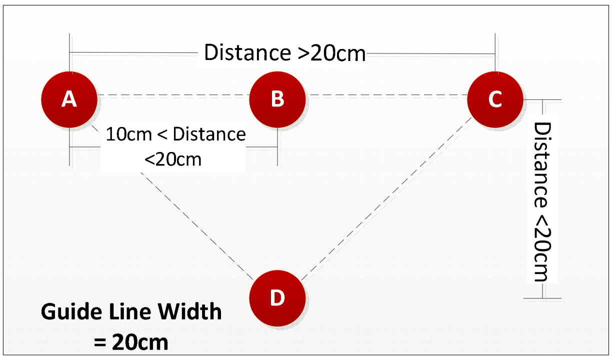


Figure 7. Arrangement of sensors in the proposed system

4. PROPOSED NAVIGATION ALGORITHM

Embedded software program is an essential part of the mobile vehicle to function properly in tracking the line as smooth as possible. The main mission of the algorithm is to move the vehicle on the line in a very smooth fashion. Apart from the task, the algorithm also depends on hardware including number of sensors, type of motors, chassis etc. Figure 8 shows the proposed algorithm. The detailed description of the algorithm is described as follows.

```
Line Tracking Navigation Algorithm
Step 1:     Read start position
Step 2:     WHILE(TRUE)
Step 2-1:     IF (Side sensors are activated)
                  Stop of the car
              END IF
Step 2-2:     IF (The line tracker sensors are activated)
                  IF (Control sensors are not activated)
                      Track line
Step 2-3:         ELSE
                      Reduce speed
                      Track line
                  END IF
              END IF
Step 2-4:     IF (The Line tracker sensor is not active)
                  Read the previous active sensor
              END IF
            END WHILE
```

Figure 8. Proposed vehicle navigation algorithm

Step 1: In this step, Initial state of car on the tracking line is specified. We assume that start position of car is on the line.
Step 2: This stage of the algorithm is an infinite loop wherein each loop executes the main navigation algorithm.
Step 2-1: In this step, the left and right sensors in front of the vehicle are checked firstly. If these sensors are activated algorithm assumes that vehicle is being deviate from the road Therefore, vehicle will stop, and this is done by reducing the vehicle speed to reach the zero speed.
Step 2-2: in this step, if line tracker sensors are activated and control sensor are not activated line tracker sensors are guided vehicles towards the destination if vehicle is on the middle line of the road. Four sensor (navigation sensors that shown in Figure 6) as the original sensors (because these sensors are guided vehicles on the road), have a duty to keep the vehicle on the road. The alignment of this sensor is shown in Figure 6. Front and back sensors move the vehicle towards the front. If the vehicle is out of the path, one of the left or right sensors (According to which one sensor is observed the line) is activated and guided the vehicle to the road.
Step 2-3: In this step, besides of four navigation sensors, there are other four sensors (named road situation sensors shown in Figure 6) placed in side of original sensor, that the vehicles are aware of road restrictions. For example; if the pattern of 1010101 are read as the outputs of these sensors it can means that car is near to the intersection therefore, it reduced speed for better control of vehicle. This action causes that vehicle navigate the path with more accuracy. By applying different patterns can be informed the vehicle from turns, high-traffic areas, overtaking prohibited or traffic jam and etc.
Step 2-4: In this step, if the vehicle is in a situation that none of the sensors is on the line (For example when the speed is high and we reach to sharp turn it may be happened) in this case vehicle based on the last sensor that has been active keeps track until return to main path.

5. EXPERIMENTAL RESULTS

We designed the proposed line tracking autonomous vehicle navigation algorithm in C++ language and implemented on an MIPS-based embedded system. Roads are simulated by a matrix that has the extracted from the coordinates on real maps. Output of the algorithm is navigated coordinates. We dumped the output points into a text file and then analyzedit using Matlab to generated informative graphs and statistical results.

The experiment and result is based upon work by Sivaraj et al [5]. Overall, both trackers have similar performance characteristic in speed accuracy but result that show our work have better performance in tracking accuracy. The main reason for this improvement is the use of guidelines template in *specialregions* and line width thus vehicle, traversal the path smoother and more robust.

Proposed navigation system is evaluated in terms of tracking accuracy, speed accuracy, and amount of deviation from the original path.

We evaluated the deviation from the path in the proposed navigation system as the average distance of the traveled path outside the tracking lines. Our experiments show that vehicle may be deviated from its path in some places (for example in turns). This excess amounts causes the path traveled by car is more than the ideal path that must be traveled. Examined path is shown in Figure 9.

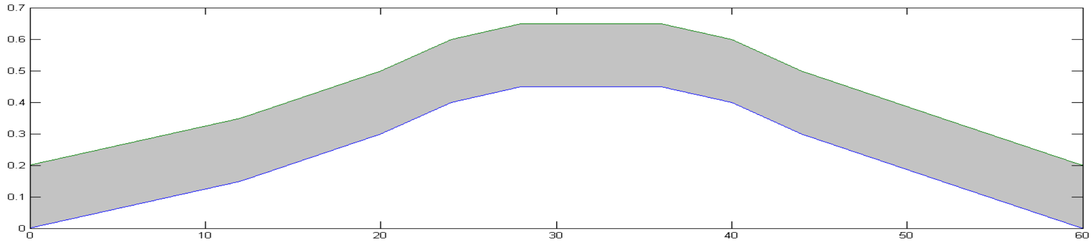


Figure 9. One of the evaluated paths

An example of the navigated path in the proposed algorithm is shown in Figure 10.

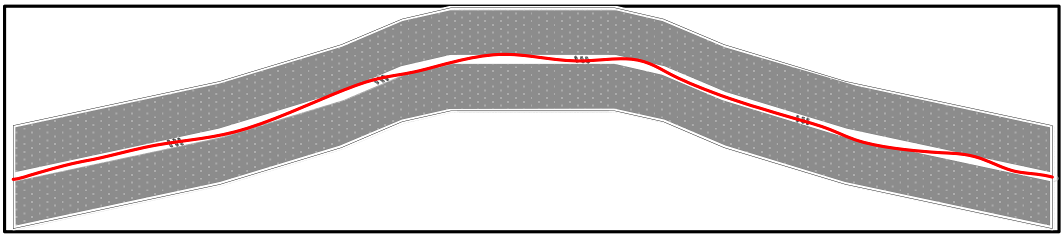


Figure 10. An example of navigated path

We defined a parameter (Elapsed distance) showing the tracking accuracy as the following equation:

$$TA = \left(1 - \left[\frac{ED - MD}{MD}\right]\right) * 100 \qquad (1)$$

Where ED is total traversed distance and MD is length of the ideal path on the tracking lines. Table 1 shows the tracking accuracy in the proposed line tracking system for various speeds. In this table, the first column represents the speed of the vehicle and two next columns show the traversed distance and minimum distance, respectively and finally, the last column addresses the tracking accuracy in percentage.

Table 1. Experimental results in terms of tracking accuracy

Speed (Km/h)		ED (meter)	MD (meter)	TA (%)
50	**NORMAL**	60.221	60	99.63
	REDUCED	60.435	60	99.27
100	**NORMAL**	60.675	60	98.87
	REDUCED	60.732	60	98.78
150	**NORMAL**	61.046	60	98.25
	REDUCED	61.353	60	97.74
200	**NORMAL**	61.46	60	97.56
	REDUCED	61.787	60	97.02
Average				**98.39%**

As can be seen in Table 1, the distance deviation of the proposed algorithm is very small even in high speed ranges. An interesting point is that the deviation in high speeds is not considerably larger than lower speeds because main parts of the deviation in some case is occurred in the turns and in rest of the road, deviation have not significant value but this small amount would be crucial in driving, especially at high speeds. Another parameter that shows the accuracy of the navigation is time accuracy. It is worth noting that time accuracy is not independent from distance accuracy but is an informative parameter. This parameter can be estimated as:

$$Speed\ Accuracy\ = \frac{Measured\ Time - MinTime}{MinTime} \quad (2)$$

Where measured time and Minimum Time are the real elapsed time and minimum possible time for traversing the path, respectively.

$$Minimum\ time\ = \frac{Minimum\ Distance}{Disired\ Speed} \quad (3)$$

Experimental results in terms of time accuracy is shown in Table 2.

Table 2. Experimental result in terms of speed accuracy

Speed (Km/h)		Traversed Distance (meter)	Ideal Time (sec)	Lap Completion time (sec)	Speed Accuracy (%)
50	**NORMAL**	60.221	5.4	5.419	99.64
	REDUCED	60.435	4.319	4.351	99.26
100	**NORMAL**	60.675	2.159	2.184	98.85
	REDUCED	60.732	2.7	2.732	98.82
150	**NORMAL**	61.046	1.8	1.831	98.30
	REDUCED	61.353	1.439	1.472	97.75
200	**NORMAL**	61.46	1.35	1.382	97.68
	REDUCED	61.787	1.079	1.112	97.03
Average					**98.42%**

As mentioned before, we implemented the proposed algorithm on a MIPS-based embedded system. Worst-case execution time of the algorithm for processing each percept is shown in Table 3. This table shows total clock cycles corresponding with code size and data size of the algorithm. This information is used to compute maximum allowable speed in Table 4. Column *Total runtime* in Table 4 shows the execution time of one step of the algorithm (for processing a percept) and column power consumption represents the estimated power of embedded system dissipated in executing one step of the algorithm. Finally the last column shows the maximum speed that is allowable in the proposed system.

Table 3. Experimental results in terms of allowable maximum speed

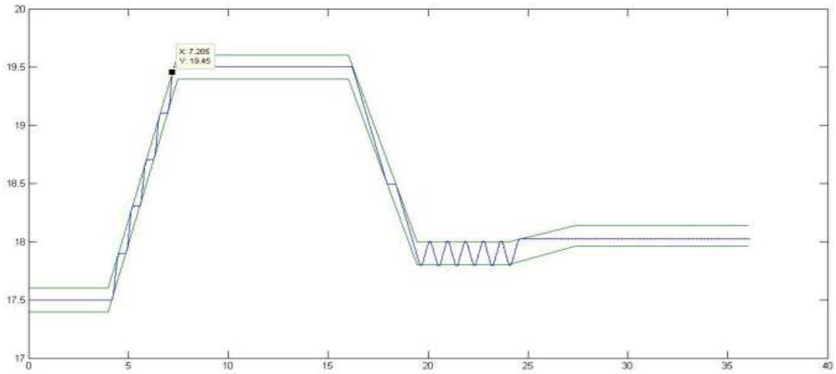
Total cycles	Code size (KB)	Data size (KB)
8152205	230	6.2

Table 4. Experimental results in terms of allowable maximum speed

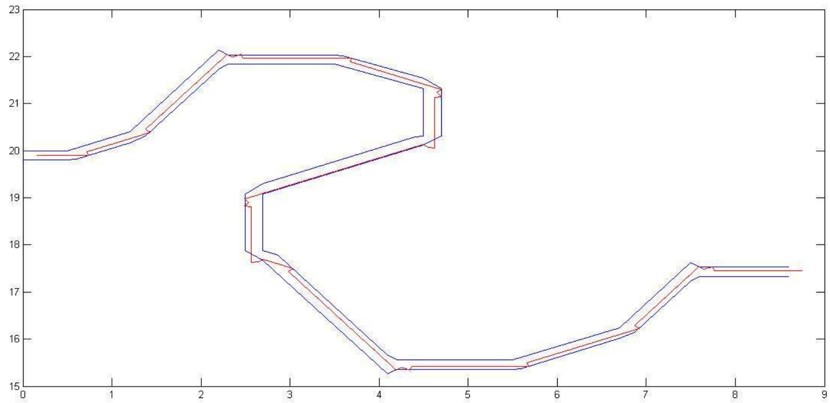
Frequency (MHz)	Total runtime (ms)	Power consumption (Watts)	Maximum allowable speed (Km/h)
200	16.30	0.56	44.17
300	10.87	0.84	66.26
500	6.52	1.40	110.43
1000	3.26	2.80	220.86
1400	2.33	3.92	309.20

As can be seen in Table 4, very high speeds are available in the proposed system with reasonable navigation correctness.

It is important that a path tracker be stable when encountering moderate offsets from the desired path. A tracker must be stable when following different path types and at different speeds. Figure 11-a and 11-b show the behavior of the vehicle in different path and at different speeds when the path comes out.



(a)



(b)

Figure 11. Behavior of the vehicle in different path and at different speeds: (a). Oscillation in the car movement to achieve stability movement; (b). Oscillation in the car movement to achieve stability movement in real world road.

6. CONCLUSION

In this paper, we proposed a customized infrared line tracking system to use for high speed vehicles navigation. We improved the arrangement for the infrared sensors to enable the low error navigation in high speed movements. Moreover, the shape of the tracking lines was revised to represents some other information about the road in addition the absolute path. Finally, we proposed a light-weight navigation algorithm to execute the positioning and planning the movement at rational time.

Experimental results show that more than 200 km/h can be viable with more than 98% navigation accuracy using a 1GHz MIPS embedded system. Our ongoing research is focused on the extending the algorithm in presence of the obstacles in the road.

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