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Accessible Lane-Keeping for All: A Low-Cost Lane-Keeping Solution

Muhammad Haroon Safdar
University of Greater Manchester
Deane Road Bolton
BL3 5AB

Ali Raza
University of Greater Manchester
Deane Road Bolton
BL3 5AB

Rameez Asif, PhD
University of Greater Manchester
Deane Road Bolton
BL3 5AB

ABSTRACT
The LKAS (Lane Keeping Assist System) system in this project is implemented on an RC (Remote Controlled) car that has a camera as a sensor at the front. The input from the camera is fed to the Single Board Computer (SBC) that makes the decision to steer left or right by giving an actuating signal to the motor attached at the front. Image processing techniques, including gaussian filtering and canny edge detection are employed to enhance the system's performance and proper detection of lane markers. SBC is also exploited for making decisions regarding lane departures. This project works well under different lighting conditions as well as provides adequate response time for the vehicle to maintain its lane. Not only does this system provide assistance in maintaining lane but it also generates a warning in case of lane departures.

Keywords
Automotive technology; Lane keeping; Deployable; Lane departure warning; Automotive safety.

1. INTRODUCTION
World Health Organization states that road traffic accidents cause 1.35 million deaths a year [1]. To reduce this number, Lane keeping has an important role to play in providing road safety. It is also a key task while driving. Normally it is not difficult to maintain a lane but driving for longer periods of time is a tiring experience and so a need for a LKAS system arises. Automotive technology is continuously evolving with time and we see better and improved safety features in modern day cars. But, many people drive cars that do not already have advanced safety driving features.

This project aims at developing a system that could be easily deployable on any automobile. The focus is on using basic image processing techniques and hardware equipment to ensure we can get optimal performance in minimum budget which would be helpful for providing a basic safety feature for the cars that do not already have it. This feature is becoming increasingly common in new generation cars, but they are still too expensive to most of the people around the world. A deployable feature not only gives us the ability to be common among the masses but also is open to change, adaptability and improvement.

LKAS system assists in maintaining the lane with the help of steering actuation. Additionally, it generates a warning when the car strays out of the lane. Combining these actions, the system actuates the steering to keep the car within the lane and also generates a warning for lane departures see Figure 1.

Figure 1. Driver assist technology [2]

2. LITERATURE REVIEW
Back in the year 1998 it was Mitsubishi who came up with the idea of a lane tracking system based on a camera [3]. It was more of an alarm-based system to warn driver in case of lane departures. Afterwards various features and techniques were discussed to distinguish between intended and unintended lane departures [4]. Afterwards in order to ensure driver involvement a new technique was proposed to provide just a percentage of the torque required to keep in lane [5]. This was done to ensure safety standards are maintained. Concerns were raised on the performance of lane detection algorithms on curved roads. To improve, particle filtering was added to hough transform [6]. Then to determine direction of travel a new technique was established that detected inner margins of lane but it was not very helpful on curved roads so eventually was discarded [7].

Another performance issue arose regarding lane detection in various lighting conditions It included vanishing point detection to determine lane position at a distance and also used invariance properties of lane colors to do well in different illumination conditions [8]. Then some advanced procedures were included in the preprocessing stage such as median and gaussian filter were applied to smooth images and reduce noise [9]. Cost has always been a major prospect and to do real time image processing with lots of filtering requires powerful hardware which is costly. Real-time image processing, especially when involving multiple filtering techniques, demands substantial computational power, often translating into expensive hardware requirements. The financial implications of such systems have driven us to seek more budget-friendly alternatives.

3. METHODOLOGY
In our Project Methodology, we have divided our project into 3 main parts which work together to make the complete project These include Mechanical, Electrical, and Software Part. The following block diagram shows the working of this project see Figure2.

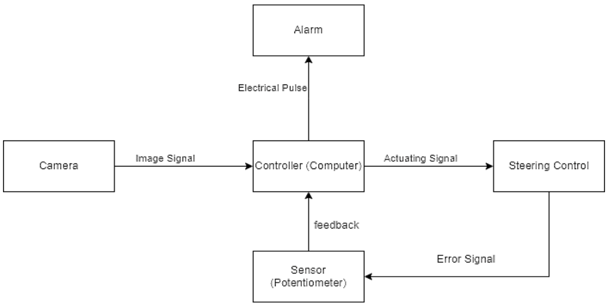

Figure:2. Block diagram of LKAS system

3.1 Physical framework:

The physical framework consists of mainly the base of RC car along with two DC motors each serving their own purpose. The motor at the front is responsible for steering actuation meanwhile the one at the back is used to power the wheels. The DC motor at the front has an angle measurement sensor attached to it which is helpful in getting feedback from the front tyres. Then there is a LiPo battery placed just near the front wheels on the base. An acrylic sheet with holes to place all the electronic components such as the SBU on it. This sheet is attached to the base of the RC car. Then there is a camera mount which is 3d printed and has three legs and an adjustable hinge to adjust camera angles. The height of this mount is made as such the camera could easily cover the lane markings ahead of the RC car.

3.1.1 CAD design

CAD design consists of the three-legged camera mount. The purpose of this mount is to hold the camera, provide adjustability and provide height for proper visibility of lane lines. There is also a slider at the front of the mount providing for a slight adjustment in the height. Also, there is a hinge just behind the camera to provide for camera angle adjustment.

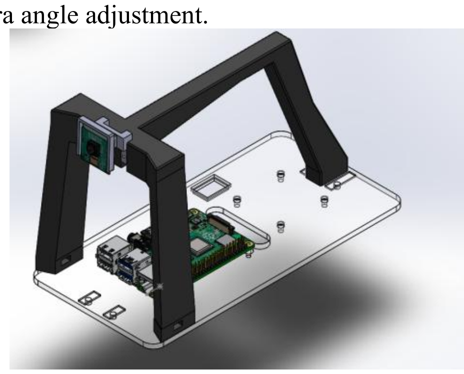

Figure. 3. CAD model of camera mount and base sheet

The bottom part with holes is an acrylic sheet that is there to place al the components and provide support to the camera mount. It is also CAD modelled but is made using laser cutting on already available acrylic sheets.

3.1.2 RC car chassis

The RC car chassis is a critical structural component that serves as the foundation for the entire vehicle. It plays a pivotal role in maintaining the stability of the car's design. This chassis incorporates several key elements, including shock absorbers, tires, motors, a steering assembly, and a designated pocket for the battery. These individual components work in tandem to enable the RC car to function effectively and perform its intended tasks.

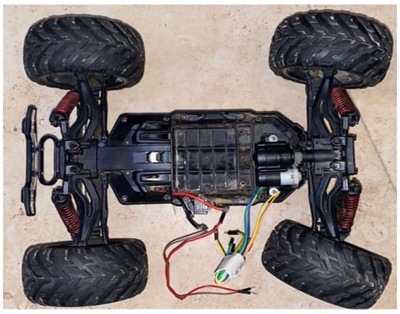

Fig. 4. RC car chassis

The final design incorporating all the hardware components is shown below:

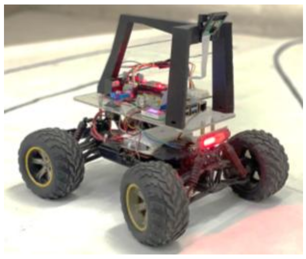

Fig. 5. Final hardware incorporating all components

3.2 System integration:

All the components serve a different purpose and aid each other in proper manoeuvring of the RC car. First, we have the camera sensor which takes input in the form of frames and passes it to the SBU which is responsible for all the computation. The SBU is also connected to an ESP32 and a couple of motor driver modules each for a separate motor. The buzzer is also connected to the SBU and is responsible for alarming when a lane departure is about to occur. All these components are connected to a LiPo battery which powers the system. The two motor driver modules are BTS7960 and L298. The BTS7960 module is used for the DC motor at the back meanwhile L298 is used for the steering actuation motor.

3.3 Algorithm Implementation:

Then comes the software part. This part has the algorithm of our lane-keeping assist system installed on our SBC. This part is the heart of the project and cannot work properly if not dealt with properly. It includes different techniques that are helpful in the imaging process. If we talk about image processing first, we get the image from the camera and convert it to grayscale. Afterwards we apply Canny Edge Detection which returns a binary image consisting of all the edges as white pixels. Then we apply Hough transform to find the lane markers in the image and identify them as right and left lanes. These lanes are used to find the required steering angle which is then used for steering motor actuation.

3.3.1 Image Preprocessing and Canny Edge Detection

First step involves taking images from the camera and then converting them from RGB to grayscale as shown below. This is done to reduce computation requirements as for an RGB image we have three values for each pixel, but grayscale has only one.

Figure: 6. RGB to grayscale conversion

Then we move on to next step which is edge detection and for this purpose canny edge detection has been used. Canny edge detection [10] itself applies a gaussian filter before edge detection to smooth the image and remove noise and afterwards finds the edges in the image as illustrated below.

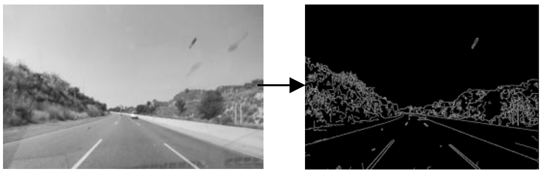

Figure. 7. Grayscale to BW after canny edge detection

Then the output image is a BW image showing edges as value 1(white) and the rest of the frame as 0(black). Now we can distinguish between the lane markers and the surroundings easily.

3.3.1 Lane marker detection and steering angle estimation:

The BW image is then used to find the lines that represent lane markers. The techniques used here is Hough transform which is responsible for fitting a line through points which in our case are white pixels [11]. Using Hough transform we get a set of lines where each line is represented by two sets of coordinates. We specifically chose those lines which are intersecting the x-axis nearest to the centre as they represent the lane markers. By this way we can identify the lane lines as shown in the figure below in red lines.

Figure: 8. Plotting lane lines

The next step is to find the required steering angle which is found by using a technique mentioned [12]. We first find the centre point of the lane lines and then find the required angle between the centre of vehicle and the lane centre as shown in the figure below:

Figure: 9. Steering angle estimation

To compute the required angle Pythagoras theorem is used where inverse of cosine gives us the required angle.

$$cos\theta \; = \frac{d_2}{d_1}$$

Where, θ = required steering angle

d2 = distance from lower centre of frame to vehicle centre

d1 = distance from lower centre of frame to lane centre

Lastly, in order to detect lane departures, the bottom intersection point of each lane line is used where we get right or left lane departures depending on which lane line comes closer towards the centre.

4. RESULTS

The results include the actuation results and as well as the RC car performance through various different turns. They also include the output we get for lane departures.

4.1 Steering Angle Feedback: Overcoming Raspberry Pi's Lack of ADC with Serial Communication

To take feedback from the steering angle sensor we require an ADC module as the SBU that is used in this project namely Raspberry pi 4 does not have any ADC. This is why an ESP32 is used to get analog data from the sensor and send it to the SBU using serial communication. The reason why ESP32 is used is that it will play the role of an ADC and will also be used to switch the RC car ON or OFF remotely using a mobile phone. The resulting steering angle we get is plotted using matlab as shown in figure below:

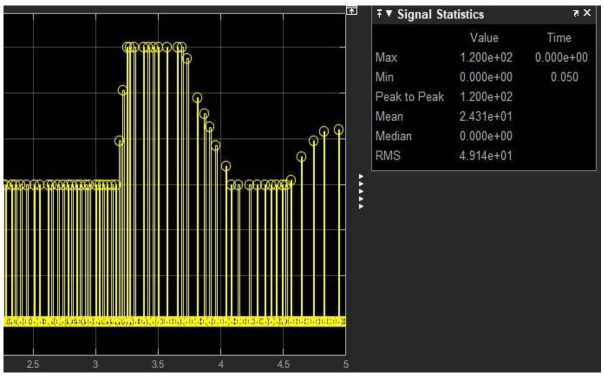

Figure: 10. Graph of output steering angle

The value we get is mapped such that the least angle we get is 60 degrees and the maximum angle is 120 degrees with 90 degrees denoting the centre. In the plot above there are multiple transitions where the front tyres turn both ways showing proper functioning of the steering actuation.

4.2 Outcome of Lane Keeping in Hardware Implementation

The hardware was tested under various conditions. Firstly, we varied the velocity from 5 to 15 ms^{-1} and tested on different road turn angles starting from a minimum of 20 degrees to a maximum of 60 degrees to get system behaviour at sharp turns. The results show us that the system performed well under lower speeds but there were some lane departures detected which at higher speeds on sharp turns which means the system performance decreases with increase in velocity. Overall, the system behaved well as per our expectations because we do not expect an impressive efficiency from a system deployed on an RC car.

Table 1 Lane departure results

Velocity (ms^{-1})	Road turn angle (degrees)	Lane departure detected
5	20	No
5	40	No
5	60	No
10	20	No
10	40	No
10	60	Yes
15	20	No
15	40	Yes

5. DISCUSSION

5.1 Camera stability

Camera stability is an important aspect of our project as we do not want distorted images which could cause instability. If we get a slight blurred or shaky image, then it becomes almost impossible for the algorithm to recognize lane lines. To deal with this, we have used shock absorbers in base of our RC car. Even though shock absorbers work fine we still get some distorted frames which give unwanted results. For this purpose, we have used averaging technique where we continuously average previous 5 frames and so even if some of the frames are blurry, it does not affect.

5.2 Camera positioning and angle:

The camera height plays a major role as well to determine the visibility of the road ahead. For our purpose we designed the camera stand at an appropriate height to get the lane lines inside the frame. At higher speeds it is not recommended to take sharp turns and in case of an RC car the stability itself get compromised and so the algorithm could not perform well.

Then camera angle is also of utmost importance as it determines the field of view. Keeping it too low will not allow to see further ahead, meanwhile if we do the opposite then we expect to miss the road just ahead of the vehicle. In this way keeping at appropriate angle is important to get the best field of view.

6. CONCLUSIONS

This project has been designed to provide a safety feature that could improve road safety, be inexpensive as well and be easily deployable to any vehicle. We tested it on RC car and it worked well but the ultimate goal is to implement it on an automobile for which certain changes will be required such as altering the steering assembly. The LKAS algorithm in this project works well and provides adequate efficiency and response time to be used for real-time image processing. Certain improvements that can be made include the use of 2^{nd} degree polynomial curve fitting for better detection of curvatures, but this would also require more computational power and so the cost may increase.

7. ACKNOWLEDGEMENT:

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