IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

VL53L0X Sensor-Based LED Steering Angle Indicator For Road Safety

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Abstract: This research offers a low-cost and innovative method of computing and visually indicating a vehicle's steering angle. It uses a VL53L0X distance sensor and an LED array driven by a microcontroller to achieve this. This system is a replacement for conventional steering angle sensors, offering an expandable solution for mitigating road accidents due to non-communicated turns by vehicles. The steering angle is linearly proportional to the intensity of the LEDs, providing immediate visual feedback to the drivers, who are located behind. This method not only enhances security but is also economical and easy to implement.

Keywords - Steering angle detection; VL53L0X sensor; Vehicle safety system; LED indicators; Arduino Uno; Distance measurement; Real-time feedback; Turn indication; Time-of-flight sensor; Embedded systems

I. INTRODUCTION

Globally, the leading cause of highway accidents is not signaling before turns or lane changes. The Society of Automotive Engineers (SAE) studies indicate that drivers never use a turn signal in 48% of lane changes and 25% of turns. This failure leads to over two million traffic accidents annually, and it is the cause of nearly one in five of all accidents—a figure more than double the number of accidents caused by distracted driving [1].

Conventional turn signals, based only on the driver's intentions, are typically an incomplete representation of the vehicle's actual steering dynamics. Drivers tend to overlook or intentionally omit using turn signals, meaning following drivers are unaware of an upcoming turn or lane shift. To eliminate this deficiency, in this paper, we introduce a new sensor-based approach that directly maps the vehicle steering angle to a set of visual cues.

This work reports on an affordable, microcontroller-powered system that leverages a VL53L0X time-of-flight distance sensor to estimate the steering angle without relying on dedicated steering angle sensors. The calculated angle is subsequently mapped to a proportional number of LEDs mounted at the back of the vehicle, providing following drivers with an obvious, real-time visual cue to the severity of the turn. By making the steering behavior of the vehicle visually conspicuous, this system is focused on increasing road safety, particularly in low-visibility situations or high-traffic areas.

II. LITERATURE REVIEW

The suggested configuration is low-cost, simple to implement in existing automotive platforms, and expandable for future features like wireless signaling or adaptive illumination. This technology can reduce accidents induced by unclear or unsigned turns, thus providing a realistic enhancement to typical automobile safety capabilities.

2.1 VL530X

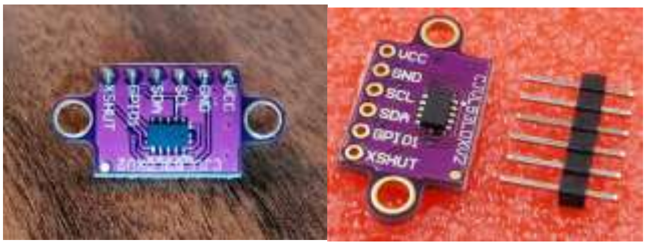

Fig.1 VL530X distance sensor

The VL53L0X sensor uses the time-of-flight (ToF) technique and works by emitting short pulses of infrared light. It calculates the distance by accurately measuring the time it takes for these light pulses to bounce back to the sensor. This sensor is able to accurately measure distances, up to 2 meters when it is used under optimal conditions[2].

2.1 Microcontroller

Fig.2 Arduino uno r3

The Arduino Uno R3 serves as the primary microcontroller unit within this system. It comes equipped with 14 digital input/output pins, six of which are capable of Pulse Width Modulation (PWM) output, along with six analog input channels, a 16 MHz ceramic resonator, a USB interface, a power jack, an ICSP header, and a reset button [3]. The digital pins facilitate connections with external components, functioning as either inputs for sensors or outputs for actuators. Each digital pin operates in one of two binary states: LOW (0V) or HIGH (5V), which corresponds to the Arduino Uno's supply voltage [4]. These pins can be set to either INPUT mode, for receiving data from external devices, or OUTPUT mode, for transmitting signals to control devices. Conversely, the analog pins are designed to read voltage values ranging from 0 to 5 volts DC, making them suitable for interfacing with sensors that produce varying analog signals.

2.3 LED Bulb

Fig.3 LED Bulb

Light Emitting Diodes (LEDs) are available in a wide variety of sizes, with 3mm being among the smallest standard types. This refers to the outside diameter of the housing of the LED. Due to their small size, 3mm LEDs are a popular selection for installations where space is scarce. Each LED has two leads: the longer one is the positive terminal (anode), and the shorter one is the negative terminal (cathode) [7].

2.4 Stick fixed with caster wheel

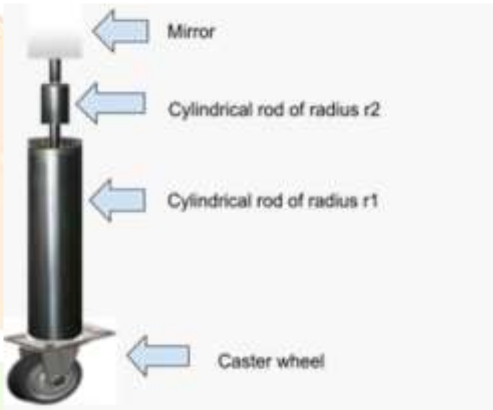

Fig.4 Component layout of a vertical sensor mounting assembly, demonstrating how a caster wheel and concentric cylindrical rods are integrated for mobility and mirror placement. (**Note:** Image generated using OpenAI, 2025)

As depicted in Figure 4 , a mirror is affixed to a small cylindrical rod with radius r1, which is subsequently joined to a larger cylindrical rod of radius r2 (where r2>r1). This larger rod is connected to a caster wheel, whose edge maintains continuous contact with the vehicle's wheel. The choice of a rotating caster wheel, as opposed to a stationary rod, serves to mitigate friction between the mechanism and the vehicle wheel, thereby minimizing heat generation during operation.

The caster wheel's rotation is restricted to a single, fixed axis, preventing it from pivoting or altering its direction. The mirror's reflective surface is positioned to face the rotational. Direction of the vehicle wheel rods positioned between the mirror and the rod of radius r_2, as well as between the rods of radii r_2 and r_1, are designed to be identical for structural uniformity and mechanical stability

2.5 Direction fixer

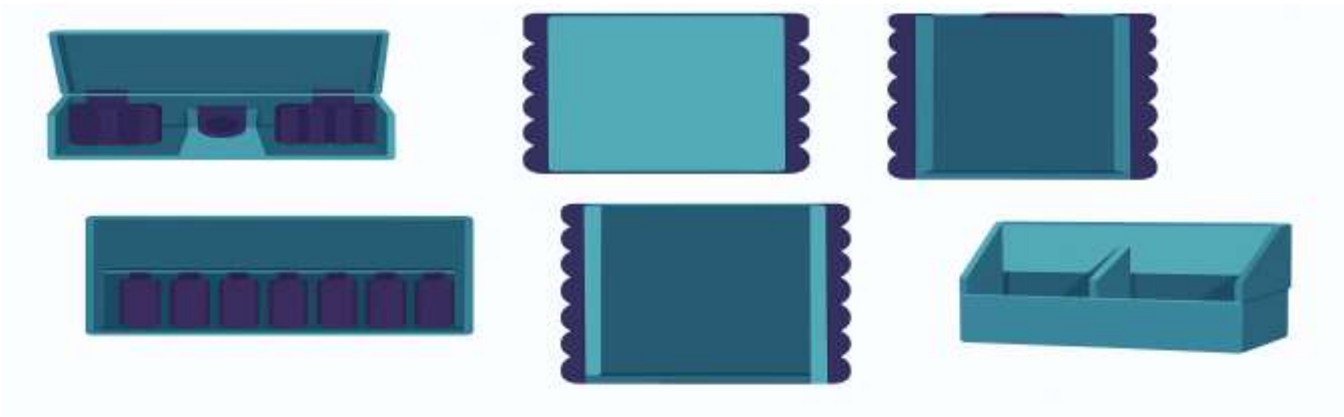

Fig.5 (a) - Front side view, (b) - Right/Left side view, (c) - Back side view, (d) - Bottom side view, (e) - Top side (**Note:** Image generated using OpenAI, 2025)

The fundamental purpose of the direction fixer is to limit the movement of the stick connected to the caster wheel, permitting it to travel solely in a single, predetermined path. As depicted in Figure 5(b), the components coloured purple are rolling cylinders, each possessing a radius designated as r_3. In Figure 5(a), a spring—defined by its spring constant K and length L—is depicted as a circular ring. The underside of the direction fixer features a centrally positioned gap, with its width (measured perpendicular to the spring's axis) identified as d. This gap is designed to effectively house and guide the cylindrical rod of radius r_3. This configuration ensures that lateral motion is restricted, thereby facilitating the precise, unidirectional alignment of the stick mechanism.

III. Experimental works details

In experimental setup for determining steering angle, a conventional steering angle sensor is replaced by a VL53L0X time-of-flight laser sensor. This sensor measures the lateral deviation of the reflective setup directly to infer the angular position of the wheel.

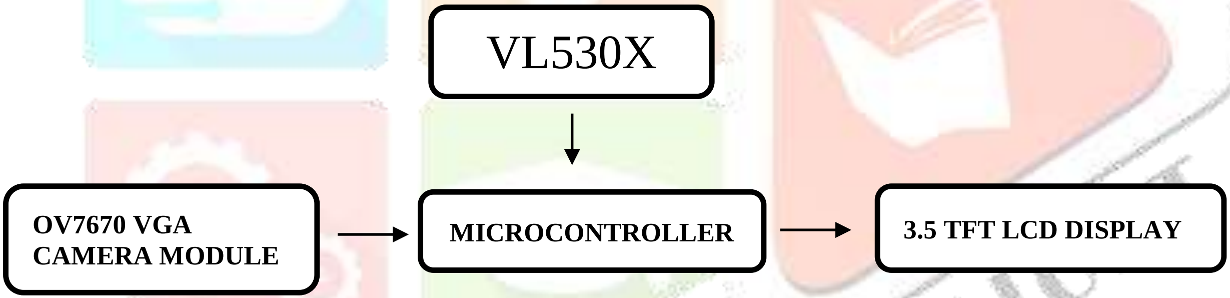

Fig.6 The VL530X distance sensor and OV7670 camera module are used in this embedded system's functional block diagram to visualize dual inputs on a 3.5" TFT LCD screen.

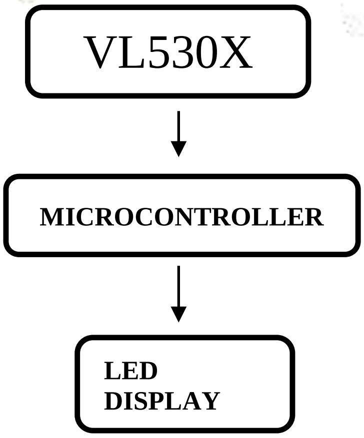

Fig.7 An overview of the VL530X distance measurement setup showing the data flow from sensor acquisition to visual output**.**

Figure 7 illustrates how the array of LEDs is disposed, indicating that the number of illuminated LEDs is a direct indicator of the steering angle of the vehicle and consequently provides a visual indication of the turn intensity. Figure 6, on the other hand, illustrates how the LCD display is disposed, which is near the driver's seat.

Placed in front of the steering wheel, this screen displays a real-time video feed from the rear view of the vehicle. Over this feed, a trajectory guide showing the present orientation of the front wheels is superimposed to guide the driver during reverse maneuvers.

3.1 Mathematics Formula

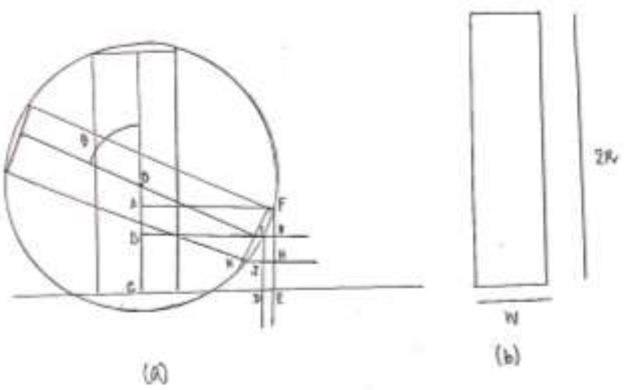

Fig.8 A geometric construction that calculates the view factor between a circular surface and a differential surface element: (a) a circular surface with projection lines and differential area elements; (b) a view factor analysis using equivalent rectangular projection.

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$X = LE$

$X = CD + DE - W/2$

In triangle OBI

$\angle IOB = \theta$

$\angle OBI = 90$

$\angle BIO = 90 - \theta$

$BI = CD$

$OI = R$

$BI = R \sin\theta \quad CD = R \sin\theta$

In triangle FIG

$\angle BIO + \angle IOF + \angle FIG = 180 \quad 90 - \theta + 90 + \angle FIG = 180$

$\angle FIG = \theta \quad IF = W/2 \quad IG = DE$

$IG = (W/2) \cos\theta \quad DE = (W/2) \cos\theta$

$X = (R \sin\theta) + ((W/2) \cos\theta) - W/2 \quad OA + AC = R$

$OA + Y = R$

$Y = R - OA \quad OA = OB - AB$

$OB = OI \cos\theta$

$OB = R \cos\theta \quad AB = FG$

$FG = IF \sin\theta \quad FG = (W/2) \sin\theta$

$AB = (W/2) \sin\theta$

$OA = R \cos\theta - (W/2) \sin\theta$

$Y = R - R \cos\theta + (W/2) \sin\theta$

3.2 Construction

The system's construction prioritizes precise detection of the front wheels' lateral displacement as a vehicle turns. This is achieved through a mechanically aided reflective setup and a VL53L0X distance sensor. The detected displacement is then converted into a visual signal using LED indicators, which are mounted on the vehicle's rear to inform trailing drivers about the steering behavior of the vehicle ahead.

The fundamental mechanical assembly comprises a stick outfitted with a caster wheel, a mirror, and a direction fixer. This configuration is engineered to maintain consistent alignment and minimize friction while accurately capturing movement resulting from wheel turns. One such assembly is utilized for each of the front wheels. The caster wheel's placement ensures it remains in contact with the rear side of its corresponding front tire, a position chosen to guarantee maximum capture of lateral movement during vehicle steering.

A mirror is affixed to a cylindrical rod, which receives further support from a series of nested cylindrical rods, progressively increasing in radius, specifically r1, r2, and r3. These rods contribute the necessary height and structural integrity, while the mirror's reflective surface is angled towards the VL53L0X sensor.

The sensor itself is securely positioned above this arrangement, oriented perpendicularly to the reflective surface. When the system is in its neutral state (i.e., no steering input), the distance between the sensor and the mirror is equal to the natural length 'L' of the spring.

The direction fixer is instrumental in stabilizing the motion of the rod mechanism. It incorporates a spring, characterized by a spring constant 'K', and two parallel rolling cylinders situated on either side of the central axis. These cylinders work to restrict the stick's movement to a single linear path, thereby preventing any angular deviations. The rod with radius r3, which is positioned between r1 and r2, fits snugly within a central gap of width 'd' on the bottom surface of the direction fixer. This design ensures that the stick undergoes only lateral movement as the tire rotates, accurately converting the mechanical shift into a detectable change in distance by the sensor.

The VL53L0X sensor is firmly mounted to a bracket, directly aligned with the mirror and facing downwards towards the direction fixer assembly. As the tire turns, it causes the caster wheel (and consequently the mirror) to undergo lateral displacement. This displacement results in the distance between the mirror and the sensor increasing from the neutral position 'L' to a maximum value.

$$L + [(R \sin\theta) + ((W/2) \cos\theta) - W/2]$$

Here, 'R' signifies the wheel's radius, 'W' denotes the distance separating the tires, and 'θ' represents the steering angle. The sensor's output is electrically connected to a microcontroller (an Arduino Uno for the basic configuration, or an ESP32 for an advanced version), which processes the incoming real-time distance measurements. This microcontroller then evaluates the data against predetermined thresholds and, in response, activates an array of 3mm LEDs accordingly. These LEDs are situated at the vehicle's rear and light up in direct correlation with the intensity of the steering. For example:

- A single LED illuminates for minor turns.
- Two LEDs activate for moderate turns.
- All LEDs turn on for sharp turns.

A regulated power supply provides electricity to the sensor, the caster wheel mechanism, and the LED system, with appropriate grounding and electrical isolation implemented to guarantee vehicle safety. Despite its mechanical simplicity, this arrangement effectively registers wheel movement without interfering with the vehicle's inherent systems, presenting a non-invasive, economical, and adaptable solution for visually indicating steering.

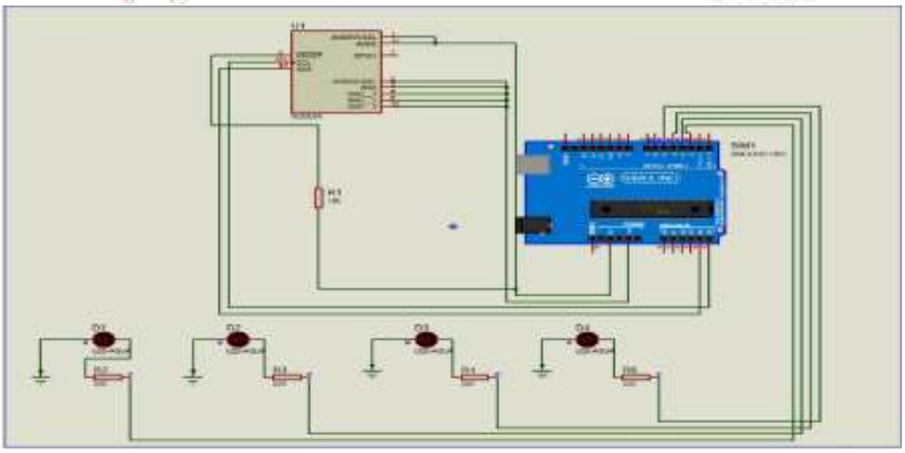

Fig.9 Proteus simulation diagram of a multi-LED, Arduino-based GSM alert system.

3.3 Operating software

```
#include <Wire.h>
#include <Adafruit_VL53L0X.h>
// Define LED pins
const int ledPins[] = {2, 3, 4, 5, 6};
const int numLeds = 5;
// Create VL53L0X object
Adafruit_VL53L0X lox = Adafruit_VL53L0X();
void setup() {
  Serial.begin(115200);
  Serial.println("VL53L0X + LEDs Distance Indicator");
// Initialize LEDs as outputs
  for (int i = 0; i < numLeds; i++) {
    pinMode(ledPins[i], OUTPUT);
    digitalWrite(ledPins[i], LOW);
  }
// Initialize VL53L0X sensor
  if (!lox.begin()) {
    Serial.println("Failed to boot VL53L0X");
    while (1);
   Serial.println("VL53L0X started");
}
void loop() {
  VL53L0X_RangingMeasurementData_t measure;
// Perform ranging measurement
  lox.rangingTest(&measure, false); // pass 'true' to get debug info
if (measure.RangeStatus != 4) {
// phase failures have status 4Serial.print("Distance (mm): ");
    Serial.println(measure.RangeMilliMeter);
  // Light LEDs based on distance thresholds (example thresholds)
    int distance = measure.RangeMilliMeter;
    int ledsToLight = 0;
if (distance < 100)       ledsToLight = 5;
    else if (distance < 200)  ledsToLight = 4;
    else if (distance < 300)  ledsToLight = 3;
    else if (distance < 400)  ledsToLight = 2;
    else if (distance < 500)  ledsToLight = 1;
    else
ledsToLight = 0;
 for (int i = 0; i < numLeds; i++) {
      if (i < ledsToLight) digitalWrite(ledPins[i], HIGH);
      else digitalWrite(ledPins[i], LOW);
    }
  } else {
    Serial.println("Out of range");
    // Turn off all LEDs
    for (int i = 0; i < numLeds; i++) {
      digitalWrite(ledPins[i], LOW);
    }
  }
 delay(200);  // small delay for stability
}
```

IV. Discussion

The system devised in this project presents an innovative and cost-effective approach to bolster road safety by automatically conveying a vehicle's steering angle to following drivers through LED signals. By employing a VL53L0X time-of-flight distance sensor and a mechanical setup featuring a caster wheel and mirror assembly, the system precisely gauges the steering degree without necessitating direct engagement with the vehicle's steering column. The distance data acquired by the sensor is then mapped to an LED array, where the number of illuminated LEDs correlates with the intensity of the turn, offering a clear and intuitive visual cue to vehicles behind.

Presently, the system is implemented using an Arduino Uno microcontroller, which provides simplicity and adequate functionality for its fundamental operation. Nevertheless, there is considerable potential to enhance the system's efficiency, responsiveness, and adaptability by substituting the Arduino with an ESP module, such as the ESP32.The ESP32's superior processing speed facilitates quicker handling of sensor data and LED response, which is vital for real-time applications. Its integrated Wi-Fi and Bluetooth capabilities unlock possibilities for wireless communication, enabling integration with smartphones or vehicle networks for live monitoring and advanced driver-assistance features. Moreover, its increased memory and computational power support more intricate operations and future upgrades, including predictive analytics or remote firmware updates.

Beyond the electronic components, the mechanical design has also been optimized for minimal friction and maximal responsiveness by incorporating a direction-fixed caster wheel mechanism. The stick, along with the mirror assembly, is positioned to remain in contact with the rear part of the front tires, ensuring accurate detection of lateral displacement during a turn. While the prototype utilizes basic 3mm LEDs, these can be upgraded to RGB LEDs in practical applications to deliver more detailed or color-coded feedback, further improving driver comprehension.

Collectively, the proposed system offers an effective improvement over conventional turn indicators, especially in situations where drivers neglect to signal. With modest hardware enhancements—particularly transitioning to more advanced microcontrollers like the ESP32—the system has the capacity to evolve into a more intelligent and integrated safety feature suitable for contemporary vehicles.

Altogether, the proposed system offers an effective enhancement to traditional turn indicators, particularly in scenarios where drivers forget to signal. With minor upgrades in hardware—especially shifting to more advanced microcontrollers like the ESP32—the system can evolve into a smarter, more integrated safety feature suitable for modern vehicles.

V. Conclusion

This project successfully showcases an economical and dependable approach for real-time steering angle indication, utilizing a VL53L0X distance sensor alongside LED indicators. By eliminating the reliance on conventional steering angle sensors and instead employing a mechanically coupled system with a time-of-flight sensor, the design offers both affordability and practical implementation for existing vehicles. The proportional output from the LEDs effectively conveys the extent of a vehicle's turn to following drivers, thereby enhancing road safety and diminishing the probability of accidents resulting from unindicated or ambiguous maneuvers. Furthermore, the system boasts ease of installation, scalability, and susceptibility to future improvements, such as the incorporation of RGB LEDs or wireless communication modules. Subsequent iterations could focus on improving precision, bolstering durability, and integrating the system with advanced driver-assistance systems (ADAS) to further reinforce vehicular safety on roadways.

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