

LED-Based Steering Angle Indicator Using VL53L0X Sensor for Enhanced Road Safety

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Abstract

This paper presents a cost-effective and innovative method for determining and visually communicating a vehicle's steering angle using a VL53L0X distance sensor and a microcontroller-controlled LED array. The system replaces conventional steering angle sensors, offering a scalable solution aimed at reducing road accidents due to uncommunicated vehicle turns. The number of LEDs activated is directly proportional to the steering angle, providing a real-time visual cue to trailing drivers. This approach promotes enhanced safety while maintaining affordability and ease of integration.

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

1. Introduction

The failure to properly indicate turns or lane changes is a significant contributor to road accidents globally. According to a study by the Society of Automotive Engineers (SAE), drivers neglect to use turn signals 48% of the time when changing lanes and 25% when turning. This negligence is responsible for over two million road accidents annually, accounting for nearly one in five accidents—more than double the number attributed to distracted driving [1].

Traditional turn indicators, which rely solely on driver intent, do not always accurately reflect the actual steering behavior of a vehicle. In many cases, drivers forget or neglect to activate the turn signals, leaving trailing motorists unaware of an impending turn or lane change. To address this limitation, we propose a novel, sensor-based solution that directly correlates the vehicle's steering angle to a series of visual indicators.

This paper introduces a cost-effective, microcontroller-based system that uses a VL53L0X time-of-flight distance sensor to estimate the steering angle without the need for dedicated steering angle sensors. The calculated angle is then

mapped to a proportional number of LEDs mounted at the rear of the vehicle, providing trailing drivers with a clear, real-time visual cue of the turn's intensity. By making the vehicle's steering behavior visually accessible, the system aims to enhance road safety, particularly in low-visibility conditions or high-traffic scenarios.

The proposed setup is inexpensive, simple to integrate into existing vehicle platforms, and scalable for future extensions such as wireless signaling or adaptive lighting. The system has the potential to reduce accidents caused by ambiguous or unindicated turns, offering a practical enhancement to conventional automotive safety features.

2. Literature review

2.1 VL530X

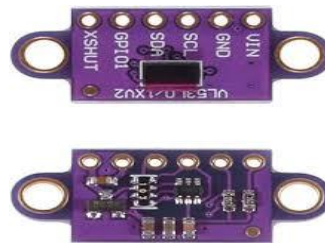


Figure 2.1.1 VL530X distance sensor

The VL53L0X time-of-flight (ToF) sensor operates using optical principles by emitting short infrared pulses and measuring the time taken for the reflected light to return to the sensor. It is capable of accurately measuring distances of up to 2 meters under optimal conditions [2].

2.2. Microcontroller

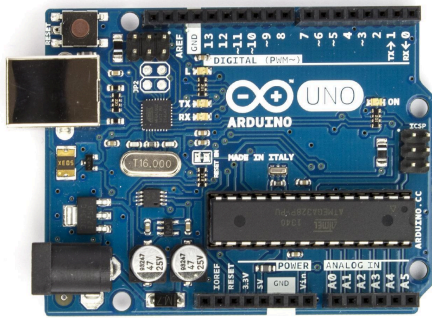


Figure 2.2.1 Arduino uno r3

The Arduino Uno R3 is employed as the central microcontroller unit in this system. It features 14 digital input/output pins (six of which support PWM output), 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 are utilized to interface with external components such as sensors (inputs) and actuators (outputs). Each digital pin operates in a binary state—either **LOW** (0V) or **HIGH** (5V), which corresponds to the supply voltage of the Arduino Uno [4]. These pins can be configured in either **INPUT** mode, for receiving data from external devices, or **OUTPUT** mode, for sending signals to control devices. Analog pins can read voltage values within the range of 0 to 5 volts DC, making them suitable for interfacing with sensors that provide variable analog signals.

2.3. LED Bulb



Figure 2.3.1 LED Bulb

Light Emitting Diodes (LEDs) are available in various sizes and form factors, with the 3mm LED being one of the smallest standard types. The size specification refers to the outer diameter of the LED package. Due to their compact size, 3mm LEDs are typically used in applications where space is limited. Each LED has two terminals: the longer lead represents the positive terminal (anode), while the shorter lead denotes the negative terminal (cathode) [7].

2.4. Stick fixed with caster wheel

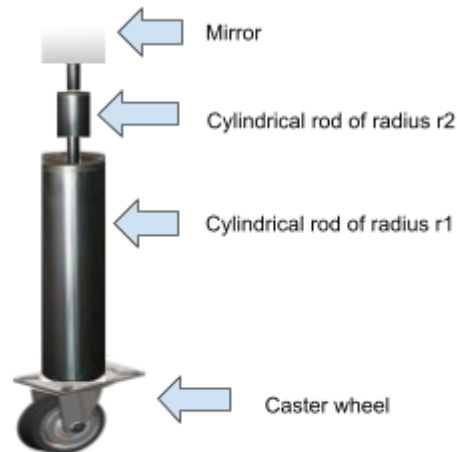


Figure 2.4.1

As illustrated in Figure 2.4.1, a mirror is mounted on a small cylindrical rod of radius r_1 , which is further connected to a larger cylindrical rod of radius r_2 ($r_2 > r_1$). This larger rod is attached to a caster wheel, whose edge remains in direct contact with the vehicle's wheel. The use of a rotating caster wheel, instead of a static or non-rotating rod, is intended to reduce friction between the mechanism and the vehicle wheel, thereby minimizing heat

generation during operation. The caster wheel is constrained to rotate only along a fixed axis and is not permitted to pivot or change direction. The reflective surface of the mirror is oriented to face the direction of the vehicle wheel's rotation. Additionally, the radii and heights of the cylindrical

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

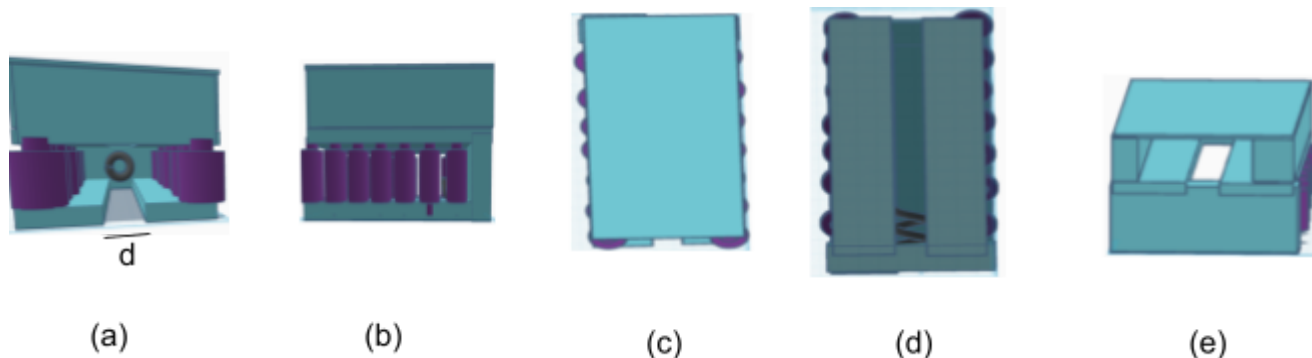


Figure 2.5.1, (a) - Front side view, (b) - Right/Left side view, (c) - Back side view, (d) - Bottom side view, (e) - Top side view

The primary function of the direction fixer is to constrain the motion of the stick attached to the caster wheel so that it can move only in a single, predefined direction. As shown in Figure 2.5.1(b), the purple-colored components represent rolling cylinders, each with a radius denoted by r_3 . In Figure 2.5.1(a), a spring—characterized by a spring constant K and a length L —is illustrated as a circular ring. The bottom surface of the direction fixer includes a centrally located gap, with its width (measured perpendicular to the axis of the spring) denoted as d . This gap allows the cylindrical rod of radius r_3 to be housed and guided effectively. The design ensures that lateral movement is restricted, enabling precise unidirectional alignment of the stick mechanism.

3. Experimental works details

The experimental setup for steering angle estimation replaces a conventional steering angle sensor with a VL53L0X time-of-flight laser sensor

to directly measure lateral displacement of the reflective assembly and infer the wheel's angular orientation.

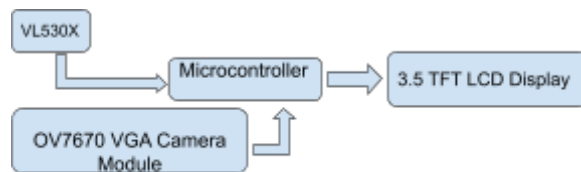


Figure 3.2

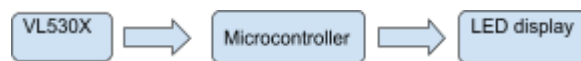


Figure 3.1

Figure 3.1 illustrates the configuration of the LED array, where the number of illuminated LEDs is directly proportional to the vehicle's steering angle, thereby providing a visual indication of the turn intensity. Figure 3.2 depicts the setup of the LCD display, which is positioned near the driver's

steering wheel. This display presents a live video feed of the vehicle's rear view, overlaid with a trajectory guide line that reflects the current orientation of the front wheels, assisting the driver during reverse maneuvers.

3.1. Mathematics formula

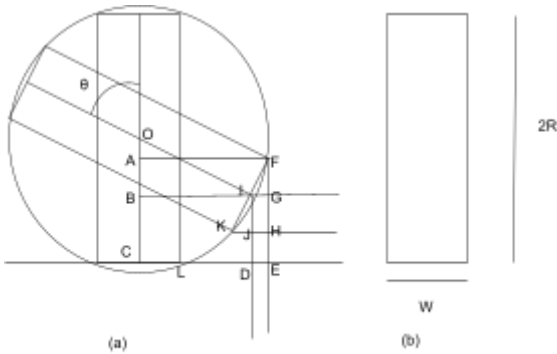


Figure 3.1.1

Figure 3.1.1 (b) is the top view of the wheel of a vehicle of width W and radius R . Y be the distance between the two points F and E . Caster wheel which is present in the stick with the caster wheel should be in contact with the wheel of the vehicle at a distance Y from the centre when viewed from the right/left side of the car, so that the displacement of the stick can be highest during the turn of the vehicle. θ represent the maximum turning angle of the vehicle. Then the maximum displacement of the stick is X , where X is the distance between the points L and E . For a vehicle the values of width of the wheel W , the radius of the wheel R and the maximum turning angle θ is known.

$$X = LE$$

$$X = CD + DE - W/2$$

In triangle OBI

$$\angle IOB = \theta$$

$$\angle OBI = 90$$

$$\angle BIO = 90 - \theta$$

$$BI = CD$$

$$OI = R$$

$$BI = R \sin\theta$$

$$CD = R \sin\theta$$

In triangle FIG

$$\angle BIO + \angle IOF + \angle FIG = 180$$

$$90 - \theta + 90 + \angle FIG = 180$$

$$\angle FIG = \theta$$

$$IF = W/2$$

$$IG = DE$$

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

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

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

$$OA + AC = R$$

$$OA + Y = R$$

$$Y = R - OA$$

$$OA = OB - AB$$

$$OB = OI \cos\theta$$

$$OB = R \cos\theta$$

$$AB = FG$$

$$FG = IF \sin\theta$$

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

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

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

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

3.2. Construction

The construction of the system focuses on accurately detecting the lateral displacement of the front wheels during a vehicle turn using a mechanically assisted reflective setup and a VL53L0X distance sensor. This displacement is then translated into a visual cue using LED indicators, mounted on the rear of the vehicle, to inform following drivers about the steering behavior of the vehicle ahead.

The core mechanical assembly consists of a stick with a caster wheel, a mirror, and a direction fixer. This setup is designed to maintain consistent orientation and reduce friction while capturing precise motion due to wheel turns. For each of the front wheels, one such assembly is used. The caster wheel is positioned so that it stays in contact with the rear side of the respective front tire—this location ensures maximum lateral movement is captured when the vehicle steers.

A mirror is fixed to a cylindrical rod, which is further supported by nested cylindrical rods of increasing radius— r_1 , r_2 , and r_3 . These rods provide the necessary height and structural stability, while the mirror's reflective surface is angled toward the VL53L0X sensor. The sensor is fixed above the setup and oriented perpendicularly to the reflective surface. In the neutral position (no steering), the distance between the sensor and the mirror equals the natural spring length L .

The direction fixer plays a crucial role in stabilizing the movement of the rod mechanism. It includes a spring (of spring constant K) and two parallel rolling cylinders on either side of the central axis. These cylinders constrain the movement of the stick to a single linear direction and prevent angular deviations. The rod of radius r_3 , which sits between r_1 and r_2 , fits snugly in a central gap of width d on the bottom surface of the direction fixer. This configuration ensures the stick only moves laterally as the tire rotates, translating the mechanical shift accurately into a change in distance as detected by the sensor.

The VL53L0X sensor is mounted securely to a bracket that aligns directly with the mirror, facing downward toward the direction fixer assembly. As the tire turns and causes lateral displacement of the caster wheel (and hence the mirror), the distance between the mirror and the sensor increases from L (neutral) to a maximum of $L + [(R \sin\theta) + ((W/2) \cos\theta) - W/2]$,

where R is the radius of the wheel, W is the width between tires, and θ is the steering angle.

The sensor output is wired to a microcontroller (Arduino Uno in the basic version, or ESP32 for an enhanced setup), which processes the real-time distance data. The microcontroller compares this data against predefined thresholds and controls an array of 3mm LEDs accordingly. These LEDs are mounted at the rear of the vehicle and illuminate in proportion to the steering intensity. For example:

- One LED lights up for small turns.
- Two LEDs for medium turns.
- All LEDs for sharp turns.

The sensor, caster wheel mechanism, and LED system are powered via a regulated power supply, with proper grounding and electrical isolation to ensure vehicle safety.

This setup, although mechanically simple, effectively captures wheel motion without interfering with the vehicle's native systems and offers a non-invasive, low-cost, and scalable solution for visual steering indication.

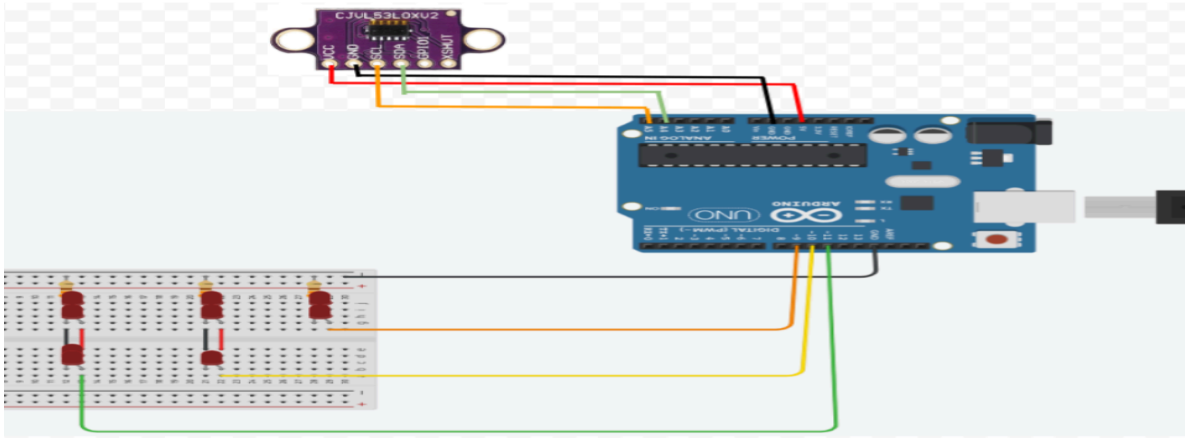


Figure 3.2.1

3.3. Operating software

Install the VL53L0X library in your Arduino IDE (Sketch -> Include Library -> Manage Libraries).

```
#include <Wire.h>
#include <VL53L0X.h>
```

```
// Create sensor object
VL53L0X sensor;
```

```
// Define LED pins
const int led1 = 9; // First LED
const int led2 = 10; // Second LED
const int led3 = 11; // Third LED
```

```
// Define distance thresholds (in mm)
// Replace x, y, z with your desired values in
// millimeters
const int threshold1 = 100; // x cm = 100 mm
const int threshold2 = 200; // y cm = 200 mm
const int threshold3 = 300; // z cm = 300 mm
```

```
void setup() {
  // Initialize serial communication
  Serial.begin(9600);
  Wire.begin();
```

```
// Initialize sensor
```

```
sensor.init();
sensor.setTimeout(500);
```

```
// Start continuous back-to-back mode
sensor.startContinuous();
```

```
// Set LED pins as outputs
pinMode(led1, OUTPUT);
pinMode(led2, OUTPUT);
pinMode(led3, OUTPUT);
}
```

```
void loop() {
  // Read distance from sensor
  int distance =
  sensor.readRangeContinuousMillimeters();
```

```
// Print distance for debugging
Serial.print("Distance: ");
Serial.print(distance);
Serial.println(" mm");
```

```
// Turn off all LEDs initially
digitalWrite(led1, LOW);
digitalWrite(led2, LOW);
digitalWrite(led3, LOW);
```

```
// Control LEDs based on distance thresholds
```

```

if (distance >= threshold3) {
  // Above z cm: All LEDs on
  digitalWrite(led1, HIGH);
  digitalWrite(led2, HIGH);
  digitalWrite(led3, HIGH);
}
else if (distance >= threshold2) {
  // Between y and z cm: Two LEDs on
  digitalWrite(led1, HIGH);
  digitalWrite(led2, HIGH);
}
else if (distance >= threshold1) {
  // Between x and y cm: One LED on
  digitalWrite(led1, HIGH);
}
// Below x cm: All LEDs remain off

// Check for sensor timeout
if (sensor.timeoutOccurred()) {
  Serial.println("Sensor timeout!");
}

// Small delay to prevent too frequent readings
delay(100);
}

```

4. Discussion

The system developed in this project provides an innovative and cost-effective approach to improving road safety by automatically indicating a vehicle's steering angle to trailing drivers using LED signals. By relying on a VL53L0X time-of-flight distance sensor and a mechanical setup involving a caster wheel and mirror assembly, the system accurately estimates the degree of steering without the need for direct access to the vehicle's steering column. The distance measured by the sensor is mapped to an LED array, where the number of LEDs illuminated corresponds to the intensity of the turn, offering a clear and intuitive visual cue to following vehicles.

Currently, the system is implemented using an Arduino Uno microcontroller, which offers simplicity and sufficient capability for basic operation. However, there is significant potential to

enhance the system's efficiency, responsiveness, and versatility by replacing the Arduino with an ESP module, such as the ESP32. The ESP32's faster processing speed enables quicker sensor data handling and LED response, which is crucial for real-time applications. Its built-in Wi-Fi and Bluetooth functionalities open possibilities for wireless communication, allowing integration with smartphones or vehicle networks for live monitoring and advanced driver-assistance features. Additionally, the increased memory and computational power support more complex operations and future upgrades, such as predictive analytics or remote firmware updates.

Beyond electronics, the mechanical design has also been optimized for minimal friction and maximum responsiveness by incorporating a direction-fixed caster wheel mechanism. The stick with the mirror assembly is placed in contact with the rear portion of the front tires, ensuring accurate detection of lateral displacement during a turn. While the prototype uses basic 3mm LEDs, these can be upgraded to RGB LEDs in real-world applications to provide more detailed or color-coded feedback, further enhancing driver comprehension.

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.

5. Conclusion

This project successfully demonstrates a cost-effective and reliable method for real-time steering angle indication using a VL53L0X distance sensor and LED indicators. By eliminating the dependency on traditional steering angle sensors and instead utilizing a mechanically coupled system with a time-of-flight sensor, the design offers both affordability and practical implementation for

existing vehicles. The proportional LED output effectively communicates the degree of a vehicle's turn to trailing drivers, thereby improving road safety and reducing the likelihood of accidents due to unindicated or ambiguous maneuvers. Furthermore, the system is easy to install, scalable, and open to enhancements, such as the use of RGB LEDs or wireless communication modules. Future iterations may focus on increasing precision, enhancing durability, and integrating the system with advanced driver-assistance systems (ADAS) to further strengthen vehicular safety on roads.

6. References

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