Proximity sensor for collision avoidance

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I. Introduction

Now a days road accident has become very common. Because of the growing population, vehicle accidents are increasing at a rapid rate. As more people use automobiles for transportation there is a greater rush on the roads which leads to more accidents. And the main reason for the accidents is People pay no attention to traffic laws and drive recklessly on the roadways. Until now there are many research are happening to modify the vehicles with the smart systems and devices to avoid accidents. But now only high-cost vehicles are available in market with collision avoidance and accident alert system. So, an ordinary person can't afford those vehicles due to the cost. In this research we are trying to design a device which can be able to detect forward collisions and give warning, able to detect line departure in roads, maintain the speed limit by analyzing the signal posts in the road and avoid collisions with the pedestrians by using AI and ML algorithms and it can be connected to any vehicles. For this device a proximity sensor with high refreshing rate and long detection range is needed. Proximity sensors plays main role to detect the nearby objects. Proximity sensor can be able to sense the nearby objects without any physical contact by emitting electromagnetic field or electromagnetic radiations. For the initial step in this research, we proposed some methods to sense the collisions and detect the distance depending on the purpose and need of application.

II. Literature review

In market there are many types of proximity sensors are available to measure distance. They have designed with different methods and techniques. Till now There are many research conducted to implement new types of proximity sensors. They have several advantages disadvantages depending on their purpose of applications.

A. Infrared distance sensors

This sensor sense the distance by emitting IR wave and calculating the angle of reflection. So, this sensor has two lenses, for emitting light beam and to sense the reflected beam. A position sensible photo detector is used to sense the reflected light. Using the angle of reflection, the distance can be measured.

Advantages of this sensor are, it can be used in both daytime and nighttime and it can be used to measure distance of objects which have complex surfaces.
Disadvantages of this sensors are range of the measurement using this sensor is very limited, hard objects can affect the measurement and environmental conditions may affect the functioning of this sensors.

B. Laser distance sensors/LIDAR

Working principle of this sensor can be understood through triangulation and pulse base. First, transmitter of the LiDAR emits laser light on the object and the reflected beam from the object is received by the receiver of LiDAR [11]. Then the distance is calculated using the constant speed of light through air and time interval between sending and receiving of light signal.
This sensor is mostly used for environmental monitoring and machine control and safety.

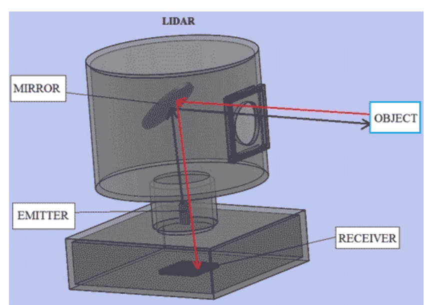


Fig.2. Model of LIDAR sensor

Advantages of this sensor are, it can be used to measure the distances regarding 3D structures, can be used in daytime and nighttime, as it has fast update rate, applicable for fast moving objects, has high measurement range, and it also can be used to measure distance with small objects.

Disadvantages of this sensor are, naked eye can be affected harmfully, cost is very high relative to IR and ultrasonic sensors.

C. LED time of flight sensors

Working principle of this sensor is like LiDAR sensor. The time gap of emission of wave pulse and moment of return to sensor is used to calculate the distance.

Advantages of this sensors are, range of measurement is wider than other type sensors, measurements are in high accuracy, capable of detecting large objects and has ability of 3D imaging.

Disadvantages of this sensors are, low Z- depth resolution and cost are relatively high.

D. VCSEL distance sensors

This sensor is still under research and only few available in market for testing purpose. This sensor consists of semiconductor laser diode which emits laser beam perpendicular to top surface [11].

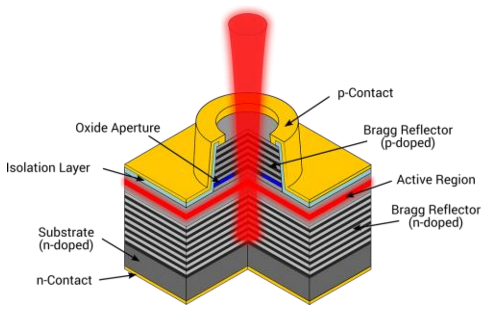


Fig.2. Model of VCSEL sensor

Advantages of this sensor are, can measure in very fine resolution, can be afford for low cost, has wide input range, can get measurement in super small minimum range.

Disadvantages of this sensors are, applicable for 12C interface only and has very small maximum range measurement.

Out of above types of distance sensors, all can be specified for measurements with different characteristics. Infrared sensors are appropriate for measuring distance with complex surfaces. Laser sensors are appropriate for measurements related to 3D structures. Infrared sensors and laser sensors can be used to take measurement in both daytime and nighttime. Especially laser sensors are suitable for measurement regarding fast moving objects. For low-cost applications and super small range measurements, VCSEL is suitable. LED can be used for getting high accuracy measurement but with low z-depth resolution. According to measurement sensors must be selected appropriately

III. METHORDS

Up to now there are many proximity sensors are implemented to detect the objects. But these mostly designed for one particular purpose. They can't be applicable for all the application. In this research we propose some methods to implement or modify the proximity sensors for collision avoidance purpose.

A. Virtual whiskers.

All mammals and humans use whiskers to rapidly collect information about the objects in order to avoid the collisions. Using novel capacitive proximity sensors, robot sense when the approach any object or human and react before they collide with them. This method of sensor proposal based on the behavior of whiskers by the means of capacitive sensors.

This sensor works in a similar way to a physical whisker but use a capacitive sensing technology. In physical sensor the rod like structure (Whisker) gets deformed by the objects during contact then the force caused by the deformation is then identified by the sensors on the surface [8]. But virtual whiskers form an electric field around them, and this field gets deformed by the objects in the surrounding without any physical contact with the sensor. Then the amount of deformation is detected by the electrodes. It can achieve a short-term response and considerably wide range of object detection.

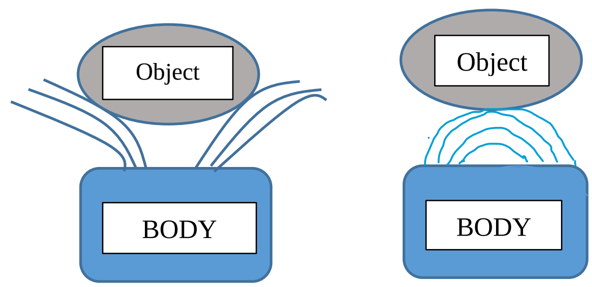


Fig.3.Left: Physical whiskers. Right: Virtual whiskers.

There is two possible ways to take the measurements with the help of the capacitive sensors.

- Differential mode - The capacitance between the two electrodes is measured by applying the voltage on one electrode(transmitter) and measure the displacement current on the other electrode(receiver). In this way the number of independent measurements can be given by $T(T-1)/2$ where T denotes transmitter.

- Single-ended mode - By measuring the displacement current arise from one/single electrode and this displacement current finally results the capacitance between the electrode (transmitter) and ground. This method gives T number of independent measurements.

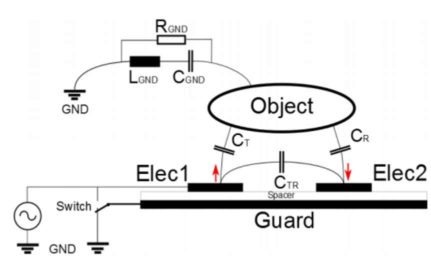


Fig.4. Capacitive measurement principle of one pair of electrodes.

Single-ended mode gives better signal to noise ratio for well-grounded objects. In the differential mode it not only senses the proximity to an object but also, it's orientation. In differential mode it is not possible to detect small conductive objects because of coupling and shielding. But the shielding mode can be minimized by the single-ended mode, so the proposed design combined with the single-ended and differential mode.

The measurement frequency can be tuned from 10kHz to 1MHz this varying frequency helpful for classification purposes. The signal which is generated can be applied to one or more electrodes and in the single-ended sensing mode it acts as active guard. The backside is connected to ground to act as differential sensing mode. Every electrode is connected to a receiver amplifier for differential sensing mode or connected to transmitter amplifier for single-ended mode.

TABLE I.

Sensor thickness	350 µm
Frequency	10kHz to 1MHz
Excitation signal	Sinusoidal signal
Measurement method	Single-ended and differential mode
Number of electrodes	T=7

[4] In this proposal a highly effective collision avoidance sensor base on capacitive method is proposed It can be able to detect the object without any physical contact when comparing to the physical whiskers. The virtual whiskers combined with the above two methods to avoid the blind spots and gives the benefit of both measurement modes. It can be able to detect not only conductive objects but also, nonconductive objects It provides a high sampling rate so it can be used in highly reactive collision avoidance applications. Physical whiskers can be able to give additional information about the properties of the surface while virtual whiskers can give information about volume properties.

The disadvantage of this sensor is it can't be able to detect the long-distance objects. It can't be used in the automated vehicles and drones because they need long distance ranging sensors to avoid accidents due to collisions. It can mostly be applicable in robotic arm to avoid collisions with unwanted objects.

B. *Proximity sensor with thermocaustic transmitter*

In most of the distance measure sensors to make the sensor small the transmitter and receiver placed closed to each other this results a coupling between the transmitter and receiver. While calculating the distance with TOF which is short as the time of transmission, the effect of coupling overlaps the reflection signal so it's difficult to differentiate the reflection signal from interfered signals. In this method of proposal thermoacoustic transmitter is used to reduce the noise and coupling effect as much as possible and thermoacoustic transmitter emits very short ultrasound, because it doesn't have any vibration [3].

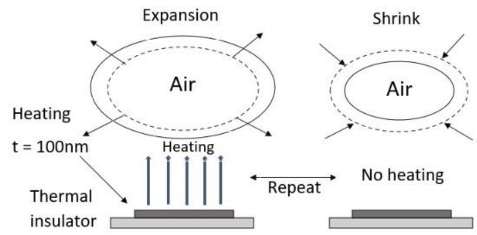


Fig.5. Principle of thermoacoustic transmitter.

The main principle used in this because of the thermal capacity of the heater is small, so it quickly changes its temperature. By applying AC current to the heater, the temperature of the heater changes up and down repeatedly the heat transfers into the air because of the thermal insulation and air expands and when this happens repeatedly it makes sound waves. The frequency of the sound wave is nearly above 100kHz. An ultrasonic receiver is used to receive the sound wave and the output of the receiver is amplified by the low noise pre-amplifier and the system then captures the output with analog to digital converter. Thermoacoustic transmitter emits only a single pulse of ultrasonic to detect the start edge of the reflection accurately. If the reflection sound is very complicated with noise, so it will be difficult to detect the start edge of the reflection from the obtained signal. So, the covariance between the received signal and emitted wave is calculated. With the help of the covariance value and searching the maximum value, the reflection signal from noisy received signal can be easily detected. By searching the maximum value it's easy to identify the weak signal and able to detect the start edge accurately [11].

The main advantage of this method is the reduction of coupling and noise. It can be mainly used in the robotic arm control system to avoid collisions. It is very thin and capable. It can give high accuracy for short range detection when it used in indoor condition.

The disadvantage of this proposal method is it can't sense the long-range distance. It is only applicable for short range detection applications. Heat emitted by the thermoacoustic transmitter can be disturbed by the surrounding heat waves and environmental conditions. Its accuracy may be low when it used in outdoors due to the unbalanced environmental conditions.

C. *TOF and self capacitance sensor.*

Many Time-of-flight sensors have been implemented in market to detect distances. A robot attached with these TOF sensor system helps to avoid collisions. But its accuracy is low when the object is less than 10*mm* so it's difficult to measure the contact. In this method a multimodal sensor array that comprises with hall-effect sensors is proposed. This sensor can be able to detect the object with certain range and can detect the condition of contact. This sensor is totally designed for robotic purpose. This sensor helps to detect the distance from proximity to contact without any blind spots. When the object approach near the robot surfaces the robot automatically avoids the unwanted contact with humans and objects because the sensor will detect the object before it contacts.

In this proposal TOF and self-capacitance sensors are combined to obtain the proximity sensor. A serial bus system is implemented to connect all the sensors attached in the surface of the robot and can efficiently detects the distance from the nearest proximity to contact without any blind spots [7]. By using the time taken to receive the light reflecting from infrared ray the TOF sensors detects the distance to an obstacle. TOF sensors have wide range of sensing ability, but it has low accuracy. On the other hand, self-capacitance sensor changes with size, property, and shape. But self-capacitance sensor has high sensitivity for short range distance it expected to detect the contact using the changes in the capacitance. So, an effective proximity and contact sensor can be obtained by combining the TOF and self-capacitance sensor. TOF sensor used to measure the distance of far away objects and self-capacitance sensor used to detect the object and distance in close range. When multiple sensors are connected it is necessary to increase the wiring and shape based on the surface [6]. To communicate between the sensor modules and master computer an I²C bus was used

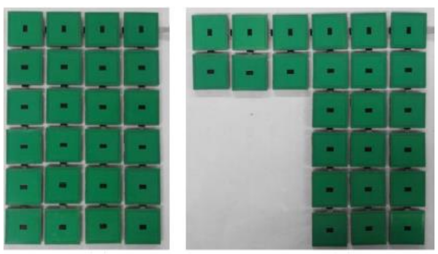
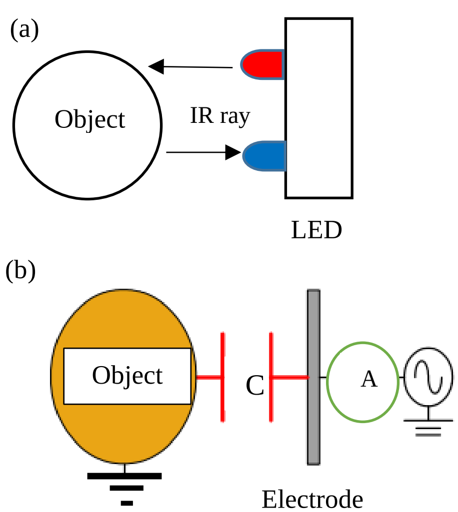


Fig.6. Connecting multiple sensors with each other.



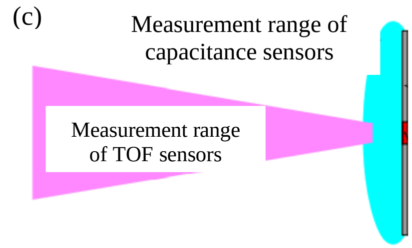


Fig.7. (a): Time-of-flight sensor. (b): Self capacitance sensor. (c): Proximity sensor that combines with time-of-flight sensor and self-capacitance sensor.

The above proposed sensor system is modified to connect with each other using a serial bus system on the application surface. The main advantage of this model is the easy expansion and implementation of the sensor and it cost very low. The TOF sensor can be able to sense 300mm distance but when it comes to measure the close range the accuracy was reduced, and the self-capacitance sensor can detect human contact also. But this sensor system can be able to use only in the robotic arm purpose. It can't detect very long range like ultrasonic sensors and lidars and can't use in collision avoidance systems in vehicles and other applications.

D. *Whiskers with multiple sensor signal transmission.*

For many biological creatures whiskers are an effective means of detecting and recognizing nearby objects. Most of the insects have whiskers and antennas outside their exoskeleton so they ca easily sense the surrounding environment. In this method of proposal, a proximity sensor is designed with whisker and a sensing element attached at the base of the whisker like tactile element. The sensor which is placed at the base of the whisker detects the flexure of the whisker when it collides or touches with any objects.

In this sensor design a whisker like tactile element and a sensor unit is attached at the base of the whisker. The whisker can be any wire with the nature of elasticity where it can restore its original shape after applying strain. In this study TiNi wire with 1mm diameter is selected as the whisker material. It has better restoring ability and highly reliable. The sensor which is attached in the base of the whisker helps to detect the contact and distance when the whisker touches an object [5]. There are two methods of sensing is presented,

1) *Digital system*

It detects the contact by only ON-OFF of the signals.

Its basic principle is detecting the contact of the electrodes attached on the base when whisker bends. If the whisker is conductive it acts as an electrode but if its non-conductive it is advisable to attach an electrode conductor around the whisker.

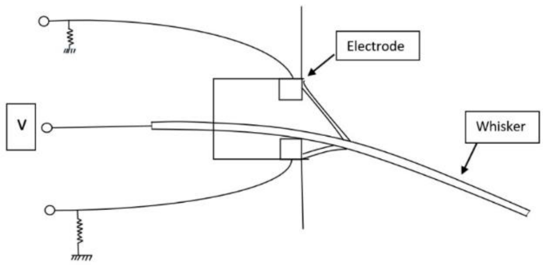


Fig.8. Basic model of digital method whisker sensor.

The advantage of the Digital method is it is compact, low cost, it can produce reliable proximity signals and the direction of the touching object can be detected by the arrangement of electrodes around the whisker.

2) Analog system

This system senses the proximity distance by the deformation of the whisker. There are many ways to implement the analog system. For instance, the strain of the structural members supporting the whisker can be detected by the system or in another system a pressure sensor is inserted in the gap between the whisker and electrode and obtain the analog signal from the sensor. In another type to measure minute displacement optical sensor and hole element is equipped.

A new type of 'whiskers with multiple signal transmission' is proposed. This sensor can be mainly applicable in robot feet and robot arm. When the feet and arms of the robot are move in highspeed and in different floor types of this sensor can withstand such harsh conditions. But the problem is a greater number of whiskers is needed to fix with the robot to obtain effective collision avoidance. The main disadvantage of this sensor is it can't detect the long-range distance and it has complex wiring system when it attached with the robot.

E. Modified ultrasonic sensor with pulse width modulation

There are many sensors available in market like lidars, stereo camera to measure distance very accurately and precisely. But they cost very high and need high performance processors to operate. Among all distance measuring sensors ultrasonic sensor is inexpensive and it can be operated by low performance processor. The main problem in ultrasonic sensor is its performance is weakened by the surrounding noise and it has lower refreshing rate [1]. For these reasons ultrasonic sensors are used in limited applications.

This proposed method mainly focused in increasing the sampling rate and signal to noise ratio to the ultrasonic sensor to obtain high efficiency. So, the maximum detection range of the ultrasonic sensor is increased.

Usually in ultrasonic sensor Time of flight method is used to measure distance. So, in this method the sensor should wait until the echo wave comes back [9]. In the case if echo is disappeared by the environmental noise the sensor must wait until of the next ultrasonic transmission. So, this reduces the efficiency of the ultrasonic sensor. In this proposal the sampling rate of the ultrasonic sensor is increased by removing the unnecessary waiting time. It will increase the signal: noise ratio of the sensor. The problem in this method is there should be a unique ness to distinguish each pulse. To avoid this problem the proposed algorithm sends the sound pulse based on the determined time intervals [2]. Each sound pulse can be distinguishable with their unique time intervals because if the pulse transmitted with particular time interval the received wave also has similar time interval.

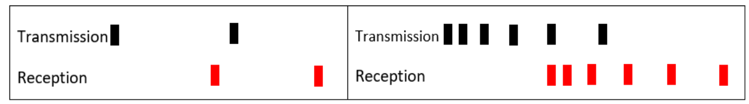


Fig.9.Left: Normal ultrasonic sensor in the market which transmit every sound pulse after the reception of the last pulse echo. Right: The proposed modified ultrasonic sensor which transmit sound pulse successively with certain time interval regardless of the echo.

In this proposal, the time interval between the two-sound pulse is $2ms$ to $10ms$ in an increment of $1ms$. After this sequence of transmission interval ends this sequence restarts from its first interval $2ms$ and continue this loop. The distance is calculated by comparing received signal and transmitted sequence. The distance (d) between the sensor module and obstacle can be calculated by this formula where c is the velocity of sound in air and t is the time of flight.

$$d = c \times t/2$$

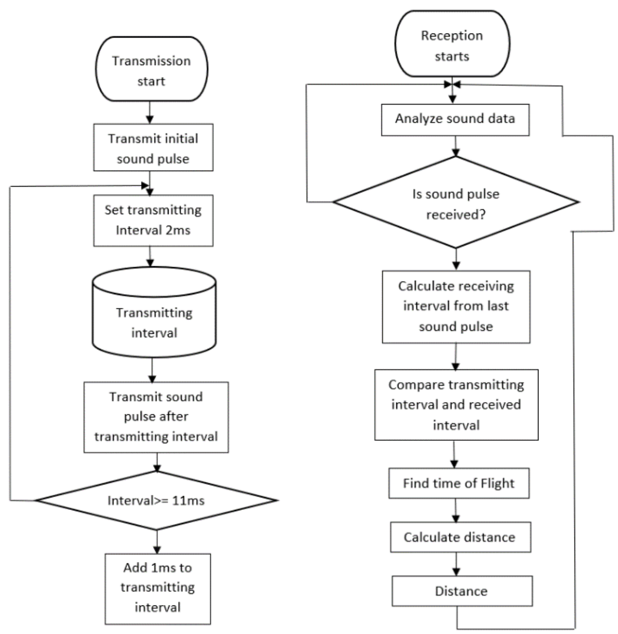


Fig.10.Left: Proposed algorithm for transmitter. Right: Proposed algorithm for receiver.

The above presented is the transmission algorithm of the modified ultrasonic sensor where the starting transmission interval is set to $2ms$, and the processor saves the transmitting interval. Then second pulse is sent after the initial transmission interval with the transmission interval having the increment of 1ms from the previous interval. This process continued until the final transmission interval 11*ms*. Then after, the interval set returned to the initial interval 2ms. In the receiving process processor determinates, the interval from the sound pulses and calculate the time of flight by comparing the interval of transmission pulse and received pulse. Then the distance can be determined by the time of flight.

This proposed method of sensor sampling rate and signal to noise ratio is high because there is no need to system to wait until the sound pulse received. This sensor method can be mainly used in long range applications such as autonomous vehicles to prevent accidents and radar systems. It more efficient than the normal ultrasonic sensor available in the market It is low cost and adorable. The main disadvantage in this sensor is it can’t detect the very low short distance and it’s not suitable for industrial robot arm for collision avoidance. The practical difficulty while implementing this sensor its need high programming knowledge to modify the algorithm.

IV. Specification

We are trying to develop a collision avoidance device which can be attached in any vehicles. It can be able to detect the forward collision with vehicles and give alert, able to detect line departure in roads, maintain the speed limit by analyzing the signposts and gives alert according to the signpost near the road and also helps to avoid collisions with the pedestrians and animals in the street. For this purpose, the proximity sensor should have high sampling rate to detect obstacle frequently nearly 140*samples/sec* is needed. The range of the sensor needed to be high to avoid the forward collisions. The maximum sensing distance of the proximity sensor needed to be 10*m* and minimum distance should be 10*cm*. The sensor needed to be not disturbed by the surrounding noise and environmental conditions. The sensor should be small and light weight approximately 9g. The sensitivity of the receiver of the sensor must be high to detect the obstacle quickly. The ultrasonic sensor modified by pulse width modulation technique proposed in the above methods is the one which can fulfill the given needs. It has high sampling rate and has high signal: noise ratio. It is compatible and can be operated by any kind of microcontrollers and processors.

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