Sensor-based Target Location Technology in Intelligent Transport Systems

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Abstract. This paper explores the critical role of sensor-based targeting in Intelligent Transport Systems (ITS). The rapid growth of vehicles put forward challenges to congestion and emissions, and most contraries' departments use ITS to solve the problem. The key to ITS is positioning the traffic participants precisely to collect the necessary data for the system operation. This study provides a review of previous research on sensor-based target localization and its importance in ITS. It discusses various sensors suitable for ITS applications, detailing their functionality and contribution to system efficiency, accuracy, and safety. In addition, this paper designs an experimental case that provides a deeper analysis of these sensors. This experiment tries to use minimum mean squared error and Kalman filtering to reduce error. The results of the study show that methods similar to minimum mean squared error and Kalman filtering can reduce the error effectively. This research contributes to understanding the use of sensors in ITS, digging their potential to revolutionize modern transport systems.

Keywords: Intelligent Transport System (ITS), Laser sensors, infrared sensors, ultrasonic sensors, sensor fusion.

1. Introduction

Background of the Study: According to Joyce Dargay and his colleagues, the number of motor vehicles worldwide is expected to increase rapidly from about 800 million in 2002 to more than 2 billion in 2030 [1]. The fast increase in the number of motor vehicles poses a substantial challenge to transportation system construction. Intelligent Transport System (ITS) is essential to solve the problems of congestion and emissions caused by the rapid increase of motor vehicles. ITS can make the operation of the transport system more efficient, smooth, and green by using internet technology, sensor technology, and artificial intelligence technology [2]. The positioning of the target plays an indispensable role in the whole ITS because each traffic participant (pedestrians, vehicles, etc.) is an essential variable in the traffic system. Only by positioning these "targets" accurately can collect the data of these traffic participants so that the ITS can make judgments in different situations and make the ITS more efficient. So that the system can make more exact judgments under different situations, making the operation more efficient, accurate, and safe.

Target location based on sensors is one of the useful methods to locate the target, and in the development of Intelligent Transport Systems, sensors as the critical hardware have also been developed significantly. This paper will mainly focus on the application of sensors in ITS.

This paper will first present the results of previous research on sensor-based localization of targets and then a discussion of several sensors that may be used in Intelligent Transport Systems (ITS) and their applications, followed by the introduction of an experimental case study that will provide an in-depth study of these sensors, and finally conclusions.

Research on the application of sensors in target localization can improve the sensitivity and accuracy of target localization, which will lead to the further development of ITS and a better solution to practical problems such as traffic congestion and emission overruns.

2. Related Work

Much relevant research has been accumulated on sensor-based localization of traffic participants. For example, an infrared sensor-based system can capture vehicles that disobey traffic rules and display the ID of the vehicle. This system uses infrared sensors to achieve high-precision traffic control, improves the efficiency of traffic at intersections and reduces violations [3]. LIDAR can also be installed in vehicles, especially trucks. This system can help the vehicle to detect the position of objects around it accurately, avoiding collisions and reducing the driver's workload [4]. In addition, the ACC system, based on conventional ultrasonic radar, can detect the distance of surrounding objects and roughly estimate their speed, which can be used to avoid obstacles [5]. However, these applications have a common disadvantage: they all use only one type of sensor to fulfill their functions, which can lead to a reduction in the accuracy of a single sensor due to the effect of environmental factors. I will introduce some commonly used sensors in the next step.

3. Sensors

3.1. Ultrasonic sensors:

The ultrasonic sensor measures distance. It measures the time it takes for ultrasonic waves to travel from the launch to the target and then returns to the receiver to calculate the target distance. It is a simple, easy-to-use, and high-precision sensor, measuring a range of up to a few meters. At a temperature of 20 degrees Celsius, the speed of sound is 344 meters per second, then calculated by the following formula, you can get the target distance:

$$\text{Distance of target} = \text{speed of sound} * \text{time}/2 \quad (1)$$

Ultrasonic sensors can measure the distance of various objects because most objects have the property of reflecting sound waves, especially in the measurement of transparent objects, thin films, liquids, and other substances. Ultrasound has an inherent advantage: ultrasonic detection is not subject to the color of the target object or the influence of light changes, so ultrasonic sensors can be exact in any light condition to measure the distance of the target, which is the advantages cannot be replaced by photoelectric sensor [6]

3.2. Laser Sensors

The laser sensor is also widely used. There are many kinds of methods that laser sensors can use to measure the distance. Some of the common methods are triangulation measurement, time-of-flight (ToF) measurement, confocal measurement, interferometry measurement, etc. Laser sensor has the advantages of compact size, high measurement accuracy, applicability to a variety of objects, etc [7] wherever the object can reflect the laser light, the laser sensor can be measured. Due to the very high speed of light, laser sensors can measure fast-moving objects. However, there are still unavoidable errors in laser sensors, especially when the ambient illumination is too high, the laser sensors will have a decline in signal-to-noise ratio [8]. The laser reflectivity of the object to be measured is also critical. High reflectivity of the object can usually achieve a better measurement result.

3.3. Infrared Sensors

The time-of-flight measurement is the most commonly used distance calculation method of infrared sensors. The principle of this method is similar to how ultrasonic sensors calculate the distance, but due to the different infrared reflectivity on different surfaces of the objects, there exist significant differences in measurement results. Furthermore, the non-linear behavior of infrared sensors makes it difficult for infrared sensors to precisely detect the distance to the object, however this does not indicate that infrared distance sensors are useless. Due to the characteristics of fast speed and high sensitivity, it often used as a proximity sensor, to determine whether there is an object approaching [9].

These sensors above can be widely used in Intelligent Transport Systems. For example, ultrasonic sensors are often equipped in cars and used as a reversing radar. Multi-group ultrasonic radar can make a comprehensive detection of obstacles near the car, and then with the combination of automatic control technology, it can make the vehicle sense the obstacles around itself, realizing the vehicle's auto-parking. Ultrasonic radar can also be a distance warning sensor to the driver. When the object in front of or behind the vehicle is fast approaching, ultrasonic radar can detect the distance between the vehicle and the object. And then, the driver will receive a warning, or the computer will take over the vehicle and activate braking or accelerating to maintain a safe distance and avoid collision [10]. The LiDAR based on the development of laser sensors, can obtain a comprehensive perception of the surrounding environment. Compared with the vision system, LiDAR has a depth of field, which means that LiDAR can determine the distance and shape of the surrounding objects more accurately. If the laser sensor and the vision sensor have a fusion, make the laser sensor responsible for detecting the distance and shape of the object, and the vision sensor is responsible for determining what kind of specific things, then it can obtain more environmental data [11]. And environmental data can be obtained to collect the data needed for autonomous driving. In addition, laser sensors can detect road signs and ground marks, allowing the vehicle to drive in the right lane at the right speed and in the right way, make the vehicle to enable autonomous driving. LIDAR can also produce high-accuracy 3D maps to support autonomous driving and navigate vehicles in a variety of complex environments. Infrared sensors can be used to detect the status of vehicle queues in front of signal lights, enabling the signal lights to be changed appropriately according to the current traffic flow to improve the efficiency of the passage. Infrared sensors can also monitor the traffic flow at intersections or motorways to let officers respond appropriately to possible future situations. Infrared sensors can even detect the arrival of pedestrians at intersections with low foot traffic, enabling the traffic lights on motorways to only change to red when someone needs to cross the road, significantly improving the efficiency of motor vehicles and reducing the potential traffic accidents. Infrared sensors can also be used to classify vehicles [12] so that motorway toll booths can charge separately for different types of vehicles (e.g., lorries, buses, cars, emergency vehicles, etc.) or restrict the movement of a certain type of vehicle (e.g., in some cities, large lorries are banned from entering the city center).

Obviously, after the above introduction, it is easy to find that different sensors have unique advantages, but there are also unavoidable inherent defects that make a certain kind of sensor is not reliable enough in specific environmental conditions, so this paper aims to explore a sensor fusion, so that a variety of sensors work together, and finally, through the fusion of the data, so that the error for the distance measurement is minimized. The fusion method is a new approach to the measurement of distance.

Based on the above introduction, the authors have chosen three typical sensors shown in Figure. 1, Figure. 3 and Figure. 4:

HC-SR04 Ultrasonic Sensor

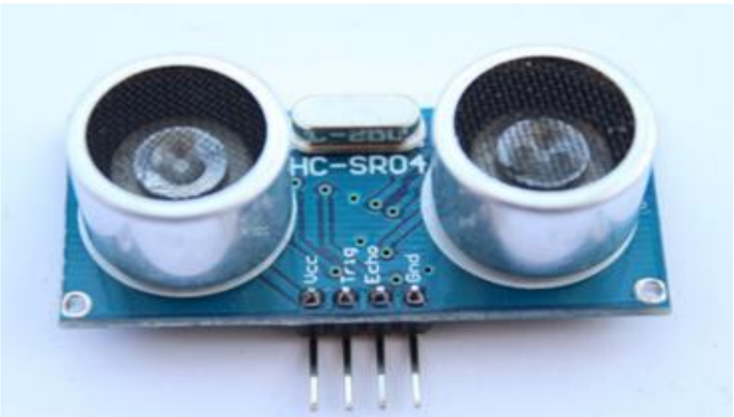

Figure. 1 Physical drawing of HC-SR04.

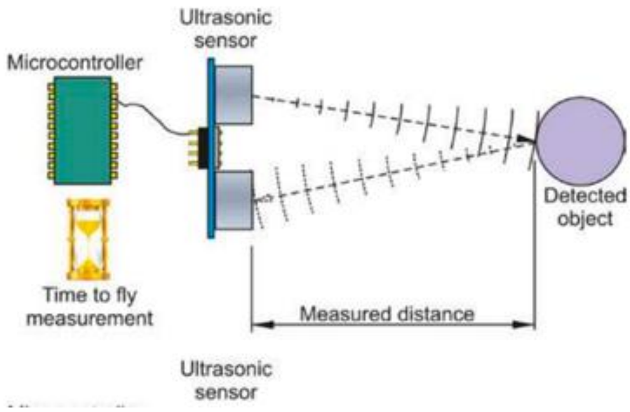

Figure. 2 Schematic of HC-SR04 [3].

The picture Figure 2 shows how HC-SR04 work, the details of this ultrasonic sensor are as Table1

Table. 1 Parameter of HC-SR04.

Voltage	5V
Detection angle	15°
Detection distance	2cm-400cm
accurate	±3cm

Pin definitions (left to right)

1. VCC: to 5V power supply
2. Trig: to a digital pin (D1)
3. Echo: to a digital pin (D2)
4. GND: to GND

This sensor's transmitter generates 8 pulses at 40 KHz, and upon receiving the reflected signal, the sensor produces a high-level output. However, this sensor's accuracy can be influenced by variations in the speed of sound caused by temperature changes. Use the speed of sound at different temperatures to correct the deviation of the transducer and obtain the correct speed of sound using the following formula:

$$c = \sqrt{(\gamma * R * T)} \tag{2}$$

- "c" represents the speed of sound
- "γ" denotes a gas's adiabatic index, which is the ratio of a gas's specific heat capacity to its specific heat capacity.
- "R" represents the gas constant, which varies for different gases.
- "T" stands for absolute temperature, usually in Kelvin (K).

GP2Y0A02YK0F Infrared Sensor

Figure. 3 Physical drawing of GP2Y0A02YK0F.

The details of this infrared sensor are as Table. 2:

Table. 2 Parameter of GP2Y0A02YK0.

Voltage	3.3V/5V
Detection distance	10cm-80cm
accurate	±0.1cm

Pin definitions (left to right)

1. Yellow Cable (V0): to an analog pin
2. Black Cable (GND): to GND
3. Red Cable (Vcc): to 5v power supply

The GP2Y0A02YK0F infrared sensor, manufactured by Sharp, uses triangulation for distance measurement. It generates an analog signal based on the sensor's output voltage due to the change of detected distance. The output value and the actual distance have a non-linear inverse relationship.

VL53L0X Laser Sensor

Figure. 4 Physical drawing of VL53L0X.

The details of this laser sensor are as Table. 3:

Table. 3 Parameter of VL53L0X.

Voltage	3.3V/5V
Detection distance	0cm-200cm
accurate	±0.5cm

Pin definitions (left to right)

VCC: to 3.3V or 5V power supply

SCL: to an analog pin (A4)

SDA: to an analog pin (A5)

GND: to GND

The VL53L0X laser distance sensor operates on a measurement principle similar to the ultrasonic sensor. However, it calculates distances by measuring the time laser light travels to the target and returns. Different from ultrasonic sensors, lasers are not affected by changes in air temperature. Yet, laser speed is influenced by variations in air composition, meaning factors like haze and fog can impact its accuracy.

4. Experiment:

Based on the above state, the authors designed an experiment aimed at investigating the fusion of data from the three sensors mentioned above. Firstly, the three sensors were connected to an Arduino, which is used to collect data on a computer. The physical diagram is as Figure. 5 and Figure. 6:

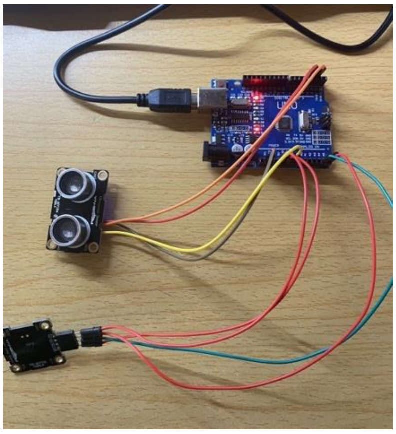

Figure. 5 Wire of laser and ultrasonic sensors.

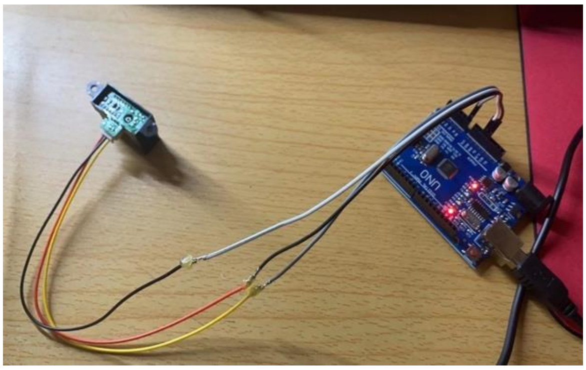

Figure. 6 Wire of infrared sensor.

And the authors wrote the appropriate code so that these sensors would work properly to collect the data.

In the second step, select five test points with an interval of 100 mm for data collection, calculate the variance, standard deviation, and mean of the data, and perform a simple data fusion process, referring to the formula (3), (4), (5). [13]:

$$y(t) = y^{(II)}(t) = \left[\sum_{j=1}^{N} R_j^{-1}(t)\right]^{-1} \sum_{j=1}^{N} R_j^{-1}(t) y_j(t) \tag{3}$$

$$C(t) = C^{(II)}(t) = \left[\sum_{j=1}^{N} R_j^{-1}(t)\right]^{-1} \sum_{j=1}^{N} R_j^{-1}(t) C_j(t) \tag{4}$$

$$\mathrm{R}(\mathrm{t}) = \mathrm{R}^{(II)}(\mathrm{t}) = \left[\sum_{\mathrm{j}=1}^{\mathrm{N}} \mathrm{R}_{\mathrm{j}}^{-1}(\mathrm{t})\right]^{-1} \tag{5}$$

Compare the processed data with a set of data modeled with Gaussian noise as follows:

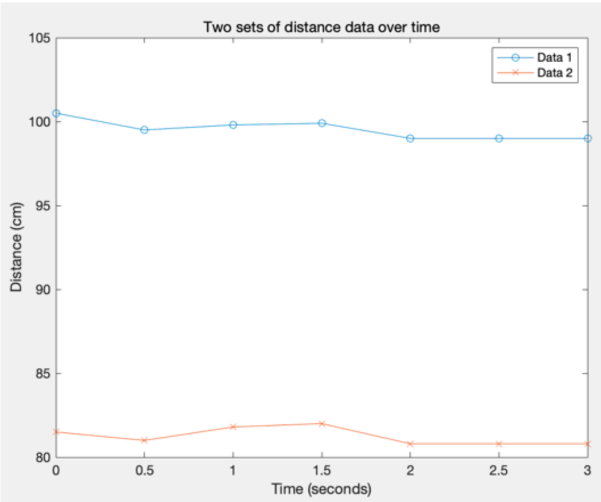

Figure. 7 Comparison of actual effect and simulation effect.

From Figure 7 can see that the fused curves of the sensor data are essentially the same as those of the simulation, from which it can be deduced that one of the primary sources of error in the sensor is Gaussian noise

The authors considered the effect of a single noise on the sensor in the above, but in real applications, the environment is more complex and variable. It can not only consider Gaussian noise, so the authors tried to introduce Kalman filtering into the experiment. [13]Collected the distance data of two sensors for a stationary object over a while, as shown in Figure 8:

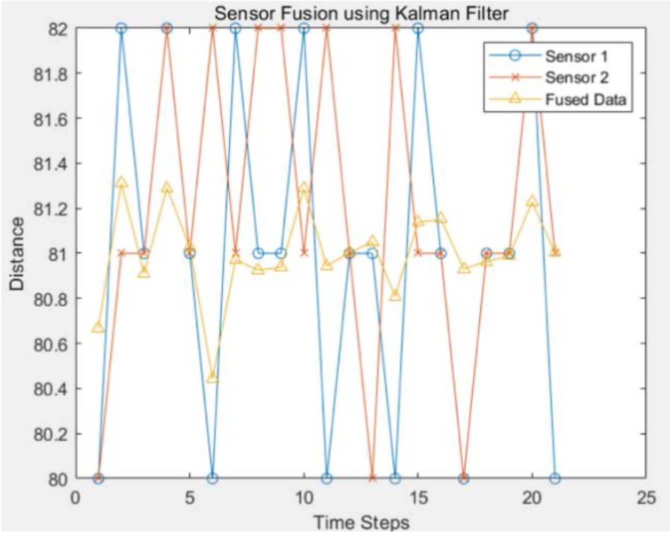

Figure. 8 Sensor Data Curves and Fusion Data Curves.

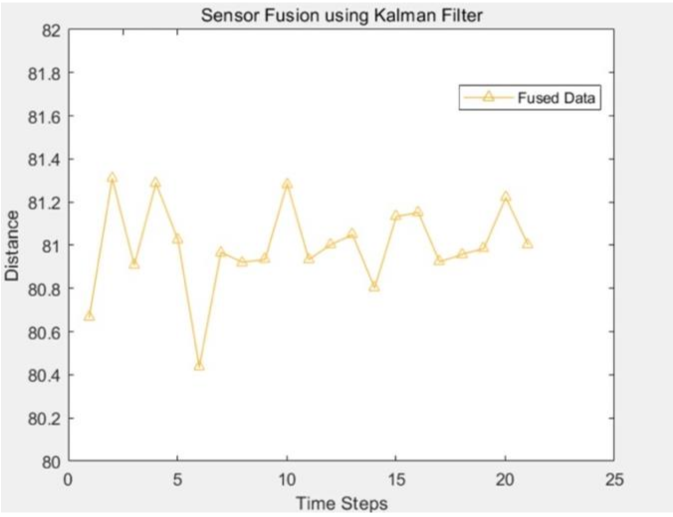

Figure. 9 Fusion Data Curves.

The authors then fused the data from the two sensors and used Kalman filtering; the blue line as well as the red line in Figure 8 are the raw data from the two sensors, and the orange line is the fused fold. Figure 9 shows the fused data separately for differentiation, and a comparison of the two figures indicates that Kalman filtering has good error reduction.

5. Conclusion

Through the discussion, it is easy to find that sensors play an important role in intelligent transport systems. Whether it is the automatic driving of vehicles, traffic flow monitoring, or intersection signal control, they all rely on a variety of sensors to work together. As the authors mentioned in the paper, different sensors will be affected by different environmental factors, especially in the operation of the transport system. The changing light conditions and weather factors will have an impact on the accuracy of the sensors. All of them will affect the accuracy of the sensors, so it is very important to study the sensor fusion and filtering to improve the credibility of the sensor data. In the above experiment, the simpler minimum mean square error estimation and the more complex Kalman filtering have been verified. However, this experiment still has the limitation that the objects involved in traffic are often moving, and the above experiments only consider the stationary case when performing Kalman filtering. It is very important to evaluate the test error of moving objects in future research, and future experiments should consider real weather conditions more often and conduct simulation experiments so as to obtain results closer to reality.

References

[1] J. Dargay, D. Gately, and M. Sommer, ‘Vehicle Ownership and Income Growth, Worldwide: 1960-2030’, Energy J., vol. 28, no. 4, Oct. 2007, doi: 10.5547/ISSN0195-6574-EJ-Vol28-No4-7.

[2] L. E. Y. (Luz E. Y. Mimbela and L. A. Klein, Summary of vehicle detection and surveillance technologies used in intelligent transportation systems. Washington, DC: Federal Highway Administration, Intelligent Transportation Systems Joint Program Office, 2000.

[3] Sikder Sunbeam Islam, K. Dey, Mohammed Rafiqul Islam, and Mohammad Kurshed Alam, ‘An infrared based intelligent Traffic System’, in 2012 International Conference on Informatics, Electronics & Vision (ICIEV), Dhaka, Bangladesh: IEEE, May 2012, pp. 57–60. Doi: 10.1109/ICIEV.2012.6317334.

[4] R. Stahn, G. Heiserich, and A. Stopp, ‘Laser Scanner-Based Navigation for Commercial Vehicles’, in 2007 IEEE Intelligent Vehicles Symposium, Istanbul, Turkey: IEEE, Jun. 2007, pp. 969–974. doi:

[5] L. Alonso, V. Milanés, C. Torre-Ferrero, J. Godoy, J. P. Oria, and T. De Pedro, ‘Ultrasonic Sensors in Urban Traffic Driving-Aid Systems’, Sensors, vol. 11, no. 1, pp. 661–673, Jan. 2011, doi: 10.3390/s110100661.

[6] M. Kelemen et al., ‘Distance Measurement via Using of Ultrasonic Sensor’, J. Autom. Control.

[7] Y. S. Suh, ‘Laser Sensors for Displacement, Distance and Position’, Sensors, vol. 19, no. 8, p. 1924, Apr. 2019, doi: 10.3390/s19081924.

[8] A. Z. Khalaf and B. H. Alyasery, ‘Laser Distance Sensors Evaluation for Geomatics Researches’, Iraqi J. Sci., pp. 1831–1841, Jul. 2020, doi: 10.24996/ijs.2020.61.7.32.

[9] G. Benet, F. Blanes, J. E. Simó, and P. Pérez, ‘Using infrared sensors for distance measurement in mobile robots’, Robot. Auton. Syst., vol. 40, no. 4, pp. 255–266, Sep. 2002, doi: 10.1016/S0921-8890(02)00271-3.

[10] L. Alonso, V. Milanés, C. Torre-Ferrero, J. Godoy, J. P. Oria, and T. De Pedro, ‘Ultrasonic Sensors in Urban Traffic Driving-Aid Systems’, Sensors, vol. 11, no. 1, pp. 661–673, Jan. 2011, doi: 10.3390/s110100661.

[11] S. Mohottala, S. Ono, M. Kagesawa, and K. Ikeuchi, ‘Fusion of a Camera and a Laser Range Sensor for Vehicle Recognition’, in Machine Vision Beyond Visible Spectrum, R. Hammoud, G. Fan, R. W. McMillan, and K. Ikeuchi, Eds., Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 141–157. Doi: 10.1007/978-3-642-11568-4_6.

[12] S. A. Ahmed, T. M. Hussain, and T. N. Saadawi, ‘Active and passive infrared sensors for vehicular traffic control’, in Proceedings of IEEE Vehicular Technology Conference (VTC), Stockholm, and Sweden: IEEE, 1994, pp. 1393–1397. Doi: 10.1109/VETEC.1994.345323.

[13] Q. Gan and C. J. Harris, ‘Comparison of two measurement fusion methods for Kalman-filter-based multisensor data fusion’, IEEE Trans. Aerosp. Electron. Syst., vol. 37, no. 1, pp. 273–279, Jan. 2001, doi: 10.1109/7.913685.