TRANSPORT PROBLEMS 2023 Volume 18 Issue 1
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2023.18.1.09

Keywords: IoT; distance sensor; low-cost system

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A LOW-COST SYSTEM FOR SUPPORTING DRIVERS IN TRAFFIC JAMS

Summary. Cases of heavy traffic congestion (commonly referred to as traffic jams) have negative influences on the economy, public health, and social life. This makes it important to assist drivers in these situations with Internet of Things (IoT) systems. The aim of this article is to present a low-cost device that supports driving in traffic jams. The system, which is based on data from a laser sensor with a range of up to 40 m, controls the distances to vehicles in front of and behind a moving car. Through audio and video signals, it warns the driver whether the vehicle in front of or behind the equipped vehicle is too close. This allows the driver to control the distance and avoid minor collisions.

1. INTRODUCTION

Traffic congestion is a road phenomenon characterized by low vehicle speed, prolonged trip times, and increased car queueing. This phenomenon has substantially worsened since the 1950s [1-2]. Population growth is the main factor that causes congestion. There are not enough roads to absorb all drivers, and the infrastructure is not well suited to the current state of car communication. Most cases of traffic congestion are attributed to traffic incidents, road conditions, and adverse weather conditions [3-4].

The negative effects of traffic congestion include wasting the time of drivers and passengers (as being stuck in traffic is clearly not a productive activity), delays resulting in late arrivals for employment and meetings, difficulties in estimating travel time accurately, increasing fuel consumption and air pollution, increasing the frequency of repairs of tires and braking systems, disturbing emergency vehicles' passage, road rage, and higher chances of crashes.

The interactions between cars can decrease the overall speed of the traffic stream. This can result in high congestion. When the number of cars exceeds the capacity of a road (or the intersections along the road), a particularly intense case of traffic congestion can arise. A traffic jam occurs when vehicles are forced to come to a full stop for significant periods. A textbook [5] provides comprehensive coverage of vehicular traffic flow dynamics and modeling. It presents different categories of traffic data. The main part is devoted to a mathematical description of the dynamics of traffic flow. It also focuses on traffic instabilities, such as congestion, and model calibration approaches related to these topics in a novel and

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systematic way. The use of the theoretical framework is shown in selected applications, such as traffic-state and travel-time estimations, depending on the level of congestion.

Another textbook [6] is devoted to the long-term growth of the problem of congestion across the US, where transportation planning legislation has mandated the monitoring and analysis of system performance and sparked a renewed interest in studying travel times and delays. The installation of traditional sensors on major roads (e.g., inductive loops) for collecting data is necessary but not sufficient, as they have limited coverage and are expensive to set up and maintain. The global positioning system (GPS)-based techniques described in [6] have been developed into an automated system that provides a realistic experience of traffic flow on roads. Compared to other systems, this technique provides the greatest degree of automation without requiring nearly as much attention from data collectors; it also processes data sets automatically. A detailed analysis greatly favored the GPS method over other methods.

A previous paper [7] focused on finding the impacts of rainfall and temperature on urban traffic characteristics, in both peak and off-peak hours, using traffic data from Greater Manchester, UK, as a case study. The effect of rainfall on urban traffic and the impacts of rainfall intensity and atmospheric temperature on traffic flow parameters in both of the aforementioned periods were considered. This research can give urban traffic policymakers crucial information that could help them modify or develop traffic planning decisions to optimize the utilization of the traffic network while preventing congestion.

In [8], the authors attempted to determine the effects of the lane kilometers of roads on vehicle kilometers traveled in cities in the US. They found that vehicle kilometers traveled increases proportionately to roadway lane kilometers on interstate highways; this effect is probably slightly weaker for other types of roads. The root causes of this extra vehicle kilometers traveled are increased time spent driving by current residents, increases in commercial traffic, and migration. Increasing lane kilometers for one type of road diverts little traffic from other types of roads. The authors did not find any evidence that the provision of public transportation affects vehicle kilometers traveled. Consequently, they concluded that the increased provision of roads or public transit is not very likely to relieve congestion.

A textbook [9] focused on the key engineering skills needed to practice traffic engineering in a broad setting. Traffic engineers deal with several critical elements of the transportation system as a critical part of the infrastructure. First and foremost, they need to have an appreciation for and an understanding of planning, design, management, construction, operation, control, and system optimization in case congestion occurs.

The processes of detecting, predicting, and alleviating traffic congestion aim to improve the standard of service of the transportation network. For large datasets, deep learning methods are used. The system dynamics of the transportation network are vastly different in non-congested and congested states. Therefore, it is necessary to understand the challenges characteristic of congestion prediction. In a survey [10], the authors overviewed the current state of the usage of deep learning techniques for the detection, prediction, and alleviation of congestion. Recurring and non-recurring congestion were discussed separately.

Traffic congestion may make drivers frustrated and can cause them to engage in road rage and other aggressive behaviors. Traffic slowdowns can cause crashes and injuries [11] because drivers become engaged in distracting activities, including driving while texting, reading, making phone calls, eating, changing the radio station, grooming, and disciplining their children. The effects of such behavior are comparable to the crashes and injuries caused by drunk driving. There are multiple social campaigns aimed at decreasing unnecessary road accidents and injuries.

The primary goals of transport policymakers are to reduce traffic congestion and road accidents [3]. The exact relationship between traffic congestion and car accidents is not clear and, to date, has not been studied extensively enough. It has been conjectured that there could be an inverse relationship between traffic congestion and road accidents. The results of [12] suggest that traffic congestion has little to no impact on the frequency of car accidents. Conversely, the results of [13] suggest that a reduction in traffic delays would reduce the number of accidents. In general, the existing literature shows that reducing congestion would likely positively affect public health [14].

Today, there are various popular Internet of Things (IoT)-related solutions. There is a large variety of easily accessible sensors. Moreover, owing to universal hardware platforms such as Arduino, it is relatively easy to equip a vehicle with auxiliary devices that do not interfere with the original car systems. These solutions are also characterized by a low net cost of production. An interesting solution for detecting anomalies on roads built on the basis of the IoT infrastructure is presented in [15]. The authors created an IoT system that collects data about driving conditions and evaluates them according to the various demands of the user. The applied module of fuzzy logic of the second type was used to analyze accelerometer signals to enable the flexible adjustment of factors like the uncertainty of evaluations of the driving expectations of each driver. The developed system was tested in different cars on various roads. The results show that the system has excellent efficiency.

Another previous work [16] proposed a method based on a visual analysis to determine the distance of an emergency vehicle from a crossroad. This solution is based on image analysis and the detection of cars in front of the subject in the turn queue. In [17-18], the locations of wireless devices (e.g., cellular phones) were monitored to measure link travel distances. Other papers [19-21] demonstrated the use of GPS, WiFi, and Bluetooth devices to collect and analyze traffic data. The impact of traveling conditions on changes in lane restrictions during construction periods was surveyed.

Another paper [22] described the use of GPSs to automatically collect data related to, for example, local time, local coordinates, and the speed of vehicles on Louisiana highways. The data-reporting procedure used a geographic information system to extract information. In [23-24], the traffic conditions leading to accidents were defined based on their real-time accident likelihood, and their use as accident predictors was confirmed. In [25-26], freeway locations with high crash potential were identified using automatic vehicle identification systems (also see [27-29] for local implementations of such systems).

Many studies have investigated the relationship between traffic volume and accidents [30-31]. A paper [32] examined the relationship between the risk of dying in a traffic accident and per capita income and applied this relationship to predict traffic fatalities based on demographics. The decrease in the number of traffic-related fatalities in developed industrialized countries in recent years has been quite substantial. The results of [33] suggest that one factor associated with the reduction in traffic-related fatalities over time has been the improvement in medical technology. In [34], an analysis was conducted on how various road infrastructure improvements can affect traffic-related fatalities and injuries while controlling for other factors that affect overall safety.

In order to prevent congestion, drivers can check traffic reports through the radio, GPSs, navigation systems, and road announcements. They can then choose an alternative road to avoid possible difficulties. Other possibilities are offered by special car systems. In this paper, we examine systems that control the distance between cars.

Existing systems use ultrasonic sensors to detect obstacles 1-2 m behind and in front of a vehicle. The disadvantage of these systems is that the sensors at the rear only work when the rear gear is engaged. The rear camera operates similarly. In modern premium-class vehicles, the range of cameras and sensors may cover 360 degrees (i.e., the entire area around the vehicle). This feature is used, for example, by automatic parking systems.

In modern high-class cars and trucks, a system is also used that employs, for example, radar sensors to detect that the vehicle in front is too close, and then applies the brakes without the driver's participation, which usually prevents accidents. This system does not guarantee accidents will be avoided, but it can significantly reduce the amount of damage and losses suffered.

Such systems are very expensive. They use many sensors, and the vehicle's computer analyzes a large data set and decides whether it has to apply the vehicle's brakes. When an obstacle is detected, the brakes are used by the system to avoid a collision, even if the driver does not react. This helps reduce the amount of damage caused if an accident occurs.

The system we propose is a cheap solution that warns drivers of danger during slow driving conditions (e.g., during a traffic jam). It does not replace the driver in the braking process, and it can be used in older car models that are often found on roads. Our system is based on a typical laser sensor (Lidar) used in industrial robots and drones to locate obstacles and measure the distance from them. To measure the speed of the vehicle, we use a GPS module that transmits data to a Raspberry Pi computer. The computer analyzes the data using the formulas and the table presented in the next chapter and provides visual and audible warnings to the driver. Data analysis can be accelerated by entering data into the computer as shown in the mentioned table.

Our system does not interfere with the vehicle's braking system, but with audible and visual warnings, it warns the driver when the distance between the vehicle and other vehicles is too close, which is related to the possibility of a collision. The system collects data about the speed of the vehicle and the distance from the vehicles in front of and behind the vehicle equipped with our system.

Moving in a traffic jam requires the driver to constantly maintain their focus due to frequent changes in speed and stopping. In unfavorable weather conditions (e.g., when it is hot), the driver may distract themself and not stay a safe distance from the vehicle in front of them. Our system helps the driver avoid such problems.

2. MOTIVATION

In a typical physical model, the vehicle stopping distance S is the sum of the distance that the vehicle will travel at the initial speed V_p along distance S_1 before the driver and the vehicle's braking systems react and the stopping distance S_2, which is related to the application of the brakes. Thus, we have:

$$S = S_1 + S_2 \tag{1}$$

with $S_1 = V_p(T_d + T_c)$, where T_d is the driver's response time and T_c is the response time of the vehicle's systems. The braking distance T_2 can be calculated from the relationship:

$$S_2 = V_p T_2 - \frac{aT_2^2}{2} and \;\; 0 = V_p - aT_2\,, \tag{2}$$

where T_2 is the braking time and a is the acceleration (movement delay). The short transformations show that:

$$S_2 = V_p \frac{Vp}{a} - \frac{a}{2}\frac{V_p^2}{a^2} = \frac{V_p^2}{a} - \frac{V_p^2}{2a} = \frac{V_p^2}{2a}\,, \tag{3}$$

which is directly proportional to the square of the initial velocity. On the other hand, the acceleration a is proportional to the gravity acceleration $a = \mu\, g$, and the coefficient μ depends on the type of road surface (asphalt, concrete, gravel, etc.) and weather conditions (sunny, rainy, snow, black ice, etc.), which affect tire friction.

Fig. 1 is a graph showing the relationship between vehicle speed and time in our model. The path S_1 is calculated from the formula of the area of the rectangle with sides $[0, V\mathrm{p}]$ and $[0, T_d + T_c]$:

$$S_1 = V_p \;\; (T_d + T_c). \tag{4}$$

It is easy to see that it is a definite integral from the constant function:

$$V = V(T) = V_p - const. \tag{5}$$

In the general situation, we can calculate the S_1 path using the formula

$$S_1 = \int_0^{T_d+T_c} V(t)dT. \tag{6}$$

This makes it possible to take into account additional factors influencing the length of the S_1 road (e.g., the slope of the road). If the road is downhill, the speed will increase; if the road is uphill, the speed will decrease.

The situation is similar for the estimation of the S_2 path, which can be calculated as the definite integral (area under the curve) from Fig. 1. In our model, we assumed a constant acceleration (delay), which led to the result $S_2 = \frac{V_p^2}{2a}$. However, taking into account additional factors requires more complicated calculations. It is sufficient to note that cars with an ABS can stoped with pulsation. The ABS prevents the wheels from locking, and in the event of such a threat, it reduces the braking force so that the driver does not lose control of the vehicle.

On the Internet, one can find stop distance calculators used by experts and car enthusiasts [35, 36]. For example, in good weather conditions (dry asphalt surface, $a = 0.5\, g$, $T_d = 0.9\, s$, $T_c = 0.4\, s$, $g =$ gravity acceleration), we obtained the following data at maximum braking for low vehicle speed values [35].

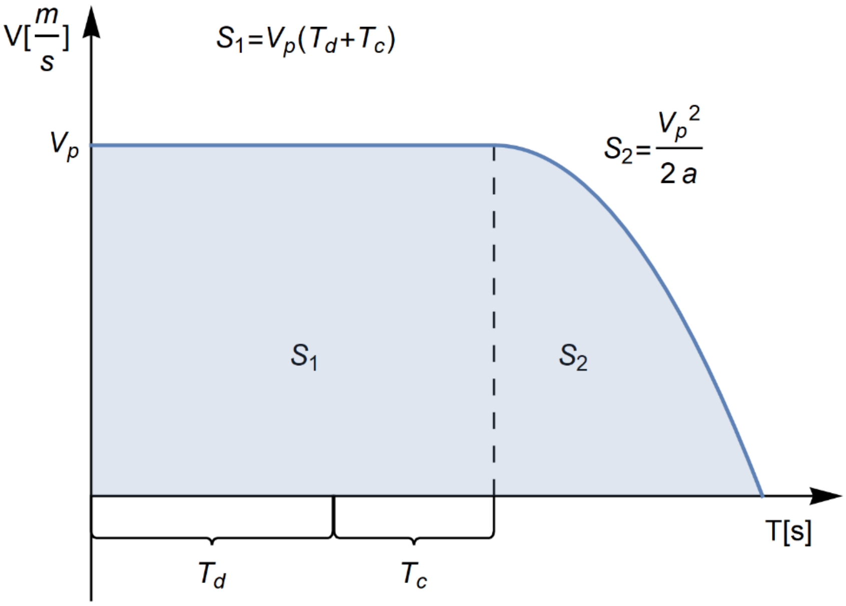

Fig. 1. The dependence of the car speed on time in our model

Table 1

List of selected vehicle speed values and the corresponding stopping and braking distances

V_p [km/h]	S_1 [m]	S_2 [m]	S [m]
5	1.82	0.20	2.02
10	3.64	0.78	4.42
15	5.46	1.76	7.22
20	7.28	3.14	10.42
25	8.97	4.76	13.73
30	10.79	6.89	17.68
35	12.61	9.41	22.02
40	14.43	12.32	26.75
45	16.25	15.63	31.88
50	18.07	19.32	37.39
55	19.89	23.41	43.30
60	21.71	27.89	49.60
65	23.53	32.76	56.29
70	25.22	37.64	62.86
75	27.04	43.26	70.30
80	28.86	49.28	78.14

The driver has practically no influence on the reduction of the stopping distance S_2, which, at low speeds, does not exceed half of the distance S_1. On the other hand, in the case of the S_1, reaction route, laziness, and insufficient focus by the driver significantly increase the distance traveled. This path is directly proportional to the initial speed V_p.

At a speed of V_p = 10 km/h, the vehicle will cover 2.78 m in one second and 5.56 m in two seconds. At a speed of V_p = 20 km/h, the distance traveled doubles. At a speed of V_p = 60 km/h, the vehicle will cover 16.68 m in one second and 33.36 m in two seconds. At a speed of V_p = 80 km/h, the distance traveled increases to 22.24 m in one second and 44.48 m in two seconds.

This shows how important it is to prevent driver distraction and delays in the drivers' reactions in traffic jams. Premium and modern vehicles are equipped with expensive safety systems that apply the vehicle's brakes when an obstacle is detected to avoid a collision, even if the driver does not react. Such systems do not prevent accidents 100% of the time, but they significantly reduce the resulting damage.

3. DESCRIPTION OF THE PROPOSED SYSTEM

The idea underlying our supporting system is presented in Fig. 2. This figure shows three situational variants of the proposed system's operations. The blue boxes around cars equipped with the system show the area controlled by the system. If there is another vehicle in front of the car in this area, the system alerts the driver about the obstacle, which is symbolically marked with the word "beep." In the event that a car approaches from the rear and crosses the safe line (marked in red), the display will flash a warning signal in the form of the words "keep distance." In a situation where there is no other vehicle in the areas in front of and behind the vehicle marked in blue, the system does not report any warning, which is marked with the words "no alert."

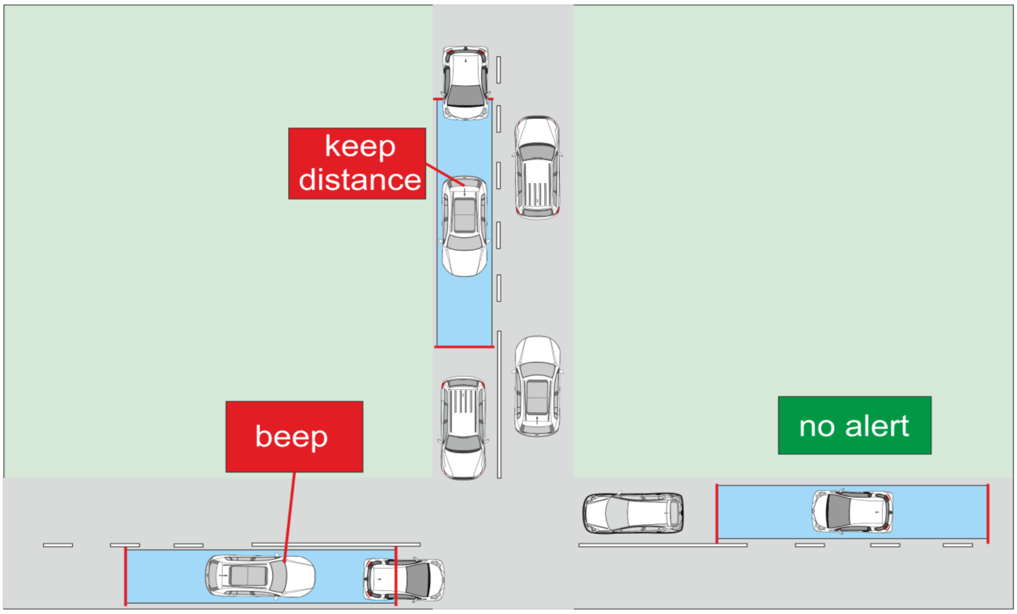

Fig. 2. Visualization of our supporting system in three different situational cases: obstacle in front of the car, obstacle behind the car, and no danger

The construction of the electronic infrastructure installed in the car must not interfere with the original vehicle systems. This means that all sensors and measurement systems used in the car operate independently. Data transmission via a WiFi wireless network was used for communication between them. This approach also means that there is no need to run leads throughout the entire vehicle (from the front to the rear bumper).

The system was built based on independent, autonomous measurement modules. Fig. 3 is a schematic diagram of the IoT infrastructure.

Fig. 3 shows obstacles in front of and behind the car (gray rectangles). The red dotted line marks the border distance; if a vehicle in front of or behind the car is past the dotted line, the system will sound an alarm or activate a warning sign, respectively. In addition, this diagram includes photos of all IoT electronic components built into the car: namely, two Lidar sensors (front and rear), a GPS sensor, and the parent unit, which is a Raspberry Pi computer.

Fig. 4 is a diagram of the concept of operation of the IoT infrastructure, which takes into account the flow of information between its individual components. The entire system has been designed based on the client-server architecture. Raspberry Pi is the main operating unit, which is an access point additionally equipped with a server application. The server application is in the form of a REST API server. All measurements and executive systems are based on the ESP 8266 system and are equipped with the appropriate software, owing to which they act as micro REST API servers. The architecture of this type allows the user to easily expand it with additional modules. In this case, the server acts as a decision-making system that operates on the basis of measurement data collected from two distance measurement modules and speed determination modules. All the information received from the sensors is supplied to the decision-making system on an ongoing basis. The fourth version of the Raspberry Pi computer, model B, was used as a decision-making system in the proposed solution. It is characterized by a quad-core processor clocked at 1.5 GHz, while the RAM memory, depending on the model, is 2, 4, or 8 GB. During operation, the entire system requires a power supply with a maximum power of 15 W.

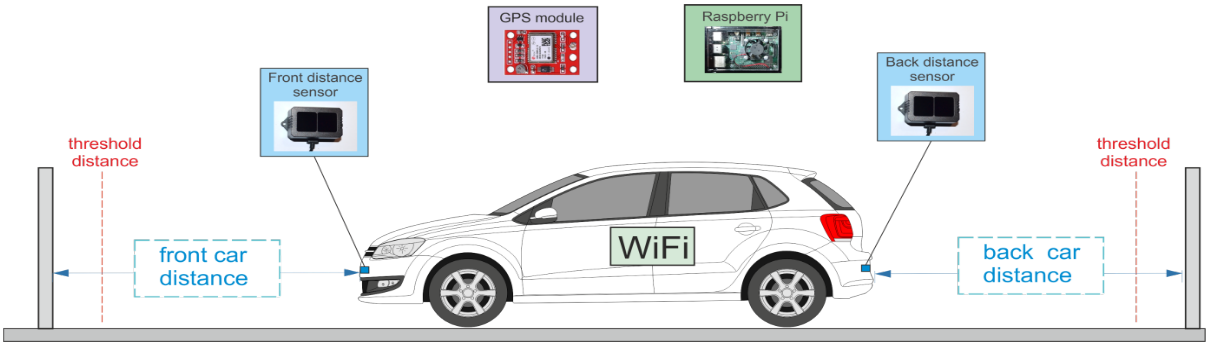

Fig. 3. Illustrative diagram of the IoT infrastructure installed in the vehicle

All built-in measuring modules are powered by a 12-V car installation voltage. This voltage is supplied to the voltage stabilizer (IC1), the purpose of which is to reduce the voltage to 3.3 V, which is required to power ESP8266 systems. In addition, each of the modules is equipped with capacitors that filter and stabilize the output voltage. ESP 8266 systems were used to ensure the wireless transmission of measurement data via a WiFi network. The basic module measures the distance to the vehicle in front of or behind the car. A schematic diagram of this module is shown in Fig. 5. This module was built on the basis of a Lidar TF02 Pro laser distance sensor built in a sealed housing and which is able to measure distances up to 40 m. This sensor has the ability to communicate via a universal asynchronous UART transceiver, as well as via I2C buses. The implemented solution makes transmissions via the UART connector. The distance sensor is connected to the master system, which is the ESP8266 system. In addition, the used distance sensor requires a voltage supply in the range of 5-12 V. Although the nominal voltage of the car installation is 12 V, the voltage of the alternator must be 13.9-14.4 V to ensure the proper charging of the car battery. The battery charging voltage exceeds the admissible supply voltage of the distance sensor, and therefore, the second voltage stabilizer (IC2) was used to lower the voltage of the car installation to 5 V, which is necessary to power the distance sensor. The rated voltage level on the data transmission lines of the distance sensor is 3.3 V; therefore, it is not necessary to use any systems on the transmission lines between the distance sensor and the ESP8266 system supplied with 3.3 V.

Photos of the distance module and the method of mounting the Lidar TF02 sensor inside the front bumper of the car are shown in Fig. 6. The photo on the left shows an open box of an electronic system built on the basis of the ESP8266 module used for the WiFi communication of the Lidar sensor, which is also shown in this photo, with the server application running on the Raspberry Pi server. The power supplies used to power the Raspberry Pi provided by the manufacturer work with an output voltage of 5 V and can provide a current of 3 A. The implemented solution uses a system that reduces the voltage of the car installation to the required level due to the requirements of Raspberry Pi. It should be noted that an Android car radio can be an alternative solution to the Raspberry Pi computer.

It is necessary to know a vehicle's speed to determine its stopping distance. Interference with the original installation of the vehicle was avoided by using another measurement module based on a GPS sensor of the GY-NEO6MV2 type to measure the speed of the vehicle. The schematic diagram of the GPS module is shown in Fig. 7.

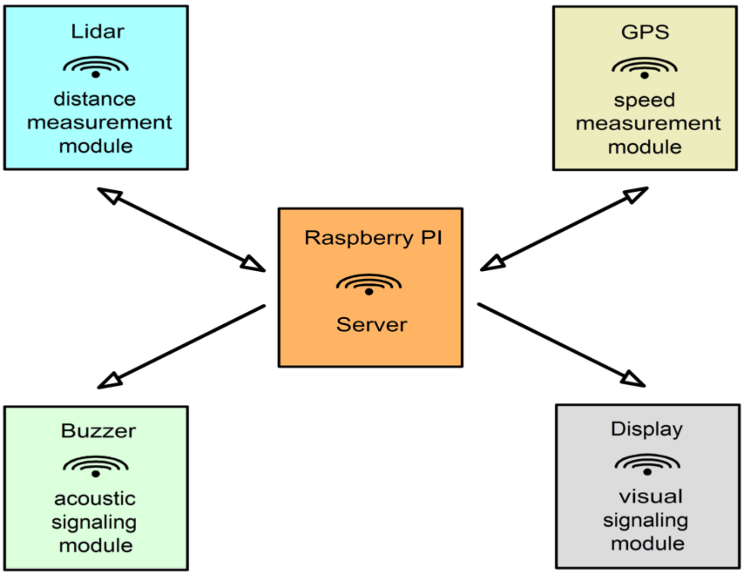

Fig. 4. A diagram of the operation of the IoT system with the data flow between its individual components

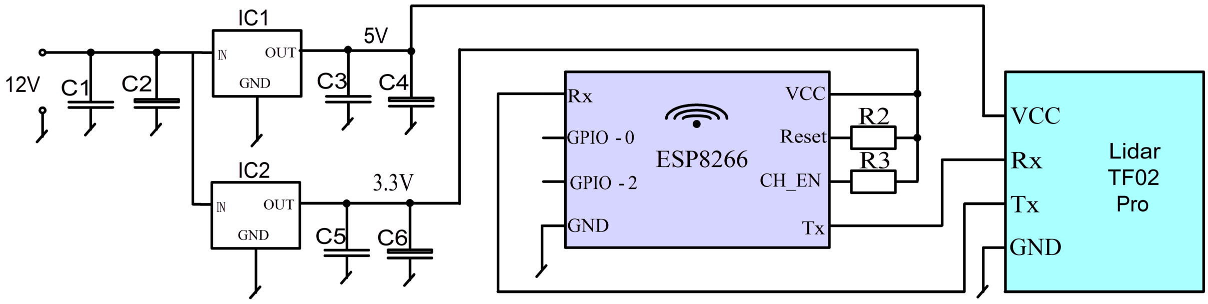

Fig. 5. Schematic diagram of the distance measurement module based on the Lidar TF02 laser sensor

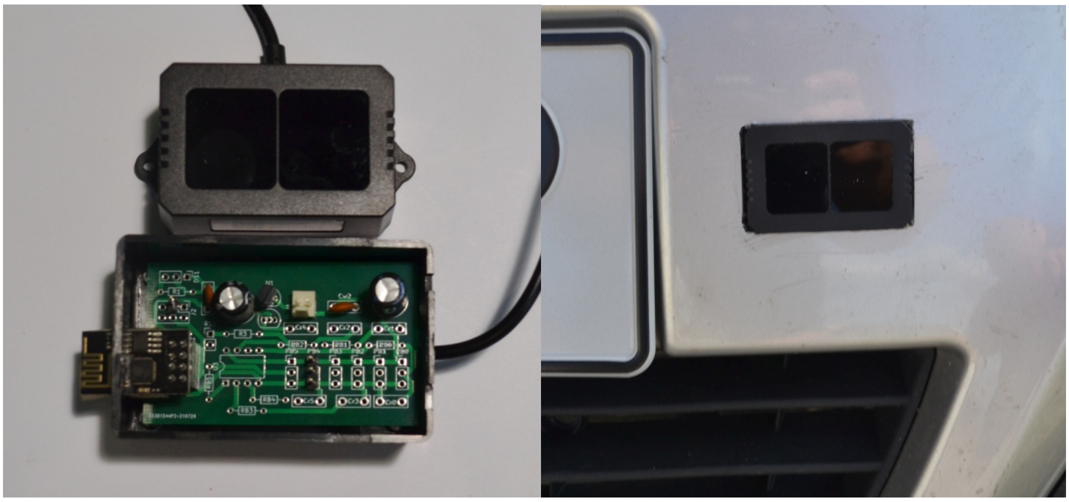

Fig. 6. Photo showing the implementation of the distance measurement module (left) and the distance sensor (Lidar TF02) mounted in the front bumper (right)

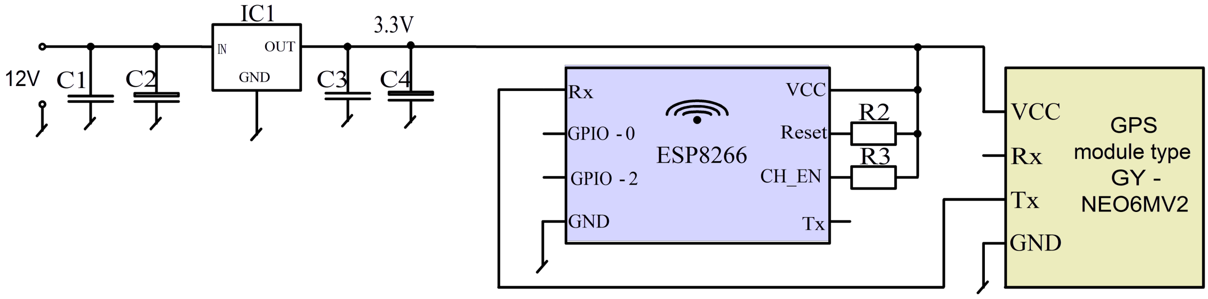

Fig. 7. Schematic diagram of the GPS module for determining the speed of the vehicle

A photo of the GPS module is shown in Fig. 8 below.

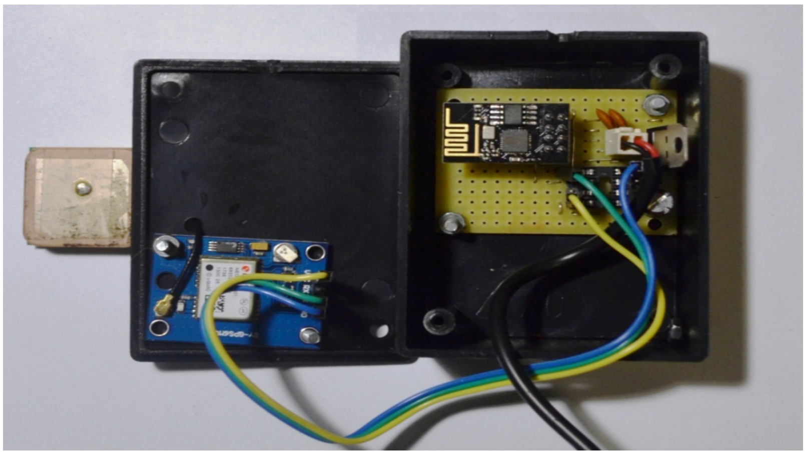

Fig. 8. Photo of the GPS module

The photo shows an open measuring box with an electronic system built into it and which operates on the basis of the ESP 8266 module. The cover of the pillowcase has a GPS connected by cable wires to the electronic module responsible for WiFi communication. In addition, the photo on the left depicts a GPS module antenna, which was mounted on the outside of the box cover so that the range of the GPS signal was not limited.

For proper functioning, this module requires a supply voltage in the range of 3.3-5 V. Owing to this, it can be powered from the same stabilizer as the ESP8266 system. Communication between the GPS and the transmission system via WiFi takes place via the UART connector; however, in this case, the ESP8266 system only receives information from the GPS module.

The actuating systems informing the driver about the danger resulting from the close proximity of vehicles in front or behind were implemented in a similar way. The executive systems also used WiFi transmissions via ESP8266 systems. However, in one case, a buzzer with a built-in generator of the YMD12A12 type was used as an alarming element (Fig. 9).

The buzzer is powered directly by the voltage of the car installation, while an additional volume control system has been added to its circuit so that the driver can adjust the level of the warning signal based on their preference. Another solution of the warning system is the warning signal display, which is also controlled by the ESP8266 system, ensuring proper WiFi communication and display activation (Fig. 10). Both the buzzer and the display activation require a change of state on one of the pins of the ESP8266 system, which receives the state change command from the system that calculates the distance required to safely stop the vehicle.

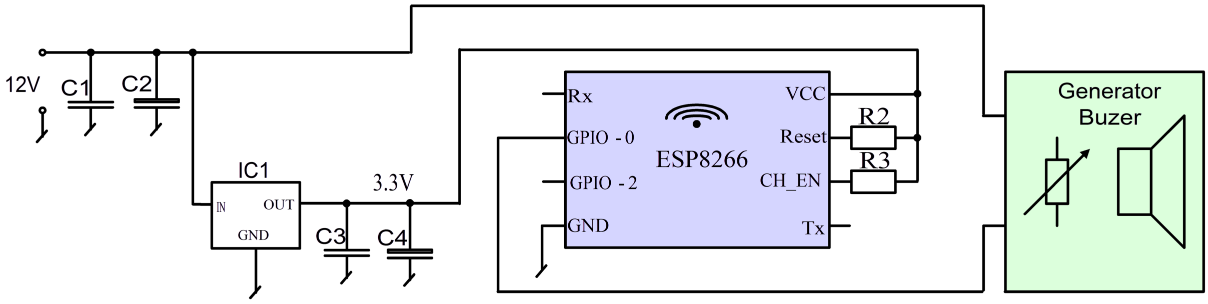

Fig. 9. A schematic diagram of the Buzzer module used to warn the driver that they are approaching an obstacle in front of the vehicle

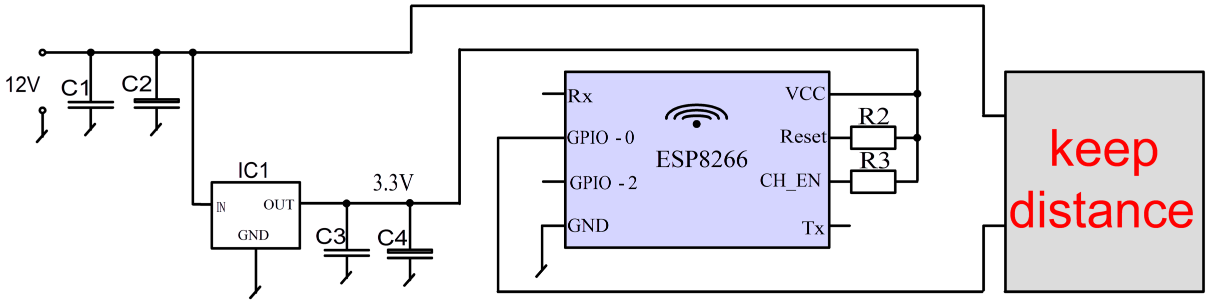

Fig. 10. A schematic diagram of the rear-view warning module used to visually alert the driver of a car dangerously approaching from behind

4. SYSTEM EXTENSIONS

In the model presented in this paper, we assumed that the driver reacts to the threat in a traffic jam as if the obstacle on the road (the vehicle in front) is not moving. In a real situation, the system could additionally take into account the speed of the vehicle in front of or behind the vehicle (see Fig. 11). In the case of the vehicle in front, the driver reacts when the brake lights of the vehicle in front turn on. In this case, the vehicle in front is already braking. Its braking distance can be added to $S_1 + S_2$, but Table 1 shows that for low vehicle speeds, this braking distance S_2 is small and should be ignored.

The situation is different for vehicles behind the vehicle equipped with the proposed system. The speed of the trailing car can be calculated by measuring the distance to the trailing vehicle, the times between distance measurements, and the speed of the equipped car. This provides the basis for calculating a safe distance between vehicles and taking this distance into account when transmitting information on the display. This requires a display with a dynamic display of information.

Another interesting direction for extending the proposed system is to implement a smartphone application. Such an application could show the basic data transmitted by the sensors after processing by the Raspberry Pi computer and indicate the traffic situation in real time. This would require the help of IT specialists and the gathering of additional experience from the functioning of our system in order to select the best visualization and communication options. It is important that the application can increase the user’s ability to influence the options selected by the computer (tables and formulas). It is also a user-friendly system.

5. CONCLUSIONS

The cost of the entire system when one Lidar sensor is used does not exceed 250 Euros. When using the Lidar sensor at both the front and rear of the vehicle, the cost of the system does not exceed 350 Euros. This cost can be reduced even further if many such systems are built due to the possibility of receiving discounts when purchasing larger quantities of parts.

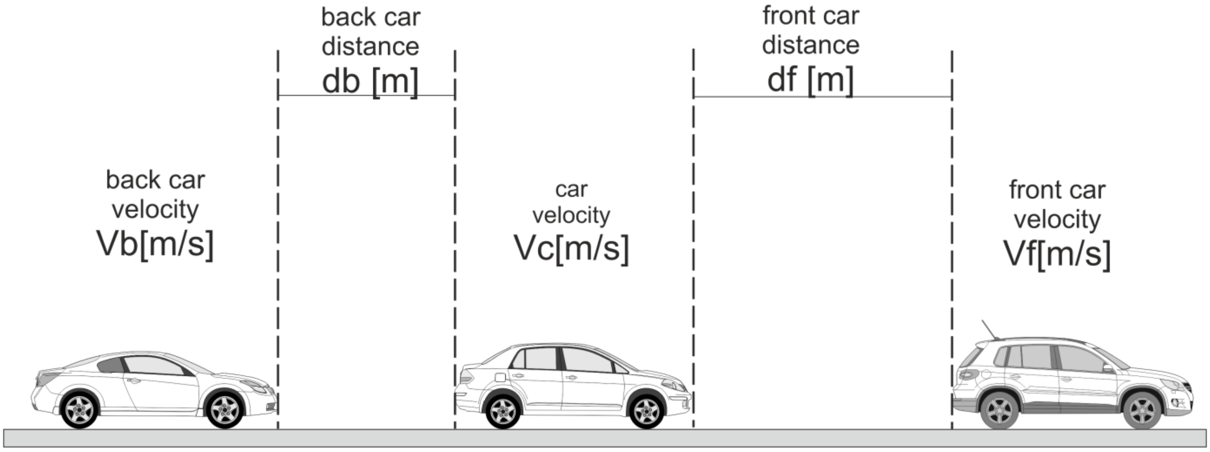

Fig. 11. Illustrative drawing showing a situation in which the speed of the car in front of and behind the monitored vehicle is taken into account

The designed system is autonomous; that is, it is not connected to any other vehicle system. The individual modules of the system only need to be connected to a power source from an electric battery. The lack of interference with the car's systems excludes the need for homologation activities. In our case, we mounted the Lidar sensor to the front bumper to show the working system for educational purposes, further development, and the study of the system. Changing the appearance of the bumper has little effect on the appearance of the car. The sensor can also be placed, for example, behind the grille of the radiator, as is done with modern car security systems.

The choice of a Lidar sensor with a range of 40 m offers the possibility of broader use beyond low-speed scenarios. On German motorways, it is assumed that a safe distance between moving vehicles (in m) is half of the value of the vehicle's speed (in km/h). Therefore, our system can be successfully used at speeds up to 80 km/h. The Lidar sensor applied in our system is used in industrial robots, automatic transport cars, and drones for detecting obstacles and controlling distance. It is also used in traffic counting systems on roads.

Installing the system in a vehicle does not require cables between modules to be pulled. This is because of the Bluetooth connection between them.

The main benefit of using our system is that it warns the driver to stay a safe distance behind the vehicle in front of them. This allows the driver to make quicker decisions and drive more carefully to avoid accidents.

The traffic jam driver assistance system presented in this paper offers a wide range of applications in old and cheap cars due to the low construction costs. Therefore, it can significantly improve road safety. Its simplicity makes it easy to expand. An additional Lidar sensor at the rear can be used to inform the driver behind that it is approaching dangerously close (by displaying a "Keep Distance" message). In the future, we plan to consider the possibility of including dynamic information in this module to give information on actual distances and safe suggested distances. The installation of an exterior temperature sensor and a hygrometer will allow the system to take into account road conditions (e.g., icing, wet pavement) in order to better use appropriate formulas for making calculations or revising previously generated tables.

Interesting possibilities are offered by the implementation of simple artificial intelligence systems in the computer that can support the safety of a group of vehicles (e.g., in a convoy). By transferring information between vehicles, a driver can react more quickly to the danger of vehicles at the rear of the convoy based on information provided by the convoy's head. It is also possible to maintain a safe distance between vehicles. We will describe such a system in our next article.

We note that, in this case, such a system would require other communication channels due to the number and distance of data transmissions. Thus, it would also be advisable to use a faster computer.

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Received 09.09.2021; accepted in revised form 26.02.2023.