INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2021, VOL. 67, NO. 2, PP. 277-282
Manuscript received December 8, 2020; revised April, 2021 DOI: 10.24425/ijet.2021.135976

A Comparison of Proximity Sensors for a Bicycle-to-Car Distance Rangefinder

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Abstract—**In the article, three types of proximity sensors that might be used in bicycle rangefinder to measure the distance between the bicycle and an overtaking car are compared. The influence of various factors on the accuracy of the distance measurements obtained using ultrasonic, infrared and laser sensors is tested, among others, light conditions, car surface type and colour, rain, pollination and vibrations.**

Keywords—**distance measurement, road taffic, proximity sensors**

I. INTRODUCTION

OVERTAKING is one of the most dangerous maneuver in the road traffic, especially when the overtaken traffic participant is vulnerable, such as cyclist [1]. In order to improve cyclists' safety, in many countries it's required that the minimum distance between the bicycle and the overtaking car is 1 m. Nevertheless, many cyclists say that the real overtaking distance is too short [2]. In the road traffic it is, however, difficult to precisely determine this distance for both cyclist and driver. The subjective estimation of the distance may be affected by various factors, such as car size and velocity, atmospheric conditions, road conditions etc. A device that could measure the distance with sufficient accuracy, regardless of actual conditions, would therefore be useful and could increase traffic participants safety.

Several attempts to measure the distance between the bicycle and the overtaking car have been reported in the literature. In [3], authors measured the influence of the bicycle driver suit on the overtaking proximity. The rangefinder used in this research was built with Arduino platform and uses a MB1200 XL-MaxSonar-EZ0 ultrasonic sensor [3]. Similar sensor (XL-MaxSonarEZ3 MB1230) was used in the device named MetreBox described in [4]. The device was placed below the bicycle saddle. Each MetreBox was individually calibrated to achieve measurement accuracy of about 1.5 cm. Another approach was described in [5], where authors used a more complex system, containing LiDAR, GPS, and two cameras. This system was used to define a novel four-phase model of overtaking maneuver. Unfortunately, due to the high power consumption by the LiDAR, it is not very useful for a typical cyclist.

In some countries, police is equipped with C3FT ("see-three-feet") ultrasonic devices [6]. The first version [7] was only a prototype created to validate the ability of the selected technologies to successfully detect vehicles overtaking a bicycle. The 2nd version [8] was built in cooperation with Police Department. The most up-to-date 3rd version [9] can be integrated with a camera to capture the video material that can be used for education and law enforcement purposes. It is not known which ultrasonic sensors were used in the C3FT devices.

A completely different approach was used to gather data used in [10]. In this case, instead of using a proximity sensor, distance was calculated from the video data recorded by a steady camera mounted few meters above the road. While such an approach is effective for traffic measurement and recording, the traffic participants are not informed immediately of the measurement results.

While ultrasonic sensors are often used to measure proximity in mobile robots and vehicles (e.g., parking sensors), they are not the only ones that can be used to measure the distance between vehicles, obstacles etc. Infrared and laser-based distance sensors could also be used to measure the proximity [12], e.g., between vehicles [11]. A short presentation of several types of proximity sensors can be found in [13].

There are several papers that consider proximity sensors accuracy in various conditions. For example, in [14], infrared and ultrasonic sensors are compared for the indoor mobile robot application – their measurement accuracy is tested for various obstacle materials. In [15], ultrasonic sensor is evaluated for its applicability to create mobile robot's environment map. In [16], the illumination model is applied to increase the infrared sensor accuracy. In [17], an infrared proximity sensor is used for an autonomous car model and analysed for its accuracy depending on the obstacle characteristics. In [18], security of ultrasonic sensors under intentional attack is discussed.

There are also several web sites that discuss the properties of various proximity sensors for various applications ([19]-[22]). Nevertheless, despite the popularity of the proximity sensors in vehicle applications, it's difficult to find any papers which present the results of complex tests of various sensors in various, laboratory and real-life outdoor applications. In this paper, environment conditions influence on the accuracy of three different proximity sensors is tested and analysed.

The rest of the paper is organized as follows. First, the elements used in the rangefinder that was designed and implemented for the tests are briefly described. Later, the results of accuracy tests are presented; the tests were performed in laboratory conditions, in a simulated road conditions and, finally, in a real-life road traffic.

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II. BICYCLE RANGEFINDER

The bicycle-mounted overtaking proximity sensor should be able to measure the distance in the range of about 30 to 150 cm with sufficient accuracy. The sensor should be mounted at the end of the steering handlebar, left or right depending on whether the traffic is right-hand or left-hand, respectively. Such a location allows the cyclist to observe the measurement results while riding. The power consumption should be as low as possible.

We have selected three sensors:

- HC-SR04 (ultrasonic) [23],
- Sharp GP2Y0A02YK0F (infrared) [24],
- self-made laser sensor [25].

The ultrasonic and the infrared sensors were connected to the ARM STM32F030F4 microcontroller. The laser sensor was connected to the LG Nexus 5 smartphone which calculated the measured distance and displayed the result together with the picture from the camera.

The measurement result from the HC-SR04 sensor is given in the form of pulse, the duration of which depends on the measured distance. Therefore, the measurement accuracy relies on the precise time measurement. To achieve maximum possible accuracy, we controlled the time measurement using interrupts, hardware timers, and counting of microcontroller cycles. As a result, we could measure the pulse time with 1 μs accuracy, which is sufficient to get precise distance measurement.

In turn, the GP2Y0A02YK0F sensor return the results as an analogue voltage, which can be measured by an ADC converter in the microcontroller. To achieve maximum possible accuracy, we calibrated the ADC before each measurement by measuring the power voltage which acted as the reference voltage. The calculation of measured distance was performed using sensor characteristics diagram [24]. The diagram was sampled for distances between 20 and 150 cm with 1 cm gap between consecutive samples. The final result is the median of 100 measurements. This was necessary, because significant percentage of measurements from the GP2Y0A02YK0F sensor were too far from the correct value.

The laser sensor was made of a no-name USB camera with VGA resolution (640x480 pixels) and the KY-008 laser pointer. The pointer was mounted at the same height as the camera, at the constant angle to the camera axis. The distance between the camera and the object was calculated basing on the coordinates of the laser spot in the camera image. The coordinates vary depending on the distance. This idea is explained in the fig. 1.

The distance was calculated using the following formula [25]:

$$h = \frac{d}{\operatorname{tg}\alpha + \left(\frac{2x}{r} - 1\right)\operatorname{tg}\frac{\beta}{2}}, \quad (1)$$

where: h – distance between the camera and the object [mm], d – distance between the laser and the camera axis [mm], α – slope angle between the laser and the camera axis [°], β – camera viewing angle [°], x – horizontal coordinate of the laser spot in the camera picture [pixels], r – horizontal resolution of the camera [pixels]. These values are shown in the fig. 2.

To achieve sufficient measurement accuracy, the following parameters values were accepted: d=200 mm, α=28°, β=44°, r=640 pixels.

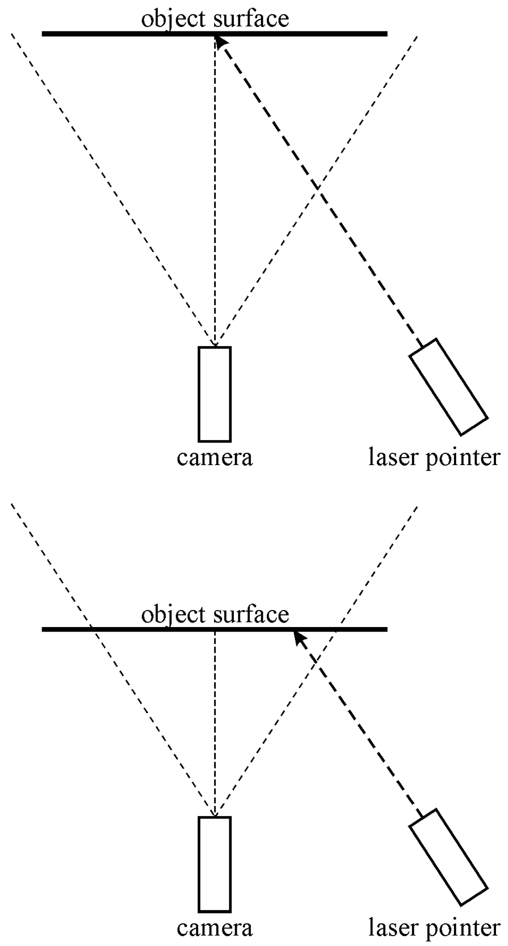

Fig. 1. Camera-to-object distance and laser dot coordinates

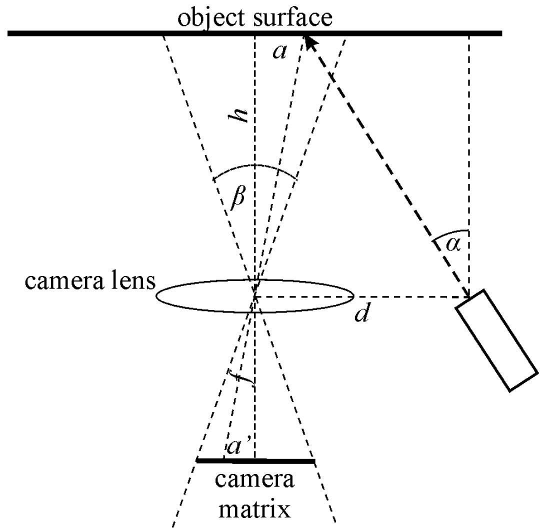

Fig. 2. Explanation of (1)

The measurement algorithm implementation used UVCCamera library to read the pictures from the camera and OpenCV library to process images. The processing was performed as follows:

- Camera signal acquisition as a series of consecutive images.

- Conversion of image to black and white.
- Erosion with square structure element, 5x5 pixels large, with central point in the center.
- Determination of the brightest pixel coordinations.
- Distance calculation using (1).

III. TESTS METHODOLOGY

The quality of measurements obtained using the aforementioned sensors may depend on electromagnetic wave frequency, road conditions (e.g., dust, vibrations), atmospheric conditions (e.g., light intensity, rain, temperature), object shape and color, etc. The tests were performed in three groups:

- Static tests in laboratory conditions (measurements of distance from various object of various surfaces, colors, in various lightning conditions).
- Tests in a simulated real-life environment (measurements in various atmospheric and road conditions, with a bicycle simulated by a stationary construction passed by vehicles).
- Tests in a real-life environment (in a road traffic).

For each test, 1000 measurements were performed. The sensors were working continuously, and then the data stream was searched for interesting measurements series during data processing. Each data sequence obtained this way began and ended with a proper result. The results in these sequences were then split into five ranges, as shown in the Table I. In this paper however, for clear presentation, we present only the percentage of results considered as exact.

TABLE I
MEASUREMENT RANGES

Range	Relation to the expected value	Measured discance for 1m [cm]
Unacceptable decreased	shorter than 6% lower	≤93
Acceptable decreased	6% to 3% lower	94-96
Exact	3% lower to 3% higher	97-103
Acceptable increased	4% to 6% higher	104-106
Unacceptable increased	longer than 6% higher	≥107

IV. LABORATORY TESTS

The laboratory tests were performed in an isolated environment, indoor at the daylight or outdoor in a dry, cloudy day (except the light conditions tests).

A. *Distance influence on measurement accuracy*

In this test, it was checked if the measurement accuracy depends on the real distance between the sensor and the object. This test was performed inside building, in a natural light. The distance between sensors and a mat wall was measured in the range of 30 to 150 cm, with 20 cm step (a shorter step of 10 cm around the most important value of 1m). The results are collected in Fig. 3.

Analyzing the presented results, one can conclude that for both ultrasonic and infrared sensors the distance to the object has no influence on the measurement accuracy. For the laser sensor, the measurement accuracy decreases with increasing distance. For 1m distance – the most important from the point of view of our goal – only 87% of results could be qualified as exact. It must be noticed, however, that these test were performed under perfect conditions and could be even worse in a real-life environment.

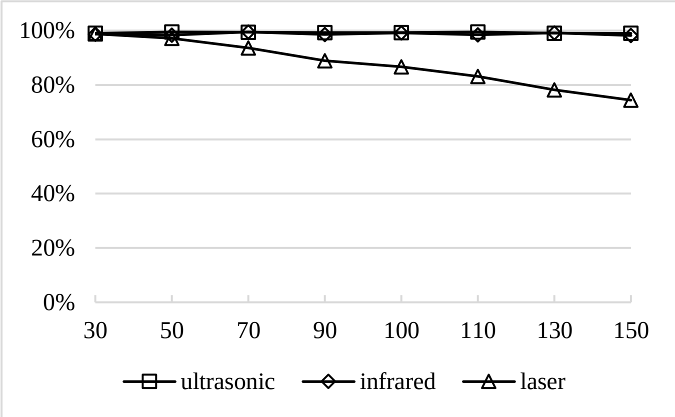

Fig. 3. Distance infleunce on proximity sensors accuracy

B. *Colour influence on measurement accuracy*

In this test, it was checked if the measurement accuracy depends on the colour of the object to which the distance is measured. This test was performed outside of the building in a dry, cloudy day. Four cars were used: white, red, grey, and black, at the distance of 70, 100 and 130 cm from the proximity sensor. The percentages of exact results are collected in Table II.

TABLE II
COLOUR INFLEUNCE ON MEASUREMENT ACCURACY

Sensor and distance*	Colour			
	Black	Grey	Red	White
U, 70 cm	99,1%	98,9%	98,9%	99,2%
U, 100 cm	99,2%	98,9%	99,0%	98,8%
U, 130 cm	98,9%	98,8%	99,1%	99,0%
I, 70 cm	90,1%	90,3%	90,0%	90,3%
I, 100 cm	88,2%	88,3%	88,7%	88,0%
I, 130 cm	86,2%	86,4%	85,3%	84,8%
L, 70 cm	94,6%	94,5%	95,1%	93,4%
L, 100 cm	87,0%	87,6%	87,3%	87,2%
L, 130 cm	79,1%	79,7%	77,7%	79,3%

*(U – ultrasonic, I – infrared, L – laser)

For the ultrasonic sensor, surface colour has no influence on measurement accuracy. About 99% of the results are within the exact results range, regardless of both colour and distance. For the infrared and laser sensors however, the accuracy decreases with distance, but practically regardless of the colour. Thus, one can conclude that the surface colour is insignificant from the point of view of measurement accuracy.

C. *Surface influence on measurement accuracy*

In this test, it was checked if the measurement accuracy depends on the object surface type (mat or shiny). The test was performed similarly to the previous one. The percentages of exact results are collected in Table III.

TABLE III
SURFACE TYPE INFLEUNCE ON MEASUREMENT ACCURACY

Sensor and distance*	Colour	
	Mat	Shiny
U, 70 cm	98,9%	99,2%
U, 100 cm	99,1%	98,8%
U, 130 cm	99,1%	99,0%
I, 70 cm	98,0%	90,3%
I, 100 cm	98,2%	88,0%
I, 130 cm	97,9%	84,8%
L, 70 cm	93,3%	93,4%
L, 100 cm	87,7%	87,2%
L, 130 cm	79,3%	79,3%

*(U – ultrasonic, I – infrared, L – laser)

The results for the ultrasonic sensor are practically independent on the surface type and the percentage of measurements qualified as exact is again close to 99%. For the infrared sensor, surface type plays an important role – shiny surface decreases measurement accuracy. Moreover, for shiny surface we observed accuracy decrease with increasing distance, which was not the case for mat surfaces. The accuracy of the laser sensor depends again on distance only, regardless of surface type.

D. *Light influence on measurement accuracy*

Optical sensor accuracy can be affected by a strong light. It was therefore tested if lightning conditions have an influence on measurement accuracy for all sensors. the distance between sensors and a car with white mat body (to avoid negative influence from shiny surfaces) was measured. The tests were performed on a sunny day, a cloudy day and after sunset. The test was performed similarly to the previous one. The results are presented in Table IV.

Analyzing the presented result, one may conclude that lighting conditions have no influence on the ultrasonic sensor measurement accuracy. As expected, strong light can significantly degrade the infrared sensor accuracy – the results achieved on a sunny day are of about 20% worse than for the other conditions. Laser sensor also suffers from a strong light, however, the accuracy degradation is much smaller than for the infrared one.

V. SIMULATED REAL-LIFE TESTS

The second part of tests were to simulate real road traffic. The measurement data were collected on a dry, cloudy day. The bicycle was replaced by a stationary stand that was passed by a car in the distance of 1m. The car was white, but its body was a little dusty and dirty, which probably allowed us to obtain better results with the laser sensor.

TABLE IV
SURFACE TYPE INFLEUNCE ON MEASUREMENT ACCURACY

Sensor and distance*	Colour		
	Sunny	Cloudy	Nightfall
U, 70 cm	98,6%	98,9%	98,6%
U, 100 cm	99,1%	99,1%	98,9%
U, 130 cm	99,1%	99,1%	98,8%
I, 70 cm	85,3%	98,0%	98,4%
I, 100 cm	81,9%	98,2%	98,6%
I, 130 cm	79,5%	98,7%	97,7%
L, 70 cm	92,6%	93,3%	94,3%
L, 100 cm	85,7%	87,7%	86,5%
L, 130 cm	76,9%	79,3%	80,0%

*(U – ultrasonic, I – infrared, L – laser)

A. *Rain intensity influence on measurement accuracy*

In some countries, the bicycles can be used in each season, in various weather conditions. However, some weather factors, e.g. snowfall or rainfall, can degrade measurement accuracy. In this test, the rain influence on measurement accuracy was checked. The results are presented in Fig 4.

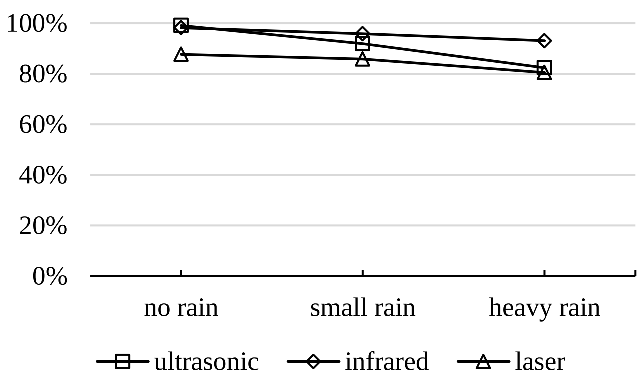

Fig. 4. Distance infleunce on proximity sensors accuracy

Analyzing the presented result, one may conclude that with rising rain intensity, the percentage of exact results decreases for all sensors. In the heavy rain conditions, over 10% results from the ultrasonic sensor were qualified as unacceptable. For the optical sensors, the accuracy degradation caused by rain is not that large. It's also worth noting that the infrared sensor is more accurate in the rain that the ultrasonic one – even in the heavy rain the percentage of exact results was over 90%.

It could also be noticed that the ultrasonic sensor, under rain conditions, shows a tendency to give more decreased results (both acceptable and unaccteptable) than increased ones. Thus, the reported distance might be a little shorter than the real one.

B. *Pollination intensity influence on measurement accuracy*

In this test, we checked the pollination influence on measurement accuracy. The results are presented in Fig. 5.

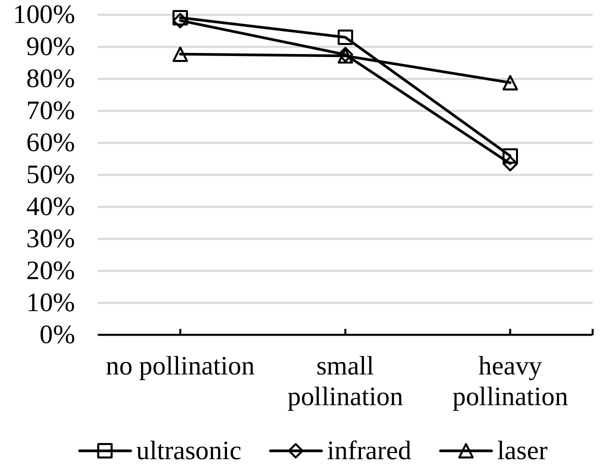

Fig. 5. Pollination intensity infleunce on proximity sensors accuracy

Analyzing the presented result, one may conclude that pollination has big influence on measurement accuracy for all sensors. For both ultrasonic and infrared sensors, heavy pollination strongly reduces the sensor accuracy – the percentage of exact measurements is only about 50%. Large number of unacceptable results means that the signal is diffused or reflected by dust particles, therefore the measurements are far from the exact value. For the laser sensor, the accuracy decrease is not that large – even with heavy pollination, about 80% of results could be qualified as exact.

It was also noticed that the ultrasonic sensor, similarly to the rain influence test, shows again the tendency to decrease the measurement result.

C. *Vibrations intensity influence on measurement accuracy*

Vibrations during bike ride are caused mainly by road surface. In this test, the vibrations influence on measurement accuracy was checked. The results are presented in fig. 6.

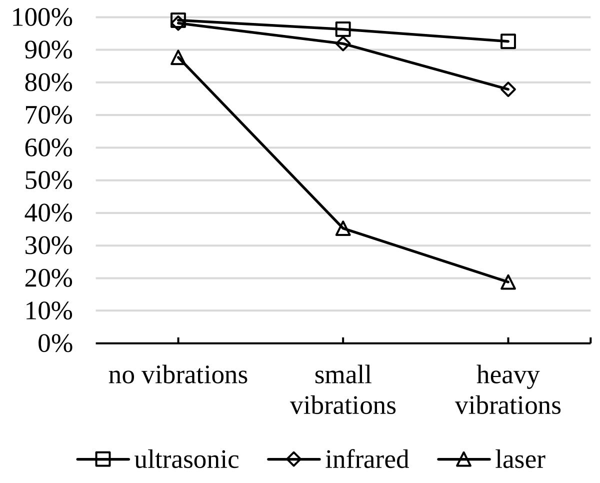

Fig. 6. Vibrations intensity infleunce on proximity sensors accuracy

Analyzing the presented result, one may conclude that small vibrations do not degrade the measurement accuracy very much. However, strong vibrations decrease the infrared sensor accuracy to about 80% of exact results. The laser sensor showed completely no immunity to vibrations – even the small vibrations reduced the percentage of exact results to about 35%, while for strong vibrations it fell below 20%.

It was also noticed that, unlike in two previous tests, the ultrasonic sensor shows the tendency to increase the measurement result.

VI. Real-life tests

The third part of tests was to show the performance of three sensor in a real environment. However, in a real road traffic, it would be necessary to know the exact distance between the bicycle and the overtaking car. Without a precise measuring device (electronic or mechanic), it’s not possible.

The real road traffic was simulated in a closed area. The bicycle was moving along a straight line. The second line was marked 1m away from the first one. The car was driven so that the right wheels were on the second line. Thus, the real distance between the bicycle and the overtaking car was known. The car body was white with a little dust and dirt.

The measurements were performed on the roads with various surfaces: asphalt, paver, or ground, in variable weather conditions. It allowed to obtain conditions with various parameters that were checked individually before: rain intensity, pollination intensity, vibrations, lightning, etc.

One of the initial assumptions that we made prior to the tests, was that the sensors should be placed on the side of the steering handlebar in order to let the cyclist observe the results easily. However, this requirement could not be fully fulfilled. The handlebar is typically about 80 cm over the road. At this height, many cars have windows. This makes the infrared sensor measurement impossible, because it can’t measure the distance from the transparent surfaces. Additionally, the laser sensor could be dangerous for the drivers’ eyes. Therefore, we decided to place the sensors lower: the laser one at about 30 cm from the road surface, the others – at about 65 cm. The measurement results for all three sensors are presented in Fig. 7.

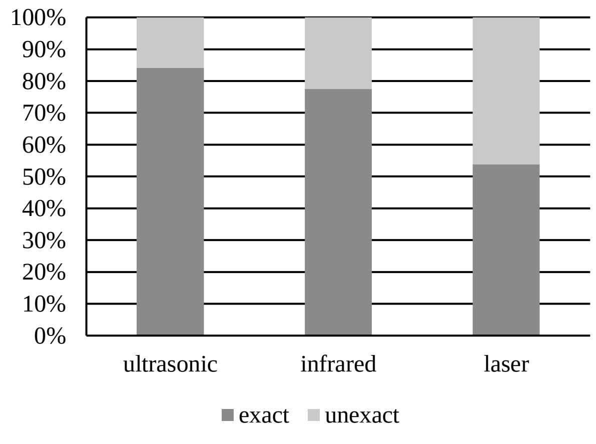

Fig. 7. Percentage of exact and acceptable vs unacceptable results

VII. Conclusion

The goal of the work was to check if the available distance sensors can be used to measure the distance in the road traffic with sufficient accuracy, especially between the bicycle and the overtaking car, and if so, which of them is the best in this application.

The results show that the ultrasonic sensor seems the best for this purpose. The measurement results are independent of car body color and surface and the lightning conditions in the environment. The sensor works well for both shorter and longer distances from the object, and the vibrations do not degrade the results very much. Unfortunately, the ultrasonic sensor is not immune to heavy rain and pollination, which significantly decrease the measurement accuracy. However, such conditions are not often met while riding a bicycle. It is also worth noting that the only rangefinder used by the police in the USA and Australia is based on the ultrasonic sensor, too.

The infrared sensor is also good for the distance measurement, however, not necessarily in the road traffic. The sensor is not immune to a strong sunlight, and the measurement accuracy is significantly degraded by not only reflections from car body. This makes the sensor practically unusable in our application, because typically bicycle traffic occurs in a good weather. Nevertheless, the infrared sensor could be used in the indoor environment, e.g., in the positioning systems, autonomic robot control, etc.

The laser sensor that was made for the purpose of the tests, is not applicable in the road traffic. Although significant measurement accuracy degradation resulting from various colors, car body surfaces, lightning conditions, rain and pollination intensity were not observed, there were many inaccurate distance measurements for the distances important for our application. The sensor is highly sensitive to vibrations, and it is not save for the road traffic participants because it can cause a temporal or even permanent eye injury.

Probably better results with the laser sensor could be achieved by modification of the device construction parameters, such as slope angle and laser to camera axis distance (α and *d* in the fig. 2, respectively). Unfortunately, the necessity to mount the device on the bicycle limited its size.

The results show that it is possible to build a cheap rangefinder that could be used for cyclists in a road traffic to know if they are overtaken with a proper distance. This might lead to the increase of vulnerable traffic participants safety.

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