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Research on operating state reliability of roadside vehicle detection sensors

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Abstract: The advancement of information technology has facilitated the development of various types of roadside vehicle detection sensors. The monitoring of these sensors constitutes a critical component of sensing systems and serves as a foundation for the reliability of diverse traffic data. Current sensing systems exhibit a significant limitation in their monitoring capabilities, as they predominantly focus on whether the sensors are operational, neglecting a more comprehensive assessment of their performance. To address this gap, this paper introduces two primary indicators: operational reliability and performance reliability, alongside five secondary indicators: online status quality, data status quality, communication status quality, regional detection location accuracy, and target detection accuracy. Through extensive monitoring of three roadside millimeter wave radars, the findings indicate that the proposed sensing system effectively fulfills the multidimensional management requirements of traffic management authorities concerning sensor performance.

Keywords: traffic engineering; sensing system; vehicle detection sensors; operating state reliability; reliability indicators

1 Introduction

With the rapid development of traffic information system, the construction of high-grade roads has become an important direction of intelligent transportation[1]. High-grade road refers to the road that can obtain comprehensive, detailed and high-precision moving target information[2], road information[3], traffic state information, and natural environment information[1], and finally form an intelligent road[4]. The key to building a high-grade road is to arrange the sensing equipment in suitable place and collect the data. Through the production practice of intelligent sensing devices and long-term infrastructure construction on the traffic edge side over the course of many years, various types of sensing devices are widely distributed on the road, forming holographic perception in target region[5], and providing a foundation for the subsequent development of intelligent and connected vehicl es system[6]. However, although a large number of sensing devices are arranged to provide corresponding traffic data, the sensing devices generate great supervision and communication pressure on the traffic system[7]. The main communication methods between the sensing deveics and system include Wi-Fi, BLUETOOTH[8], TCP/IP, UDP[9], MQTT, WEBSOCKET, HTTP. The intelligent supervision and maintenance of various types of sensing devices must be put on the agenda. Only by carrying out refined, data-based and comprehensive sensing device supervision can coordinate all sensing devices to generate system value.

The intelligent sensing system is a system for collecting various spatio-temporal traffic data in the target perception region. Its purpose is mainly to provide data support for various business platforms at the upper layer, such as traffic management platform[6], vehicle-road coordination platform[10], and intelligent and connected cloud control platform[11]. As the sensing devices are main source of traffic information, the stability and high accuracy of the sensing devices play a vital role in the sensing system. However, in the actual construction process, there are many potential factors include various types of devices, complex communication protocols,

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complex communication methods, and different sensing objects, which have a great impact on the sensing efficiency and accuracy of the sensing system[12]. In the past engineering practice, the sensing devices will be debugged and calibrated during the installation process[13]. However, in the operation stage, the operating state reliability of the sensing devices is limited to the online state supervision, and many sensing systems lack supervision and only passively receive the data, the data reliability is also a big problem. The failure state of sensing devices can only be found in the periodic manual check, which has a great impact on the high-quality operation requirement of the designed sensing system. Therefore, it is of great practical value to study the factors affecting the operation quality of sensing devices[14], conduct unified online real-time supervision of sensing devices, and provide guidance for the operation and maintenance of sensing devices. In the field of mechanical engineering and rail transit, the safety of production and the demand for high-precision operation are considered, the supervision of operation has made great progress. However, in the field of highway traffic, the construction of sensing system ignores the basic operating state reliability for high-performance work of sensing devices with the purpose of data visualization. With the increasing demand for high security requirements cloud control system, comprehensive and effective sensing devices supervision will inevitably become a new trend.

The operation quality monitoring technology is based on the real-time data package received from the sensing devices, the short-term performance fluctuation and the long-term failure state of the sensing devices can be calculated by the indicators in each stage of the sensing data flow process, so as to identify the operating state reliability problem. The monitoring technology considers the data collection, encoding and decoding, communication method, network quality, data processing and structured data extraction in the data flow to realize real-time monitoring of sensing device.

2 Influencing factors of sensors operating state reliability

Vehicle detection sensor is one kind of equipment distributed in the traffic environment to collect traffic data and transmit it to the sensing system, which is widely used in road construction. Especially with the development of information technologies. The types, accuracy and perception range of sensors have been greatly developed for the last decades. The state of sensing devices has a key influence on the overall traffic information collection reliability of sensing system, and the quality of information collected by sensing devices is mainly affected by the following factors: data collection quality of devices, communication quality between devices and system, and data process quality of devices. The working process of the sensing devices is as follows: the sensing devices are installed at specific positions according to requirements; after the sensing devices collect target information in a target region, the sensing devices transmits encoded data to the sensing system in a agreed communication method, sensing system decodes the received byte stream data to acquire the target information, forms structured data from the original data, and the effective data will be stored and published to the other platform. According to the process, the sensing device quality supervision framework is shown in Figure 1.

Online status supervision is a basis component of sensing devices quality operation quantity management, Factors such as natural, artificial, mechanical failure, resulting in power supply and network problems, causing devices offline, sensing devices disconnection is the key problem leading to sensing system problems.

With the improvement of the precision of sensing technology, the preset position of sensing devices has a great influence on the quality of sensing information. At present, a large number of sensing devices need to be installed with calibration, and it has become an important trend in the development of sensing devices. The calibration of sensing equipment refers to obtaining the high-precision sensing information of the target by adjust high-precision positioning, sensing angle and position of the sensing target region of the device itself, and using the coordinate system transformation method to get the world coordinate system position. The sensing devices can be divided into fixed, mobile and software sensing devices according to the arrangement mode. The sensing devices need to be calibrated is mainly fixed and mobile. The fixed sensing devices comprises high-precision camera, laser radar, millimeter wave radar, and have high requirements for the installation of the equipment itself.

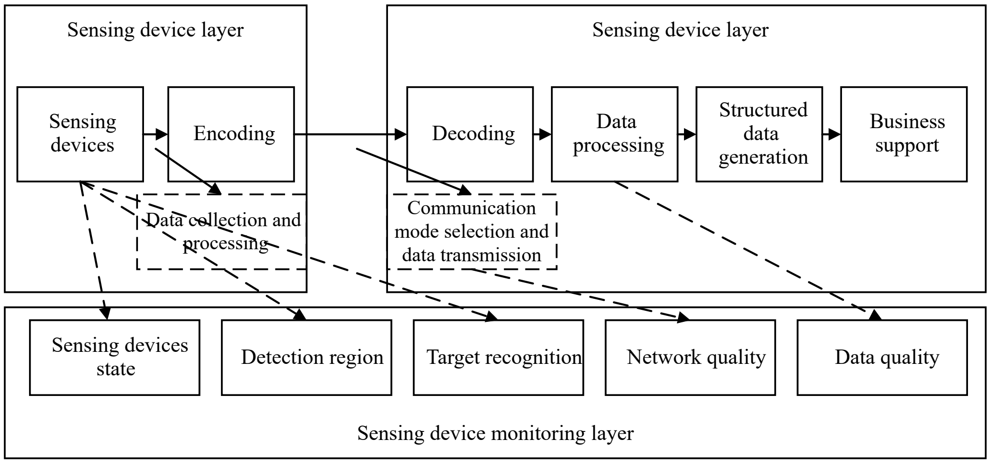

Fig. 1 Sensing device monitoring framework

Fixed sensing devices are greatly affected by the environment such as wind, vibration caused by automobiles, and deformation of rods. Various external factors will lead to changes in the monitoring region, the error of coordinate system conversion method, and the reduced precision of target perception. Software-based sensing devices mainly refer to virtual devices that collect effective information from the network environment, including driver complaint messages and induction notification information. It has higher requirements for time validity of relevant information. Mobile sensing devices usually have highest positioning precision and timeliness for expensive internal GPS positioning module.

Communication refers to a way to complete data transmission by using communication protocol, which is an important method for sensing device data to transmit data to the sensing system. Communication has a great impact on data quality, but in the existing sensing system, the quality of communication is rarely considered. The use of communication protocols is mainly based on the characteristics of the data collected by the device, and each communication mode has its own advantages and disadvantages. The influence of communication mode on data mainly comes from two aspects: communication rate and communication bandwidth. Network transmission rate is particularly important for devices with high real-time requirements, such as roadside laser radar applied to intelligent and connected vehicle tracking. Poor network speed under TCP transmission will lead to serious packet sticking, and the vehicle position will rapidly display multiple times in shot time or just stay in the same place. Poor network speed under UDP transmission will lead to packet loss and vehicle position will jump forward suddenly at the display interface.

Different sensing devices collect target objects according to different requirements, which are mainly divided into two categories: target driven acquisition and indicator driven acquisition. Target perception mainly refers to the information collection of moving targets in specific region, such as laser radar, high-precision cameras, data processing algorithms use the raw data to obtain target information. such sensors in the road construction account for a growing proportion. Application scenarios contain pedestrian tracking based on video processing algorithms, vehicle tracking based on radar point cloud data. The implementation algorithm is complex and Information about the target object is susceptible to environment. Indicator driven sensing devices are mainly classical sensors, such as video, coil, speedometer, which have a long history in traffic detection and have high detection accuracy for indicator data.

3 Methods for sensors operating state reliability monitoring

3.1 Indicators for sensors operating state reliability monitoring

(1) Factors influencing operating state reliability

According to the process of data acquisition and transmission of sensing equipment, the main causes of operation quality problems of sensing devices are as follows: a. Sensing devices disconnection caused by devices failure, power supply and network. b. Sensing devices positioning failure caused by severe weather, road vibration and rod deformation after devices installation. c. Network transmission delay and data package lost caused by excessive number of data package or poor network quality. d. Target positioning and indicator failure caused by the poor performance of the algorithms in sensing devices which do not meet the requirements.

(2) Indicators for operating state reliability

According to the factors influence the operating state reliability of sensing devices, the indicator to indicate the operating state reliability is divided into two categories: real-time indicator and periodic indicator. Through the real-time and periodic supervision of the sensing devices, the reliability of the operating state reliability can be quickly identified, and the maintenance of the sensing devices can be conducted in time. The general supervision content of the operating state reliability of the sensing devices is shown in Table 1.

Table 1 Indicator for sensing devices operating state reliability

Monitoring indicators	Primary indicators	Secondary indicators	Content of indicators
Real-time indicator	Running state	Online state	Online heartbeat
		Data package state	Correctness of data package
Periodic indicator	Sensing performance	Data communication state	Delay of communication
		Detection region deviation	Offset of the detection region
		Target positioning accuracy	Offset of the target position

3.2 Secondary indicators for operating state reliability calculation

(1) Online state monitoring

The sensing devices transmits data with the sensing system through certain communication methods, and the online status of the sensing device also needs to be supervised through the communication process. Sensing devices online state refers to whether the sensing device is stably sending data with the system. The main supervision methods include heartbeat mechanism and communication port connection test. In the process of data transmission protocol formulation, the sensing devices usually define the heart beat mechanism, which means that the sensing devices sends the state information of the devices to the system at a fixed frequency. Taking the road measurement millimeter wave radar as an example, the heartbeat data package sent by the radar is shown in Table 2.

One sensing device online state monitoring example based on heat beat message verification can be shown in Figure 2.

The heart beat mechanism has a wide range of application scenarios, which can realize the system side's supervision of the online state of the sensing devices. The heart beat data transmission frequency also determines the supervision intension of the system on the sensing devices. The heart beat mechanism is a discrete supervision mechanism. In order to avoid the heart beat data sending period is too long or some devices lack heartbeat mechanism to cause monitoring data abnormal, the sensing devices client port testing can be used as a supplement to the continuous online state monitoring, but this kind of monitoring method is mainly suitable for connections based on TCP, WEBSOCKET, HTTP communication mode.

(2) Data package state

Sensing devices communication quality affects the integrity and real-time performance of data from the device side to the system side. After collecting the original data, the sensing devices processes the data and form the structured data according to the agreement through a certain algorithm. After encoding, the data is tra-

Table 2 Content in heat beat data package of millimeter wave radar

Device No.	Device IP	Device type	Longitude	Latitude	Time	Message type
LR14002301	192.168.10.1	Radar	121.921 455 7	34.863 976 3	1 679 879 379 750	Heat beat
LR14002301	192.168.10.1	Radar	121.921 455 7	34.863 976 3	1 679 879 379 850	Heat beat
LR14002301	192.168.10.1	Radar	121.921 455 7	34.863 976 3	1 679 879 379 950	Heat beat

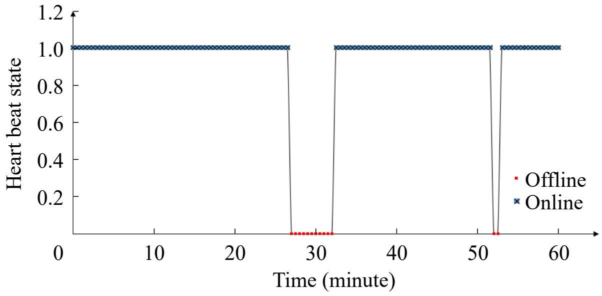

Fig. 2 Online state of sensing devices based on heat beat message

nsmitted to the system side through a certain communication mode. Data not required by the protocol which randomly emerge in the network is also an important factor that causes great interference to the system. Affected by various factors such as data collecting process wrong format, wrong encoding method, wrong verification in message, the message can no be decoded correctly by system.

The data accuracy rate represents the number of all collected data packets that meet the protocol requirements and can be successfully decoded. Define the number of data packets collected by the system from device k in a period of time be m, and the collected data packets are denoted as P_1, P_2, P_3, $\cdots$, P_m respectively. For the data packet $P_i(1 \leqslant i \leqslant m)$, the following logic functions are introduced to identify whether the data packet can be decoded correctly and the data can be obtained:

$$g_k(i) = \begin{cases} 1 & P_k \quad \text{decoded} \quad \text{correctly} \\ 0 & P_k \quad \text{decoded} \quad \text{incorrectly} \end{cases} \tag{1}$$

where $g_k(i)$ represents the status of package decoding.

Thus, the correct rate formula of all data packets in time period t can be shown as follows.

$$Q_{k,t} = \frac{1}{m}\sum_{i=1}^{m} g_k(i) \tag{2}$$

where $Q_{k,t}$ represents the successful resolution rate of all packets of sensing device k in time period t.

(3) Data communication state

The quality of network data transmission is affected by the network quality and the amount of data transmitted. The system has different requirements for network data in different application scenarios. The real-time requirements of sensing signal control, automatic driving target recognition, vehicle equipment and road side equipment communication are higher, and the delay of data transmission process has a great impact on the scene implementation.

Data delay is described by the time difference between the timestamp field in the data packet and the timestamp received by the system. The time required for the packet i to be collected from the device side to the system side to complete the packet reception is as follows:

$$d_{k,t} = t_{g_k(i)} - t_{s_k(i)} \tag{3}$$

where, $d_{k,t}$ represents the delay time of the i data packet from the sensing device k to the system after receiving and processing; $t_{g_k(i)}$ represents the time of the sensing system receiving the i data packet from the sensing device k; and $t_{s_k(i)}$ represents the sending time of the i data packet in the sensing device k.

The delay formula of all data packets in time period t can be shown as follows:

$$D_{k,t} = \frac{1}{m}\sum_{i=1}^{m} d_{k,t} \tag{4}$$

where $D_{k,t}$ denote the average delay of all packets of sensing device k in time period t.

(4) Detection region deviation

The sensing device position is a very critical parameter for sensors with high accuracy requirements. Lane-level video detectors and radar detectors commonly used on roads need to calibrate the detection position in advance to ensure that the internal coordinate system of the device can be transformed into the world coordinate system correctly, and key parameters such as vehicle position and lane information are obtained at the same time. Both classic radar and camera in autonomous driving need calibrate the relative position and direction of the vehicle to collect environmental parameters. However, for some sensors with low position accuracy requirements, or where the position of the devices cannot be changed such as coils, speed meter basically maintain a good detection position. The deviation of detection region is a complex process, there are two kinds of region deviation: temporary and permanent deviation, the deviation of detection region position caused by pavement vibration and wind is temporary and recoverable, rod deformation, mechanical installation structure deformation of equipment is permanent, not recoverable. One detection region can be shown in Figure 3.

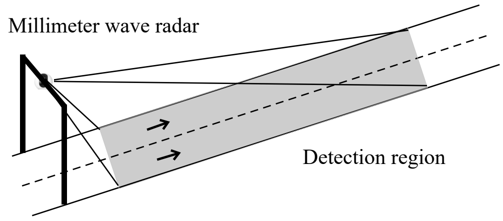

Fig. 3 Detection region of millimeter wave radar

The detection region of lane-level sensing devices needs to obtain accurate lane-level target information through calibration in advance. Taking millimeter wave radar as an example, static and dynamic parameters of different targets can be obtained according to the point cloud, including vehicle size, vehicle type, vehicle speed, heading Angle, lane number and other parameters. At the same time, due to factors such as clustering of vehicles into a point, calculation error, equipment error and other influences, there is a certain deviation relative to the real vehicle position. In order to analyze the accuracy of the detection region through the vehicle trajectory data, the lane center line is approximately described by fitting the curve of all vehicle trajectories in a specific lane within a period of time. Considering the complexity of road line shape, the road linearity is described in the form of multiple straight-line segments as follows:

$$f(x)=\begin{cases} k_1\times x+b_1 & a_1<x\leqslant a_2\\ k_2\times x+b_2 & a_2<x\leqslant a_3\\ \cdots & \\ k_n\times x+b_n & a_{n-1}<x\leqslant a_n\end{cases}\tag{5}$$

When target information is collected by a specific sensing device, the main aspect affected by the change of the detection region of the device is the overall deviation of the target position information, including the rotation and translation of the whole region. Therefore, one method compares the rotation and translation between the track lines in different time periods is proposed. Considering the complexity of road linearity, a certain number of track points are taken at a fixed interval for each straight line, and the overall translation error of each straight line is calculated by the average error of the track points, as shown in the formula.

$$E_i=\frac{1}{n}\sum_{j=1}^{n}\sqrt{\left(x_{t,j}-x_{t-1,j}\right)^2-\left(y_{t,j}-y_{t-1,j}\right)^2}\tag{6}$$

where, E_i denotes the average error of the straight line segment i in the detection region; $x_{t,j}$ denotes the abscissa of the track point j in time period t; $x_{t-1,j}$ denotes the abscissa of the track point j in time period $t-1$; $y_{t,j}$ denotes the ordinate of j in time period $t-1$; and $y_{t-1,j}$ denotes the ordinate of j in time period $t-1$.

(5) Target positioning accuracy

Sensing devices accuracy quality refers to whether the accuracy of the data meets the requirements of the system in the actual sensing process. Different sensing devices have different data quality indicators according to the characteristics of the target object. Speed meter has high-precision speed parameter acquisition requirements, high-definition camera has high-accuracy license plate and vehicle type recognition requirements, and lidar has high-precision static target position detection and dynamic moving state detection requirements. Define each dimension of target l information collected by the sensing device k be $A_{k,j}=\left\{a_1,a_2,\cdots,a_j,\cdots,a_n\right\}$, where a_j represents the j dimension index of target l, and the accuracy of target recognition by the sensing device is as follows:

$$Q_k=\frac{1}{q\times n}\sum_{l=1}^{q}\sum_{j=1}^{n}\frac{a_{l,j}-\tilde{a}_{l,j}}{\tilde{a}_{l,j}}\tag{7}$$

where, Q_k represents the accuracy error of sensing device k; q represents the number of targets detected by sensing device k; n represents the total dimension of state parameters of target l; and $\tilde{a}_{l,j}$ represents the theoretical accuracy of the j parameter of target l.

The parameters of high-precision sensing devices in high-level roads have multiple dimensions, including longitude, latitude, direction angle, speed, target size, among which latitude and longitude are the most basic and important parameters. Therefore, this paper supervises the data quality of sensing devices from the perspective of latitude and longitude.

3.3 Primary indicators for operating state reliability calculation

(1) Running state

Running state is described as the quality of the data transmission for sensing devices, define R_t as the running state in time period t. the formula is shown as follows:

$$R_t=O_t\times\int_1^m g_t(i)\times\int_1^m\frac{D-d_t(i)}{D}\tag{8}$$

where, O_t represents the online state in time period t; m represents the number of data packages in time period t;

$g_t(i)$ represents the correct state of data package i; D represents the accepted largest delay; $d_t(i)$ represents the delay of data package i.

(2) Sensing performance

Sensing performance is described as the quality of target recognition for sensing devices, define S_t as the sensing performance in time period t, the formula is shown as follows:

$$P_t = \frac{TD - \omega_1 \times E_t + \omega_2 \times Q_t}{TD} \tag{9}$$

where, ω_1 represents the weight of detection region deviation; E_t represents the average detection region deviation in time period t; ω_2 represents the weight of target recognition accuracy; Q_t represents the average target recognition accuracy in time period t; TD represents the largest accepted deviation.

4 Experimental analysis of sensors operating state

4.1 Data collection

The raw data collected by multiple millimeter wave radar sensing devices were used for the experimental analysis of operating state reliability monitoring. The radar is installed above the road for vehicle data acquisition. Taking three millimeter wave radars consecutively installed on a fixed straight road as an example, the radar goes through a calibration step in the installation process and collects target information on a specific 200-meter-long one-way single-lane road. The radar processes the vehicle movement data collected in each frame to form the structured data required by the system. The radar collects vehicle target data 25 times per second. The main parameters that can be obtained by radar are shown in Table 3.

According to the above protocol, the radar organizes the data of each frame to be uploaded in a certain data encoding format, and the system side decodes the data by byte through the corresponding protocol to obtain structured data. The target information of each frame is in the message content field, which mainly includes the vehicle target ID, target length, width and height, target type, target latitude and longitude, target heading angle, and target moving speed. Theoretically, the system end can obtain 25 pieces of vehicle target information in the corresponding monitoring region per second.

The target position information detected by three consecutive radars in one week is shown in the Figure 4.

4.2 Secondary indicators analysis

(1) Online state

The system decodes the data uploaded by the radar through TCP communication, and the data content is shown in Table 3. Through the use of JAVA tools on the system, the processing of data decoding and the calculation of operating state reliability related indicators are carried out. At the same time, in order to ensure the real-time quality supervision of radar operation, all data packets belonging to radar are directly analyzed in the way of stream at the system, so as to reduce the delay caused by the data storage and distribution process. Taking a day with good weather as an example, the radar is set to report heart beat data in a period of 30 s. 1 means that the system receives heart beat data during the period, and 0 means that the system does not receive heart beat data. The heart beat of the three radar devices in a day with large network fluctuations is shown in the Figure 5.

Through the supervision of radar by the system, it is found that the integrity rate of radar hardware heart beat

Table 3 Content in target data package

Field name	Data type	Data length	Field description
Frame head	Fixed text content: 0x7E, 0x7D	2 bytes	Beginning of the message
Message type	String	2 bytes	Target information
Device ID	String	4 bytes	Unique identification
Message length	Integer	n+6 bytes	Length of message
Message content	String	n bytes	Content of target
Timestamp	Long	2 bytes	Time when get message
Check code	String	2 bytes	Verification of the message
Frame tail	Fixed text content: 0x7E, 0x7D	2 bytes	End of the message

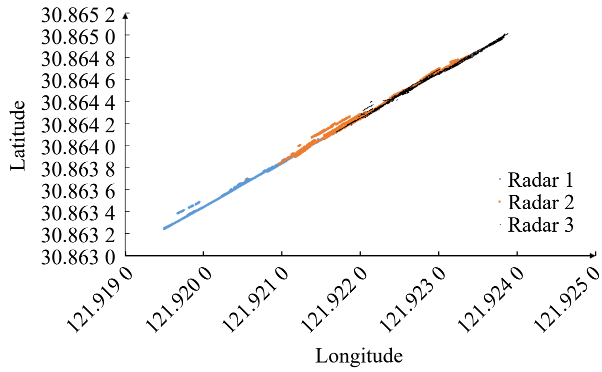

Fig. 4 Target trajectories of different radars

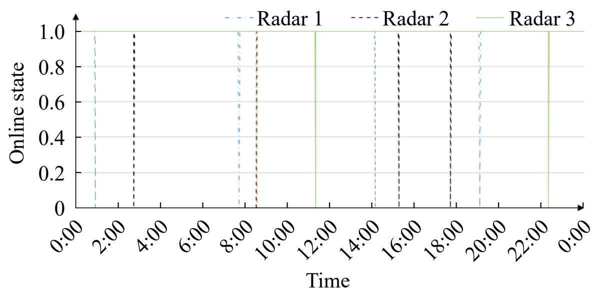

Fig. 5 Online state of different radars

performs well in the case of LAN TCP/IP network communication. The missing heart beat data of radar basically occurs between 0 and 5 times a day, and the loss of heart beat data may be affected by the quality of the network and the creation of heart beat data of the equipment itself.

(2) Data package state

The data transmission between the radar and the sensing system server is carried out by TCP/IP communication, which has high reliability. At the same time, the incidence of packet loss and data packet error is low when the radar and the sensing system server are in the same network segment. Through the inspection of the data packet, in the case that check codes of the data packet frame are verified, the three radars have zero error packets within a week, and all fields in the data packet can be successfully decoded. However, some packet check codes fail. Radar equipment uses XOR to encode the content of a packet. XOR means to perform operation on all bytes in sequence, that is, compare each bit of two bytes, in the same case the bit becomes 0, and the bit becomes 1 in different cases, after forming a new byte, continue to compare it with the next byte. Until all data operations are completed, a check code is completed. The correctness of the data packet can be verified by carrying out XOR algorithm on the whole data packet except for the frame header, frame tail and check code. According to the test results, the correctness supervision results of the three radars in one month are shown in Table 4.

Table 4 Correctness of data packages

Radar number	Correctness of check code	Correctness of field
LR14002301	99.98%	100%
LR14002302	99.99%	100%
LR14002303	99.98%	100%

(3) Data communication state

In the process of sending various types of data packets from the sensing devices, there is a data record timestamp field, which describes the time of data packet formation. It takes a certain time for the data packet to be resolved through network communication. The radar and the sensing system server are in the same local area network segment, and the three radars transmit through the local area network with a fast transmission rate and low delay as shown in Figure 6.

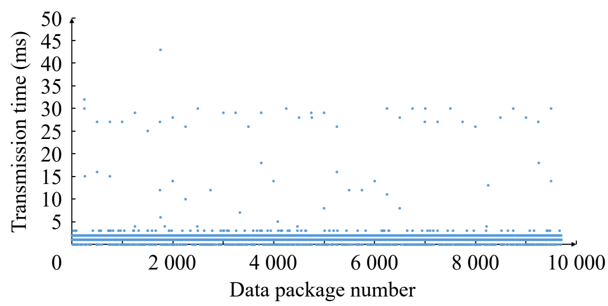

Fig. 6 Delay of different data package

When data transmission is carried out in the same network segment, the data transmission rate is fast, basically within 3 milliseconds, which meets the requirement of the sensing system for quickly capturing the dynamic information of targets.

(4) Detecting region deviation

The road detected by the radar is a one-way single-lane section, the width of the vehicle lane is 3.5 m, and there are 1-meter-wide reserved lanes on both sides of the vehicle lane. The distribution of all vehicles target trajectory points collected by the radar 3 within a week is shown in Figure 7.

The targets detected by radar 3 are basically located within the motorway region, but at the same time, some detection targets are located outside the region, and there

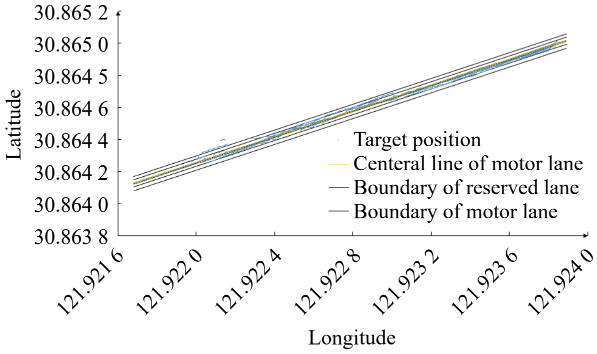

Fig. 7 Detection region and target position of radar 3

are certain errors. There are many sources of error of target trajectory points outside the detection region, including lens vibration, rod vibration, and clustering points outside the region when existing large vehicles. The position deviation of the radar's detection region was carried out with a period of 60 min. The linear fitting of all track points was carried out every 60 min, and the error between the track line and the lane center line was calculated. Considering that the rotation deviation is more obvious at the farther distance from the radar, the detection region is divided into three segments on average. Since the detection region is a straight road segment, the fitting of trajectory points is carried out by linear function. Every 60 min, the distance between the target fitting line perceived by the three parts of radar 3 and the center line of the road segment is shown in Figure 8.

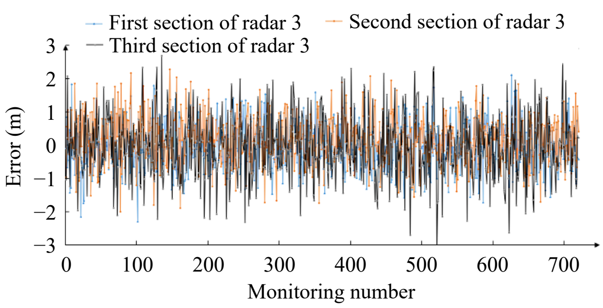

Fig. 8 Deviation of three sections in radar 3 detection region

The overall deviation trend is on both sides of the road center line, and there is no continuous expansion trend, indicating that there is no long-term irreversible perception angle deflection on radar 3 within a month. At the same time, the three parts have different performance in detecting the target. The first part and the third part float up and down with the center line position of the motorway, but the third part floats relatively more, indicating that there is a larger error in the distant object perceived by radar 3. The second part is slightly higher than the other two parts, indicating that there is a certain conversion error in the transformation of the internal coordinate system into the world coordinate system.

The relative deflection errors in the three radar detection regions are shown in Figure 9.

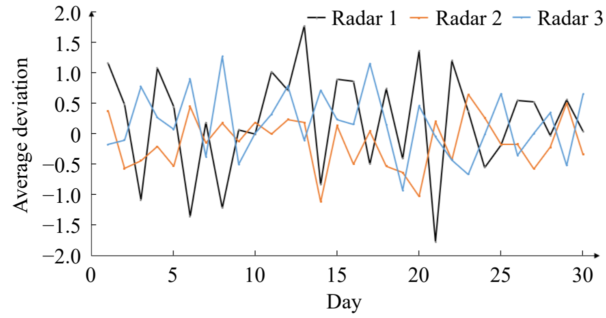

Fig. 9 Average deviation of three radars' detection region

Each radar did not show a trend of increasing deviation in the first month, indicating that there was no irreversible deformation on the rod of the radar equipment.

(5) Target positioning accuracy

The accuracy of road target perception is affected by many factors includes large size of the vehicle objects, the different location of the high-precision positioning module in the location of the vehicle and the clustering point of the captured target, and the rod waggle. The randomness occurs in all directions is the same. The on-board positioning module is used for testing, because the camera acquisition frequency and the on-board positioning module position acquisition frequency are inconsistent. When there is no unified calibration, the timestamp of data uploaded is difficult to synchronize due to the influence of data transmission and data processing, so the process of positioning accuracy verification through a single point is difficult to measure. The line trajectory of the vehicle positioning module and the line trajectory identified by the camera are used to calculate the target positioning deviation, and the positioning accuracy of the vehicle high-precision positioning module is 0.01 m. The average deviation of target recognition relative to detection distance is shown in Figure 10.

After a long time of testing, it is found that the general accuracy of the radar installed on the rod has a certain deviation compared with the high-precision positioning module, and 90% of the target positioning deviation is within 0.5 m, which is on the premise of the adjusted

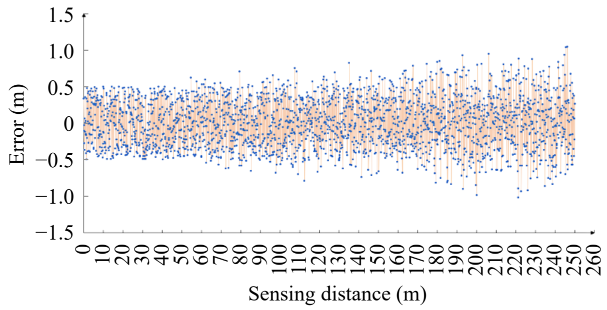

Fig. 10 Average deviation of target recognition relative to sensing distance

design of the target cluster center and the placement of the high-precision module. At the same time, it can be found that the farther away from the detection equipment, the more likely the detection error is to become larger. According to the analysis of the actual environment, the main reasons for the deviation come from the deflection of the rod and the failure of the target recognition algorithm.

4.3 Primary indicators analysis

(1) Running state

According to online state indicator, data package state indicator and data package accuracy indicator, running state of three radars is analyzed as shown in Figure 11.

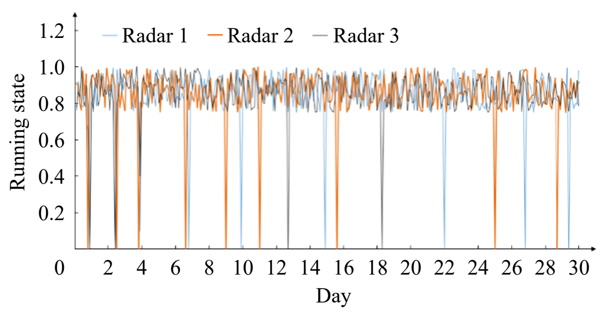

Fig. 11 Running state of three radars

(2) Sensing performance

According to detection region deviation indicator and target recognition indicator, sensing performance of three radars is analyzed as shown in Figure 12.

5 Conclusion

This paper proposes one vehicle detection sensors operating state reliability measuring approach which considers the running state and sensing performance. The indicator system has five secondary indicators include online state, data package state, data package accuracy, detection region deviation and target recognition accuracy.

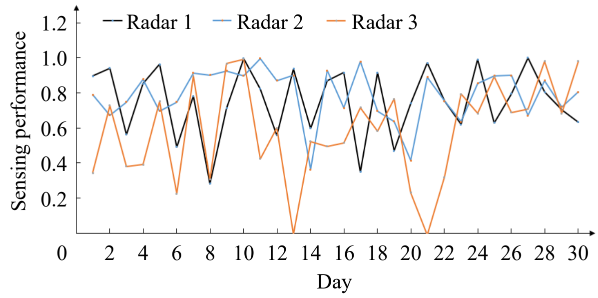

Fig. 12 Sensing performance of three radars

This method can make up for the lack of traffic sensing devices supervision at present, and make data collected from sensing devices more confident.

Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

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