Positioning accuracy estimation for on-board data processing at the road surface defects monitoring

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Abstract. In this work, an approach has been developed to analyze data on the movement of a vehicle obtained as a result of measurements carried out using a satellite navigation system. The issues of increasing the accuracy of such measurements are of great importance in quality monitoring of road maintenance for geo-referencing of detected roadway defects. When using the proposed approach, the speed of a vehicle is considered as a stationary random process, the correlation function of which belongs to one of the specified classes. Based on the monitoring results, the value of the correlation function parameter is selected, which, in a certain sense, best matches the measurement results. The problem is also solved in a certain sense of the optimal choice of the duration of the averaging interval of the velocity values obtained as a result of monitoring, while taking into account how much, for the selected duration of the averaging interval, the sample obtained correlation function of the velocity corresponds to the correlation function from the hypothetical class for the selected parameter value.

1. Introduction

Vehicle traffic monitoring is relevant for the tasks of flow control, road safety and correct routing, as a driver assistance. One of the most problematic road conditions associated with road accidents in the Russian Federation is the poor condition of the road surface. The challenge is to improve the accuracy of GPS / Glonass vehicle speed data.

Monitoring issues on highways were considered in works [1,2]. In [1], the issues of obtaining and analyzing the results and the theory of traffic flows, including those related to the model of following the leader [3, 4], are considered. In [5], the issues of assessing and improving the accuracy of measurement results, in which the movement of vehicles is monitored using satellite navigation positioning systems, is considered.

In this article, an algorithm has been developed for analyzing changes in the speed of a vehicle on a short section of the highway using data obtained as a result of measurements carried out on the highway. The process of changing the speed on a section of the highway is characterized by a stationary random process, the mathematical expectation and correlation function of which are estimated on the basis of the measurement data carried out using a GPS sensor.
2. Recognition in the theory of traffic flows (TF)

Automatic processing of video and audio information about the characteristics of TF has been developed at MADI (GTU) since the early 2000s. Technologies that perform computer processing of video recording of a multi-lane road traffic flow in laboratory conditions were tested on sections of the «Central Russia» highways adjacent to Moscow. Subsequently, the tasks of assessing the intensity, density, composition of traffic flows were implemented in real time without intermediate laboratory processing of video material. The work of recognizing TF by audio signals was also carried out, which makes practical sense in conditions of insufficient visibility. In the course of work, it turned out that the range of practical problems that can be solved by processing the signal of a video source is extremely wide. A large package of algorithms for automatic monitoring on the road, which can work in parallel, is called MonStr (Street Monitoring). This software package is based on the analysis of video and photo-stream received from video and photo cameras, which are installed in a mobile laboratory and allow research and multipurpose monitoring. Among the goals are: monitoring the condition of the road, assessing the quantitative and qualitative characteristics of the TF composition, assessing road traffic controls, assessing compliance with traffic rules. Video and photographic material obtained from the source is processed on a computer for each of the tasks. The work of the program is based on the analysis of the chromaticity matrix of the pixels of each frame of the flow.

The sources of information through which monitoring is carried out are devices classified according to the type of data acquisition: video camera, photo camera, navigation device (GPS), microphone, various sensors (light, vibration), etc. Depending on the task and the developed scheme of the algorithm, the device can be located both in the cabin of the mobile laboratory (ML) and fixed outside.

So, the fastening of the video camera is carried out on an external tripod attached to the ML body (for example, on the trunk). However, in winter, at low temperatures, fastening can be carried out inside the ML on a specially equipped tripod. The work of all devices is coordinated by a computer with an installed software package (for each subtask its own subroutine). The computer is installed in the ML compartment and carries out bi-directional operation and data collection from all connected devices, controls the recording mode of video and photographic equipment, collects data on the current coordinates received from the navigation device.

After the central computer receives data from the video camera, the frame matrix of the video stream is scanned in real time according to the mask of a given area and issues a command, depending on the task being performed, either to the video camera to switch to the recording mode, or to the camera to the photography mode. Regardless of the command issued, the received information is stored in the computer, which allows further analysis and processing of data in the laboratory. Also, the computer memorizes the navigation coordinates (latitude and longitude) and saves them to the database, which allows the binding with an accuracy of 2m.

Used devices and equipment:

- a computer of the Notebook type, or a small-sized personal computer;
- a video camera and a camera supporting the architecture of working with a computer;
- GPS navigation device;
- tripod for video and photographic equipment;
- peripherals: directional microphone; a device for measuring illumination.
3. **Basics of technology for monitoring and analyzing road conditions**

The control car - a mobile laboratory is moving along one of the lanes of a multi-lane road. On board of the ML there is a set "Video camera - computer". The camera operates in the observation mode, and the selected frames are processed in accordance with the current task. If, in addition, the camera is mounted on a mobile controlled tripod, the computer can control the shooting angle and optical zoom. This simulates the workings of the human eye. At the same time, the camera-computer pair, in contrast to the eye-brain ligament, can perform a large number of tasks in parallel. Let's describe the main tasks.

The problem of determining the intrinsic velocity of the ML as a function of time can be solved by means of ORZ technologies. However, even in this case, the analysis of periodic perturbations of the chromaticity of a special area of the screen (for example, pillars of illumination) can give an accuracy comparable to modern technologies.

![Figure 1. Installation options for ML equipment.](image-url)
Figure 2. a) the control area automatically recognizes road markings; b) the section of the road marking defect is highlighted; c) the control area automatically recognizes the uniformity of the roadway and gives an estimate of its area; d) an unevenness on the roadway was revealed and its area was estimated as $\sim 0.3 \text{ m}^2$.

Similarly to the previous one, the problem of determining the speed of vehicle moving along a multi-lane road is solved if the speed of the ML is known. The practical significance consists in the classification of vehicles according to the speed of movement (fast, correct, slow (obstacles)) and observance of traffic rules. Note also that on the basis of the speedometer and the above-mentioned speed estimates, it is easy to determine the degree of wheel slip relative to the road surface.

Inverse problem: checking periodic structures on the road using information about the speed of the ML. The control of the uniformity of the placement of objects of a certain type on the road (for example, pillars of fastening of the separation barrier) is carried out. In this case, the speed of the ML does not have to be constant.

Control over the continuity of solid marking lines is implemented in several modifications. First, with stationary observation from a high point behind a large piece of a solid line (double solid line). In case of violation, the vehicle is identified and recorded in the database. Secondly, checking the quality of the markup and localizing areas where it needs to be updated. Thirdly, the analysis of the roadway for the presence of foreign components (individual objects, dirt, snow, etc.).

Dynamic clearance protection (DC) - part of the line in front of the ML, necessary for traffic safety. DC depends on the ML speed and is determined automatically. In the event of an intrusion into the DC area of any vehicle, video recording and identification of the intruder takes place. DC is necessary for the analysis of the road surface according to the described technology in conditions of saturated flows.

Integral estimation of road smoothness (flatness). By constructing the function of changing the position of a fixed point on the computer screen of the ML moving at a fixed speed, the total smoothness of the motion is determined. Then, on a section of a flat road at the same speed, the natural oscillations of the ML are determined. The results of these two functions are used to estimate the smoothness.

Determination of the geometric parameters of the road. The behavior of the projection of the ML velocity vector is analyzed. It was noted earlier that the length of the vector determines the size of the dynamic dimension. Changing the direction, in addition, allows you to evaluate other geometric parameters of the trajectory of motion: curvature, torsion.
Checking the uniformity of the road surface. Color analysis of the inviolable dynamic dimension of the ML allows to identify on the roadway such components as patches, cracks, pits, foreign objects, dirt, puddles. Each of the components has a physical nature and, therefore, can be represented as the total color components.

Determination of the area of patches. The method is based on checking the homogeneity of the road surface for the search for components - patches (5.8.) And uses formulas for transforming the perspective of the image into units of area. The parameters of the controlled area of the DC are used, such as the width, length, distance from the camera to the area and the height of the camera above the roadway.

Estimation of the volume of road surface defects. The approach is based on the estimation of the volumes of holes and potholes on the road when approximating by cylindrical bodies, and the side is separated from the base by the difference in illumination.

Determination of the secretion of the lanes. The method is based on the analysis of the color difference between two parallel lines along the movement.

Estimation of the intensity and composition of the vehicle "from the inside" in the mode of movement on one of the highway lanes. The intensity conversion is used taking into account the known velocity of the ML movement.

Constructing a mixing matrix and estimating the capacity of a complex intersection. Building a road illumination map. Identification of places with insufficient or poor illumination. Road portrait or recognition technology. A photo or video map of the road is created, which is stored in the computer’s memory and serves as a reference. In the process of observation in real time, the area is recognized and compared with the standard. The goal is to determine changes in the speed of the ML with reference to the map.

4. Estimation of mathematical expectation and velocity correlation function
In this section, an algorithm has been developed for analyzing changes in the speed of a vehicle on a short section of the highway using the data obtained as a result of measurements carried out on the highway. The process of changing the speed on a section of the highway is characterized by a stationary random process, the mathematical expectation and correlation function of which are estimated on the basis of the measurement data carried out using a GPS sensor.

Suppose that as a result of measurements, $n$ values of the vehicle speed $v_1, v_2, ..., v_n$ were obtained. We assume that the velocity $v(t)$ over the time interval $(0, T)$, at which measurements are carried out, is a stationary random process [6]. The values of the velocity are fixed at times $i\Delta, i = 1, ..., T = n\Delta$, where $\Delta$ is the duration of the time interval after which the speed values obtained as a result of measurements are recorded. Let $v_i$ be the speed value obtained as a result of measurement at time moment $i\Delta$, $i = 1, ..., n$. Let $m, D$ be the sample values of the mathematical expectation and variance of the velocity; $k(\tau), \rho(\tau)$ are sample values of the correlation function and the normalized correlation function, respectively, at the value argument equal to $\tau$. For the sample mean we have

$$m = \frac{1}{n} \sum_{i=1}^{n} v_i.$$  

In order to smooth out fluctuations in the velocity values obtained as a result of measurements, we will average the velocity values over time intervals of duration $a\Delta$ (the size of the grouping interval in the terminology of the general theory of statistics [10]). The original sample $v_1, ..., v_n$ is replaced by the sample

$$v_i(a) = \frac{1}{a} \sum_{j=(i-1)a+1}^{ia} v_j, i = 1, ..., \left\lfloor \frac{n}{a} \right\rfloor.$$
where square brackets represent the integer part of the number.

Let \( k^*(l, a) \) be the value of the correlation function \( k(\tau) \) estimated from the measurement results for the argument value \( \tau = l\Delta \), where \( l \) is a non-negative integer, \( 0 \leq l < [n/a] \), under the assumption that the estimation is performed with an averaging interval of duration \( a\Delta \).

For the corresponding estimates, we have

\[
k^*(l, a) = \frac{1}{[n/a] - l} \sum_{i=1}^{[n/a]-1} (v_i(a) - m)(v_{i+l}(a) - m)
\]

(here the velocity correlation function is estimated by averaging over the products of velocity deviations from the sample mean on the intervals \( (i - l)a\Delta, (i + l)a\Delta \), with an averaging interval equal to \( a\Delta \); the number of such pairs of intervals is \([n/a] - l\), since the last such pair, belonging to the entire measurement interval is the pair \((([n/a] - l - 1)a\Delta, ([n/a] - l)a\Delta)\) and \( (([n/a] - 1)a\Delta, [n/a]a\Delta)\)).

\[D(a) = k(0, a),\]
\[
\rho^*(l, a) = \frac{k^*(l, a)}{D(a)}
\]

5. Estimation of the parameter of the velocity correlation function under the assumption that the correlation function belongs to a given class

Let us make the assumption that the normalized velocity correlation function belongs to one of the following classes:

\[\rho(\tau, \beta) = e^{-\beta|\tau|^2},\]
\[\rho(\tau, \beta) = e^{-\beta|\tau|},\]
\[\rho(\tau, \beta) = e^{-\beta|\tau|(1 + \beta|\tau|)}.
\]

For a given class and given values \( \beta \) and \( \alpha \), the mean square error of the approximation \( F(\beta, \alpha) \) is calculated by the formula

\[F(\beta, \alpha) = \sqrt{\frac{1}{[n/a]} \sum_{i=1}^{[n/a]} (\rho^*(i, \alpha) - \rho(\alpha\Delta))^2} \quad (1)
\]

When choosing in practice the averaging interval of the speed values obtained as a result of measurements, the value of the error calculated by formula (1) is taken into account. If the averaging interval is too small, then it can be expected that, due to random fluctuations in the measured values of the velocity, calculated by formula (1) may be large. On the other hand, if the duration of the simulation interval is long, then information about the dynamics of the vehicle speed over the measurement time interval is lost.

6. Conclusion

Suppose that there is data on the coordinates of the points of location of the vehicle at successive equidistant points in time. For example, the coordinate values were recorded using a satellite navigation system at intervals of 1 sec. These coordinate values are used to determine the speed
values of the given vehicle in intervals in seconds. Due to fluctuations in the error in determining the value of the coordinate, the obtained speed values will change abruptly. These fluctuations can be smoothed out by averaging the obtained velocity values by combining adjacent intervals of greater duration. The speed values obtained as a result of averaging more accurately approximate the real dynamics of the vehicle speed. In this work, an approach to the choice of the averaging interval has been developed, according to which the empirical correlation function of the velocity should be well approximated by the correlation function from the hypothetical class with the appropriately chosen parameter value.

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