Development of a distributed mobile system «SiLOK» for the task of reconstructing a three-dimensional model of a roadbed rut

M V Yashina1,2, I A Kuteynikov1,2, O S Lavrov1,

1 Moscow Automobile and Road Construction State Technical University (MADI), Leningradsky Prospect 64, Moscow, 125319, Russia
2 Moscow Technical University of Communications and Informatics (MTUCI) Aviamotornaya 8-a, Moscow, 111024, Russia

E-mail: ivankuteynikov09@gmail.com

Abstract. Roadbed defects are inconvenient, especially in developing countries, and can often result in vehicle damage or physical injury to passengers. By using smartphones as a source of information on roadbed conditions, drivers can be warned of approaching problem areas in real time. In addition, the location of problem areas can be saved and shared to help other drivers and road services. This paper presents a client-server mobile system "SiLOK" for reconstruction of a three-dimensional model of a roadbed rut based on a smartphone and a profilometer. The system allows the driver to register the presence of a roadbed rut, after which data about it is transmitted to the server and recorded in the database as feedback. Also, the system, based on the analysis of the route processed by other users of the system, warns the driver about approaching the roadbed rut section.

1. Introduction
The growing pace of motorization and road construction around the world is making it more and more expensive to maintain and repair existing areas. Roads are increasingly stressed and worn out faster, leading to roadbed ruts that can lead to road accidents. The problem of roadbed rut formation and its elimination has been considered one of the most important tasks for many countries of the world for a long time.

The main reasons for roadbed rut formation include wear of the top layer of the pavement as a result of the combined effect of wear and premature abnormal destruction of the asphalt concrete layer under the influence of external factors, which include, along with the impact of wheels, precipitation, temperature changes and exposure to the sun [1].

Rutting on the road leads to loss of fuel, tire wear and further damage to the vehicle. All of these problems require systematization of the collection of information about bad road conditions and direction towards analysis, driver warning and road repair.

A group of scientists from the Department of Higher Mathematics of MADI under the leadership of Professor A.P. Buslaev since the end of the 20th century has been engaged in the development of traffic flows, optimal control taking into account traffic jams and engine load modes in various road conditions, using automatic processing of data collected from mobile laboratories [2]. As a solution to the roadbed rut detection problem, a client-server system based on a smartphone running Android operating system
and a mobile laboratory "OTROK" of the Department of Higher Mathematics "Smartphone and Laboratory Track Processing" (SiLOK) is proposed.

At the stage of collecting information, a vehicle with a smartphone with a camera installed on its frontal part moves along the road, filming a video. During the analysis phase, this data will be processed by an algorithm to detect the roadbed rut in front of the laboratory.

2. Methodology
The operation of the system includes the use of computer vision algorithms for rut detection using video/photo data, as well as mathematical methods for processing data from profilometers. The use of two methods simultaneously improves the detection accuracy in cases of poor visibility or foreign objects on the road.

2.1 Recognition using computer vision methods
One of the operating modes of the three-dimensional roadbed rut model restoration system is a visual approach using video data from a smartphone, processed using computer vision algorithms without the need for machine learning algorithms.

The proposed rut detection method begins with the selection of a trapezoidal area in front of the vehicle (Fig. 1 a)) and its transformation into a black and white image (Fig. 1 b)). Binarization is carried out by comparing the brightness of each pixel with a threshold $t$ ($0 < t < 1$). Based on the comparison results, the pixel is assigned a value of 0 (black) or 1 (white).

To clean up the image and remove noise, a median filter is applied to it (Fig. 1 c)). This filter takes the values of its neighbors for each pixel, sorts and sets this pixel to the mean value.

After all transformations to detect the rut, the found clusters of pixels are highlighted in a straight line by interpolation in brightness, which is applied to the original image (Fig. 1 d)).

The advantages of this method include the simplicity of design and relatively low cost, depending on the price of the smartphone. The disadvantages are the requirements for illumination and weather conditions, as well as low measurement accuracy.

2.2 Recognition using a profilometer
The profilograph is based on laser sensors. The measuring system is used to measure the rut depth on the roadway.

A beam of light from a semiconductor laser diode, while driving, hits the roadbed surface at a frequency of 6 Hz. A detector installed in the sensor housing determines the profile of the roadbed, i.e. its deviation from the usual average level and converts the obtained value into an electrical signal, on the basis of which electronic devices can calculate the actual distance to the measuring object. The design of the laser sensor allows measurements in the range of an average height of 100 mm from its bottom edge to a distance of 300 mm. The measurement resolution of the laser sensor is 3 mm. Measurements are taken every 10 cm of the vehicle's path. All signals are transmitted digitally.

The advantages of this method are: high measurement accuracy (up to 0.1 mm) and the ability to work in bright sunlight. The disadvantages are high cost and design complexity.
3. **Hardware architecture of the "SiLOK" system**

The hardware basis of the system is a combination of a smartphone with a camera and a GPS module and a mobile laboratory with a profilometer and a laptop.

3.1 **Mobile laboratory "OTROK"**

Mobile laboratory "OTROK" ("Equipment for Telematics and Image Recognition on Wheels") (Fig. 2. a)), built on the basis of the VOLSWAGEN TARNSPORTER T5 car, has combined several key properties at once. The main thing was versatility, in particular, in terms of technical training and equipment.

The OOM-MADI profilometer, installed on the mobile laboratory "OTROK" (Fig. 2. b)), was developed by the students of the Department of Higher Mathematics A. V. Tikhonov, A. N. Nigmatulin and Gorodnichev M.G. under the guidance of Doctor of Physical and Mathematical Sciences prof. A.P. Buslaev [3]. To implement the recognition function, five Dimertrix DLS-C30 laser distance sensors (rangefinders) are used, attached to a transverse rod, which is attached to the front amplifier of the mobile laboratory. Also used is the RS signal concentrator MOXA, which receives the data obtained by the rangefinders during operation and transmits them to the USB port of a laptop installed in a mobile laboratory. The laptop transfers data from the profilometer to the server.

![Image](image)

**Figure 2.** a) Mobile laboratory "OTROK". b) OOM-MADI profilometer.

3.2 **Terminal device for a smartphone of the "SiLOK" system**

Currently, smartphones are created on the basis of System on a Chip [4]. It includes the following components (Fig. 3):

1. An application processor responsible for executing user application software using instructions from middleware and an operating system (OS).
2. A baseband processor (or modem) with its own OS components, performing radio transmission in the main frequency band and receiving audio, video and data.
3. Various user interface peripherals, including high resolution camera, an accelerometer, a gyroscope, a magnetometer, proximity and light sensors.
Figure 3. Smartphone Hardware Architecture.

Data from the smartphone camera along with GPS coordinates are transmitted to the server for further processing.

4. Software architecture of the "SiLOK" system

4.1 Client part

Currently, the Android operating system is the most widespread mobile operating system in the world (~75% of all mobile devices) [5]. It is suitable for creating applications using hardware sensors and has extensive capabilities for measuring and storing the kinematic parameters of the device and the electromagnetic characteristics of the environment. Almost all Android devices are equipped with microelectromechanical sensors, they are of two types: real (provide initial data) and virtual (provide the necessary level of abstraction between the application code and low-level device components).

The client part on the smartphone is implemented on the Android platform. It is responsible for receiving the image, sending it to the application server and displaying the processing results. The JSON stream received from the server is used to display the classification results.

The client side on a smartphone has the following features:

- Ensuring the operation of the user interface - the client part includes the interface of the entire system. Using XML layouts from Android APIs, an interactive user interface is created. Using the interface, the user can access the camera and start receiving video data.
- Link to Object Extraction Components - Provides a channel for transferring the captured image to the Object Extractor component.
- Providing an interface for communication with the server - allows the client to receive messages from the server.
- Display results - responsible for displaying results from the server. Runs the JSON parser and provides the result to the user.
- Latency logging - The profiler is used to track the time spent on application components on the mobile side.

The client part on a laptop running under the Windows 10 operating system is implemented in Java. The tasks of the software product include collecting, primary processing of data received via the USB port from the profilometers, sending data to the server and receiving data, followed by visualization of a two-dimensional model and a 3D model of a road track.
Client-server communication protocol. The communication protocol is part of the client applications on both devices. The function of the protocol is to provide a standard mechanism for the exchange of data between the server and the client application. The client side uses the standard HTTP protocol to communicate with the server. For a developed application, Android provides standard APIs that must be called to implement this protocol.

The client part on a laptop running under the Windows 10 operating system is implemented in Java. The tasks of the software product include collecting, primary processing of data received via the USB port from the profilometers, sending data to the server and receiving data, followed by visualization of a two-dimensional model and a 3D model of a roadbed rut.

4.2 Server part

The server part of the application consists of an application server, which is responsible for the implementation of machine vision algorithms for recognizing tracks from images received from a smartphone, as well as processing and interpolating data obtained from the profilometer. Before starting the algorithm for restoring the three-dimensional model of the roadbed rut, we must create a database on the database server. This database stores images, GPS coordinates and data from the profilometer.

The server software includes a number of utilities for the subsequent processing of the received data, as well as from Internet scripts for automatically superimposing the received data on the maps of the Google Maps service.

The application server uses Java EE technology. The Jakarta Enterprise Edition platform includes libraries that provide functionality for deploying fault-tolerant, distributed, layered Java software based primarily on modular components running on a server. WildFly Application Server was selected as the server because it is a Jakarta EE certified platform for developing and deploying enterprise Java and web applications. WildFly Application Server also provides full Jakarta EE functionality as well as advanced enterprise services including clustering, caching and storage.

The server side database contains the relevant information about the image as a vector element. Depending on the type of application, the database may contain additional information about the image such as GPS or time stamp. The request from the client can also contain additional parameters to further refine the information required to access the database.

After recognition is complete, the application queries the database to retrieve the metadata for the image. The server communicates with the client via HTTP. The server communication components
receive information in the form of a formatted JSON file. It is then sequentially sent to the mobile client for further processing.

5. **Logical scheme of the "SiLOK" software package**

The developed technology is intended for automatic processing of information in real time received from a smartphone and mobile laboratory profilers about the state of the road infrastructure.

Since the camcorder shoots with a frequency of ~ 25 frames/sec. Due to the limited server performance in real time and small changes in the scene in the image, it is possible to select the image transmission interval (every 1-12 frames/sec.) and the GPS coordinates transmission interval.

In a multitasking environment, you can parallelize the running processes of subtasks and distribute them across several processors. Thus, each of the subtasks will work in parallel and independently of each other and at the same time access the same source data, including images, GPS data, data from profilometers, etc. Therefore, all records created by the system can be processed by a different class of subroutines. This conceptual feature allows for complex monitoring and information processing not only in real time, but also in laboratory conditions.

6. **The results of the "SiLOK" software package**

The interface of the mobile application allows to select the frame sampling rate, the transmission interval of GPS coordinates, the ability to set a new route or continue the existing one, create a route on Google Maps (Fig. 5 a)).

The application interface on a laptop allows communication with the component parts of the profiler via COM ports (Fig. 5 b)). Each of the ports associated with the laser rangefinder through the MOXA RS signal concentrator transmits data to the system in the RS-232 standard format (Fig. 5 c)). The same window is used to read/write data from the profilometer.

![Figure 5. Interface of the "SiLOK" software package. a) Mobile application interface b) Interface for connecting to profilometers c) Receiving data from profilometers](image)

The data from the profilometers is drawn step by step at a specified interval. Rangefinder lasers act as points on the graph. Applying linear interpolation, the points are connected by straight line segments, as a result of which a transverse profile of the road surface is drawn (Fig. 6).
Based on the obtained GPS data and track detection methods, it is possible to build a route of movement [6], displaying sections with a roadbed rut on it (Fig 7.). Thus, other drivers and road services who have access to the system will be aware of the presence / absence of ruts on the route.

![Figure 6. a) a roadbed without a rut; b) roadbed with a rut](image)

**Figure 6.** a) a roadbed without a rut; b) roadbed with a rut

**Figure 7.** An example of displaying the received coordinates on the Google Maps service.

7. **Conclusions**
The paper presents a distributed mobile system "SiLOK" for the task of reconstructing a three-dimensional model of a roadbed rut. The principles of the system operation, applied methods and algorithms are described. The description of the client-server architecture and the primary results of the roadbed analysis are given.

As a further work, data collection for the application of machine learning algorithms is considered, which should lead to an increase in the accuracy of rut detection from a smartphone camera.

**References**

[1] Lugov S V and Kalenova E V 2013 The possibility of pavement wear valuation at rutting predicting *Bulletin of the Moscow Automobile and Road Construction State Technical University (MADI)* 4 53–59

[2] Buslaev A P, Dorgan V V, Kuzmin D M, Prikhodko V M, Travkin V Yu and Yashina M V 2005 Recognition of Images and Monitoring of Road Conditions, Traffic Flows and Safety *Bulletin of the Moscow Automobile and Road Institute (State Technical University)* 4 102–109

[3] Tikhonov A V and Nigmatulin A N 2012 Technology for automatic capture of information about the parameters of distributed dynamic systems. Mobile laboratory of intelligent monitoring *OTROK: teaching aid* (Moscow: Tekhpoligraftsentr) ISBN 978-5-94385-085-1

[4] Furber S B 2000 *ARM system-on-chip architecture* (Pearson Education)
[5] The share of mobile operating systems in the world market Available at: https://gs.statcounter.com/os-market-share/mobile, last accessed 2020/10/20

[6] Abyshov R, Buslaev A, Kuprianov U and Yashina M 2011 Distributed system for maintenance monitoring of motor roads *Bulletin of the Moscow Automobile and Road Construction State Technical University (MADI)* 1 79–85