A road sign inventory system based on radio-frequency identification [*]

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Abstract

Recently, the number of road signs on the streets has been increasing, and therefore there is a need to automate the inventory of road signs. This work presents a developed system for inventory of road signs and other technical means of traffic management. The system provides information acquisition using radio frequency identification (RFID) technology. To reduce the time spent on inventory of road signs, it is proposed to install an RFID tag reader on public transport. During the flight, the reader collects all the data from the read RFID tags, fixed on the road signs. The hardware, middleware and software for the inventory system were developed. The hardware is represented by the RFID Reader/Writer and RFID Tag. The software provides functions for accounting of road signs, resolving problems during the inventory and the formation of an inventory report. Middleware provides the interaction of software and hardware. In the work, a comparative analysis of several ways of inventorying road signs was carried out: using manual processing (field surveys), using a system based on video cameras, and using the developed system. As an efficiency criterion, we used the average time for an inventory of 1 km of road in urban (street) and suburban (highway) conditions, including the time to collect the initial data and enter records into the database. The time taken to inventory of 1 km of street in urban conditions was reduced by 53%, while in suburban conditions time was reduced by 69%. In conditions of the continuous reduction in price of passive RFID tags, the application of the proposed approach seems justified.

1 Introduction

Road signs are installed to increase the safety of vehicles and pedestrians. Therefore, it is necessary to take timely measures in case of their absence or damage. Recently, the number of road signs should be not only their typical, but also detailed characteristics [1].

An inventory of road signs can be performed by automated systems based on stereo vision [2]. Such systems analyze video streams from several cameras and, if a road sign is detected, record information about it and its geolocation obtained using a GPS receiver or odometer. Basically, work in this area is aimed at improving the quality of recognition of road signs [3], for example, at the expense of complex multi-stage approaches that take into account the characteristics of roads [5].

Existing modern approaches well recognize well-known road signs, but cannot recognize complex signs and their characteristics necessary for carrying out an inventory. In [6, 7], approaches using a convolutional neural network were proposed, which make it possible to recognize complex road signs, but the question of obtaining the characteristics of road signs is still not resolved.

Most of the research in the field of artificial intelligence and neural networks is focused on the development of technologies for recognizing road signs, and the issues of matching signs with their standard image are almost not available [8]. Road signs are not standard, which can lead to misinterpretation by the driver and a traffic accident [9]. This is not only compliance with the actual position of the road sign on the road [10], but also compliance with standard templates and other characteristics.

A number of works are devoted to the analysis of publicly available Big Data, for example, based on the analysis of photographs with geotags from Google Street View, it is possible to obtain sufficiently accurate information about the signs and its location [11, 12], which can be used for inventory and updating databases.

The development of "smart cities" makes it possible to use radio frequency communications (RFID) technologies in solving a wide range of problems [13, 14]. In [15], theoretical aspects of radio wave propagation were considered and experimental approbation of technology for inventory of road signs based on passive RFID tags was carried out.

This work presents a developed inventory system that collects information about road signs and other technical means of traffic management using RFID technology. The system provides both the collection of information from passive RFID tags fixed to road signs and the updating of information in tags, if necessary.

2 RFID-based Approach to Road Sign Inventory

2.1 Approach Description

The following approach to conducting an inventory based on RFID technologies is proposed (Figure 1).

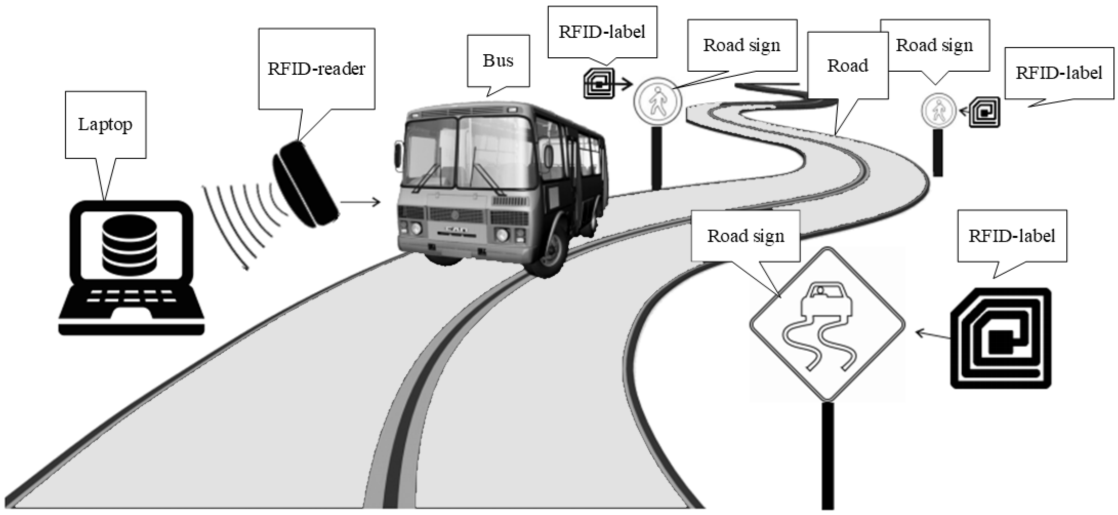


Figure 1: RFID-based inventory approach

Inventory information about a road sign (or other technical means of traffic management) is recorded in a passive RFID tag fixed on the back of the road sign. To reduce the time spent on inventory of road signs, it is proposed to install an RFID tag reader on public transport. During the flight, the reader writes down all the data about the read marks attached to the road signs. Public transport must pass in both directions, since modern RFID technologies provide a reading radius of about 15 meters. At the end of the flight, the data is transmitted to a server that checks the data received from the reader. In this case, collisions may occur, for example, if one of the labels does not appear repeatedly, this may mean its mechanical damage, absence or inability to read due to the state of the environment. If the label does not appear for several times, then this may mean the loss of a road sign.

Figure 2 presents an algorithm that describes the functioning of the inventory system using the proposed approach.

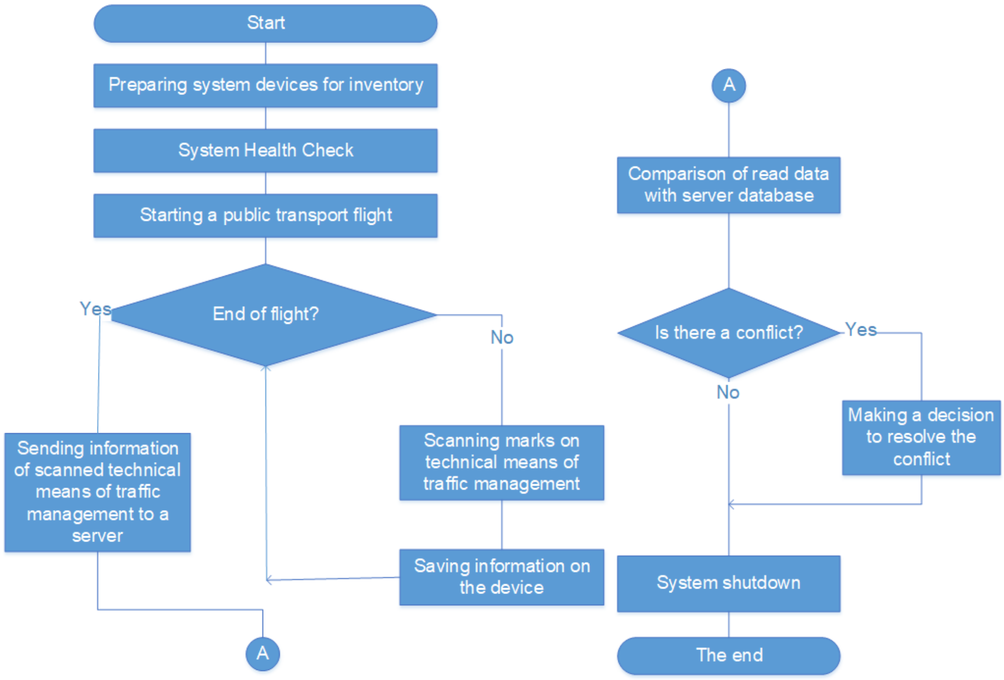


Figure 2: Road sign inventory algorithm

2.2 Inventory Record Model

The inventory record model is described as follows.

Many technical means of traffic management are denoted by $\tilde{T} = \{\tilde{t}_i{}^X\}$. A bunch of $\tilde{T}$ contains the following subsets:

- $\tilde{T}^{RS} \subset \tilde{T}$ – many road signs;
- $\tilde{T}^{TL} \subset \tilde{T}$ – many traffic lights;
- $\tilde{T}^{RF} \subset \tilde{T}$ – many sections of pedestrian and road fences.

An object $\tilde{T}$ defined by type: $\text{type}^{TX} \in \{1, \ 2, \ 3\}$, where each type is associated with a number: “Road Sign” – 1; “Traffic Light” – 2, “Road Fencing” – 3.

Class objects $\tilde{t}_i{}^X \in \tilde{T}$ define attributes:

- unique identification number $\text{id}^{EX} \in N = \{1, \ 2, \ \ldots, \ n\}$;
- type $\text{type}^{TX} \in \{1, \ 2, \ 3\}$;

The objects “Road sign” $\tilde{t}_i^{RS} \in \tilde{T}^{RS}$ define the following basic attributes:

- type $\text{type}^{TRS} \in N = \{1, \ 2, \ \ldots, \ n\}$;
- face value (digits on the road sign) $\text{value}^{TRS} \in N = \{1, \ 2, \ \ldots, \ n\}$ or $\text{value}^{TRS} \in \mathfrak{R}$, where $\mathfrak{R}$ – set of real numbers;
- size $\text{size}^{TRS} \in \{\text{I}, \ \text{II}, \ \text{III}, \ \text{IV}, \ \text{other}\}$;
- a sign that the sign has a yellow fluorescent substrate $\text{if\_yellow}^{TRS} \in \{\text{yes}, \ \text{no}\}$;
- sign of the presence of LEDs in the design of the sign $\text{if\_diode}^{TRS} \in \{\text{yes}, \ \text{no}\}$;
- state of the sign $\text{state}^{TRS} \in \{A, \ B, \ C\}$;
- location of the road sign $\tilde{t}_i^Z$ on electronic map $\text{coord}^{TRS} \in Z^{1\times 2}$, where $Z^{1\times 2}$ – many vectors of size 2.

The combination of these attributes determines the basic immanent properties of the “Road Sign” class. The immanent properties of the classes “Traffic Light” and “Road Fencing” is defined similarly.

3 System Components

The hardware, middleware and software for the inventory system were developed. Hardware using RFID reader / writer and RFID tags. The software provides functions for accounting for road signs, resolving problems during the inventory and the formation of an inventory report. Middleware provides the interaction of software and hardware.

3.1 RFID Reader/Writer

An RFID reader / writer hardware circuit has been developed (Figure 3). A passive system of the UHF 860 ~ 960 MHz band is used, standard EPC Class 1 Generation 2 (ISO / IEC 18000-63) – Gen2. A stationary reader was selected that provides the maximum speed and range of registration due to the use of high-performance digital signal processors that emit a weak tag response signal against the background of the carrier radio frequency, noise and interference.

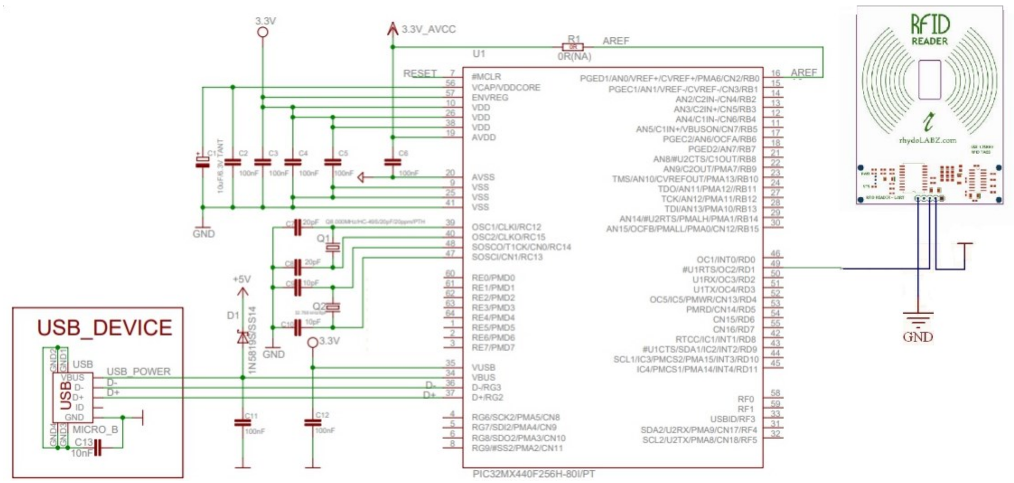


Figure 3: Schematic diagram of RFID reader / writer

The developed device allows both reading data from the tag and writing it to it. Effective range – 15 meters, reading speed – 400 tags per second.

3.2 RFID Tag

For use in the road sign inventory system, a UHF tag operating in the UHF band (860-960 MHz) and having the longest reading range was selected. Such a tag has a built-in identifier that allows you to quickly find and identify it. Thus, the label contains the following information of the road sign:

- ID – unique tag number;
- SignType_ID – type number of the road sign;
- SignState_ID – state of the road sign;
- SignSize_ID – number of the size of the road sign;
- Nominal – face value of the road sign;
- If_Diode – whether the road sign is LED;
- If_Yellow – whether the road sign has a yellow backing;
- InstallDate – date of installation;
- InspectionDate – date of the last inventory.

3.3 Middleware

For the microcontroller, which is used in the RFID reader / writer, developed middleware in the C programming language, which provides the following functions:

- writing and reading data to / from RFID tags;
- checking the operability of the device;
- collection of information about read tags (up to 13.5 thousand);
- transfer of an array of data to the server.

3.4 Database

PostgreSQL / PostGIS was chosen as the database management system, because it provides geo-data to describe the location of road signs. The developed database structure of the system is shown in Figure 4.

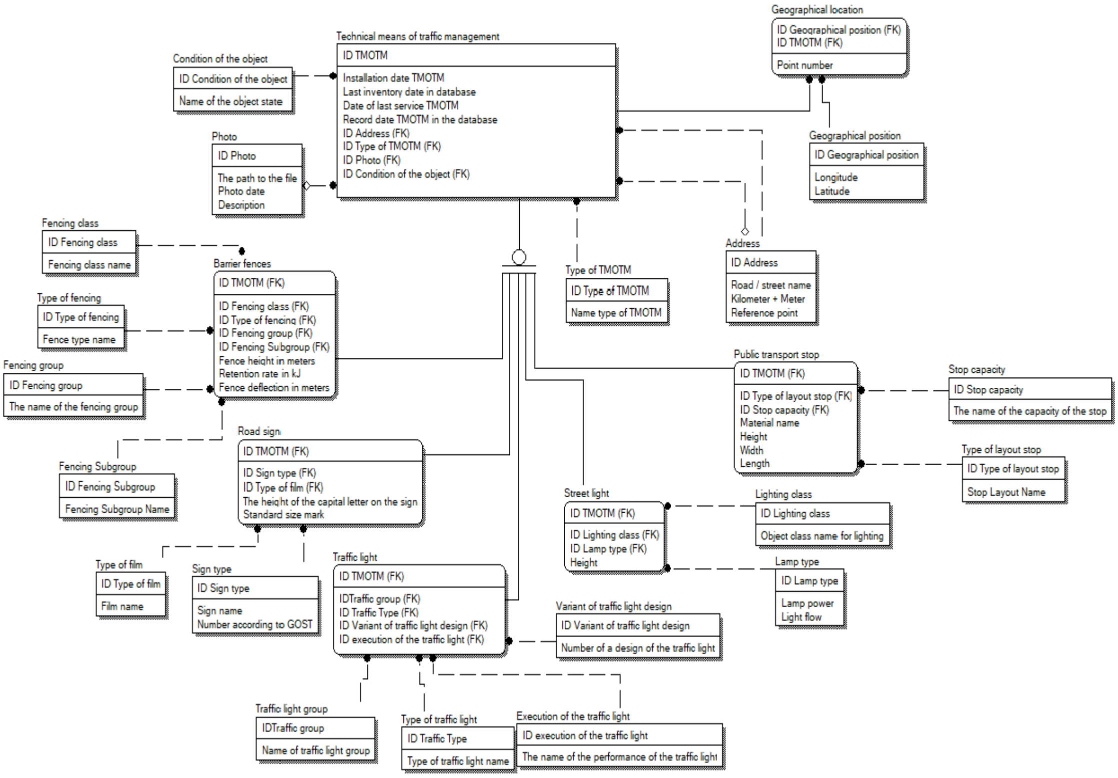


Figure 4: ER data model

The database implements the Inventory Record Model – it distinguishes the parent class “Technical means of traffic management”, from which the descendant classes: “Road Sign”, “Traffic Light”, “Barrier Fences” and others are inherited.

The database is used to store inventory records from read tags and is used in accounting software.

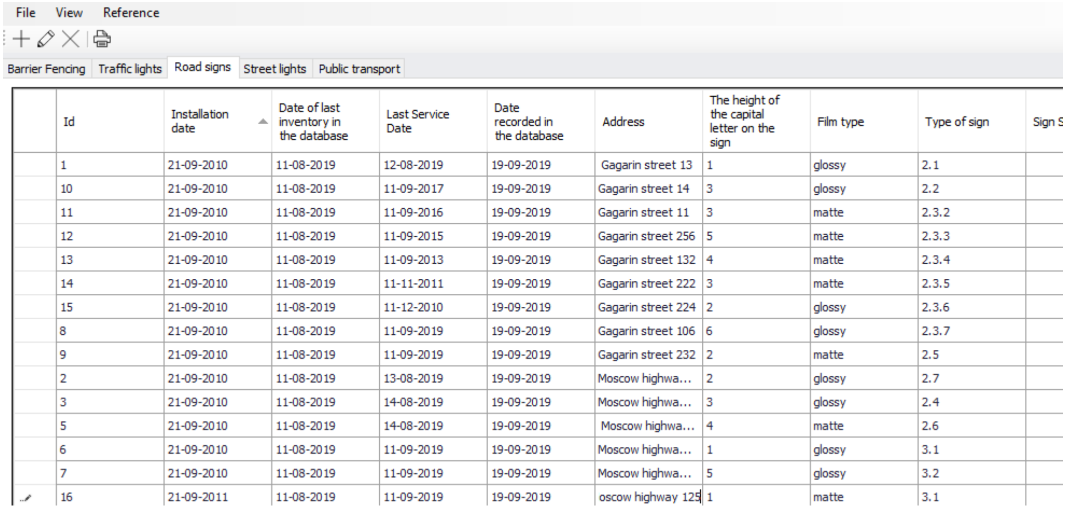
3.5 Accounting Software

Accounting software has been developed for the inventory system in C# in the Visual Studio 2017 programming environment. The main user form is shown in Figure 5. A classic table view with the ability to sort and filter is implemented.

Accounting Software provides the following functions:

— adding / deleting / editing entries in manual mode;

— updates of information based on data received from RFID Reader / Writer;
— conflict resolution;
— formation and printing of an inventory report.


File View Reference

Barrier Fencing | Traffic lights | Road signs | Street lights | Public transport

Id	Installation date	Date of last inventory in the database	Last Service Date	Date recorded in the database	Address	The height of the capital letter on the sign	Film type	Type of sign	Sign S
1	21-09-2010	11-08-2019	12-08-2019	19-09-2019	Gagarin street 13	1	glossy	2.1	
10	21-09-2010	11-08-2019	11-09-2017	19-09-2019	Gagarin street 14	3	glossy	2.2	
11	21-09-2010	11-08-2019	11-09-2016	19-09-2019	Gagarin street 11	3	matte	2.3.2	
12	21-09-2010	11-08-2019	11-09-2015	19-09-2019	Gagarin street 256	5	matte	2.3.3	
13	21-09-2010	11-08-2019	11-09-2013	19-09-2019	Gagarin street 132	4	matte	2.3.4	
14	21-09-2010	11-08-2019	11-11-2011	19-09-2019	Gagarin street 222	3	matte	2.3.5	
15	21-09-2010	11-08-2019	11-12-2010	19-09-2019	Gagarin street 224	2	glossy	2.3.6	
8	21-09-2010	11-08-2019	11-09-2019	19-09-2019	Gagarin street 106	6	glossy	2.3.7	
9	21-09-2010	11-08-2019	11-09-2019	19-09-2019	Gagarin street 232	2	matte	2.5	
2	21-09-2010	11-08-2019	13-08-2019	19-09-2019	Moscow highwa...	2	glossy	2.7	
3	21-09-2010	11-08-2019	14-08-2019	19-09-2019	Moscow highwa...	3	glossy	2.4	
5	21-09-2010	11-08-2019	14-08-2019	19-09-2019	Moscow highwa...	4	matte	2.6	
6	21-09-2010	11-08-2019	11-09-2019	19-09-2019	Moscow highwa...	1	glossy	3.1	
7	21-09-2010	11-08-2019	11-09-2019	19-09-2019	Moscow highwa...	5	glossy	3.2	
16	21-09-2011	11-08-2019	11-09-2019	19-09-2019	oscow highway 125	1	matte	3.1	

Figure 5: Accounting software

4 Results

In the work, a comparative analysis of several ways of inventorying road signs was carried out: using manual processing (field surveys), using a system based on video cameras and using the developed system based on RFID technology. As an efficiency criterion, we used the average time for an inventory of 1 km of road in urban (street) and suburban (highway) conditions, including the time to collect the initial data and enter records into the database.

The studies were conducted in the urban district of Samara, Russia. As the urban street, “Prospekt Maslennikova” was selected with a length of 1.67 km (Figure 6).

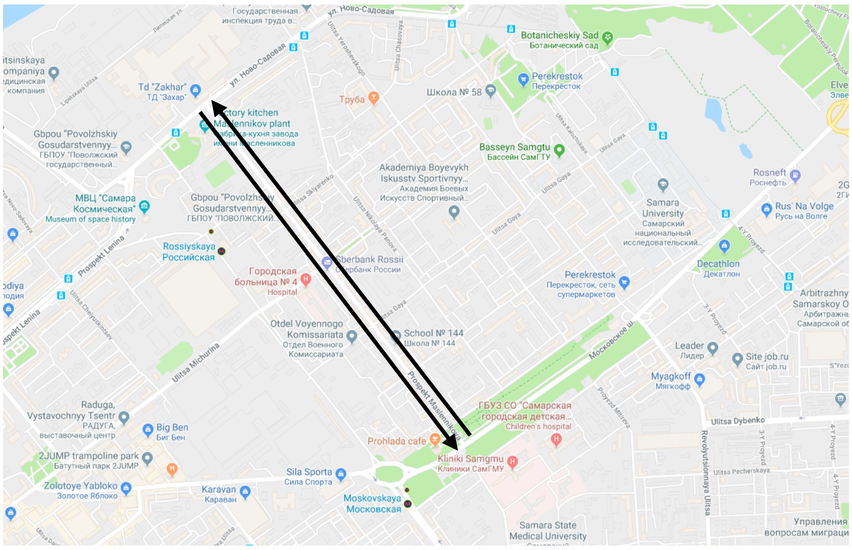


Figure 6: Directions of movement during experiments (urban street)

The section of the “Krasnoglinskoye Shosse” highway with a length of 5.42 km was selected as a highway (Figure 7).

On a suburban highway, the number of road signs and the density of their installation are less than on an urban street. Another significant difference between urban and suburban surveys is the speed of the automobile laboratory. On the urban street, the average speed was 17 km per hour, on the suburban highway – 41 km per hour.

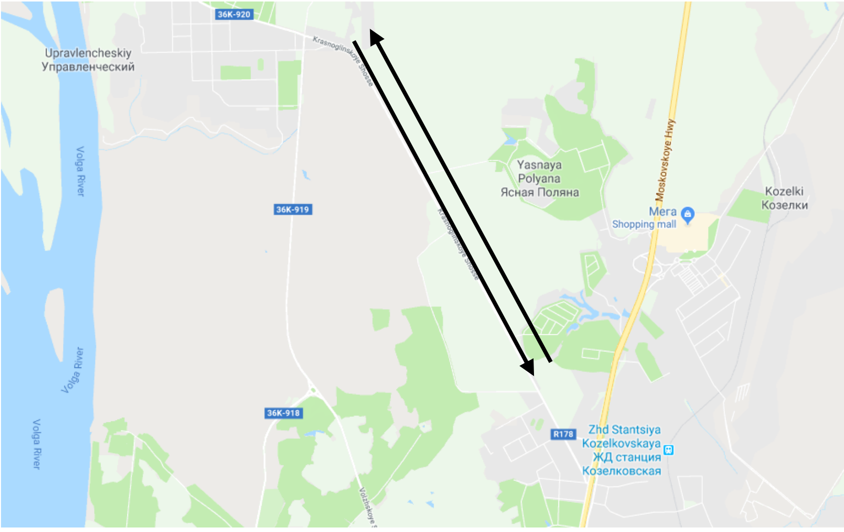


Figure 7: Directions of movement during experiments (suburban highway)

Field surveys were carried out by 1 specialist surveyor, data were entered by 1 operator. As an inventory system based on video cameras, the "WayMark" system [16] was used in combination with 2 cameras directed forward and to the right by 45 degrees to the direction of movement. The developed system based on RFID technology used 1 receiver. Thus, both road laboratories had to pass each road twice (in the forward and reverse directions) in order to fix signs on both sides of the road. The calculation results are shown in table 1.

Table 1. Survey Results

Inventory system	Time for an inventory of 1 km, [minutes]	
	Urban street	Suburban highway
Field surveys	55	39
Camera-based system	17	13
RFID-based system	8	4

Thus, the time taken to take an inventory of 1 km of street in urban conditions was reduced by 53%, while in suburban areas time was reduced by 69% compared to the "WayMark" system.

5 Conclusion

Thus, there is presented an approach to inventory road signs and other transport infrastructure objects using RFID technology. The approach is implemented as an automated inventory system containing a set of technical and hardware tools. The inventory system implements the following functions:

- recording of inventory information in tags, which are fixed on the road signs;
- collecting information from tags fixed on road signs using RFID technology;
- decision making in case of conflict;
- maintaining a database of road signs and other technical means of traffic management;
- formation of an inventory report.

Comparison of the effectiveness of the developed system with an inventory system based on video processing showed that the time taken to inventory of 1 km of street in urban conditions was reduced by 53%, while in suburban conditions time was reduced by 69%. It is also important to reduce the influence of the human factor, which helps minimize labor costs and reduce risks. In conditions of the continuous reduction in price of passive RFID tags, the application of the proposed approach seems justified. However, there are difficulties with the operation of this approach on multi-lane highways, due to the limited range of the RFID receiver.

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