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Container transportation in the urbanized environment using the «Internet of things» technology

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Introduction. The paper considers aspects of practical application of the "Internet of things" technology in the transport industry. The logistics problem of transporting empty containers is solved. The technology of container transportation in an urbanized environment is presented. The influence of the proposed technology on the environmental safety of transportation in the urban environment is considered.
Problem Statement. The purpose of this study is to solve the logistics problem of transporting empty containers using the "Internet of things" technology, and to estimate the technology influence on the environmental safety.
Theoretical Part. The technology is based on the smart container which is being developed. It can automatically fold and unfold and is controlled via a mobile app. It also allows you to remotely monitor the parameters of cargo transportation using built-in sensors. The reduction of harmful substances emissions while reducing the number of unproductive runs of transport as a result of the use of transformer containers is evaluated according to the criteria for reducing the mass consumption of harmful substances.
Conclusions. A new package product called "SmarBoxCity" is a unique and unparalleled product of the Fourth technical revolution. Its implementation makes it possible to improve the environmental safety of transport by reducing the emission of pollutants by 18.2 %.

Keywords: Internet of things, IoT, transportation, city, monitoring, container, environmental safety.

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Introduction. In the modern world, in the context of the fourth technological revolution, there is fierce competition in all areas of production of goods and services. At the same time, modern technologies have risen to a completely unimaginable level, when they allow to implement complex projects for people, who are not narrow specialists in the field of information technology or robotics, but only have an idea, a clear (or not very clear) idea of who can buy it and why. In addition, you need some skills in mastering technical innovations and, if necessary, finding a team of specialists. And everything will work out, and not in many years, but very soon. The world is developing very quickly and will not wait. Let us look at one of the most important problems in the field of transport and the ways to solve it using the Internet of Things (IoT) technology.

Problem statement. A logistical problem associated with the transport of empty cargo containers as returnable containers. A huge volume of empty containers is transported by vehicles, which leads to unjustified expenses for fuel, labor, and depreciation of vehicles, causes traffic congestion, and has a huge impact on the environment.

In large cargo-handling points such as freight terminals, sea ports, companies are often able to avoid empty run of containers, provided a sufficiently effective operation of the logistics services. However, this task in an urbanized environment is quite difficult or not solved at all, since few urban infrastructure objects can simultaneously serve as cargo-generating and cargo-absorbing points, not to mention individuals who need to deliver their own cargo from point A to point B. When performing such transportation orders, reverse travel cannot be loaded. This significantly reduces the efficiency of container transport, despite their undeniable positive aspects.

Theoretical part. The idea of folding containers to improve transport efficiency is not new in itself. Such container systems are already operating in the world [1-6]. For example, a Staxxon container that folds vertically or a Cargoshell plastic container that folds horizontally [7]. There are also domestic developments [8]. Their advantages when transporting empty are obvious. However, they have one significant drawback in common: additional lifting and transport equipment (cranes or loaders) is required for their folding and unfolding. This reduces the efficiency and applicability of this technology.

But the modern world is a world of smart things that smart people learn to do without help.

There was an idea to teach a car folding container to fold and unfold without external equipment, as well as to communicate with the outside world in real time with information about its location, cargo condition, possible violations of transportation conditions, signals for opening or closing doors, and many other parameters. At the same time, with the help of special equipment (soft containers), the smart container will be able to transport not only package cargo, but also bulk or liquid cargo, which will significantly expand its scope of use.

Of course, such a smart thing can't exist on its own. Its successful application requires support for mobile and web applications, servers, and cloud technologies, as well as an algorithm for using a smart container in this system using road transport, and an algorithm for working with road transport, taking into account the interaction of all participants in the process and the discretely changing states of these elements of the system (Fig. 1) [9]. As a rolling stock, it is rational to use self-loaders with cranes of the appropriate load capacity.

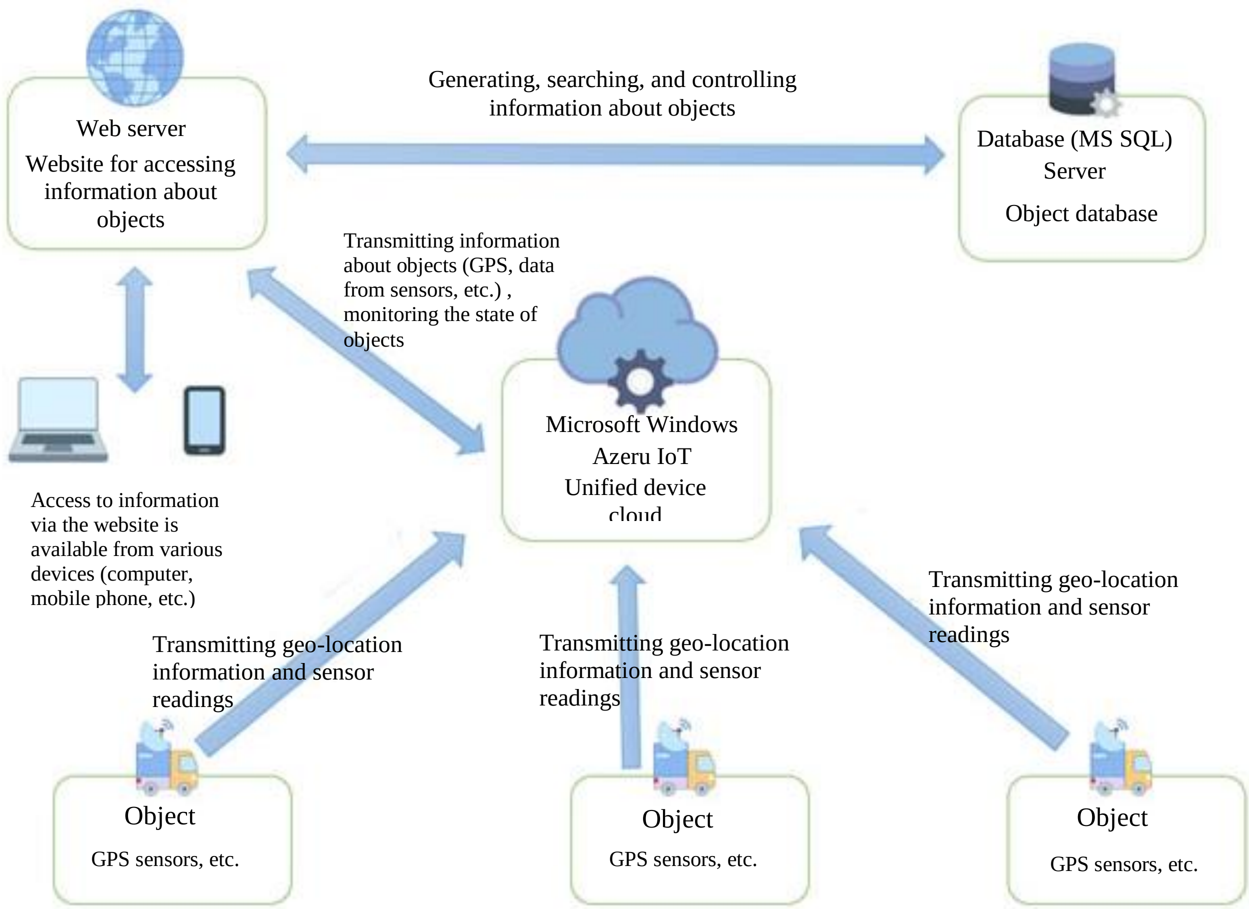


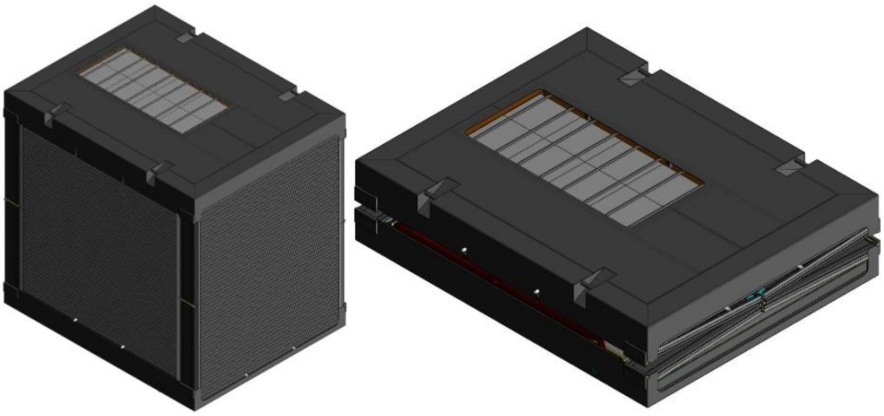
Fig. 1. Operation diagram of the smart container system

Now let us look at what we need to implement such an idea. First, the container structure itself is one of the previously developed or newly created ones [8]. Second, it is the system of driving mechanisms for folding and unfolding the container. This can be electric motors or such an interesting implementation of reciprocating motion as an electric linear actuator. These are the most expensive parts of the smart container.

And, what will serve as the "brains" of this smart thing is the most interesting. There are a lot of options now: from Arduino microcontrollers (Uno, Mega, Nano) and ESP boards equipped with Wi-fi and Bluetooth (8266 and ESP 32) with a price of several hundred rubles, to advanced Raspberry Pi from Microsoft and some similar developments with a cost of several thousand rubles. These microcontrollers are made to "think" by a special firmware (called "sketch") written to the permanent memory of the microcontroller in one of the languages supported by the board. There is a technology for creating such programs without using language code based on the use of ready-made blocks in a graphical environment (Flprog, XOG, etc.).

You will also need a wide variety of sensors (load cell, temperature, humidity, position, shock, tightness, etc.) and auxiliary elements (voltage stabilizers and dividers, relays, motor drivers, and so on).

As a result, after developing and connecting all the hardware and software parts of the system together, we get a package product consisting of the smart containers themselves (Fig. 2), mobile applications for car drivers and users (transportation customers) with the container management function, and an Internet site with the functionality of calculating the cost of transportation, processing and paying for a transportation request.



a) *b)*

Fig. 2. General view of the smart container in the working (unfolded) (a) and transport (assembled) (b) position

The proposed system is called SmarBoxCity [10], and the first copies market launch is in 2020.

Next, you need to evaluate how to reduce the negative impact of transport on the city's environment when implementing the SmarBoxCity package product.

To assess the reduction of the negative impact of road transport on the environment when implementing the SmarBoxCity package product, we will perform a comparative calculation of the amount of pollutants emitted when performing the same volume of transport using conventional containers and the proposed transformer containers.

As a vehicle for comparative analysis, we will choose a KAMAZ 65117 with a Ferrari 726 articulating crane.

Let us assume that you need to transport a single-piece cargo that occupies four medium-tonnage containers at a distance of 10 km between the shipper and the consignee. The initial data for the calculation are shown in Table 1.

Table 1

Source data for calculating the environmental performance of SmarBoxCity

Transport system parameters	Options	
	Regular containers	SmarBoxCity
Car model	KAMAZ 65117 with Ferrari 726 articulating crane	
Number of containers, pcs.	4	4
Number of cars, pcs.	2	2
Transportation distance, km	10	10
Zero haul, km	5	5

The amount of pollutants released per unit of engine power is determined by the dependencies shown in Table 2 [11].

Table 2

Dependencies for calculating the emission of pollutants from a diesel engine

Pollutant	Range of relative power changes $\overline{N}$	Concentration, c_i, g/m^3
CO	0–1,0	$5{,}6754\overline{N}^4 - 11{,}758\overline{N}^3 + 9{,}9078\overline{N}^2 - 3{,}5046\overline{N} + 0{,}7996$
NO_x	0–1,0	$4{,}2667\overline{N}^4 - 19{,}2\overline{N}^3 + 18{,}933\overline{N}^2 - 1{,}2\overline{N} + 0{,}7$
C	0–1,0	$-1{,}332\overline{N}^4 + 2{,}7531\overline{N}^3 - 1{,}5837\overline{N}^2 + 0{,}3629\overline{N} + 0{,}0194$
$C_{20}H_{12}$	0–1,0	$2{,}4308\overline{N}^2 - 0{,}8536\overline{N} + 0{,}4121$, mkg/m^3

Average speed of transportation in an urban environment [11]

$$\text{v}_{jг} = 0,4467 \cdot 1,8665\text{v}, \tag{1}$$

where v – the average speed of traffic flow, m/s.

$$\text{v}_{jг} = 0,4467 \cdot 1,8665 \cdot 4,24 = 3,53 \text{ m/s}.$$

Mass flow rate M_i, i-th pollutant [11]

$$M_i = Q_{Oг} c_i, \tag{2}$$

where $Q_{Oг}$ – where is the volume flow of exhaust gases, m^3/s;

c_i – concentration of i-th pollutant in exhaust gases, g/m^3.

Exhaust gas volume flow rate [11]

$$Q_{Oг} = 0,0007\text{v}^2 - 0,0256\text{v} + 0,3184, \tag{3}$$

$$Q_{Oг} = 0,0007 \cdot 3,53^2 - 0,0256 \cdot 3,53 + 0,3184 = 0,237 \text{ (m}^3\text{/s)}.$$

The relative power of the engine is determined from the equation [11]

$$\overline{N}N_{ном} = \frac{\left[k_\phi \rho_в F_s v_j^2 + mg\cos\gamma\left(f \pm tg\gamma\right) \pm \delta_{вр} am\right] v_j}{\eta_{тр}}, \tag{4}$$

where $\overline{N}N_{ном}$ – the effective power of the engine ($N_{ном}$ –номинальная rated power of the engine, W), W;

$k_ф$ – flow coefficient;

$\rho_в$ – air density,, $\rho_в$ = 1,293 kg/m^3;

F_s – the area of the front surface of the truck, m^2 (we take up F_s =7,5 m^2);

m – weight of the loaded truck, kg (we take up m = 25900 kg);

g – acceleration of gravity, m/s^2;

f– coefficient of rolling resistance, we take up f = 0,02;

$\delta_{вр}$ – rotational inertia coefficient;

a – vehicle acceleration, m/s;

$\eta_{тр}$ – mechanical efficiency of the transmission.

The expression $\delta_{вр} a$ is determined as [11]

$$\pm\delta_{вр} a = g\left(0,5502 v^{-1,11} - \Psi\right), \tag{5}$$

where Ψ – the coefficient of reduced road resistance, $\Psi = 0,02$.

$$\delta_{вр} a = 9,87\left(0,5502 \cdot 3,53^{-1,11} - \Psi\right) = 1,142.$$

The mechanical efficiency of the transmission is determined as [11]

$$\eta_{mp} = -1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755. \quad (6)$$

So, from equation (4) we get

$$\bar{N} = \frac{\left[0,45 \cdot 1,293 \cdot 7,5 \cdot 3,53^2 + 25900 \cdot 9,87 \cdot 1 \cdot 0,02 + 1,142 \cdot 25900\right] \cdot 3,53}{154000(-1,3238\bar{N}^3 + 1,118\bar{N}^2 - 0,031\bar{N} + 0,8755)}. \quad (7)$$

We get four roots, of which the real one is $\bar{N} = 0,351$.

Then for KAMAZ 65117

$c_{NO_x} = 4,2667 \cdot 0,351^4 - 19,2 \cdot 0,351^3 + 18,933 \cdot 0,351^2 - 1,2 \cdot 0,351 + 0,7$,

$c_{NO_x} = 1,846$ *г/м*^{3};

$c_{CO} = 5,6754 \cdot 0,351^4 - 11,758 \cdot 0,351^3 + 9,9078 \cdot 0,351^2 - 3,5046 \cdot 0,351 + 0,7996$,

$c_{CO} = 0,368$ *г/м*^{3};

$c_C = -1,332 \cdot 0,351^4 + 2,7531 \cdot 0,351^3 - 1,5837 \cdot 0,351^2 + 0,3629 \cdot 0,351 + 0,0194$,

$c_C = 0,051$ *г/м*^{3};

$c_{C_{20}H_{12}} = 2,4308 \cdot 0,351^2 - 0,8536 \cdot 0,351 + 0,4121$,

$c_{C_{20}H_{12}} = 0,412$ *мкг/м*^{3}.

Thus, the mass consumption of pollutants by a single vehicle

$M_{NO_x} = 0,237 \cdot 1,846 = 0,4375$ g/s;

$M_{CO} = 0,237 \cdot 0,368 = 0,0872$ *г/с*

$M_C = 0,237 \cdot 0,051 = 0,0121$ *г/с*;

$M_{C_{20}H_{12}} = 0,237 \cdot 0,412 = 0,0976$ mkg/s.

The mass consumption of pollutants by vehicles involved in the process is determined as [11]

$$\sum M_{ijk} = M_{ijk} \cdot m \cdot L / \upsilon, \quad (8)$$

where *m* – the number of vehicles involved in the process, pcs.;

L – total distance for transportation, km.

We will calculate the vehicle mileage for the compared options and determine the mass emission of pollutants during delivery.

According to the traditional container scheme, one empty container is loaded for each vehicle at the container base. Since there are two cars for four containers, they will have to make two zero cycles (from the storage location to the shipper). After loading the containers, you will need to perform one ride with each loaded container out of four.

According to the scheme with the use of transformer containers, one car can carry up to four stacked containers, that is, as many as the shipper needs. Thus, they can be delivered to the loading point on a single ride. Loaded transformer containers are transported one at a time by car, as well as the traditional ones.

Let us fill in Table 3 according to the above reasoning.

Table 3

Calculation results of the environmental efficiency of SmarBoxCity

Parameters	Options	
	Regular containers	*SmarBoxCity*
Total mileage for completing the transportation task, km	55	45
Mass flow:		
NO_x, g	13633,14	11154,39
CO, g	2717,28	2223,23
C, g	377,05	308,50

Parameters	Options	
	Regular containers	*SmarBoxCity*
$C_{20}H_{12}$, mkg	3041,36	2488,39

Table 3 shows that the use of the SmarBoxCity package product reduces the emission of harmful substances to the environment by 18.2%.

Conclusion. A new package product on the market of transport and logistics services in an urban environment called SmarBoxCity is a unique product of the fourth technological revolution. Its implementation makes it possible to improve the environmental safety of transportation by reducing the emission of pollutants by 18.2%. Of course, we expect significant technological and economic efficiency of this package product. Their comprehensive assessment is the task of further research.

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