Unmanned all-terrain cargo and passenger transportation system for operation conditions when automobile roads are unavailable

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Abstract. The task of creating a reliable Far North transportation system is important given the existing strategy for developing the arctic regions of Russia and high complexity of the operating conditions for motor vehicles in this region. In this paper we undertake the task of outlining the shape of an unmanned all-terrain vehicle (UATV) with ultra low-pressure tires used to create an unmanned intersettlement transportation system. We have set out the design requirements for such UATVs and have made a comparative evaluation of a UATV and an all-terrain vehicle (ATV) having a driver cabin. Finally, we present the concept of the UATV and the strategy of cargo transportation on winter roads during spring-autumn and summer periods.

1. Introduction
Cargo and passenger transportation in the low-temperature tundra conditions to the hard-to-reach settlements in the northern latitudes of Russia are carried out by motor vehicles at high risk for the lives of drivers and passengers as well as for the vehicles and the cargo itself. The cargo motor traffic in such conditions is only possible in wintertime on seasonal roads made from pressed snow or on river ice – so-called winter roads; at summer and spring-summer periods cargo transportation is only possible using tracked vehicles or by river rafting. The condition of winter roads in these periods is presented in Figure 1.

Figure 1. Winter roads in spring and summer periods
In the Sakha Republic winter roads make up more than 50% of all roads. The number of winter roads is decreasing year by year because of climate change, at the same time the number of traffic accidents caused by the poor state of the seasonal roads is increasing. The common incidents include vehicles falling under the ice, vehicle rolling over on the roadside slopes and at steep gradients, head-on collisions caused by narrow roads, mobility loss far away from settlements. The similar road situation can be observed in such regions of Russia as Nenets Autonomous Okrug, Yamalo-Nenets Autonomous Okrug, Krasnoyarsk Krai, Magadan Oblast and Chukotka Autonomous Okrug. The creation of a reliable transportation system, which is capable of operating without automobile roads regardless of the time of the year, is an important task given the existing programs for developing the Arctic [1] and the northern regions of Russia, the increase in cargo traffic between settlements and the growing geopolitical importance of the Arctic regions [2].

2. Requirements for a UATV

Using UATVs is a sensible choice for ensuring safe cargo trafficking on roadless terrain at low temperatures [3] and on swamped terrain or during spring season when the roads are impassable. Using this type of vehicle makes cargo transportation more reliable. Having no driver cabin in the vehicle allows removing the life support systems and improves weight distribution and vehicle arrangement.

However, the specificity of vehicle operation in the northern latitudes and the unmanned vehicle configuration imposes a number of requirements for the unmanned ground vehicle (UGV). The most important requirements are the following.

The UGV must have good or super passability. In this case, the algorithms for evaluating traffic conditions are becoming simpler and the UGV keeps most of its passability in the toughest road conditions. The UGV has to be capable of moving off road, fording, moving through swamps, watercourses, snowbanks. The important feature of the UGV is the capability of moving on ice.

The next crucial UGV requirement is increased reliability. When moving in challenging road conditions in hostile weather environment (frost, snowstorm) the UGV shutdown can lead to chassis failure especially if the UGV powerplant shuts down and cools down (restart is impossible in this case). There is a possibility of conducting field repair if the driver is present; the chances of getting going again without a driver after a breakdown are very low.

The topsoil must not be destroyed by the UGV especially when operating in the same directions and trajectories, which is very typical of the UGVs. It is required not only for maintaining the original environmental conditions but also for preventing road damage. Hence, the requirement to be capable of moving on winter roads must be fulfilled as this is the most common road type during winter period.

3. Comparative analysis of unmanned and manned vehicle configurations

Using ATVs on ultra low-pressure tires as a basis for the UATV is the most rational choice given the above requirements. As the main factor affecting passability in no-road conditions is the unit pressure of the mover on the support surface, the matter of the overall constraints imposed on the mover of the wheel ATV in manned and unmanned configuration is looked into next.

The arrangement of any manned ground vehicle includes the zone for the controls and the driver seat as well passenger seats. The volume of the body “A” including the aforementioned zones is shown in Figure 2.
The driver seat availability imposes some constraints related to the human body anatomy, ensuring adequate range of visibility and the possibility of getting in and out of the vehicle. It is important to mention that the outer overall dimension constraints are just as important. The width is limited to 2250 cm in order to be able operate on public roads and the height is limited by the maximum permissible aspect ratio so that the vehicle would not roll over on steep slopes.

Let us take for the sake of the comparative analysis the overall dimensions of the Treckol-32995 ATV: 5660 / 2540 / 2678 mm (L / W / H). The cargo and passenger compartment «B» of the ATV is presented at Figure 3.

![Figure 3. Arrangement of the cargo and passenger ATV](image)

The front view shows a drawback of this arrangement – large wheel arches. Their dimensions are specified by suspension. The body volume between wheels of the back coupled axles required for comfortable passenger leg placement significantly reduces the width of the tires. Increasing mover width is also unfeasible because the suspension is placed between them. Thus, the useful body volume for the cargo configuration of the ATV imposes constraints detrimental to the movers, which directly influences GV passability. These constraints also influence the tire diameter that also depends on the overall GV height and the transmission strength.

The imposed AGV mover constraints can be altered in the case of an unmanned ATV. The arrangement of the UGV within Treckol-32995 overall dimensions is presented at Figure 4.

![Figure 4. Arrangement of the cargo and passenger UATV](image)

The overall dimensions of the UGV compared to the manned configuration are the same. Having no driver seat allows increasing the length of the cargo platform thus compensating for the overall useful volume reduction by the area between wheel arches of the rear axles. Thus the constraints caused by having a person inside the body are removed and the chassis arrangement is getting more space under the cargo compartment. The next goal is to maximize the support surface area of the movers. The diameter of the tire remains constant in order to preserve the overall ATV height, but its width can be increased given that having suspension in a cargo ATV is not necessary.

4. UGV concept
The schematic structure of the UATV is presented in Figure 5. The distinct features of the design include having no suspension, no cabin, having large useful volume of the cargo compartment and...
equipment for unmanned operation. The wheel formula of the ATV is 8WD, the change of movement direction is done by skid steering.

![Cargo container]

**Figure 5.** Schematic structure of the unmanned ATV

As a powerplant we suggest using a hybrid diesel-electric set implemented as a series structure: the diesel engine rotates the generator which in turn powers the traction drive. This approach is not commonly used in multi-axle wheel machines, it is competing with hydrostatic transmission[4]. This solution is fully using such advantages of the diesel internal combustion engines such as high fuel economy, simplicity, low price, reliability and such advantages of the electric motors as high torque at low speed and transmission compactness. Besides having no mechanical transmission increases UGV reliability as the shaft breakdown probability is decreasing and there is no need to use freeze-resistant lubrication. Wheels are driven by individual electric motors thus allowing optimal distribution of the torques on wheels thus compensating for the absence of suspension and steering system with stub axles. Elastic properties of the ultra low-pressure tire are sufficient to ensure the required level of vibration loading of the ATV’s units and cargo. The feasibility of simulating and studying motion of ultra low-pressure tire and wheeled vehicle dynamics has been proven in the works of Russian authors [5-10].

The hybrid drive actuates a buffer energy storage device providing uninterrupted power supply to the electric motors. Thus the ATV onboard energy can be stored by recuperation during braking, which will increase vehicle efficiency.

Modular concept based on the changeable cargo container can be implemented by having unmanned autonomous chassis. This makes possible a strategy of uninterrupted cargo shipments based on the possibility of rapid swapping of cargo containers in the points of destination. The modularity of the transportation system also involves being able to form UGV caravans. Such approach enables sending large cargo volumes in one direction.

In order to enable unmanned operation the ATV an onboard additional machine vision equipment has to be installed, its type is determined by operating conditions. The standard equipment set of the existing UGVs moving on asphalt in cities and on highways includes a lidar, ultrasonic sonars, radars that work in the electromagnetic range, cameras [11]. The traffic condition in the northern latitudes, unlike public roads, has much fewer disturbances and fast changing details (Figure 6). However, weather conditions place some constraints: blizzards, snowflakes, snow glare, camera blinding by sun deteriorate accuracy of traffic condition evaluation. For instance, ultrasonic or electromagnetic signals reflect poorly from snow, precipitations and shadows will produce an illusion of presence of some object in from of lidar and camera. Besides, sensor contamination by snow and dust should not be neglected.
Figure 6. Comparison of the traffic condition on city and winter roads

It also makes sense to use inertial navigation system with correcting algorithms besides global satellite navigation system. The UATV can be remotely controlled for maneuvering in complicated situations and destination points. When the UATV reaches the destination point it relocates to the holding bay and passes the control over to the operator. Test journeys for collecting traffic condition data have to be made in both directions in order to organize an unmanned traffic route.

For example, let us consider organization of the unmanned transportation in Yamalo-Nenets Autonomous Okrug. Possible UGV routes connecting the Salekhard, Nadym, the villages Aksarka, Yar-Sape in summer and spring-autumn periods are shown in Figure 7. Red-dotted lines mark the parts of the route closing down at temperatures about 0 °C. At that time cargo trafficking on these route parts stops completely which in turn makes the task of organizing UGV traffic much easier.

Figure 7. Example of organizing UGV routes

5. Conclusion

Using unmanned transportation system can enable cargo trafficking in the hard-to-reach settlement in the northern latitudes of Russia in the periods when seasonal winter roads close down. Moreover, cargo trafficking will not entail any risk for the lives of drivers. Wheel chassis having good passability and relatively low driving resistance is the most suitable basis for a UGV. At the same time, using unmanned control technology will allow increasing the vehicle operational efficiency by improving the arrangement, weight distribution and carrying capacity. The combination of superpassable chassis on ultra low-pressure tires, machine vision equipment and simplified process of traffic condition evaluation makes the task of creating an unmanned transportation system feasible. Materials of this paper were presented at the Science and Engineering Seminar “Mobility of process transport machines” in Nizhny Novgorod State Technical University named after R.E. Alekseev. This paper was written within the framework of the project "Development of scientific and technical solutions for creating a combined Russian powertrain for small class city and suburban buses" which is being implemented as a part of Agreement No 14.574.21.0178 (Unique identifier: RFMEFI57417X0178) with financial support by the Russian Ministry of Higher Education and Science.
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