Application of adaptive tire pressure control system in agricultural robots

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Abstract. Recently, robotics has been actively introduced into the agricultural industry. Many different field works related to sowing, processing and harvesting are efficiently carried out by various robotic systems. However, the need for frequent movement between fields, increased productivity and power of equipment, the use of additional tools to perform various works leads to an increase in the mass of the robot itself. The sealing effect of agricultural robot running systems has long been considered a serious problem. The proposed method of adaptive control of tyre pressure allows to reduce negative impact of agricultural robot on soil without deterioration of its dynamic and economic parameters.

1. Introduction
In view of the need to increase agricultural output, the goal is to increase the number of agricultural robots of various types. The development of robotics allows you to increase the economic efficiency of production and reduce labor costs. The most complex and time-consuming operations must be entrusted to robots, allowing a person only to control the operation of equipment and set up control algorithms if necessary.

In the case of agricultural work related to the cultivation of grain and fruit crops, robots can perform a wide range of tasks: mechanized soil treatment, transportation of seedlings and its sowing, elimination of weeds, spraying of plants, mowing, care of fruit trees, as well as harvesting.

However, after the passage of quite heavy robotic equipment, the wet soil is too compacted. The porous layer of soil turns into tightly compressed lumps, which negatively affects the seedlings, worsens the structure and composition of the soil [1].

It is noted that a large percentage of the energy of robotic agricultural equipment is spent to compensate for damage caused to the soil by other robots. A highly compacted layer of soil interferes with the growth of plant roots, ventilation and moisture penetration. The number of earthworms is also significantly reduced, which harms the soil at the biological level [2-5].

Various methods are used to solve this problem. In some cases, special double tires are used on tractors to reduce the pressure on the soil, shown in figure 1. However, when using such wheels, there was a strong compression of the ground between the wheels. There were models of tractors with three wheels on the axle, but such machines took up too much space and did not fit on ordinary roads.
The use of tracked tractors has less negative impact on the soil than conventional wheeled vehicles. However, crawler engines destroy road surfaces, transmit vibrations from the engine to the soil, which is bad for its properties and unevenly distribute pressure over the contact spot with the ground [6-9].

To further reduce the pressure on the ground and make it more uniform, it was proposed to combine the good vibration absorption of the pneumatic wheel with a large contact area at the track.

The rubber pneumatic track consists of separate pneumatic elements. Each pneumatic element is a rubber-cord shell filled with air and consisting of a power belt reinforced with metal cord and a pneumatic cylinder with a developed support surface with tether pitons. Air is pumped into the element during operation and the air pressure is controlled through a standard valve installed in each element. But in a pneumatic track, compared to a conventional one, the possibility of a puncture increases. Various tests have revealed sensitivity to low temperatures and low traction qualities on slippery surfaces. Also, the repair of such equipment becomes much more difficult.

An effective way to reduce the pressure is to replace the wheel with three-axle bogies with a Quadtrac track chain, shown in figure 2. At the same time, the advantages of both high-speed wheel thrusters and low-specific ground pressure crawler thrusters are maintained. But this method is quite expensive, and many manufacturers of agricultural equipment prefer to avoid this solution.

Also, one of the ways to solve this problem is to use a system for reducing the air pressure in the tires. Agricultural all-terrain vehicles were developed on ultra-low-pressure tires, shown in figure 3, which allowed to increase the contact spot and evenly distribute the pressure, which leads to a significant reduction in the specific pressure on the soil.
As a result of testing such tires it was found that due to the closer contact of the tire with the soil, the tractor's pulling force increases by 15-20%. There is also a significant reduction in tire wear and puncture resistance. In a conventional tire, the pressure reaches 2 atmospheres, and in a wide-profile one it is 0.5-0.6 atm. The tire moves gently across the field and simply copies all the bumps. In addition, the use of ultra-low pressure tires can reduce fuel consumption by up to 30%.

But ultra-low-pressure tires also have their drawbacks. They cannot be used to travel at high speed. That is, they allow you to improve cross-country performance in difficult conditions, but with high-speed movement on a normal road to the work site, it leads to wear of the entire suspension.

Also, the disc profile and the tire pressure must consider the type of ground on which the movement is carried out. As a rule, the tire pressure is selected according to the tables in the technical documentation. But the table cannot consider all the features of the agricultural robot and the specific conditions of field work.

2. The main part
In this regard, to ensure the optimal pressure of the tires of the agricultural robot on the soil, depending on its type and humidity, it is proposed to use an adaptive control system, shown in figure 4.

To determine the type and humidity of the soil, it is possible to use optical sensors located on the rim of the robot wheel. After making a series of measurements of the minimum distance between the support surface and the wheel rim, the adaptive control system can judge the need to inflate the tires or vice versa, to drain excess air from the tires. When working on slopes, this system will allow changing the air pressure in the tires of the left and right wheels, depending on the transverse slope of the support base of the agricultural robot.

Basic recommendations for choosing the required pressure depending on the type of soil and its humidity are given in many agricultural reference books. Using this data, as well as the information obtained from the sensors about the current humidity and the distance between the support surface and
the wheel rim, you can set the required tire pressure in the agricultural machine. At the first launches of such a system, it will be important to evaluate the impact of various properties on the robot's performance, varying the tire pressure in a certain range and identifying the dependence of the performance on the tire pressure. After the accumulation of certain data, the control algorithm will be able to perform the task after receiving several data on the state of the environment.

If you need to return to the base and drive a certain distance on a normal road, the control algorithm will automatically determine the area where the movement on uneven ground will change to the movement on the paved area and will pump the tires to the required level. The necessary change in tire pressure will be carried out even when working on the field, for example, on a slope, when water accumulates on lower sections. When driving on slopes, this system will make the agricultural robot more stable, since changing the air pressure in the tires allows you to adjust the direction of the center of gravity vector.

Figure 5. Block diagram of tire air pressure control.

The block diagram of the system for automatic control and maintenance of air pressure in tires is shown in figure 5. The robot's measuring sensors monitor various parameters of movement and soil – humidity, soil hardness, speed of movement, vibration. The received signals are processed using an analog-to-digital converter and fed to the control system. There, they are processed according to a special algorithm and, if necessary, the program sends a control signal to the actuators to influence the tire pressure level. The pneumatic pressure control system corrects the air pressure in the wheel tires. In the event of a lack of air pressure in one of the wheels, automatic pumping takes place, and the pressure is brought to the required value. In the case of overpressure, the pressure is also reset to the required value.

In some cases, for example, when driving on an asphalt highway or working on a swampy, impassable area, the pressure change will take place in all tires at once. If the optimal positioning of the agricultural robot on the slopes is required, the pressure change is only possible for a specific wheel or group of wheels. It is also possible to maintain the desired level of pressure in the tire with minor damage and punctures. In the event of more significant damage to the tires, the adaptive control system will be able to identify the problem and command the robot to return to the base to fix it.

3. Conclusion

The development of an adaptive tire pressure control system for agricultural robots allows you to set the recommended tire pressure depending on the type and humidity of the soil. The introduction of such a system will significantly reduce the negative impact on the soil, expand the possibility of using the robot when working on slopes, increase the smoothness of the ride and, accordingly, reduce the dynamic loads affecting the transmission, as well as reduce fuel consumption, respectively, increasing economic performance.

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