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# PROSPECTS FOR IMPROVING THE DESIGN OF CLASSIC TRACTORS THROUGH THE INTEGRATION OF AUTOMATED MOTION CONTROL SYSTEMS.

*The article addresses the modernization of agricultural machinery through the integration of automated control systems, emphasizing this approach as one of the most effective means of enhancing the efficiency of agricultural production. It presents a comprehensive overview of current solutions in automatic control, outlining their specific characteristics and potential directions for further development. Particular emphasis is placed on their contribution to improving tractor performance, lowering operational costs, and creating safer and more comfortable working conditions for operators.*

*A review of scientific literature highlights the principal benefits of adopting automated systems, including higher precision in technological processes, reduced fuel and lubricant consumption, more rational resource management, and decreased reliance on human factors. The study also examines the economic dimension of implementation, focusing on payback periods, possibilities for retrofitting existing machinery, and the adaptability of these technologies to the conditions of different agricultural enterprises.*

*The influence of equipment-induced vibrations on the stability of RTK correction signals is analyzed, with findings showing that such vibrations may cause short-term disruptions in satellite reception and reduce positioning accuracy. To mitigate these issues, the article suggests solutions such as vibration-damping platforms, digital signal filtering, and advanced software-based correction techniques.*

*In addition, the article considers the technical, financial, and organizational challenges that arise when retrofitting tractors with automated control systems. A comparative evaluation of different system types and their compatibility with existing machinery is provided, with key selection criteria for optimal modernization strategies clearly identified.*

*Finally, practical guidelines are proposed for planning and executing tractor fleet upgrades, with attention to economic viability, technical integration, and future prospects for broader automation. The study's outcomes may serve as a foundation for implementing innovations in agricultural production aimed at improving productivity and competitiveness.*

***Keywords:*** *automated control, tractor, automation, RTK system*

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# ПЕРСПЕКТИВИ ВДОСКОНАЛЕННЯ КОНСТРУКЦІЇ КЛАСИЧНИХ ТРАКТОРІВ ШЛЯХОМ ІНТЕГРАЦІЇ АВТОМАТИЗОВАНИХ СИСТЕМ КЕРУВАННЯ РУХОМ.

*У статті розглядається модернізація сільськогосподарської техніки шляхом інтеграції автоматизованих систем керування, підкреслюючи, що цей підхід є одним із найефективніших засобів підвищення ефективності сільськогосподарського виробництва. У ній представлено комплексний огляд сучасних рішень в галузі автоматичного керування, окреслено їхні специфічні характеристики та потенційні напрямки подальшого розвитку. Особлива увага приділяється їхньому внеску в покращення продуктивності тракторів, зниження експлуатаційних витрат та створення безпечніших і комфортніших умов праці для операторів.*

*Огляд наукової літератури висвітлює основні переваги впровадження автоматизованих систем, включаючи вищу точність технологічних процесів, зменшення витрат палива та мастил, більш раціональне управління ресурсами та зменшення залежності від людського фактору. У дослідженні також розглядається економічний аспект впровадження, зосереджуючись на термінах окупності, можливостях модернізації існуючої техніки та адаптивності цих технологій до умов різних сільськогосподарських підприємств.*

*Проаналізовано вплив вібрацій, викликаних обладнанням, на стабільність коригувальних сигналів RTK, і результати показують, що такі вібрації можуть спричиняти короткочасні перебої в прийомі супутників та знижувати точність позиціонування. Для пом'якшення цих проблем у статті пропонуються такі рішення, як платформи для гасіння вібрацій, цифрова фільтрація сигналів та передові методи корекції на основі програмного забезпечення.*

*Крім того, у статті розглядаються технічні, фінансові та організаційні проблеми, що виникають під час модернізації тракторів автоматизованими системами керування. Надається порівняльна оцінка різних типів систем та їхньої сумісності з існуючою технікою, з чітким визначенням ключових критеріїв вибору для оптимальних стратегій модернізації.*

*Нарешті, пропонуються практичні рекомендації щодо планування та виконання модернізації тракторного парку з особливим акцентом на економічну доцільність, технічну інтеграцію та майбутні перспективи ширшої автоматизації. Результати дослідження можуть слугувати основою для впровадження інновацій у сільськогосподарське виробництво, спрямованих на підвищення продуктивності та конкурентоспроможності.*

***Ключові слова:*** *автоматизоване керування, трактор, автоматизація, система RTK*

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## Statement of the problem

The modern development of the agricultural sector is focused on the active introduction of digital and automated technologies that ensure increased productivity, accuracy and cost-effectiveness of agricultural processes. One of the key areas of agricultural machinery modernisation is the use of automatic driving systems (ADS) in tractors.

They reduce the human factor, decrease fuel consumption, minimise soil compaction and increase the accuracy of machine movement.

At the same time, a significant part of the tractor fleet of Ukrainian farms consists of outdated models that are not equipped with modern control systems. The purchase of new equipment with integrated ADS requires significant financial investments, which are not always available to agricultural producers. Therefore, the issue of retrofitting existing tractors with automatic driving systems as a more economically viable alternative is becoming relevant.

Among the main issues that need to be studied are the technical compatibility of AD systems with traditional tractors, the economic efficiency of their installation, their impact on the productivity and quality of field work, and the return on investment. In addition, it is necessary to take into account regulatory requirements and the possibility of adapting technologies to the conditions of Ukrainian agriculture.

Thus, research into the feasibility of equipping conventional tractors with automatic driving systems is of great practical and scientific importance. It will contribute to the modernisation of agricultural production, reduce equipment operating costs and increase the competitiveness of domestic agricultural enterprises.

**Analysis of literary sources**

In the course of researching the topic 'Prospects for improving the design of classic tractors through the integration of automated motion control systems,' considerable attention is paid to the analysis of scientific sources that highlight the technical, economic, and environmental aspects of this process.

One of the key areas is improving the efficiency of agricultural machinery through automation. Thus, Kalinin E. I., Rebrov O. Yu. and Kolodnenko V. M. [1] study the peculiarities of the tracking movement of wheeled tractors in conditions of their automatic driving. The authors prove that the introduction of such systems allows minimising the influence of the human factor and ensuring high accuracy of operations.

The works of Myhal V. D., Shulyak M. L. and Shevchenko I. O. [2] consider intelligent control systems for modern tractors, including telematics and precision driving systems. It is noted that the integration of such solutions is a necessary condition for the digital transformation of agricultural production.

The research of Hrushetskyi S., Oleksiik S. and Tykhoi M. [3] highlights the implementation of GPS navigation and adaptive control systems in agricultural machinery. Scientists emphasize the economic and technological advantages of these solutions, including reduced fuel consumption, increased productivity and accuracy of work.

The problems of energy conservation in general-purpose tractors are analysed by Lebedev A., Shulyak M. and Raputa V. [4]. The authors point out that optimising the use of energy resources is an important basis for the implementation of automatic driving systems, as it reduces costs and increases the efficiency of equipment operation.

Some studies also focus on the technical problems of AAS compatibility with traditional tractor models and the need for proper training of personnel to work with modernised equipment. This is of significant importance in the context of the development of the Ukrainian agro-industrial complex.

Equally important are the environmental benefits, which include reduced $CO_2$ emissions through optimised machine movement and lower fuel and lubricant consumption. This is in line with modern sustainable farming requirements.

Thus, a literature review confirms that retrofitting classic tractors with automatic driving systems is a technically feasible and economically viable solution. It contributes to increasing the efficiency of agricultural operations, reducing operating costs, improving working conditions and reducing the environmental impact.

Table 1

**Chronology of the development of automated driving systems**

| Period | Technological stage | Main characteristics | Effectiveness of implementation |
|---|---|---|---|
| 2000-2010 | Basic parallel driving systems | GPS navigation, accuracy ±30 cm | 10% reduction in overlaps |
| 2011-2015 | Advanced autopilot systems | RTK correction, accuracy ±2 cm | Resource savings of up to 15% |
| 2016-2020 | Intelligent control systems | Integration with precision farming systems | 25% increase in productivity |
| 2021- present tense | Autonomous control systems | AI, machine learning, remote control | Comprehensive process optimisation |

**Advantages of implementing automatic vehicle control systems.**

The introduction of automatic driving systems (ADS) on conventional tractors opens up vast opportunities for improving agricultural production efficiency. ADS are radically changing the approach to vehicles in agriculture, construction and logistics. They are based on high-precision technologies that ensure efficiency, economy and safety.

One of the key advantages is the ability to work at any time and in various weather conditions. Thanks to automatic control systems, tractors, combines and other equipment can operate even at night or in poor visibility conditions (fog, rain, snow). This allows for an increase in overall productivity and more efficient use of working time.

Modern ADS employ machine learning and artificial intelligence, enabling real-time data analysis and the generation of optimal movement strategies for agricultural machinery, as shown in Figure 1. These intelligent systems can integrate information from various sensors, including GPS, LiDAR, and cameras, to ensure precise navigation and adapt to changing field conditions.

Another significant advantage of ADS is the reduction of operator fatigue. By minimizing the need for continuous manual control, the workload on machine operators decreases, which not only improves safety but also extends the duration of productive work shifts. Furthermore, automatic driving systems enhance the uniformity of field operations, leading to better seed distribution, reduced overlaps and omissions, and more efficient use of fertilizers and pesticides.

From an economic perspective, ADS contribute to fuel savings and lower maintenance costs by optimizing routes and ensuring smoother machine operation. This directly impacts the cost-effectiveness of agricultural enterprises, particularly in large-scale farming where resource optimization plays a critical role.

Additionally, the environmental benefits of ADS should not be overlooked. By reducing redundant operations and fuel consumption, these systems contribute to lowering carbon emissions and promoting sustainable farming practices. Their implementation aligns with global trends in precision agriculture, which aim to balance productivity with environmental responsibility.

In summary, the deployment of automatic driving systems on conventional tractors represents a crucial step toward digital transformation in agriculture. It not only improves efficiency and economic returns but also supports the sustainable use of resources, ultimately contributing to the competitiveness and resilience of agricultural enterprises in the modern world.

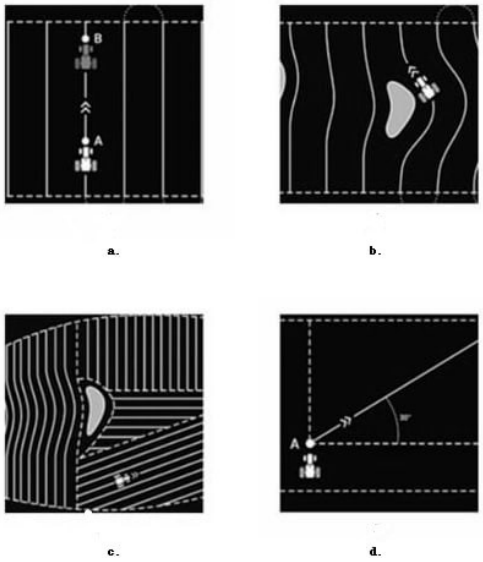


**Fig. 1. Movement patterns used by modern autopilots**
**a. - straight movement; b. - obstacle avoidance; c. - group of guide lines; d. - diagonal movement**

Figure 1 demonstrates various options for organizing the movement of agricultural machinery in the field: straight-line movement between points on a flat area (a), avoiding obstacles while maintaining the direction of work passes (b), working in fields of complex configuration with boundaries and internal objects (c), as well as movement at a given angle using automatic driving or navigation systems (d), which ensures complete coverage of the area, high accuracy and efficiency of technological operations.

For example, the system can obtain information about the terrain, soil density, and moisture level, and based on this data, it can adjust the trajectory to achieve maximum efficiency. Another important aspect is reducing the load on the operator.

Ivanyshyn V. V. [8] notes that the use of automatic driving systems allows field work to be carried out in conditions of limited visibility, including at night and in fog. This significantly expands the time available for performing technological operations and increases the seasonal load on the equipment. Automatic driving reduces the need for a second driver, which is especially important during long seasonal operations. The operator can focus on monitoring the parameters of the equipment instead of constantly driving the vehicle. Automatic driving systems help reduce the human factor. This reduces the risk of errors, such as overlapping or skipping when sowing and cultivating fields. As a result, the distribution of fertilisers, plant protection products and crops is more uniform.

The introduction of automatic driving opens up the possibility of working with unmanned equipment. Autonomous tractors, combine harvesters and trucks are already being developed that can operate without human presence, increasing the efficiency of agricultural and transport processes. Such systems have environmental benefits. Optimising driving techniques reduces harmful emissions into the air, cuts fuel consumption and minimises the impact on the soil by reducing its compaction. This contributes to the sustainable development of agriculture and the conservation of natural resources.

In general, the automatic control system is a step forward in the development of modern technologies. They not only increase production efficiency, but also open up new prospects for automation and the implementation of various innovative solutions in various industries.

According to research by Bulgakov V. M. and co-authors [5], automation of the control process significantly improves the quality of technological operations.

The article by R. M. Lipnytsky and V. B. Ryaboshapka [6] examines ways to modernize classic tractors by integrating automatic driving systems. The authors analyze the technical limitations, economic efficiency, and organizational conditions for implementing such systems in agricultural production. The study emphasizes the prospects of automation as a direction for increasing productivity and rational use of resources.

The main technological advantage is the increased accuracy of the movement of aggregates. Veselovskaya N. R. and co-authors [7] note that the use of automatic driving systems allows reducing the overlap of passages to 2-3 cm, while with manual control this figure is 30-40 cm. This leads to savings in seed material, fertilisers and plant protection products.

Fedorenko V. I. [11] emphasises the importance of hydraulic systems in ensuring control accuracy. Automatic driving allows maintaining the optimal speed of movement and ensures the uniformity of technological materials application. According to the research of Kuvachov V. P. [9], this contributes to an increase in crop yields by 7-12%.

Table 2

**Impact of automated driving on operational performance**

| Indicator | Without automatic driving | With automatic driving | Improvement, % |
|---|---|---|---|
| Fuel consumption, l/ha | 12,5 | 10,2 | 18,4 |
| Productivity, ha/hour | 2,8 | 3,5 | 25,0 |
| Blocking of passages, cm | 35 | 2,5 | 92,9 |
| Downtime, min/hour | 15 | 5 | 66,7 |

According to Table 2, the use of automatic driving systems in agriculture has a comprehensive positive impact on production efficiency. First of all, there is a decrease in fuel consumption from 12.5 to 10.2 l/ha, which means savings of 18.4%. This not only reduces production costs, but also contributes to more environmentally friendly farming, as the amount of harmful emissions is reduced. An increase in productivity is also important: from 2.8 to 3.5 ha/h, i.e. by 25%, which allows you to perform a much larger amount of work in a shorter time, especially during peak load periods.

An equally significant indicator is the reduction in aisle overlaps: from 35 to 2.5 cm, which is a 92.9% improvement. This ensures accuracy of cultivation, reduces seed and fertilizer losses, and also creates conditions for uniform plant development. In addition, the use of automatic driving allows you to significantly reduce the time of simple equipment - from 15 to 5 min/h, that is, by 66.7%, which increases the efficiency of working time and reduces the risks of delays in field work.

Therefore, the implementation of automatic driving is economically justified and practically expedient, because it allows you to simultaneously reduce costs, increase labor productivity and ensure more accurate and rational use of resources. As a result, the farm receives not only financial benefits, but also a strategic competitive advantage in the agricultural products market.

As noted in their research by Rud A. V. and colleagues [10], the use of automated driving systems significantly reduces both the physical and psycho-emotional stress on the operator, which, in turn, has a positive effect on their performance and the quality of agricultural operations. In addition, the use of such systems contributes to the preservation of soil structure thanks to a more rational trajectory of machinery movement and a reduction in the number of repeated passes across the field.

**The impact of vibrations generated during tractor operation on the accuracy of the CAW**

Vibrations generated during tractor operation can significantly affect the accuracy of the RTK (Real-Time Kinematic) signal, as they create both mechanical and electronic interference with the navigation system.

One of the main problems is micro-shifts or vibrations of the RTK receiver antenna. Vibrations can change its spatial position, leading to instability in the reception of signals from satellites and the base station. Even slight antenna displacement can cause errors in coordinate determination, especially considering that RTK technology provides centimetre-level measurement accuracy.

Another important factor is the impact of vibrations on the electronic components of the RTK receiver. Prolonged exposure to vibrations can cause microcracks in solder joints, weakening of contacts, or gradual degradation of connections, which can lead to equipment malfunctions. Although some RTK systems are equipped with signal filtering and smoothing algorithms that partially compensate for short-term deviations, intense or constant vibrations can lead to serious positioning errors.

In addition, vibrations can cause temporary signal loss. Antenna oscillation changes the reception geometry, sometimes causing short-term interference or complete disconnection from satellites. This is critical in automatic driving systems, where signal stability and continuity are essential.

To reduce the negative impact of vibrations, it is advisable to ensure reliable antenna mounting using shock-absorbing bases or damper elements that minimise the transmission of vibrations from the tractor to the receiver. Additionally, it is recommended to use high-quality RTK receivers with adaptive correction algorithms that can partially compensate for errors caused by vibration.

You can also improve accuracy by calibrating the system before you start working and doing regular maintenance to prevent mechanical damage to the equipment. In some cases, you can put the antennas somewhere else on the tractor where there's less vibration, like on special brackets or on the roof of the cab.

In general, the impact of vibrations on the RTK system can be significantly reduced by proper installation and the use of appropriate stabilisation methods.

The process of retrofitting classic tractors with automatic driving systems is accompanied by a number of technical, economic and organizational challenges that require careful planning and a comprehensive approach.

Technical difficulties are primarily related to the compatibility of electronic components of automatic driving systems with standard tractor systems. Many older models are not equipped with electronic control systems, which complicates integration. Additional problems are the stability of the RTK navigation signal, the need to upgrade the electrical system and accurate calibration of the steering mechanism, hydraulics and sensors.

Economic challenges relate to the high costs of modernization, especially in cases where the equipment does not have basic electronic systems. The return on investment depends on the scale of the farm, the frequency of use of machines and the level of resource savings. Significant costs can also arise due to the purchase or maintenance of RTK stations or the use of differential correction services.

Table 3

**Main challenges in tractor conversion**

| Call category | Specifics of the problem | Possible solutions | Forecasted costs, thousand UAH |
|---|---|---|---|
| Technical | Equipment compatibility | Modular systems | 50-75 |
| Organizational | Staff training | Specialized courses | 25-40 |
| Operational | Service | Contracts with suppliers | 30-45 |
| Software | Data integration | Unified protocols | 20-35 |

As can be seen from Table 3, the implementation of precision seeding technology is associated with technical (equipment compatibility), organizational (staff training), operational (need for service) and software (data integration) problems. The proposed solutions - the use of modular systems, specialized courses for employees, contracts with suppliers and unified data exchange protocols - allow to effectively overcome these challenges. The costs of implementing such measures, according to the table, range from 20 to 75 thousand UAH, which is a justified investment given the expected savings in resources and increased yield.

Among the organizational aspects, training of personnel who must master new technologies is important. In addition, the implementation of automatic driving requires regular maintenance, software updates, and adaptation of production processes to new equipment capabilities.

Modernization of tractors should begin with an analysis of the existing fleet of machines and determining their technical condition in order to understand which models are appropriate to equip with automatic driving systems. The economic analysis should take into account not only the costs of equipment and installation, but also the expected fuel savings, increased productivity, and accuracy in the use of material resources.

The selection of automatic driving technologies should be carried out taking into account compatibility with existing systems, the possibility of further expansion, and support for data exchange standards. Particular attention should be paid to the selection of navigation correction services that provide high positioning accuracy.

Effective project implementation involves a phased plan: selection of equipment, its purchase and installation, configuration, personnel training, and test trials. It is also important to foresee the prospects for further automation - integration of equipment into the precision farming system, implementation of monitoring, data analysis, and forecasting. This will contribute to the creation of a single digital ecosystem and the maximum use of the advantages of modern technologies in agriculture.

## Conclusions

Retrofitting classic tractors with automatic driving systems is a promising direction of modernization of agricultural machinery, which allows to increase the accuracy, efficiency and cost-effectiveness of agricultural operations. The implementation of such systems helps to reduce fuel costs, optimize resource use and reduce the load on the operator.

However, the process of retrofitting is accompanied by a number of technical, economic and organizational challenges. Technical difficulties are associated with the compatibility of electronic components, the impact of vibrations on the accuracy of the RTK signal, the need to modernize the electrical system and conduct thorough calibration of the equipment. Economic aspects include the high cost of installing systems, the need for regular maintenance and possible additional costs for software and personnel training.

The calculation of the cost of installing CAV for KhTZ and John Deere tractors showed that the total cost of retrofitting a domestic tractor is 392,900 UAH, and a foreign one is 420,000 UAH. This indicates a significant initial investment that pays off through increased productivity and reduced operating costs.

Successful implementation of automatic driving systems requires a comprehensive approach that includes a thorough analysis of existing equipment, selection of compatible equipment, calculation of economic efficiency and adaptation of technological processes. Also important are personnel training and the use of modern stabilization methods, in particular shock-absorbing antenna mounts, to reduce the impact of vibrations on navigation accuracy.

In general, tractor control automation is appropriate for medium and large agricultural enterprises, as it ensures high accuracy of equipment movement, minimizes the human factor and contributes to increasing the efficiency of agricultural production.

Based on the study, it can be recommended that farms of various forms of ownership consider the possibility of gradually re-equipping the existing tractor fleet with automatic driving systems. In this case, it is important to ensure a comprehensive approach to the selection of technical solutions and their implementation, taking into account the specifics of a particular farm and available resources.

Promising areas of further research include studying the possibilities of integrating automatic driving systems with other elements of precision agriculture, developing methods for optimizing system settings for various types of

agricultural work, and studying the impact of automation on the durability of equipment and the quality of technological operations.

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