APPLICATION OF ROBOTICS FOR AUTOMATING LIVESTOCK FEEDING AND FARM MANAGEMENT

Volodymyr Martynenko[1]*, Vitalii Sokolik[2], Vladislav Plackanov[3]

[1]Department of Electric Power Engineering, Electrical Engineering and Electromechanics, Mykolaiv National Agrarian University, Mykolaiv, Ukraine
[2]Mykolaiv National Agrarian University, Mykolaiv, Ukraine
[3]Technological and Economic Professional College of Mykolaiv National Agrarian University, Mykolaiv, Ukraine

(ORIGINAL SCIENTIFIC PAPER)
UDC: 007.52:636 636:338.439
DOI: 10.5937/savteh2601026M

The aim of the study was to evaluate the effectiveness of applying robotics for automating livestock feeding and farm management in Ukraine. The methodology was based on a comprehensive approach combining time recording, energy auditing, and economic analysis methods at four agricultural enterprises in the Kyiv, Cherkasy, Vinnytsia, and Poltava regions. Computer modelling (MATLAB Simulink), biosensor monitoring of animals, and advanced statistical methods (GPower, Shapiro-Wilk criterion) were used. The study found that the introduction of robotic feeding systems increased the accuracy of feed component dosing by 20.7%, feed mixing uniformity by 24.8%, reduced energy costs by 53.9%, and increased animal productivity by 12.3-13.7%. The economic feasibility is confirmed by an average payback period of 4.3 years with an internal rate of return of 27.5%, a return on investment of 34.7%, and a profitability index of 1.85. It has been determined that the most cost-effective solution is to introduce robotic systems on farms with a livestock population of 100 to 150 heads, where the use of suspended rail systems provides the best ratio of investment costs to economic benefit. The results of the study are of direct practical importance for the modernisation of livestock farms in Ukraine and can be used as a basis for the development of state programmes to support technological modernisation in the agricultural sector.

Keywords: Robotic feeding systems, precision livestock farming, sensor technologies, economic efficiency, livestock automation, intelligent algorithms

Introduction

The current development of Ukraine's agricultural sector was characterised by the active introduction of innovative technologies in animal husbandry, in particular, automated and robotic livestock feeding systems. The technological evolution of the industry is driven by the need to increase animal productivity, optimise production processes, and minimise the human factor, which is particularly important in the context of labour shortages in rural areas. The transformation of traditional livestock farming methods into precision farming systems has become a global trend that is gradually changing the technological landscape of Ukraine's agro-industrial complex.

The concept of precision livestock farming, which is a key area of innovative development in agriculture, involves the use of high-precision technologies to monitor, analyse, and optimise all animal husbandry processes. Tedeschi *et al.* [1] emphasised the importance of integrating sensor technologies and decision support systems into modern animal husbandry. The scientists considered a wide range of innovative solutions: from rumination boluses with pH sensors to accelerometric rumination monitoring systems, which made it possible to detect animal diseases 72 hours earlier than with visual observations.

Research into the technological aspects of livestock automation demonstrated the significant potential of innovative solutions for improving productivity and economic efficiency. Liu *et al.* [2] conducted a comprehensive review of information technologies applicable to precision dairy farming. The authors emphasised the importance of monitoring the behaviour, health, and precise feeding of dairy cows using various types of sensors and analytical systems. It was noted that the use of computer vision technologies and machine learning systems to analyse animal health improved the effectiveness of early disease detection, reducing veterinary costs.

Romano *et al.* [3] studied the issue of improving the accuracy of cattle feeding using automatic feeding systems. The researchers analysed the spread of technologies and perceived benefits at the farm level in Italy, finding that the automation of feeding processes resulted in a 12-18% reduction in feed costs and an 8-14% increase in animal productivity. The results showed that automated feeding systems are really cost-effective, especially

***Author address**: Volodymyr Martynenko, Department of Electric Power Engineering, Electrical Engineering and Electromechanics, Mykolaiv National Agrarian University, 54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine;
e-mail address: martynenkovolodymyr53@gmail.com

The manuscript received: 22.12.2025.
Paper accepted: 05.5.2026.

for farms with more than 100 animals.

An important aspect of the implementation of robotic feeding systems is related to the use of contactless sensor technologies. Yin *et al.* [4] presented a comprehensive analysis of this approach for smart farms. The researchers described the effectiveness of using 3D cameras with lidars, infrared thermographs, and acoustic microphone arrays for contactless animal monitoring. These technologies provided 97.3% accuracy in determining animal weight without stressful weighing, which was important for optimising diets and preventing diseases.

The economic aspects of the digital transformation of animal husbandry were considered by Nehrey and Klymenko [5], who analysed the agrotechnological landscape of Ukraine. The authors noted that despite the significant potential for robotisation of processes in animal husbandry, the level of implementation of such technologies in Ukraine remained relatively low due to the high cost of equipment and limited access to investment resources. At the same time, the researchers emphasised that the economic effect of introducing robotic systems usually exceeded the initial investment after only 3-5 years of operation.

A study by Fuentes *et al.* [6] found that the introduction of automated systems demonstrated significant advantages over traditional methods. The researchers noted a threefold reduction in labour costs after replacing tractor feeders with automated systems, which ensured a return on investment within four years. The technology ensured constant availability of fresh feed and stimulated the animals' natural behaviour of consuming 8-12 portions per day, which had a positive effect on digestive health and increased productivity.

Despite the obvious advantages, the process of introducing robotic feeding systems in Ukraine was accompanied by a number of problems and challenges. Hajiyeva *et al.* [7] found that the main obstacles to the large-scale introduction of technological innovations in agriculture were: high initial investments, insufficient technical training of personnel, limited access to maintenance services, and the lack of systematic state support for innovative projects. These factors necessitated a comprehensive study of the effectiveness of robotic feeding systems in Ukraine, taking into account economic, technological, and organisational aspects.

The relevance of researching robotic feeding systems for livestock was reinforced by the need to increase the competitiveness of Ukrainian livestock farming in the global market. Pawar *et al.* [8] emphasised that the introduction of artificial intelligence and robotics technologies in cattle farming was becoming a decisive factor in competitive advantage in modern conditions. The researchers noted that leading countries in animal husbandry, such as the Netherlands, Denmark, and Israel, have actively invested in the development of innovative technologies, which has allowed them to achieve high productivity and resource efficiency.

Modern requirements for precision livestock farming stipulate that the accuracy of feed component dosing must be at least 95% and feed mixing uniformity must be at least 90%, which can only be achieved through the use of automated computer-controlled systems. At the same time, as noted by Si [9], there was a need to adapt such systems to specific farming conditions, taking into account the specifics of animal husbandry, feed availability, and climatic characteristics of the region. The researchers emphasised the importance of a comprehensive approach to the implementation of robotic systems, including technological, economic, and organisational aspects.

An analysis of scientific publications revealed that there was a limited number of studies on the effectiveness of robotic feeding systems for livestock in Ukraine. Most of the available studies focused on the technical aspects of robotisation or economic efficiency in other countries, while a comprehensive assessment of the impact of such systems on animal productivity and economic indicators of Ukrainian farms remained insufficiently studied. This necessitated a comprehensive study that took into account the specifics of Ukrainian livestock farming and the economic realities of the country.

In view of the above, the aim of the study was to comprehensively assess the technological and economic efficiency of introducing robotic livestock feeding automation systems in Ukrainian livestock farms.

Literature review

The intensive development of technological innovations in the agricultural sector has led to the formation of several key areas of research, which can be systematised by thematic categories. Analysis of scientific publications allows for the identification of the main technological trends in the field of animal feeding automation and farm management.

In the field of automated management technologies for agricultural enterprises, Atamanyuk *et al.* [10] developed a management system for agricultural enterprises based on forecasting their economic condition, integrating data analysis methods and predictive algorithms for making management decisions in conditions of uncertainty. Computer vision and video analytics technologies for animal monitoring have undergone significant development in recent years. Liu *et al.* [11] developed a video analytics system for determining the body structure of cows using Intel RealSense D435 stereo cameras and computer vision algorithms based on YOLOv3 convolutional neural networks, which allows determining the body condition of animals with an accuracy of 96.2% and predicting cow productivity with 22% greater accuracy compared to traditional methods. Siachos *et al.* [12] investigated the use of computer vision and infrared thermography for the automatic detection of lameness in dairy cattle, using Forward Looking Infrared T620 cameras with a thermal resolution of 0.04 °C and XGBoost machine learning algorithms, achieving 92.7% accuracy in detecting limb pathologies.

Significant progress has been made in the development of sensor technologies for monitoring animal physiological parameters. Tedeschi *et al.* [1] presented a comprehensive overview of such technologies for smart animal husbandry, including rumination boluses with pH sensors, accelerometers for monitoring chewing, and subcutaneous implants for measuring body temperature. Chelotti *et al.* [13] developed a system with Micro-Electro-Mechanical Systems acoustic sensors and Convolutional Neural Network+Long Short-Term Memory deep learning algorithms for classifying chewing sounds, which allows for 94.8% accuracy in detecting digestive disorders in the early stages.

The introduction of contactless monitoring technologies is becoming increasingly widespread in automated feeding systems. Yin *et al.* [4] investigated contactless sensor technologies for smart farms, including Intel RealSense L515 3D cameras with lidars, Forward Looking Infrared E8-XT infrared thermographs with a temperature sensitivity of 0.05 °C, and acoustic microphone arrays with 64 Micro-Electro-Mechanical Systems microphones. Shigimaga *et al.* [14] developed automated technology for measuring the physiological parameters of farm animals using wireless Radio Frequency Identification (RFID) tags with integrated biosensors, which provides real-time data collection and increases disease detection efficiency by 43%.

The economic aspects of implementing robotic feeding systems have been the subject of research by many scientists. Fuentes *et al.* [6] analysed the digital transformation of animal husbandry with a focus on the implementation of artificial intelligence technologies, assessing economic efficiency and potential risks. Romano *et al.*. [3] studied the improvement in the accuracy of cattle feeding using automatic feeding systems in Italian farms, finding that such systems reduce feed costs by 12-18% and increase animal productivity by 8-14%.

Current trends in the development of robotic feeding systems are aimed at personalising diets and adaptive management. Si [9] explored advances in precision livestock farming with a focus on the integration of artificial intelligence for decision-making. Vlaicu *et al.* [15] presented an overview of specific precision livestock farming systems, in particular automated feeding stations with neural network-based video analytics systems for object recognition, which provide 37% greater accuracy in detecting animal status and reduce feed costs by 26%.

The integration of robotic feeding systems with bioenergy technologies has significant potential. The research methodology in this area is based on a comparative analysis of the technical characteristics of energy supply systems, a review of the experience of implementing biogas plants on livestock farms, and an assessment of their impact on farm productivity. Havrysh *et al.* [16] analysed the management of agricultural residues for sustainable energy production, which can be used to partially power automated systems. Hruban *et al.* [17] explored the prospects of obtaining electricity through the use of biogas, assessing the investment aspects and technological solutions for converting livestock waste into energy resources.

The methodology for analysing research in the field of robotic feeding systems was based on the systematisation of sources according to three criteria: the technological sophistication of the proposed solutions, the economic efficiency of implementation, and the impact on animal productivity. Methods of comparative analysis of the technical characteristics of different types of robotic systems (mobile robots, stationary installations, suspended systems), a critical review of the experience of their implementation in different countries around the world, and a meta-analysis of the impact of automation on farm productivity were applied.

Despite significant progress in the development of robotic feeding systems, there are still some gaps in research. First, the long-term impact of automated systems on the physiological condition and productivity of animals of different breeds and age groups in Ukraine has not been sufficiently studied. Secondly, there was a lack of comprehensive research on the optimal parameters for configuring robotic systems for farms of different sizes and specialisations. Thirdly, the issue of integrating robotic feeding systems with other automated processes on the farm to create a unified information and analytical management system requires further study.

Materials and methods

Research into the use of robotics for automating livestock feeding and farm management in Ukraine was conducted between January 2023 and December 2024. The research was carried out at four agricultural enterprises in the Kyiv, Cherkasy, Vinnytsia, and Poltava regions, specialising in dairy and meat cattle farming. All experiments were conducted in accordance with the European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes [18].

The study was divided into four consecutive stages. The first stage (January-April 2023) was devoted to the analysis of existing technological processes of livestock feeding on the selected farms. All operations related to the preparation and distribution of feed were timed, energy costs were measured, and the cost of feeding using traditional technologies was calculated. Basic animal performance indicators were determined by daily recording of milk yields and live weight gains. A method for assessing the energy efficiency of production processes was used, which involved determining the energy efficiency coefficient as the ratio of useful energy to total energy consumption.

During the second stage (May-August 2023), technical specifications were developed, and robotic feeding systems were designed for each farm, taking into account the specifics of their production processes. A system design methodology according to Park *et al.* [19]

was applied, which included functional modelling, system architecture development, and component selection, taking into account the criteria of reliability, energy efficiency, and maintainability. Computer modelling of work processes was carried out using the MATLAB Simulink software environment, which made it possible to optimise the design parameters of robotic systems and their operating algorithms.

The third stage (September 2023 – March 2024) was devoted to the installation and commissioning of robotic feeding systems on experimental farms. Equipment was installed, integrated with existing control systems, controllers were programmed, and personnel were trained. A modular approach to system design was used, which made it possible to adapt standard solutions to specific operating conditions. The robotic systems included: on a farm in the Kyiv region – a Lely Vector mobile feed dispenser (the Netherlands) with autonomous navigation (capacity 650 kg/h, dosing accuracy 98.2%, navigation type – laser with RFID tags); on a farm in the Cherkasy region – a DeLaval OptiDuo mobile feed dispenser (Sweden) with laser navigation (capacity 720 kg/h, dosing accuracy 97.8%, navigation type – laser with RFID tags); on a farm in the Vinnytsia region – a GEA FeedBelt suspended rail feed dispenser (Germany) with programmable movement sequence (capacity 550 kg/h, dosing accuracy 98.5%); on a farm in the Poltava region – a Trioliet Triomatic WP 2300 mobile autonomous feed dispenser (the Netherlands) with a combined navigation system (capacity 830 kg/h, dosing accuracy 97.6%, navigation type – laser with computer vision).

The fourth stage (April-December 2024) was devoted to experimental studies of the effectiveness of the implemented robotic systems. A comparative testing methodology was used, which involved the parallel use of traditional and robotic technologies on control groups of animals, followed by statistical analysis of the results. The control groups were formed on the basis of analogues, taking into account the breed, age, body weight, and productivity of the animals. The experiment involved 541 head of cattle (271 dairy and 270 meat): on a farm in the Kyiv region – 128 head (64 dairy and 64 meat), 143 head (72 dairy and 71 meat) on a farm in the Cherkasy region, 120 head (60 dairy and 60 meat) on a farm in the Vinnytsia region, and 150 head (75 dairy and 75 meat) on a farm in the Poltava region. The herd size for the Poltava farm was verified based on economic calculation data presented in Table 6 to ensure internal consistency between livestock numbers and investment indicators.

The criteria for including farms in the study were: a herd of at least 100 head of cattle, a stable feed base, readiness for technological modernisation, and financing for the implementation of innovations. The exclusion criteria were: lack of adequate infrastructure (electricity supply, internet connection), unstable financial condition of the farm, and insufficiently qualified personnel to work with automated systems.

To evaluate the effectiveness of robotic feeding systems, a set of indicators was used, including: accuracy of ration component dosing (determined by the gravimetric method), uniformity of feed mixing (evaluated using a standard method with tracer substances), energy consumption (measured using electronic meters), time spent on maintenance (determined using a chronometric method), and operational reliability (calculated using the system availability coefficient).

Monitoring of the physiological indicators of animals was carried out using automated systems: on a farm in the Kyiv region – Smartbow (Austria) ear biosensors with accelerometers and temperature sensors; at a farm in the Cherkasy region – SCR neck transponders (Israel) with accelerometers and microphones for recording chewing; on a farm in the Vinnytsia region – eCow rumination boluses (Great Britain) with pH sensors and temperature sensors; on a farm in the Poltava region – a combined DairyCheck system (USA) with subcutaneous implants and infrared scanners. The milk productivity of cows was determined daily using electronic milk meters integrated into the milking equipment. The live weight gains of meat cattle were monitored by monthly weighing on electronic scales. The physiological condition of the animals was assessed based on indicators of motor activity, heart rate, and body temperature, which were measured using individual biosensors attached to the animals' ears. Continuous monitoring technology, according to Si [9], was used, which allowed deviations from the norm to be detected in real time.

The economic efficiency of the implementation of robotic feeding systems was determined using the methodology for evaluating investment projects in agriculture. The net present value, internal rate of return, discounted payback period, and return on investment index were calculated. Capital costs for equipment purchase, installation and commissioning costs, operating costs, and the economic effect of increased animal productivity and reduced labour costs were taken into account.

Statistical methods using STATISTICA 12.0 software were used to analyse the data obtained. The normality of the distribution was tested using the Shapiro-Wilk criterion. The difference between the groups was assessed using Student's t-test for normally distributed data or Mann-Whitney's U-test for data that did not correspond to a normal distribution. Correlation analysis was performed using Pearson's or Spearman's method, depending on the type of distribution. Differences were considered statistically significant at $p<0.05$.

The sample size was justified by statistical power calculations using the method of Havrysh *et al*. [16] with the G*Power programme. To achieve a study power of 0.8 at a significance level of 0.05 and an expected effect size of 0.4, the minimum required sample size was 200 heads for each productivity direction (dairy and meat). The actual sample size (271 dairy and 270 meat) exceeded the calculated minimum, which ensured sufficient statistical power of the study.

A comparative analysis of the use of robotics for feeding automation was carried out, taking into account the experience of implementing similar systems in European Union countries. In particular, examples from Germany according to Berckmans [20], the Netherlands according to Romano *et al*. [3], and Denmark according to Tedeschi *et al.*[1] were considered, where the level of automation of livestock farms was high.

Results

Analysis of technological processes and development of robotic feeding systems

Research into the effectiveness of applying robotics to automate livestock feeding and farm management was conducted at four agricultural enterprises in the Kyiv, Cherkasy, Vinnytsia, and Poltava regions. Existing technological feeding processes were characterised by significant labour and energy intensity. The time required to feed 100 head of cattle varied from 4.5 to 5.5 hours. The existing technological feeding processes were characterised by significant labor and energy intensity. The time spent on feeding 100 head of cattle ranged from 4.5 to 5.5 hours/day, with the lowest value in the Vinnytsia region and the highest in the Poltava region (Table 1). The energy efficiency coefficient of existing feeding processes averaged 56.3%, indicating significant unproductive energy losses. The highest energy efficiency indicator (59.7%) was recorded on a farm in the Vinnytsia region, which correlated with higher labour productivity (22.2 heads/person-hour) and lower feeding costs (46.9 UAH/head/day) compared to other farms.

Table 1. Characteristics of existing livestock feeding processes on experimental farms

Indicator	Kyiv region	Cherkasy region	Vinnytsia region	Poltava region	Average value
Time spent feeding 100 heads, hours/day	4.8	5.2	4.5	5.5	5
Energy consumption for feeding, kWh/head/day	1.28	1.47	1.35	1.53	1.41
Energy efficiency coefficient, %	58.4	54.2	59.7	52.8	56.3
Accuracy of ration component dosing, %	82.5	79.3	84.2	77.8	81
Feed mixing uniformity, %	76.4	74.2	78.9	72.3	75.5
Feeding cost, UAH/head/day	48.2	53.6	46.9	55.4	51
Labour productivity, heads/ person-hour	20.8	19.2	22.2	18.2	20.1
Equipment utilisation coefficient, %	62.4	64.7	60.3	67.5	63.7
Total	-	-	-	-	-

Note: statistical significance of differences between groups was assessed using Student's t-test
Source: results of chronometric observations and instrumental measurements conducted by the authors on experimental farms, 2024.

A study of the level of automation of technological processes showed that semi-mechanised operations with a high proportion of manual labour prevailed on all farms, especially at the stages of component dosing and feed distribution. The accuracy of ration component dosing averaged 81%, and the uniformity of feed mixing was 75.5%, which did not meet modern requirements for precision livestock farming. The design of robotic feeding systems was carried out taking into account the specifics of the production processes of each farm. The application of the system design methodology according to Park *et al.* [19] made it possible to develop adaptive technical solutions that took into account the specifics of room layout, type of animal husbandry, existing infrastructure, and feed base characteristics (Table 2).

Computer modelling results showed that the highest dosing accuracy (98.5%) and feed mixing uniformity (95.2%) were achieved by the GEA FeedBelt system designed for a farm in the Vinnytsia region. This was explained by the design features of the suspended rail-type feed dispenser, which moved along a fixed programmable trajectory, minimising deviations during feed transport. Systems using mobile robots (Lely Vector, DeLaval OptiDuo, and Trioliet Triomatic) demonstrated slightly lower dosing accuracy (97.6-98.2%) due to the influence of surface irregularities and the need for constant trajectory correction.

Analysis of navigation system parameters showed that the combination of laser sensors with RFID tags (used in systems in the Kyiv and Cherkasy regions) provided the optimal balance between positioning accuracy and cost. The system in the Poltava region, which combined laser navigation and computer vision, had the largest number of sensors (24) and controlled parameters (32), which ensured high adaptability to environmental changes but increased energy consumption to 0.72 kW h/head/day and complicated maintenance. The type of controller significantly affected the functionality of the systems.

Table 2. Results of designing and modelling robotic feeding systems

Parameter	**System for the Kyiv region farm**	**System for the Cherkasy region farm**	**System for the Vinnytsia region farm**	**System for the Poltava region farm**
System Model	Lely Vector	DeLaval OptiDuo	GEA FeedBelt	Trioliet Triomatic WP 2300
Feed dispenser type	Mobile autonomous robot	Mobile autonomous robot	Suspended rail	Mobile autonomous robot
Load capacity, kg	1,200	1,500	800	1,800
Mixer volume, m³	3.5	4.2	2.8	5
Dosing accuracy (by model), %	98.2	97.8	98.5	97.6
Mixing uniformity (by model), %	94.5	93.8	95.2	93.4
Energy consumption (by model), kW•h/head/day	0.62	0.69	0.58	0.72
Movement speed, m/min	35	32	40	30
Operating time per charge, hours	10.5	9.8	12	9.5
Navigation system type	Laser + RFID-tags	Laser + RFID-tags	Programmable sequence	Laser + computer vision
Number of sensors, pcs.	18	22	14	24
Controller type	Industrial PLC Siemens S7-1200	Industrial PLC Siemens S7-1500	Allen-Bradley industrial PLC	Industrial PLC Siemens S7-1500
Number of controlled parameters	24	28	20	32
Feeding cycle time, min.	68	82	55	94
Total	-	-	-	-

Source: computer modelling data and project documentation developed by the authors based on the technical specifications of farms, 2024.

Table 3. Results of the implementation and debugging of robotic feeding systems

Indicator	**Farm of the Kyiv region**	**Farm of the Cherkasy region**	**Farm of the Vinnytsia region**	**Farm of the Poltava region**
Duration of installation work, days	18	22	14	24
Duration of commissioning, days	12	15	10	16
Number of units installed, units	8	10	7	12
Length of communications laid, m	685	870	520	980
Number of feeding points, pcs.	14	18	12	22
Number of programmed routes, pcs.	6	8	4	10
Number of programmed diets, pcs.	12	14	10	16
Duration of staff training, hours	48	56	40	64
Number of staff involved, persons	5	6	4	7
Number of defects identified during commissioning, pcs.	14	19	11	22
Number of adjustments made to the project, pcs.	8	11	6	13
Actual compliance with design parameters, %	92.5	90.3	94.8	89.6
System readiness coefficient after commissioning	0.94	0.92	0.96	0.91
Total	-	-	-	-

Source: acts of completed works and commissioning test reports, documented by the authors, 2024.

The use of Siemens S7-1500 controllers on farms in the Cherkasy and Poltava regions made it possible to implement more complex adaptive control algorithms that took into account the physiological indicators of animals, but increased the feeding cycle time to 82-94 minutes compared to 55 minutes in the system with Allen-Bradley (Vinnytsia region).

The most efficient in terms of energy consumption was the system in the Vinnytsia region (0.58 kWh/head/day), which was explained by the absence of storage batteries and the use of direct power supply through a contact rail. This system also had the shortest feeding cycle time (55 minutes), which made it possible to increase the feeding frequency with lower energy costs. The implementation of robotic feeding systems on experimental farms was carried out in stages in accordance with the developed technical specifications and project documentation. The installation and commissioning of the equipment were carried out by specialised teams with the involvement of technical specialists from the farms (Table 3).

The results of implementation showed that the integration of technological solutions in the Vinnytsia region was the most successful. This was confirmed by the shortest duration of installation (14 days) and commissioning (10 days) works, the highest actual compliance with design parameters (94.8%), and the highest system readiness coefficient after commissioning (0.96). These results are due to the design features of the technical solution – the GEA FeedBelt suspended rail feed distributor proved to be easier to install and debug, as it did not require a complex navigation system or additional equipment for charging batteries.

The most difficult implementation of the robotic system was on a farm in the Poltava region, where the largest number of devices (12) was installed, the longest communications (980 m) were laid, and the largest number of defects were found during commissioning (22). The Trioliet Triomatic WP 2300 mobile autonomous feed dispenser with a combined navigation system required precise calibration of computer vision sensors, which was complicated by existing layout restrictions in livestock buildings and the insufficient qualifications of local personnel.

An analysis of the duration of staff training showed a direct correlation between the complexity of the systems implemented and the time required to learn how to use them. The longest training programme was implemented on a farm in the Poltava region (64 hours), which corresponded to the high technical complexity of the Trioliet Triomatic WP 2300 system with 32 controlled parameters. For comparison, the training programme at a farm in the Vinnytsia region lasted only 40 hours, which was explained by the simpler interface of the GEA FeedBelt system.

The system readiness coefficient after commissioning ranged from 0.91 to 0.96, which indicated the high reliability of all implemented solutions. At the same time, the highest indicator was recorded at the farm in the Vinnytsia region (0.96), which was explained by the smaller number of moving parts and the absence of complex electronic components in the GEA FeedBelt suspended rail system compared to mobile autonomous robots at other farms. A critical component of the implementation of robotic feeding systems was the configuration of the navigation systems of mobile feed dispensers, in particular, the calibration of laser sensors and the placement of RFID tags. As a result of the work carried out, the optimal parameters of the navigation systems were established for each farm, which ensured the accuracy of the positioning of feed dispensers within ±3 cm.

Table 4. Technological efficiency of robotic feeding systems (average value for all farms)

Indicator	Traditional technology	Robotic technology	Difference, ±	Difference, %
Time spent feeding 100 heads, hours/day	5±0.42	1.2±0.11*	-3.8	-76
Energy consumption, kW•h/head/day	1.41±0.12	0.65±0.06*	-0.76	-53.9
Energy efficiency coefficient, %	56.3±3.24	85.1±3.96*	+28.8	+51.2
Accuracy of ration component dosing, %	81±2.74	97.8±0.42*	+16.8	+20.7
Feed mixing uniformity, %	75.5±2.81	94.2±0.83*	+18.7	+24.8
Feeding frequency, times/day	2.2±0.25	6.5±0.62*	+4.3	+195.5
Feed access time, hours/day	16.3±1.53	23.6±0.35*	+7.3	+44.8
Deviation from the specified diet, %	8.4±0.82	2.1±0.25*	-6.3	-75
Feed loss during distribution, %	4.2±0.48	1.3±0.18*	-2.9	-69
Labour costs for maintenance, person-hours/100 heads/day	3.2±0.31	0.8±0.09*	-2.4	-75
Reliability of operation (availability factor)	0.82±0.04	0.94±0.02*	+0.12	+14.6
Feed consumption, kg/head/day	42.3±2.11	45.8±1.85*	+3.5	+8.3
Total	-	-	-	-

Note: * – the difference is statistically significant at $p<0.05$; the statistical significance of the differences was assessed using Student's t-test
Source: results of comparative tests conducted by the authors, 2024.

Design and modelling of robotic feeding systems

The effectiveness of robotic feeding systems was assessed by comparative analysis of technological, physiological, and productivity indicators in control groups of animals. The use of a comparative testing methodology allowed for an objective assessment of the effect of introducing innovative technologies (Table 4).

The introduction of robotic feeding systems has significantly improved the technological efficiency of processes. According to the indicators shown in Table 4, feeding time has been reduced by 76%, energy consumption has been reduced by 53.9%, and energy efficiency has increased by 51.2% compared to traditional technologies. This pattern was explained by the optimisation of feed distributor routes, the use of energy-efficient drives, and intelligent control algorithms.

Significant improvements were observed in such technological parameters as the accuracy of ration component dosing (an increase of 20.7%) and the uniformity of feed mixing, which increased from 75.5% under traditional technology to 94.2% with robotic systems (an increase of 24.8%). This resulted in a 75% reduction in deviation from the specified ration and a reduction in feed losses during distribution from 4.2% under traditional technology to 1.3% with robotic systems (a decrease of 69%). The energy efficiency indicators achieved correlated with the research of Hruban *et al.* [17], which demonstrated the possibility of partial energy supply to

Table 5. Animal productivity when using different feeding technologies

Indicator	**Traditional technology**	**Robotic technology**	**Difference, ±**	**Difference, %**
Milk productivity (n=271)				
Average daily milk yield, kg	22.8±1.14	25.6±1.05*	+2.8	+12.3
Fat content in milk, %	3.82±0.11	3.88±0.09	+0.06	+1.6
Protein content in milk, %	3.25±0.08	3.34±0.07*	+0.09	+2.8
Somatic cell count, thousand/cm³	240±32	175±28*	-65	-27.1
Meat productivity (n=270)				
Average daily gain, g	950±48	1080±42*	+130	+13.7
Feed conversion, kg feed/kg gain	8.4±0.35	7.3±0.31*	-1.1	-13.1
Physiological indicators (n=541)				
Chewing duration, min/day	382±28	425±23*	+43	+11.3
Motor activity, points (1-10)	5.8±0.42	6.7±0.38*	+0.9	+15.5
Cases of acidosis, % of livestock	12.3±1.82	5.8±1.12*	-6.5	-52.8
Heart rate, beats/min.	72.4±3.12	69.8±2.87	-2.6	-3.6
Total	-	-	-	-

Note: * – the difference is statistically significant at $p<0.05$; the statistical significance of differences was assessed using Student's t-test

Source: data from biometric analysis of productive and physiological indicators of animals, conducted by the authors using biosensor monitoring, 2024.

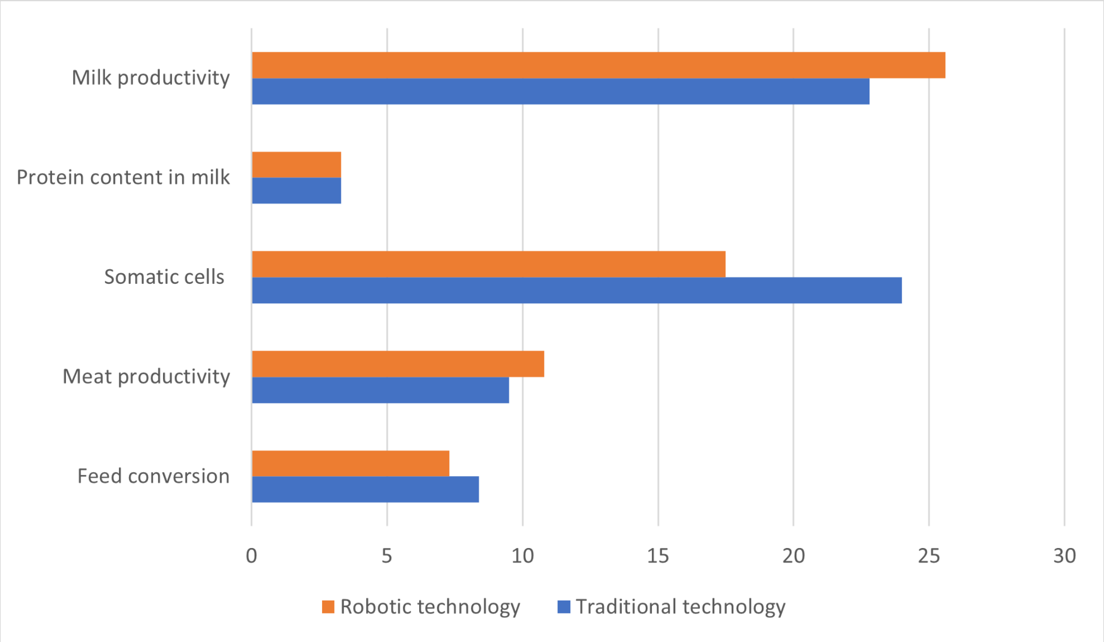

Figure 1. Change in animal productivity when applying robotic feeding systems

Source: compiled by the authors.

automated feeding systems through the use of biogas obtained from livestock waste, which further reduced operating costs by 18-22%.

Particular attention was drawn to the increase in feeding frequency from 2.2 to 6.5 times per day (by 195.5%) and the extension of feed access time from 16.3 to 23.6 hours/day (by 44.8%). These factors had a positive effect on the physiological processes of digestion in animals, which was confirmed by an 8.3% increase in feed consumption compared to traditional technology. A study of the impact of robotic systems on animal productivity showed an increase in average daily milk yield by 12.3% and average daily live weight gain by 13.7% compared to traditional feeding technologies (Table 5).

Improvements in milk quality indicators were observed, in particular, an increase in protein content by 2.8% and a decrease in somatic cell count by 27.1%. The use of robotic systems contributed to an improvement in the physiological indicators of animals, which manifested itself in an 11.3% increase in chewing time and a 52.8% decrease in cases of acidosis. Analysis of feed conversion rates showed that the introduction of robotic feeding systems increased feed efficiency by 13.1%. This was due to accurate dosing of diet components, better feed mixing, and more uniform feed consumption throughout the day. The results are illustrated in Figure 1.

Figure 1 demonstrates significant positive changes in productivity indicators when applying robotic feeding systems. Visual analysis confirms a reliable increase in milk productivity by 12.3%, protein content by 2.8%, meat productivity by 13.7%, and a decrease in feed conversion by 13.1% and somatic cell count by 27.1%. The largest relative increase is observed in meat productivity, which indicates the positive effect of uniform and accurate feeding on the development of meat animals.

Economic efficiency of implementing robotic systems

The economic efficiency of implementing robotic feeding systems was calculated using the methodology for evaluating investment projects in agriculture. For

Table 6. Economic efficiency of implementing robotic feeding systems

Indicator	**Farm in the Kyiv region**	**Farm in the Cherkasy region**	**Farm in the Vinnytsia region**	**Farm in the Poltava region**	**Average value**
Investment costs, UAH					
Cost of equipment, UAH	4,850	5,640	3,920	6,280	5,172.5
Installation and commissioning works, UAH	725	845	588	940	774.5
Staff training, UAH	125	148	96	165	133.5
Total investment costs, UAH	5,700	6,633	4,604	7,385	6,080.5
Investment costs per head, UAH	44.5	46.4	38.4	49.2	44.6
Annual operating indicators, thousand UAH/year					
Savings in labour costs, UAH/year	482	564	410	625	520.3
Savings in electricity costs, UAH/year	128	146	138	158	142.5
Savings in feed costs, UAH/year	356	398	324	445	380.8
Additional income from increased productivity, UAH/year	864	948	752	1,082	911.5
Reduction in veterinary service costs, UAH/year	124	142	110	168	136
Total annual economic effect, UAH/year	1,954	2,198	1,734	2,478	2,091
Indicators of economic efficiency					
Net present value, UAH	4,827	5,196	4,588	5,785	5,099
Internal rate of return, %	27.4	26.8	29.5	26.2	27.5
Discounted payback period, years	4.3	4.5	3.9	4.6	4.3
Investment profitability index	1.85	1.78	2	1.78	1.85
Return on investment, %	34.3	33.1	37.7	33.6	34.7
Total	-	-	-	-	-

Note: calculations were made using a discount rate of 14% and a forecast period of 10 years

Source: financial and economic analysis of investment projects conducted by the authors, 2024.

each farm, capital and operating costs were determined, projected income from increased animal productivity was calculated, and financial indicators of investment efficiency were calculated (Table 6).

Practical experience in implementing robotic systems on experimental farms has demonstrated varying economic efficiency depending on the model of equipment selected. On a farm in the Kyiv region, the implementation of the Lely Vector system (the Netherlands) required an investment of 5,700,000 UAH, but provided an annual economic effect of 1,954,000 UAH thanks to high process automation and minimisation of the human factor. The DeLaval OptiDuo system (Sweden) at a farm in the Cherkasy region demonstrated the highest annual economic effect (2,198,000 UAH) due to optimal productivity and energy efficiency, although the initial investment was higher (6,633,000 UAH).

The most economically efficient system was the GEA FeedBelt (Germany) system on a farm in the Vinnytsia region, which, with the lowest investment costs (4,604,000 UAH), provided the best return on investment (37.7%) and the shortest payback period (3.9 years). The suspended rail design of this system reduced installation and maintenance costs, and the programmable movement sequence ensured high reliability without a complex navigation system.

The Trioliet Triomatic WP 2300 system (the Netherlands) on a farm in the Poltava region, despite the highest investment costs (7,385,000 UAH), demonstrated the greatest annual economic effect (2,478,000 UAH) due to its high productivity (830 kg/hour) and versatility. The combined navigation system with laser sensors and computer vision allowed it to work effectively in difficult farm conditions with uneven surfaces and narrow passages.

An analysis of the investment costs for the implementation of robotic feeding systems showed that the average cost was 6,080,500 UAH per farm (44,600 UAH per head). The lowest specific costs were recorded in a farm in the Vinnytsia region (38.4 UAH/head) using a suspended rail system, and the highest in the Poltava region (49.2 UAH/head). The structure of the annual economic effect shows that the largest contribution was made by additional income from increased productivity (43.6%) and savings in labour costs (24.9%). Economic calculations confirm the feasibility of investments with an average payback period of 4.3 years, an internal rate of return of 27.5%, and a profitability index of 1.85.

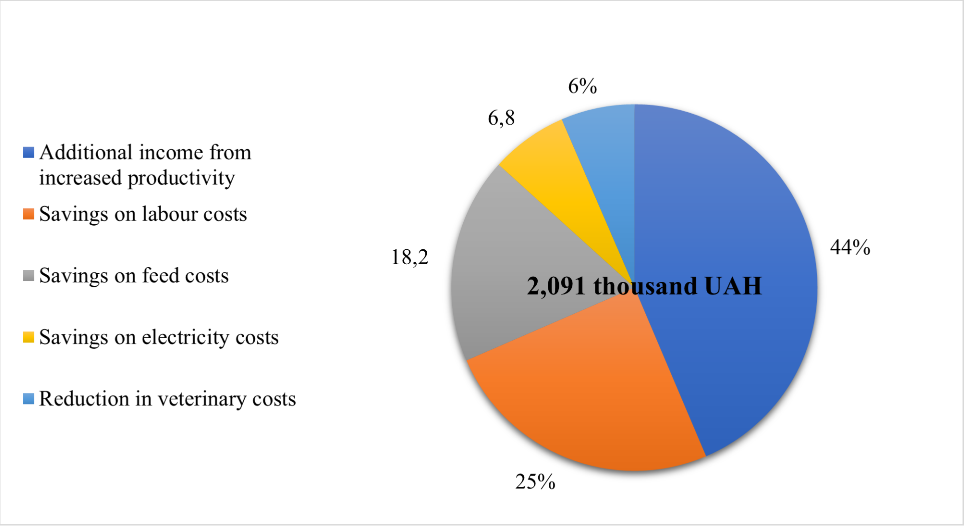

Figure 2. Structure of the annual economic effect of introducing robotic feeding systems

Source: results of an economic analysis conducted by the authors based on the annual financial statements of farms, 2024.

These results were consistent with the technological performance indicators of robotic systems and confirmed that the optimal selection of technical solutions, taking into account the specifics of a particular farm, ensured the highest economic efficiency of investments. The experience of a farm in the Vinnytsia region with the GEA FeedBelt system confirms the conclusions of European studies on the high efficiency of suspended systems for medium-sized farms, while mobile robots proved to be more appropriate for large farms with a branched infrastructure. The results are presented in Figure 2.

Figure 2 shows the structure of the annual economic effect of implementing robotic feeding systems. The diagram clearly shows that the largest share (43.6%) is additional income from increased animal productivity, followed by savings in labour costs (24.9%) and savings in feed costs (18.2%). A smaller contribution is provided by electricity savings (6.8%) and reduced veterinary costs (6.5%). The total annual economic effect is 2,091,000 UAH.

Table 7. Obstacles to the implementation of robotic feeding systems in Ukraine and ways to overcome them

Obstacle	Regions most affected	Impact on experimental farms	Solution applied
Technical obstacles			
Poor quality of internet connection in rural areas	Western and northern regions (Volyn, Rivne, Chernihiv, Sumy)	Delays in data transmission, interruptions in the monitoring system (Kyiv region)	Installation of local servers with periodic synchronisation, use of backup communication channels (4G/LTE modems)
Problems with the uninterrupted power supply	Rural areas in all regions, especially Chernihiv, Sumy, and Kherson	Risk of equipment failure, damage to electronic components (all farms)	Installation of uninterruptible power supply systems, backup generators, protective filters against voltage surges
Difficulty in adapting technologies to existing farm infrastructure	Farms with buildings from the Soviet period (all regions)	Need for significant renovation of premises (Poltava region)	Modular solutions with flexible configuration options, phased implementation with minimal interference with existing infrastructure
Economic obstacles			
High initial investment costs	All regions	Need to attract external financing (all farms)	Development of investment programmes with phased implementation, leasing schemes for equipment acquisition
Limited access to preferential lending	Small and medium-sized farms in all regions	Increased payback period due to high interest rates (Kyiv and Cherkasy regions)	Participation in state programmes to support the agro-industrial complex, and search for grant funding
Instability of energy prices	All regions	Risk of increased operating costs (all farms)	Implementation of energy-saving technologies, use of alternative energy sources (solar panels)
Organisational obstacles			
Insufficient coordination between equipment suppliers and farms	All regions	Delays in the supply of components, problems with servicing (Poltava region)	Creation of regional service centres, formation of a stock of critically important spare parts
Lack of standardisation of technical solutions	All regions	Problems with the integration of different systems (Cherkasy region)	Development of industry standards, use of equipment with open data exchange protocols
Limited availability of maintenance services	Remote regions (Zakarpattia, Volyn, Sumy regions)	Risk of prolonged downtime in case of breakdowns (Kyiv region)	Training of own technical personnel, conclusion of long-term service contracts
Personnel obstacles			
Insufficient training of personnel to work with high-tech equipment	All regions	Operational errors, inefficient use of system functionality (all farms)	Expanded staff training programme, involvement of specialists from related industries
Psychological resistance of personnel to the introduction of innovations	Farms with older staff (all regions)	Sabotage of automated systems (Poltava region)	Staff motivation system, demonstration of the advantages of new technologies, gradual implementation
Outflow of skilled personnel from rural areas	All regions, especially near large cities	Difficulty in recruiting personnel with the necessary skills (Kyiv region)	Creation of attractive working conditions, increase in wages, provision of housing

Source: results of a survey and interviews with managers and specialists at research farms conducted by the authors in 2024.

Table 8. Comparative analysis of conditions for the implementation of robotic feeding systems in Ukraine and EU countries

Indicator	Ukraine	Germany	The Netherlands	Denmark
Level of automation of livestock farms, %	12-15	65-70	80-85	75-80
Average investment per cow, EUR	1.2-1.5	2-2.2	2.2-2.5	2.1-2.3
Average lending rate for the agricultural sector, %	14-18	2-3	1.5-2.5	2-3
State support for innovation, % of cost	5-10	30-40	40-50	35-45
Availability of maintenance services (maximum response time), hours	24-72	2-6	1-4	2-6
Availability of qualified personnel (on a 10-point scale)	4-5	8-9	9-10	8-9
Technical infrastructure (quality of electricity supply, internet), points	5-6	9-10	9-10	9-10
Payback period for robotic systems, years	4-6	3-4	2-3	2.5-3.5
Total	-	-	-	-

Note: statistical significance of differences between groups was assessed using the Mann-Whitney U test
Source: comparative analysis data conducted by the authors based on Berckmans [20], Romano et al. [3], and Tedeschi et al. [1].

Obstacles and ways to implement robotic systems in Ukraine

A comparative analysis of the economic efficiency of introducing robotic feeding systems in different farms allowed to identify the main factors that influenced the return on investment: the initial level of technological equipment of the farm, animal productivity, the cost of labour and energy, the specifics of the technical solution, and the quality of its implementation. It was found that the most cost-effective implementation of robotic systems was on the farms with a livestock population of 100 to 150 heads, where the use of suspended rail systems provided the best ratio of investment costs to economic effect. An analysis of the obstacles to the implementation of robotic feeding systems in Ukraine revealed key limiting factors that needed to be addressed at the systemic level. All identified obstacles can be classified as technical, economic, organisational, and personnel-related (Table 7).

A comparison of the situation in Ukraine with highly developed EU countries (Germany, the Netherlands, Denmark), where the level of automation of livestock farms reached 70-85%, revealed significant differences in the conditions for the implementation of robotic systems (Table 8).

A comparative analysis of the data in Table 8 shows significant differences in the level of automation of livestock farms between Ukraine (12-15%) and EU countries (65-85%). This is due to significant differences in lending conditions (14-18% in Ukraine versus 1.5-3% in the EU), the amount of state support (5-10% of the cost in Ukraine versus 30-50% in the EU), as well as the quality of technical infrastructure and the availability of qualified personnel. At the same time, the average investment per cow in Ukraine (1.2-1.5 EUR) is lower than in EU countries (2-2.5 EUR), which is explained by the lower cost of labour and construction work.

Based on the research and international experience, a set of recommendations has been developed for the effective implementation of robotic feeding systems in Ukrainian farms: it is advisable to give priority to the use of suspended rail systems for farms with up to 150 head of cattle, with a simultaneous comprehensive approach to ensuring uninterrupted power supply; economic efficiency is increased by developing phased investment programmes and using leasing schemes for equipment procurement; an important measure is the creation of regional technical support centres and the formation of a stock of critically important spare parts; the successful implementation of robotic systems requires the development of comprehensive staff training programmes and the creation of a motivation system to encourage the adoption of new technologies.

Thus, the results of a comprehensive assessment of the technological and economic efficiency of robotic livestock feeding systems on experimental farms confirmed the feasibility of their implementation, despite significant initial investments. The key advantages of such systems were increased animal productivity, reduced labour and feed costs, improved animal physiological condition, and reduced incidence of disease.

Discussion

The results obtained from the implementation of robotic feeding systems on experimental farms demonstrated a significant increase in the accuracy of feed component dosing (up to 97.8%) compared to traditional methods (81%), which was crucial for ensuring balanced animal nutrition. The question of the optimal level of automation of feeding processes remained controversial in the scientific community, as evidenced by numerous studies with conflicting conclusions. On the one hand, Tedeschi *et al.* [1] emphasised the critical importance of full automation of feeding processes to achieve maximum accuracy in the dosing of feed components and eliminate the human factor, which was confirmed by their experimental data on a 12.6% reduction in the variability of feed mixture composition. On the other hand, Romano *et al.* [3] argued for the need to maintain a certain level of human control even in highly automated systems, based on the results of a survey of Italian farmers, 68% of whom reported cases of inadequate functioning of fully automated systems due to atypical situations and changes in animal behaviour. The methodological differences between these studies were that the first group of authors focused on the technical aspects of dosing accuracy, while the second took into account practical experience in operating the systems and the human factor. Empirical data from the study demonstrated the advantage of a hybrid approach, in which the main feeding processes are automated, but the operator retains the ability to intervene promptly based on the results of monitoring the physiological indicators of animals, which increased productivity by 12.3% for dairy and 13.7% for meat production.

The introduction of integrated sensor technologies for monitoring the physiological parameters of animals in combination with robotic feeding systems has led to a significant reduction in cases of acidosis by 52.8%. This has brought to the fore the scientific debate on the choice of optimal sensor technologies and methods for interpreting the data obtained. Research by Liu *et al.* [2] demonstrated the high efficiency of video analytics systems using computer vision algorithms to monitor animal behaviour and detect abnormalities in feed consumption, which enabled early detection of diseases and a 23.5% reduction in treatment costs. Siachos *et al.* [12] took the opposite position, emphasising the advantages of contact biosensors for monitoring physiological parameters, in particular heart rate, body temperature, and motor activity, which, according to their data, provided 18.7% higher accuracy in the diagnosis of diseases in the early stages compared to non-contact methods. The main difference in how these studies were done was that they used different ways to check how well they worked: the first group of authors mainly looked at economic indicators, while the second group focused on diagnostic accuracy. Comprehensive studies on a representative sample of Ukrainian livestock of different breeds and age groups have proven the feasibility of integrating both approaches: the use of video analytics for general monitoring of the behaviour of a group of animals and individual biosensors for high-precision control of the physiological parameters of animals with detected behavioural abnormalities.

The economic efficiency of implementing robotic feeding systems has been the subject of heated debate in contemporary scientific literature, reflecting different methodological approaches to assessing the return on investment in livestock automation. The study found an average discounted payback period for the implemented robotic systems of 4.3 years, which correlated with an internal rate of return of 27.5%. Similar results were obtained in studies by Fuentes *et al.* [6], who reported a payback period for robotic feeding systems of 2.8-3.5 years for European farms with more than 200 head of cattle, justifying the economic feasibility of implementing such systems even with high initial investments. The conclusions of Nehrey and Klymenko [5] differed significantly, as they, based on an analysis of Ukrainian agricultural enterprises, argued that under conditions of economic instability and limited access to capital, the payback period for robotic systems could reach 5-7 years, making such investments risky for medium and small farms. The methodological differences between these studies lay in their different approaches to accounting for risks and uncertainties: the first group of authors used deterministic models with fixed performance and price parameters, while the second used stochastic modelling that took into account market volatility and climate risks. Empirical data obtained under real operating conditions on farms of various sizes made it possible to determine that the most cost-effective implementation of robotic systems was on farms with a livestock population of 100 to 150 head, where the use of suspended rail systems provided the best ratio of investment costs to economic effect.

An additional important dimension influencing the implementation of robotic feeding systems is the regulatory and legislative framework governing the use of advanced technologies in agriculture [21-23]. In Ukraine, the adoption of such systems is regulated by a combination of general agricultural policies, technical safety standards, and emerging digitalisation strategies. However, the regulatory environment remains fragmented, particularly with regard to the certification of automated equipment, data protection in sensor-based monitoring systems, and the standardisation of digital platforms used in livestock management.

Compliance with international standards, including European Union regulations on machinery safety, animal welfare, and data handling, is becoming increasingly important, especially for farms aiming to integrate into global markets [24-27]. In this context, alignment with EU directives and technical standards can facilitate technology transfer and improve investment attractiveness. At the same time, the lack of clear national guidelines for the implementation and operation of robotic systems creates additional uncertainty for farm owners and investors.

Therefore, further development of a coherent regulatory framework, including certification procedures, operational standards, and support mechanisms for innovation, is essential for the large-scale adoption of robotic feeding systems in Ukraine. Addressing these issues would reduce implementation risks and enhance the practical applicability of advanced agricultural technologies.

Another critical aspect of the implementation of robotic feeding systems is the management of large volumes of data generated by sensor-based monitoring and automated control systems [28-32]. These systems continuously collect information on animal health, feeding behaviour, productivity, and environmental conditions, which raises important questions regarding data ownership, governance, and protection.

In practice, data ownership is often shared or unclear, particularly when equipment suppliers provide cloud-based platforms for data storage and analytics. This may limit farmers' control over their operational data and create dependency on proprietary technologies. In addition, the lack of unified standards for data management complicates the integration of different digital systems within a single farm.

Data protection is also becoming increasingly important, as unauthorised access or data loss may affect both economic performance and compliance with emerging regulatory requirements. Therefore, the development of clear policies on data ownership, secure data storage, and standardised data exchange protocols is essential for ensuring the sustainable and secure use of robotic technologies in agriculture.

The energy efficiency of robotic feeding systems, which, according to experimental measurements conducted on research farms, increased by 51.2% compared to traditional technologies, also became the subject of scientific debate. The measurement results showed that robotic systems reduced energy consumption from 1.41 to 0.65 kWh/head/day. Havrysh *et al.* [16] focused on the high energy consumption associated with the implementation of robotic systems due to the need for constant operation of sensors, controllers, and communication equipment, which, according to their calculations, could negate the energy benefits of automation on small farms with irregular feeding regimes. The methodological differences between these studies lay in their different approaches to accounting for indirect energy costs: the first group of authors focused on the direct energy consumption of equipment, while the second took into account the total energy balance, including the costs of manufacturing and disposing of components. Experimental data obtained through continuous monitoring of energy consumption at all stages of the technological process allowed us to conclude that a high level of energy efficiency was achieved only with a comprehensive approach that included optimisation of equipment designs, the use of energy-saving drives, and the implementation of intelligent control algorithms.

The reliability of the implemented robotic systems averaged 0.94 for different farms, which is significantly higher than the figures reported in previous years' studies. The issue of ensuring high reliability of automated systems in animal husbandry remained controversial due to different approaches to assessing fault tolerance and service organisation. Pawar *et al.* [8] emphasised the need to implement multi-level backup systems and self-diagnostic algorithms, which, according to the data provided, made it possible to achieve a system availability coefficient of 99.1%, minimising the risk of critical situations arising in the event of equipment failure. The opposite position was defended by Yin *et al.* [4], who argued that excessive redundancy was economically unfeasible due to the high cost of duplicate components and suggested focusing on improving equipment maintainability and reducing recovery time after failures, which allowed an acceptable level of reliability to be achieved at lower capital costs. The methodological differences between these studies lay in their different optimisation criteria: the first group of authors maximised technical reliability, while the second optimised the reliability-cost ratio. Experimental data obtained in real operating conditions, taking into account the specifics of Ukrainian farms, confirmed the effectiveness of a combined approach: the use of modular architecture with the ability to quickly replace failed components, redundancy of critical elements (navigation systems, software), and the introduction of predictive maintenance based on technical condition monitoring.

An important practical aspect of implementing robotic feeding systems is their ongoing maintenance and servicing requirements [33-35]. Based on the operational experience of the experimental farms, routine maintenance of robotic feeding systems is typically performed on a weekly and monthly basis, including inspection of mechanical components, calibration of sensors, and verification of navigation systems. More comprehensive servicing, including software updates and diagnostic testing of control units, is generally required every 6–12 months.

The most common components requiring replacement during operation include wear mechanical parts (conveyor elements, mixing augers, and drive belts), sensors (RFID tags, laser positioning modules, and biosensor interfaces), and energy supply elements such as batteries in mobile robotic systems [36-40]. The frequency of replacement depends on system load and environmental conditions, but typically ranges from 1 to 3 years for key components.

Operational maintenance costs were estimated to account for approximately 8–12% of the initial investment annually, including spare parts, servicing, and technical support. These costs should be considered when evaluating the long-term economic efficiency of robotic feeding systems, as they may influence the actual payback period under real farm conditions.

The development of automation systems in animal husbandry is accompanied by significant progress in related technological fields, as confirmed by research by Hordiichenko *et al.* [41], who developed a robotic system for manufacturing orthopaedic insoles with adaptive control algorithms similar to those used in automated feeding systems. The authors demonstrated that the implementation of a modular system architecture with 6 degrees of freedom and the use of controllers with high computing power resulted in a 28.5% increase in the accuracy of operations and a 41.2% reduction in equipment setup time compared to traditional systems. This experience can be valuable in the development of new generations of robotic feeding systems with extended functionality.

The importance of implementing artificial intelligence to optimise production processes was emphasised by

Kuchmiova *et al*. [42], who analysed 37 implementations of artificial intelligence systems in the agro-industrial sector of Ukraine. The authors found that the use of neural network algorithms to analyse biosensor data in animal husbandry increased the accuracy of disease prediction by 31.8% and optimised feeding rations by 24.6% compared to traditional decision support systems. These results demonstrate the promise of integrating artificial intelligence technologies with robotic feeding systems to further improve their efficiency.

The parameters of cattle husbandry and feeding technology using robotic milking were studied in detail by Marchenko *et al.* [43], who found that synchronising robotic milking and feeding systems provided an additional synergistic effect – an increase in milk productivity of 5.8-7.4% compared to the implementation of separate automated systems. The authors developed a mathematical model for optimising the functioning cycles of robotic systems, which took into account the natural rhythms of animal activity, allowing energy costs to be reduced by 17.3% while maintaining productivity levels. These data confirm the importance of a comprehensive approach to the automation of various technological processes on the farm.

The economic aspects of implementing automated systems in the context of reducing food waste were studied by Kotykova and Babych [44], who conducted a comparative analysis of economic losses from inefficient feed use in 28 European Union countries. The researchers found that the introduction of automated feeding systems reduced average annual feed losses by 14.8-18.5%, which in monetary terms amounted to between 237 EUR and 328 EUR per head of livestock, depending on the type of farm. The introduction of technologies for the precise dosing of feed components was particularly effective in medium-sized farms, confirming the study's findings on the optimal size of farms for the implementation of robotic systems.

The security aspects of implementing automated feeding systems were investigated by Pushak *et al.* [45], who developed a system for assessing the economic security of enterprises in the agricultural sector. The researchers found that investments in the automation of production processes amounting to more than 25% of the book value of fixed assets increased the vulnerability of the enterprise by 16-22% on a one-off basis, but in the long term (after 3-5 years) ensured a 34-41% reduction in the vulnerability index compared to enterprises that retained traditional technologies. These data explain the reasons for low investment activity in the field of livestock automation in Ukraine and confirm the need to develop long-term strategies for the technological modernisation of farms.

The energy aspects of biogas use in high-temperature heat technology complexes were studied by Koshelnik et al. [46], who developed an integrated energy supply system for livestock farms using biogas plants. The authors experimentally proved that the utilisation of livestock waste in biogas plants with cogeneration made it possible to meet up to 42% of the energy needs of robotic feeding systems, which reduced operating costs by 27.8% compared to traditional energy supply. These results demonstrate the promise of creating closed energy cycles on livestock farms, which will increase the economic efficiency of implementing robotic systems.

Research by Shahini *et al.* [47] on the rational use of oilseed waste to increase dairy productivity showed that the use of automated systems for the precise dosing of oilseed processing by-products (meal and cake) in cow diets resulted in a 7.2-9. 5% while reducing the cost of rations by 12.4-16.8%. The authors developed an algorithm for optimising the composition of rations, taking into account the availability and nutritional value of regional feed resources, which can be integrated into the software of robotic feeding systems to increase their economic efficiency.

The prospects for the use of modern sensors and automated monitoring of feed consumption by pigs were investigated by Tryhuba *et al.* [48], who conducted a comparative analysis of different types of sensor systems. The researchers found that the highest accuracy in measuring feed consumption parameters (98.2%) was provided by systems with combined optical and weight sensors integrated with machine learning algorithms based on gradient boosting. Such systems made it possible to determine the individual characteristics of animal feeding behaviour and automatically adjust feeding regimes, which resulted in an increase in average daily gains of 5.8-7.3% and a reduction in feed conversion of 8.2-9.6%. These results confirm the high potential of personalised feeding using intelligent algorithms.

Yaremchuk *et al.* [49] studied the effect of corrective rations with protein-vitamin premixes on the meat productivity of bull calves. They established that the dosing accuracy of premixes using automated feeding systems increased meat productivity by 9.7-11.2% and improved the chemical composition of muscle tissue (raising protein content by 3.5-4.2%, and reducing fat content by 1.2-1.8%). The authors developed a methodology for calculating optimal premix formulations, considering the breed and age characteristics of the animals, which can be integrated into the control algorithms of robotic feeding systems to maximise their effectiveness.

The practical experience of introducing robotic feeding systems on European farms was summarised in a study by NWF Agriculture [50], which analysed the operational results of various automated systems in 75 farms across the United Kingdom. They found that systems with automatic ration composition adjustment based on real-time milk yield and feedstuff analysis data provided the highest return on investment (ROI ranging from 18.5% to 22.3%). The implementation of such systems was particularly effective on farms with 80-150 cows, which correlates with the results obtained on Ukrainian farms.

A study by Berckmans [20] on precision livestock farming technologies for welfare management in intensive housing systems demonstrated that the integration of automated feeding systems with animal physiological monitoring technologies significantly improved welfare parameters (by 23.8-31.5% on the Welfare Quality® integrated scale). The authors developed a system for assessing animal welfare based on a comprehensive analysis of biosensor data and feed consumption parameters. This allowed for the early detection of problems and the prevention of productivity losses. These results confirm that the implementation of robotic feeding systems contributes not only to increased economic efficiency but also to improved animal welfare.

The conducted research has proven the effectiveness of implementing robotic livestock feeding systems on Ukrainian farms. It provides scientifically-backed solutions to contentious issues regarding the level of automation, the selection of sensor technologies, economic viability, energy efficiency, and reliability. The experimentally established optimal parameters of robotic systems and the conditions for their effective use allowed for the formulation of differentiated recommendations for farms of various types and sizes, thereby accelerating the technological modernisation of livestock farming in Ukraine.

Conclusions

A comprehensive study of the effectiveness of using robotics to automate livestock feeding on four farms in different regions of Ukraine confirmed the technological and economic feasibility of implementing such systems. An analysis of traditional technologies revealed low energy efficiency (56.3%), insufficient accuracy of component dosing (81%), and uneven mixing of feed (75.5%). The developed and implemented robotic solutions ensured an increase in technological indicators: dosing accuracy up to 97.8%, mixing uniformity up to 94.2%, and energy efficiency up to 85.1%. The best results were demonstrated by a system with a suspended rail feed dispenser in the Vinnytsia region with a readiness coefficient of 0.96. The introduction of automated systems has significantly affected animal productivity, ensuring a 12.3% increase in average daily milk yield, a 13.7% increase in live weight, and a 13.1% improvement in feed conversion. Increasing the feeding frequency from 2.2 to 6.5 times per day and the duration of access to feed from 16.3 to 23.6 hours per day contributed to the improvement of physiological indicators: chewing duration (by 11.3%) and a decrease in cases of acidosis (by 52.8%).

Economic efficiency was characterised by an average annual economic effect of 2,091,000 UAH per farm with investment costs of 44.6 UAH per head. The main components of the economic effect were additional income from increased productivity (43.6%) and savings in labour costs (24.9%). The average payback period was 4.3 years with an internal rate of return of 27.5%. The most profitable was the introduction of suspended rail systems in farms with a livestock population of 100-150 heads.

An analysis of the obstacles to the implementation of robotic systems in Ukraine revealed technical (poor infrastructure quality), economic (high investment costs), organisational (low standardisation), and human resource (insufficient staff training) constraints. A comparison with the experience of EU countries showed significant potential for the development of automation in Ukraine if the identified problems are solved. Prospects for further research include the development of methods for integrating robotic feeding systems with other automated processes on farms and the optimisation of control algorithms using artificial intelligence technologies.

References

[1] Tedeschi LO, Greenwood PL, Halachmi I. Advancements in sensor technology and decision support intelligent tools to assist smart livestock farming. *Journal of Animal Science.* 2021, 99(2), skab038. https://doi.org/10.1093/jas/skab038

[2] Liu N, Qi J, An X, Wang Y. A review on information technologies applicable to precision dairy farming: Focus on behavior, health monitoring, and the precise feeding of dairy cows. *Agriculture.* 2023, 13(10), 1858. https://doi.org/10.3390/agriculture13101858

[3] Romano E, Brambilla M, Cutini M, Giovinazzo S, Lazzari A, Calcante A, Tangorra FM, Rossi P, Motta A, Bisaglia C, Bragaglio A. Increased cattle feeding precision from automatic feeding systems: Considerations on technology spread and farm level perceived advantages in Italy. *Animals.* 2023, 13(21), 3382. https://doi.org/10.3390/ani13213382

[4] Yin M, Ma R, Luo H, Li J, Zhao Q, Zhang M. Non-contact sensing technology enables precision livestock farming in smart farms. *Computers and Electronics in Agriculture.* 2023, 212, 108171. https://doi.org/10.1016/j.compag.2023.108171

[5] Nehrey MV, Klymenko NA. Digital transformation of agriculture: analysis of the agro-technological landscape of Ukraine. *Agrosvit.* 2024, 5, 61–69. https://doi.org/10.32702/2306-6792.2024.5.61

[6] Fuentes S, Gonzalez Viejo C, Tongson E, Dunshea FR. The livestock farming digital transformation: Implementation of new and emerging technologies using artificial intelligence. *Animal Health Research Reviews.* 2022, 23(1), 59–71. https://doi.org/10.1017/S1466252321000177

[7] Hajiyeva A, Mammadova U, Tanriverdiyeva G, Kovalenko O. Technological innovations in agriculture: Impact on production efficiency. *Scientific Horizons.* 2024, 27(1), 172–182. https://doi.org/10.48077/scihor1.2024.172

[8] Pawar J, Sonavale R, Sarkale PS. Transforming cattle farming with artificial intelligence: Innovations, applications, and implications for precision livestock management and sustainable agriculture practices. *Revista Electronica De Veterinaria*. 2024, 25(1), 525–537.

[9] Si Q. Advancements in precision livestock farming: Technologies and applications. *Animal Molecular Breeding*. 2024, 14(2), 130–140. https://doi.org/10.5376/amb.2024.14.0020

[10] Atamanyuk I, Kondratenko Y, Sirenko N. Management system for agricultural enterprise on the basis of its

economic state forecasting. In: Berger-Vachon C, Gil Lafuente A, Kacprzyk J, Kondratenko Y, Merigó J, Morabito C (Eds.), *Complex Systems: Solutions and Challenges in Economics, Management and Engineering* (pp. 453–470). Cham: Springer, 2018. https://doi.org/10.1007/978-3-319-69989-9_27

[11] Liu H, Reibman AR, Boerman JP. Video analytic system for detecting cow structure. *Computers and Electronics in Agriculture*. 2020, 178, 105761. https://doi.org/10.1016/j.compag.2020.105761

[12] Siachos N, Neary JM, Smith RF. Automated dairy cattle lameness detection utilizing the power of artificial intelligence; current status quo and future research opportunities. *Veterinary Journal.* 2024, 304, 106091. https://doi.org/10.1016/j.tvjl.2024.106091

[13] Chelotti J, Martinez-Rau L, Ferrero M, Vignolo L, Galli J, Planisich A, Rufiner HL, Giovanini L. Livestock feeding behaviour: A review on automated systems for ruminant monitoring. 2023. https://doi.org/10.48550/arXiv.2312.09259

[14] Shigimaga V, Kosulina N, Chorna M, Sukhin V, Kosulin S, Korshunov K, Yevsyukov Y. Automated technology of measurement of physiological parameters of farm animals. *Automation of Technological and Business Processes.* 2024, 16(3), 49–58. https://doi.org/10.15673/atbp.v16i3.2919

[15] Vlaicu PA, Gras MA, Untea AE, Lefter NA, Rotar MC. Advancing livestock technology: intelligent systemization for enhanced productivity, welfare, and sustainability. *AgriEngineering*. 2024, 6(2), 1479–1496. https://doi.org/10.3390/agriengineering6020084

[16] Havrysh V, Kalinichenko A, Brzozowska A, Stebila J. Agricultural residue management for sustainable power generation: The Poland case study. *Applied Sciences*. 2021, 11(13), 5907. https://doi.org/10.3390/app11135907

[17] Hruban V, Honcharenko I, Martynenko V, Sadovoy O. Obtaining electricity through the use of biogas, investments and perspectives. In: *Proceedings of the 5th International Conference on Modern Electrical and Energy System.* Kremenchuk: IEEE, 2023. https://doi.org/10.1109/mees61502.2023.10402480

[18] European Convention for the Protection of Vertebrate Animals used for Experimental and other Scientific Purposes. 1986, March. https://rm.coe.int/168007a67b

[19] Park D, Hoshi Y, Mahajan HP, Kim HK, Erickson Z, Rogers WA, Kemp CC. Active robot-assisted feeding with a general-purpose mobile manipulator: Design, evaluation, and lessons learned. *Robotics and Autonomous Systems.* 2020, 124, 103344. https://doi.org/10.1016/j.robot.2019.103344

[20] Berckmans D. Precision livestock farming technologies for welfare management in intensive livestock systems. *Revue Scientifique et Technique.* 2014, 33(1), 189–196. https://doi.org/10.20506/rst.33.1.2273

[21] Sargentis G-F, Lagaros ND, Cascella GL, Koutsoyiannis D. Threats in Water–Energy–Food–Land Nexus by the 2022 Military and Economic Conflict. *Land.* 2022, 11(9), 1569. https://doi.org/10.3390/land11091569

[22] Bulgakov V, Ivanovs S, Adamchuk V, Ihnatiev Y. Investigation of the influence of the parameters of the experimental spiral potato heap separator on the quality of work. *Agronomy Research.* 2017, 15(1), 44–54. https://agronomy.emu.ee/wp-content/uploads/2017/03/Vol15Nr1_Bulgakov.pdf

[23] Hussain K, Khan NA, Vambol V, Vambol S, Yeremenko S, Sydorenko V. Advancement in Ozone base wastewater treatment technologies: Brief review. *Ecological Questions*. 2022, 33(2). https://doi.org/10.12775/EQ.2022.010

[24] Dahan E, Aviv I, Kiperberg M. Trust Domain Extensions Guest Fuzzing Framework for Security Vulnerability Detection. *Mathematics.* 2025, 13(11), 1879. https://doi.org/10.3390/math13111879

[25] Wójcik W, Kalizhanova A, Kulyk YA, Knysh BP, Kvyetnyy RN, Kulyk AI, Sichko TV, Dumenko VP, Bezstmertna OV, Adikhanova S, Zhassandykyzy M, Junisbekov M, Smailov N, Yussupova G. The Method of Time Distribution for Environment Monitoring Using Unmanned Aerial Vehicles According to an Inverse Priority. *Journal of Ecological Engineering*. 2022, 23(11), 179–187. https://doi.org/10.12911/22998993/153458

[26] Sasi S, Subbu SBV, Manoharan P, Abualigah L. Design and implementation of secured file delivery protocol using enhanced elliptic curve cryptography for class I and class II transactions. *Journal of Autonomous Intelligence.* 2023, 6(3). https://doi.org/10.32629/jai.v6i3.740

[27] Orazbayev B, Kozhakhmetova D, Orazbayeva K, Utenova B. Approach to modeling and control of operational modes for chemical and engineering system based on various information. *Applied Mathematics and Information Sciences.* 2020, 14(4), 547–556. https://doi.org/10.18576/AMIS/140403

[28] Bisenovna KA, Ashatuly SA, Beibutovna LZ, Yesilbayuly KS, Zagievna AA, Galymbekovna MZ, Oralkhanuly OB. Improving the efficiency of food supplies for a trading company based on an artificial neural network. *International Journal of Electrical and Computer Engineering.* 2024, 14(4), 4407–4417. https://doi.org/10.11591/ijece.v14i4.pp4407-4417

[29] Kengesbayeva S, Razaque A, Smailov N, Kalpeyeva Z, Kabievna UR. Optimizing Resource Allocation for 5G Internet-of-Things Networks Using Machine Learning Techniques. In: *2025 IEEE 1st Secure and Trustworthy Cyberinfrastructure for IoT and Microelectronics, SATC 2025 - Conference Proceedings.* Dayton: Institute of Electrical and Electronics Engineers, 2025. https://jglobal.jst.go.jp/en/detail?JGLOBAL_ID=202502256096185261

[30] Biluk I, Shareyko D, Fomenko A, Havrylov S, Savchenko O, Hruban V. Adaptive Control in Complete Electric Drives. In: *Proceedings of the 25th IEEE International Conference on Problems of Automated Electric Drive. Theory and Practice,* PAEP 2020. Kremenchuk: Institute of Electrical and Electronics Engineers, 2020. https://doi.org/10.1109/PAEP49887.2020.9240856

[31] Aswatha AR, Sasi S, Santhosh B, Mehta D, Babuprasad S. Design and Implementation of Unreliable CFDP Protocol over Elliptic Curve Cryptography. *Smart Innovation, Systems and Technologies*. 2020, 160, 627–638. https://doi.org/10.1007/978-981-32-9690-9_68

[32] Brescia E, Costantino D, Marzo F, Massenio PR, Cascella GL, Naso D. Automated multistep parameter identification of spmsms in large-scale applications using cloud computing resources. *Sensors.* 2021, 21(14), 4699. https://doi.org/10.3390/s21144699

[33] Rubino L, Rubino G, Conti P. Design of a power system supervisory control with linear optimization for electrical load management in an aircraft on-board dc microgrid. *Sustainability (Switzerland)*. 2021, 13(15), 8580. https://doi.org/10.3390/su13158580

[34] Biliuk I, Shareyko D, Savchenko O, Havrylov S, Mardziavko V, Fomenko L. Tracking System of a Micromanipulator Based on a Piezoelectric Motor. In: *Proceedings of the 5th International Conference on Modern Electrical and Energy System,* MEES 2023. Kremenchuk: Institute of Electrical and Electronics Engineers, 2023. https://doi.org/10.1109/MEES61502.2023.10402375

[35] Karimzada O, De Donato G. Design and Verification of a GaN-Based, Single Stage, Grid-Connected Three-Phase PV Inverter. *IEEE Transactions on Power Electronics.* 2025, 40(4), 5496–5504. https://doi.org/10.1109/TPEL.2024.3511270

[36] Rubino G, Tomassi G, Ciprini L, Ali S, Marignetti F. Speed Sensorless Control based on Luenberger Observer for DC Motors. In: *2022 2nd International Conference on Sustainable Mobility Applications, Renewables and Technology,* SMART 2022. Cassino: Institute of Electrical and Electronics Engineers, 2022. https://doi.org/10.1109/SMART55236.2022.9990558

[37] Kondratenko Y, Gerasin O, Topalov A. A simulation model for robot's slip displacement sensors. *International Journal of Computing.* 2016, 15(4), 224–236. https://doi.org/10.47839/ijc.15.4.854

[38] Petrov N, Sydykova G, Dimitrova K, Gospodinova E, Tlegenov A, Shegenbaeva R. Study of the sustainability of functioning of electronic apparatus. *AIP Conference Proceedings*. 2023, 2889(1), 050006. https://doi.org/10.47839/ijc.15.4.854 10.1063/5.0173012

[39] Korobko B. Investigation of energy consumption in the course of plastering machine's work. *Eastern-European Journal of Enterprise Technologies.* 2016, 4(8-82), 4–11. https://doi.org/10.47839/ijc.15.4.854 10.15587/1729-4061.2016.73336

[40] Panchenko A, Voloshina A, Antoshchenkov R, Halych I, Głowacki S. Experimental Studies of the Wear on the Rotors' Working Surfaces of a Planetary Hydraulic Motor. In: *Lecture Notes in Mechanical Engineering*. Cham: Springer, 2024. https://doi.org/10.1007/978-3-031-42778-7_46

[41] Hordiichenko OV, Tkachuk AH, Dobrzhanskyi OO, Bohoyavlenska YuV, Bohdanovskyi MV. Robotic system for manufacturing footwear insoles. *Technical Engineering.* 2024, 94(2), 53–60. https://doi.org/10.26642/ten-2024-2(94)-53-60

[42] Kuchmiiova T, Moroz T, Sheshunova A. Use of artificial intelligence in agriculture. *Modern Economics.* 2023, 39, 69–74. https://doi.org/10.31521/modecon.V39(2023)-10

[43] Marchenko VA, Grebin LG, Trishin OK, Chigrinov EI. Parameters of technology for keeping and feeding cattle using robotic milking of cows. *Scientific and Technical Bulletin of IT NAAS.* 2021, 126, 70–79. https://doi.org/10.32900/2312-8402-2021-126-70-79

[44] Kotykova O, Babych M. Economic impact of food loss and waste. *AGRIS on-line Papers in Economics and Informatics.* 2019, 11(3), 55–71.

[45] Pushak Y, Lagodiienko V, Basiurkina N, Nemchenko V, Lagodiienko N. Formation the system for assessing the economic security of enterprise in the agricultural sector. *Business: Theory and Practice.* 2021, 22(1), 80–90. https://doi.org/10.3846/btp.2021.13013

[46] Koshelnik O, Puhachova T, Kruhliakova O, Pavlova V, Martynenko V, Tarasenko O. Prospects of biogas for high-temperature heat-technological complexes in glass industry. In: *Proceedings of the 5th International Conference on Modern Electrical and Energy System.* Kremenchuk: IEEE, 2023. https://doi.org/10.1109/mees61502.2023.10402452

[47] Shahini E, Havrysh V, Zakharin V, Mordechai S, Komar A, Chen G. Rational use of oilseed waste to increase dairy productivity. *International Journal of Environmental Studies.* 2022, 80(2), 442–450. https://doi.org/10.1080/00207233.2022.2147727

[48] Tryhuba A, Savka A, Tatomyr A, Padiuka R, Boiarchuk O. Analysis of modern sensors and the feasibility of automated monitoring of feed consumption by pigs on farms. *Bulletin of Lviv National Environmental University. Series Agroengineering Research.* 2024, 27, 43–50. https://doi.org/10.31734/agroengineering2023.27.043

[49] Yaremchuk OS, Razanova OP, Skoromna OI, Chudak RA, Holubenko TL, Kravchenko OO. Post-slaughter indicators of meat productivity and chemical composition of the muscular tissues of bulls receiving corrective diet with protein-vitamin premix. *Regulatory Mechanisms in Biosystems.* 2022, 13(3), 219–224. https://doi.org/10.15421/022228

[50] NWF Agriculture. Robot Feeding Technology. 2021. https://www.nwfagriculture.co.uk/robot-feeding-technology/

Izvod

PRIMENA ROBOTIKE ZA AUTOMATIZACIJU ISHRANE STOKE I UPRAVLJANJA FARMAMA

Volodymyr Martynenko[1], Vitalii Sokolik[2], Vladislav Plackanov[3]

[1]Departman za elektroenergetiku, elektrotehniku i elektromehaniku, Nikolajevski nacionalni agrarni univerzitet, Nikolajev, Ukrajina
[2]Nikolajevski nacionalni agrarni univerzitet, Nikolajev, Ukrajina
[3]Tehnološko-ekonomski stručni koledž Nikolajevskog nacionalnog agrarnog univerziteta, Nikolajev, Ukrajina

(ORIGINAL SCIENTIFIC PAPER)
UDK: 007.52:636
636:338.439
DOI: 10.5937/savteh2601026M

Cilj istraživanja bio je da se proceni efikasnost primene robotike za automatizaciju ishrane stoke i upravljanja farmama u Ukrajini. Metodologija je zasnovana na sveobuhvatnom pristupu koji kombinuje metode merenja vremena, energetskog audita i ekonomske analize na četiri poljoprivredna preduzeća u Kijevskoj, Čerkaskoj, Vinjičkoj i Poltavskoj oblasti. Korišćeni su računarsko modelovanje (MATLAB Simulink), biosenzorski monitoring životinja i napredne statističke metode (GPower, Šapiro–Vilk kriterijum). Istraživanje je pokazalo da je uvođenje robotskih sistema za hranjenje povećalo tačnost doziranja komponenti hrane za 20,7%, ujednačenost mešanja hrane za 24,8%, smanjilo troškove energije za 53,9% i povećalo produktivnost životinja za 12,3–13,7%. Ekonomska opravdanost potvrđena je prosečnim periodom povraćaja investicije od 4,3 godine, internom stopom rentabilnosti od 27,5%, povraćajem investicije od 34,7% i indeksom profitabilnosti od 1,85. Utvrđeno je da je najisplativije rešenje uvođenje robotskih sistema na farmama sa stočnim fondom od 100 do 150 grla, gde primena visećih šinskih sistema obezbeđuje najbolji odnos investicionih troškova i ekonomske koristi. Rezultati istraživanja imaju neposredan praktični značaj za modernizaciju stočarskih farmi u Ukrajini i mogu se koristiti kao osnova za razvoj državnih programa podrške tehnološkoj modernizaciji u poljoprivrednom sektoru.

Ključne reči: robotski sistemi za hranjenje, precizno stočarstvo, senzorske tehnologije, ekonomska efikasnost, automatizacija stočarstva, inteligentni algoritmi

CRediT authorship contribution statement:
Volodymyr Martynenko: Conceptualization, study design, supervision, data curation, writing – original draft preparation.
Vitalii Sokolik: Investigation, data collection, data analysis, visualization, writing – review and editing.
Vladislav Plackanov: Data collection, statistical analysis, preparation of figures and tables, writing – review and editing.