METROLOGY AND MEASUREMENT-INFORMATION SYSTEMS IN SMART AGRICULTURE WITH THE APPLICATION OF ARTIFICIAL INTELLIGENCE

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ABSTRACT

One area of dynamic development in modern technological trends is smart agriculture with the application of artificial intelligence algorithms. Elements that are often overlooked in this type of development, which represent some of the key challenges of the smart agriculture concept as well as artificial intelligence algorithms, include the metrological characteristics of smart agriculture systems and the quality of measured data, which serve as input for artificial intelligence algorithms. This paper presents the mentioned concepts and discusses the outlined challenges. The study was conducted on two simulations using artificial intelligence module in one and traditional agricultural production model in the other. By comparing the results of these two simulations, appropriate results and conclusions were reached about the potentials and benefits of using artificial intelligence in precision agriculture.

INTRODUCTION

When we consider the application of information technologies in conjunction with metrological principles through the prism of the economy, the first thing that comes to mind is precision agriculture. Precision agriculture, as part of Industry 4.0, represents a true revelation and innovation. This new technology not only integrates the principles of the economy, agrarian economy, and information technologies, but also metrology.

In every field, including agriculture, agrarian and processing industries, the measure or unit of measure is of great importance. It determines whether you are in the positive or negative balance, and in agriculture, this is of enormous significance. The calibration of sensor systems and models applied in precision agriculture and smart villages represents one of the best examples of the application of information technologies and metrology in economic science and industry.

This is particularly evident today, as the prices of agricultural products are rising. When the "breadbasket of Europe," as Ukraine is called, is in a state of war. Food and agricultural supply chains were disrupted to such an extent that food prices drastically increased. Precision agriculture is now being implemented by countries that are not known for agricultural exports, such as China and Russia, which have become significantly food independent thanks to new technologies.

Artificial intelligence is slowly becoming part of our everyday lives, in the economy, agriculture, scientific research, medicine, ecology, and energy management, indicating the necessity of understanding the rules and tools for using this incredible resource. The advantages of artificial intelligence include incredible time savings and resource optimization in performing daily tasks in numerous economic and general social areas, where we could not even imagine that machines would replace humans. I would emphasize the significant importance of artificial intelligence in education, especially in lifelong learning, as artificial intelligence enables us to obtain reliable information, data, facts, and knowledge in a matter of seconds. The resource savings that can be obtained, for example in time, and time is an irreplaceable resource, are enormous.

From acceleration, automation, greater efficiency and effectiveness in work, learning, creativity, generating ideas, access to information and data via the Internet, to creating websites and basic program codes for applications and software, this innovation represents a revolutionary solution for elevating human intellectual processes to a higher level, saving time in performing mental, but also physical efforts primarily. In the era of acceleration and globalization, as well as multidisciplinarity and interdisciplinarity, artificial intelligence represents a significant resource.

The paper presents research that the authors conducted by developing code in the C# programming language as part of a script for a Unity simulation/game that includes an agent moving through different zones and performing certain actions. The script includes functions for initializing zone colors, moving the agent to the next position, checking if the agent is stuck, and updating the target zone. In addition, the code based on the UnityEngine.AI programming module, which applies certain functions of artificial intelligence in the Unity software environment, calculates the total distance traveled, total time, and average speed of the agent by applying the concept of feedback.

CLASSES AND SIMULATION METHODS

In our research on simulating fertilization of agricultural land covering an area of one acre, several classes and methods of the UnityEngine.AI module were utilized. The classes and methods from UnityEngine.AI include the following:

1. NavMeshAgent: Used for setting the destination by employing agent.SetDestination(targetPosition) to move the agent to a specific position.
2. Adjusting Speed: Dynamically adjusted in the Update method based on performance metrics.
3. Remaining Distance: Checked in the Update method to determine if the agent has reached the destination.

4. Path Calculation (Vector3, NavMeshPath): Used in the SetTargetPosition method to calculate the path to the target position.

Additionally, the NavMeshPath is used for:

1. Initialization: Creating a new NavMeshPath object in the SetTargetPosition method.
2. Status Check: Verifying if the calculated path is complete (NavMeshPathStatus.PathComplete).

The mentioned code utilizes the UnityEngine.AI module to implement a feedback mechanism for adjusting the speed of the NavMeshAgent based on the remaining distance and elapsed time. The feedback mechanism for adjusting the speed of the NavMeshAgent is implemented in the Update method and the CalculateSpeed method.

The Update method performs the following tasks:

1. If the target zone is fertilized, it calls MoveToOptimalZone() to find a new target zone.
2. Sets the agent's speed using agent.speed = currentSpeed.
3. Calculates averageSpeed based on recorded speeds.
4. Checks if the agent has reached the destination and updates the status of the target zone as needed.
5. Updates maximumSpeed and minimumSpeed based on the current speed.
6. The CalculateSpeed method adjusts the agent's speed based on the total distance traveled and elapsed time.
7. Calculates distanceFactor as 1.0f - (totalDistance / 1000), reducing speed as the total distance increases.
8. Calculates timeFactor as 1.0f - (Time.time / 400), reducing speed as time passes.

The speed adjustment based on feedback combines distanceFactor and timeFactor to calculate adjustedSpeed. In this case, the UnityEngine.AI module is applied to control the movement of the NavMeshAgent and implements a feedback mechanism to adjust the agent's speed based on the remaining distance and elapsed time. The properties and methods of NavMeshAgent are used to set destinations, calculate agent movement paths, and dynamically adjust speed to ensure efficient navigation and performance.

RESEARCH METHODOLOGY

Regarding the methodology used in the development of this work, significant literature from the young but penetrating field of information technologies was employed. The scientific hypothesis method, experiment method, analysis and synthesis methods, as well as the observation method were utilized. The fundamental hypothesis in the work is that simulation technology using a method based on the artificial intelligence module UnityEngine.AI can significantly optimize and rationalize the use of resources in agricultural production (in this case, precise fertilizer application to agricultural land zones based on yield rates from previous years, environmental protection, and rationalization and optimization of time, as the most significant resource).

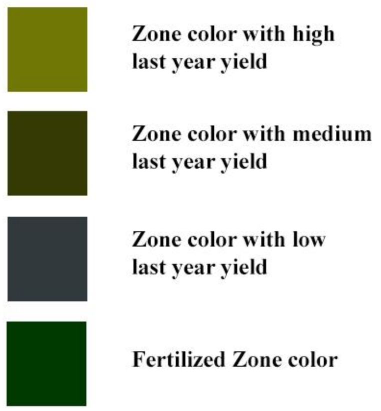
From qualitative methods, we employed the comparative method, programming methods, observation method, and forecasting method. The conducted research also utilized the experiment method, as demonstrated in the given study. Two simulations of agricultural production were developed through the experiment method. Specifically, the simulation with optimized process of fertilizing agricultural land divided into 100 zones with different yield characteristics from the previous year, and a simulation without the application of artificial intelligence, i.e. traditional sequential fertilization processes.

Based on the yield rate from the previous year, artificial intelligence incorporated into the simulation applies optimization of the movement path of the object or Agent simulation for the fastest and shortest distance fertilization. The primary process, as set through the program code, first fertilizes the zones with the highest yield rates from the previous year (yields above 70%, randomly assigned to specific zones), then with the average yield rate (from 30 to 70%, also randomly assigned to individual zones), and finally with the lowest yield rate (below 30% in random zones).

Using the analysis method, we considered a hypothetical agricultural land covering an area of one acre divided into 100 zones of equal dimensions (one meter by one meter) with randomly selected yield rates from the previous year. We also analyzed the optimization of the fertilization process in terms of distance covered and time spent compared to the second simulation we developed. The second simulation has the same characteristics in terms of agricultural land covering an area of one acre but is fertilized sequentially, from the first to the last closest zone without the influence of the previous yield rate. A comparison and analysis were conducted on the measured distance covered, time required for fertilizing agricultural land in both simulations, and the average speed developed.

In the simulation using artificial intelligence, the speed is variable and determined based on feedback. Elements affecting the variable speed, including maximum, minimum, and average, are determined by the remaining distance for fertilizing the entire agricultural land and the elapsed time from the beginning of the fertilization process. As the remaining distance decreases, the Agent's speed decreases. With the passage of time, the Agent's speed also decreases. By analyzing these elements and comprehensively understanding artificial intelligence and its complex functioning, together with the simulation implementing these principles, results can provide insights into better functioning and optimization of the agricultural process.

The significance goes beyond market demand and sales deadlines in the sense that timely fertilization can ensure that crops are ready for harvest at the optimal time, maximizing market value and profitability. Early fertilization can give crops a competitive advantage over weeds. Healthy, fast-growing crops can outperform weeds in the competition for resources, reducing the need for herbicides and weeding.



Picture 1 Color of the Zones during fertilization simulation

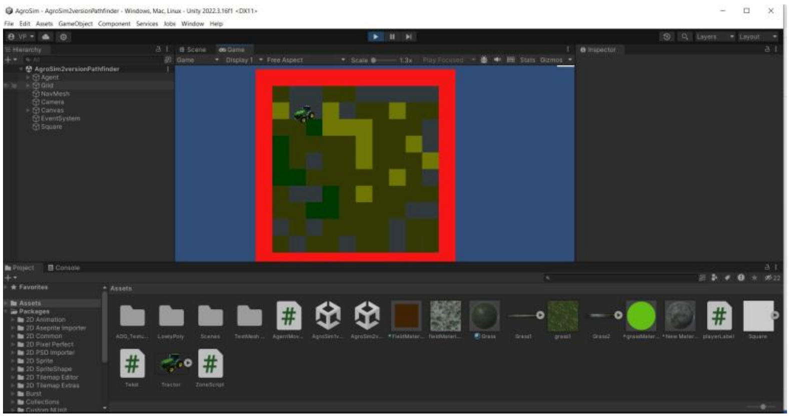
Timely fertilization ensures that plants receive the right nutrients at the right time, leading to optimal growth and higher yields. Fertilizing early in the growing season can take advantage of favorable weather conditions, which is extremely important for improving yields. Delaying fertilization could coincide with unfavorable weather conditions, making the efficient application of fertilizers more challenging. Weather conditions are of utmost importance, and optimizing and mitigating the adverse effects are significant advantages of this technology.

Fertilizing zones of agricultural land with high and medium yield rates before rainfall is particularly important. The opposite situation can cause serious pollution of watercourses and the natural environment, as well as reduce the positive effects on crop growth. Rain helps break down fertilizers and their penetration into the soil, increasing their efficiency, as fertilizers applied before rain can be better absorbed into the soil. Applying fertilizers just before rain provides an additional multiple effect, reducing the risk of nutrient leaching and using natural rainwater, reducing the need for additional irrigation. This can lead to water and energy savings required for irrigation.

ARTIFICIAL INTELLIGENCE (AI)

The UnityEngine.AI programming module is a key component of Unity's ecosystem for developing simulations and games, providing robust capabilities for pathfinding necessary to create intelligent and feedback-driven features for objects (Agents). Unity's AI tools, including UnityEngine.AI, enable developers to create Agents in simulations and games that are convincing and interactive.

These Agents can navigate through complex environments, avoid obstacles, and interact with participants in a way that enhances the overall simulation or gaming experience. The AI module is versatile, supporting game development in both 2D and 3D, and is applicable to the development of mobile games. The AI system in Unity, including UnityEngine.AI, enables sophisticated navigation and pathfinding, allowing Agents to move through simulations or video game worlds in a realistic manner. Through



Picture 2 Unity software working environment with simulation

intelligent resource management, AI helps optimize the performance of simulations and video games, enabling complex environments to operate smoothly.

The UnityEngine.AI module is evidence of Unity's potential to provide powerful tools for implementing artificial intelligence in simulations and video games.

THE STATE OF AGRICULTURE TECHNOLOGY IN THE REPUBLIC OF SERBIA

From slightly over five million hectares of agricultural land, approximately 3.4 million hectares, or about 67%, are cultivated [1]. The land is cultivated using around 480,000 tractors, with the oldest ones being in Eastern and Southern Serbia. The fields are predominantly cultivated using old IMT tractors [1].

It is estimated that there are around 460,000 tractors in Serbia, with as much as 90% of them being over 20 years old [2]. The most well-known models, IMT 533 and IMT 539, are easy to handle, extremely mobile, and agile [3]. Their legendary status goes back from the period when they represented the mechanization expansion in rural areas during the second half of the 20th century [3].

Based on literature, it has been established that the prevalence of IMT tractors is significant in the Republic of Serbia, and their potential speeds and capabilities have set the initial operational speed of the Agent or tractor at 4 m/s [4].

Even with this situation in the Republic of Serbia, regarding the modernization of agricultural machinery, there is a possibility of implementing precision agriculture (Variable Rate Technology - VRT) on a tractor that is 20 years old [5]. Modern VRT systems are designed to be compatible with a wide range of tractor models and attachments, regardless of their age [5]. Compatibility is a key characteristic of this technology. Many VRT systems are designed to be compatible with practically any tractor brand or attachment currently in use. This means that even older tractors can be equipped with VRT systems [5].

However, the most significant advantage of precision agriculture technology is that it enables the precise application of inputs such as fertilizers, seeds, and pesticides, which can lead to increased farm profitability and sustainability, which subsequently means the environmental protection and the implementation of the concept of sustainable development [5].

To implement VRT technology on an older tractor, sensors and control systems that can manage the application of variable rates may need to be installed. These systems may include NDVI sensors, GPS units, and automated flow and application controls. However, their implementation on older agricultural machinery is possible in any case.

In terms of cost and investment, although a significant initial investment may be required to equip an older tractor with VRT, the long-term benefits in terms of increased efficiency, reduced input costs, and improved yields can make this investment profitable in the long run.

METROLOGICAL CHARACTERISTICS

Based on the simulation results, we can determine that the total distance covered in the simulation using the artificial intelligence module in C# programming code is 127.21 meters. Additionally, the required time for applying fertilizers, first in zones with high yield rates, then in zones with medium yield rates, and finally in zones with low yield rates is 35.88 seconds for one hectare of land. The average speed during this process is 3.55 meters per second. The maximum speed achieved in this case is 4 m/s, while the minimum is 3.18 m/s. In the second simulation, without the application of artificial intelligence and yield rates, but with sequential fertilization, i.e., traditional agricultural production, at a uniform speed of 4 meters per second, the result obtained was a total distance covered of 113.89 meters. The required time for fertilizing agricultural land of one hectare was 28.47 seconds.

By analyzing the results of both simulations, it can be concluded that in the simulation of the fertilization process with the artificial intelligence module, the tractor covered a greater distance by 13.32 meters, which is logical considering the random distribution of primary zones with high and medium yield rates. The simulation of precision agriculture with selective and accurate fertilization required 11.7% more distance covered compared to fertilization without precision agriculture and the application of the artificial intelligence module. The time required to perform this process was 26% longer in the case of the simulation with artificial intelligence. The difference in the speed of simulated tractor movement without the application of precision agriculture and artificial intelligence compared to the average speed of the tractor in the simulation with the application of artificial intelligence is 12.7%.

SIMULATION RESULTS

The simulation of precision agriculture required 11.7% more distance covered compared to traditional agricultural methods, which can be attributed to the selective and precise fertilization techniques used in precision agriculture, requiring the tractor to move more to target specific areas or zones more accurately. The simulation based on artificial intelligence required 26% more time to complete the process, which may be the result of additional calculations and decisions made by the AI system, potentially leading to better results in terms of crop yields or resource utilization.

With the rapid development of technology and artificial intelligence, as well as processing capabilities, these differences will diminish, allowing all the benefits of implementation with minimal negative effects such as longer durations and consequently higher fuel consumption.

The difference in speed between the simulated movement of the tractor without precision agriculture and AI and the average speed of the tractor in the AI-based simulation was 12.7% higher. This suggests that the tractor moved faster in the simulation of traditional agriculture, which is an assumption introduced into the simulation and real speed corresponds more to lower operating speeds of tractors, especially in a larger number of farms in the Republic of Serbia with machinery that is 20 to 40 years old [1].

However, in developed Western economies, average operating speeds of tractors can be around 12 m/s. The fastest tractor in the world comes from Finland [6]. The accurately measured speed was 36.1569 km/h, while the standard maximum speed of this tractor under normal operating conditions is around 13.8889 km/h [6].

CONCLUSION

This topic is extremely relevant in today's world, with the rise in agricultural product prices due to unrest and conflicts, sanctions, increased inflation, and the dynamic growth of the global population. The application of artificial intelligence is of great importance both in the present and will continue to be in the future. Statistical data processing, mathematical modeling, and the functions and algorithms used by these information technologies can be applied in any area of society. It is evident that, due to various crises, conflicts, and climate change worldwide, there is a shortage of the most basic necessities and provisions. Consequently, food and drinking water become key commodities around which regional and global military and geopolitical conflicts are likely to revolve or have revolved for domination over the remaining resources.

To fully harness the potential of the remaining natural resources, especially basic necessities such as arable land and drinking water, it is necessary to smartly utilize the technology, techniques, and science, primarily the mathematical and statistical methods at our disposal. This is where precision agriculture and smart agriculture come into play, optimizing the agricultural production process, not only in the allocation of numerous resources but also in their optimization.

Our research in simulated agricultural production shows that selective and precise fertilization of primary zones of agricultural land with high and medium yield rates required 11.7% more distance covered compared to fertilization without precision agriculture and the application of artificial intelligence. The simulation based on artificial intelligence required 26% more time due to additional calculations and decisions made by the AI system. Both of these results indicate a longer time period required for selective fertilization and greater distance covered, which leads to higher fuel consumption, but potentially can lead to better results in terms of crop yields and resource allocation, optimization, and usage. This is particularly significant in environmental protection, the implementation of the concept of sustainable development, as well as the timely placement of agricultural products to the market to achieve better prices and profitability in agricultural production.

LITERATURE

[1] https://www.blic.rs/biznis/privreda/srpske-njive-obraduju-stari-traktori-kako-do-nove-mehanizacije/cjn7lq5

[2] https://www.rts.rs/lat/vesti/ekonomija/5250898/njive-u-srbiji-obradjuju-traktori-stari-u-proseku-tri-decenije-za-nabavku-novih-proizvodjaci-nemaju-para.html

[3] https://traktoriprikljucnemasine.rs/traktori/najbolji-traktori-u-srbiji-inovativni-i-efikasni-modeli/

[4] R. Nikolic et al., "Research of the bases for development of agricultural tractors.," pp. 59–67, Jan. 2007, [Online]. Available: https://www.cabdirect.org/cabdirect/abstract/20103268585

[5] https://ww2.agriculture.trimble.com/blog/understanding-vra-and-vrt-what-is-variable-rate-technology-and-how-can-i-use-it-on-my-farm/

[6] https://www.b92.net/o/automobili/razno?yyyy=2015&mm=04&nav_id=979556

[7] Ratko Zelenika, Znanstvene kvantitativne metode-metode izrade znanstvenog djela, IQ plus d.o.o.-Kastav, Rijeka, 2015.

[8] Franz Lanzinger, 3D Game Development with Unity, 1st ed. CRC Press, 2022.

[9] Lynne Hamill and Nigel Gilbert, Agent-Based Modelling in Economics, 1st ed. Wiley, 2016.

[10] Kiyoshi Arai, Hiroshi Deguchi, and Hiroyuki Matsui, Eds., Agent-Based Modeling Meets Gaming Simulation (Agent-Based Social Systems, 2), 2005th ed. Springer, 2006.

[11] Jeff W. Murray, C# Game Programming Cookbook for Unity 3D*, 2nd ed. CRC Press, 2021.

[12] Marko M. Kostić, Precizna poljoprivreda, Poljoprivredni fakultet, Univerzitet u Novom Sadu, Novi Sad, 2021.

[13] Radovan Pejanović, Ogledi iz agrarne i ruralne ekonomije, Poljoprivredni fakultet, Novi Sad, 2013.

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