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© O. Auyelbekov[1,3], E. Bostanov[2], R. Berkutbayeva[2,4]*, A. Seidildayeva[2], I. Musabekova[5], 2025.
[1]Institute of Information and Computational Technologies, Almaty, Kazakhstan;
[2]Civil Aviation Academy, Almaty, Kazakhstan;
[3]Kazakh National Women's Pedagogical University, Almaty, Kazakhstan;
[4]Al- Farabi Kazakh National University, Almaty, Kazakhstan;
[5]№210 school-gymnasium, Almaty, Kazakhstan.
E-mail: barr_0609@mail.ru

ANALYSIS OF AGRICULTURAL YIELDS IN KAZAKHSTAN USING UNMANNED AERIAL VEHICLES AND AI

O. Auyelbekov — Candidate of Physical and Mathematical Sciences, Associate Professor, Institute of Information and Computational Technologies; Kazakh National Women's Pedagogical University,
E-mail: omirlan.auelbek@gmail.com, https://orcid.org/0000-0002-2903-9086;
E. Bostanov — senior-lector, Civil Aviation Academy,
E-mail: bostanovernar0929@gmail.com, https://orcid.org/0000-0002-8753-0244;
R. Berkutbayeva — 1st year doctoral student of Al-Farabi Kazakh National University; senior-lector, Civil Aviation Academy,
E-mail: barr_0609@mail.ru, https://orcid.org/0000-0002-5915-1941;
A. Seidildayeva — Candidate of Technical Sciences, Associate Professor, Civil Aviation Academy,
E-mail: oimautova_1966@mail.ru, https://orcid.org/0000-0002-0551-9552;
I. Musabekova – teacher-master №210 school-gymnasium,
E-mail: Balauka_nurai@mail.ru, https://orcid.org/0000-0002-2406-7990.

Abstract. This work focuses on methods for recognizing and analyzing agricultural yields in Kazakhstan using data collected from unmanned aerial vehicles (UAVs), or drones, in combination with artificial intelligence (AI). With the rapid advancement of technology and the growing need for efficient agricultural resource management, the integration of UAVs and AI presents new opportunities for crop monitoring and yield analysis. The study explores modern UAV technologies equipped with high-resolution cameras and sensors that collect accurate and frequent data on agricultural fields. These images are processed using machine learning and neural network algorithms to identify key factors influencing crop yields. The research aims to develop a system capable of automatically collecting, processing, and interpreting data on crop conditions. The main focus is on applying machine learning and deep learning techniques to automatically recognize different crop types, evaluate plant health, and forecast yields. The study also analyzes the effectiveness of various big data processing approaches and develops models that incorporate climatic and agrotechnical factors. As a result, an integrated system is expected to be created that significantly enhances the management of agricultural resources and increases the resilience of Kazakhstan's agricultural sector to external challenges. The application of this system has the potential to improve crop yields and farmer incomes, promoting the sustainable development of agriculture in the region.

Keywords: artificial intelligence, unmanned aerial vehicles, agriculture, yield, OpenCV, InceptionV3, crop monitoring, technology integration

© Ө. Әуелбеков[1,3], Е. Бостанов[2], Р. Беркутбаева*[2,4], А. Сейдилдаева[2], І. Мусабекова[5], 2025.

[1]Ақпараттық және есептеу технологиялары институты, Алматы, Қазақстан;
[2]Азаматтық авиация академиясы, Алматы, Қазақстан;
[3] Қазақ ұлттық қыздар педагогикалық университеті, Алматы, Қазақстан;
[4] Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан;
[5]№210 мектеп гимназия, Алматы, Қазақстан.
E-mail: barr_0609@mail.ru

ҚАЗҚАСТАНДА АУЫЛ ШАРУАШЫЛЫҒЫ ӨНІМДІЛІГІН ҰШҚЫШСЫЗ ҰШУ АППАРАТТАРЫ МЕН ЖАСАНДЫ ИНТЕЛЛЕКТ КӨМЕГІМЕН ТАЛДАУ

Ө. Әуелбеков — физика-математика ғылымдарының кандидаты, қауымдастырылған профессор, Қазақ ұлттық қыздар педагогикалық университеті; Ақпараттық және есептеу технологиялары институты, Алматы, Қазақстан,
E-mail: omirlan.auelbek@gmail.com, https://orcid.org/0000-0002-2903-9086;
Е. Бостанов —сениор-лектор, Азаматтық авиация академиясы, Алматы, Қаақстан,
E-mail: bostanovernar0929@gmail.com, https://orcid.org/0000-0002-8753-0244;
Р. Беркутбаева — Әл-Фараби атындағы Қазақ Ұлттық университетінің 1-курс докторанты; сениор-лектор, Азаматтық авиация академиясы, Алматы, Қазақстан,
E-mail: barr_0609@mail.ru, https://orcid.org/0000-0002-5915-1941;
А. Сейдилдаева — техника ғылымдарының кандидаты, қауымдастырылған профессор, Азаматтық авиация академиясы, Алматы, Қазақстан,
E-mail: oimautova_1966@mail.ru, https://orcid.org/0000-0002-0551-9552
І. Мусабекова — педагог-мастер, №210 мектеп-гимназия, Алматы, Қазақстан,
E-mail: Balauka_nurai@mail.ru, https://orcid.org/0000-0002-2406-7990.

Аннотация. Бұл жұмыс Қазақстандағы ауыл шаруашылығы өнімділігін тану және талдау әдістерін зерттеуге арналған. Зерттеу барысында пилотсыз ұшу аппараттарынан (ПҰА), яғни «дрон (квадрокоптер)» деп аталатын құрылғылардан алынған деректер негізінде жасанды интеллект (ЖИ) қолдану қарастырылады. Технологиялардың қарқынды дамуы мен ауыл шаруашылығы ресурстарын тиімді басқаруға деген сұраныстың артуы ПҰА мен ЖИ-дің қолданылуы егін жағдайын бақылау және талдау саласында жаңа мүмкіндіктер ашып отыр. Зерттеу аясында ауыл шаруашылығы алқаптарын бақылаудың заманауи технологиялары қарастырылады, олар жоғары дәлдік пен жиілікпен сапалы суреттер мен басқа да деректерді жинауға мүмкіндік береді. Зерттеудің мақсаты – ауыл шаруашылығы жерлерінің жай-күйі туралы деректерді автоматты түрде жинай, өңдей және түсіндіре алатын жүйені әзірлеу және енгізу. Пилотсыз ұшу аппараттары (ПҰА) озық сенсорлармен, камералармен және деректерді беру жүйелерімен жабдықталған, бұл ауыл шаруашылығы алқаптарының егжей-тегжейлі бейнелерін алуға мүмкіндік береді. Бұл бейнелер машинамен оқыту әдістері мен нейрондық желілерді қолдану арқылы өңделіп, ауыл шаруашылығы өнімділігіне әсер ететін негізгі факторларды анықтауға көмектеседі. Жұмыста ПҰА арқылы алынған үлкен деректерді өңдеудің түрлі тәсілдерінің тиімділігіне талдау жүргізіліп, ауыл шаруашылығы өнімділігіне әсер ететін климаттық және агротехникалық факторларды ескеретін модельдерді әзірлеу де қамтылған. Зерттеу нәтижесінде ауыл шаруашылығы ресурстарын басқару тиімділігін айтарлықтай арттыра алатын және Қазақстанның ауыл шаруашылығы секторының сыртқы жағдайлар өзгерісіне төзімділігін күшейтетін кешенді жүйе әзірлеу көзделіп отыр. Қазақстанда әзірленген бұл кешенді жүйені қолдану өнімділік пен табысты едәуір арттыруға мүмкіндік береді, бұл өз кезегінде өңірде тұрақты ауыл шаруашылығын дамытуға оң ықпал етеді.

Түйін сөздер: жасанды интеллект, пилотсыз ұшу аппараттары, ауыл шаруашылығы, өнімділік, OpenCV, InceptionV3, технологияларды біріктіру

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[2] Институт информационных и вычислительных технологий, Алматы, Казахстан;
[2]Академия гражданской авиации, Алматы, Казахстан;
[3] Казахский Национальный Женский Педагогический университет, Алматы, Казахстан; [4] Казахский Национальный университет имени аль-Фараби, Алматы, Казахстан;
[5] Школа-гимназия №210, Алматы, Казахстан.
E-mail: barr_0609@mail.ru

АНАЛИЗ СЕЛЬСКОХОЗЯЙСТВЕННОЙ УРОЖАЙНОСТИ В КАЗАХСТАНЕ С ПОМОЩЬЮ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ И ИИ

О. Ауелбеков — кандидат физико-математических наук, ассоциированный профессор, Казахский Национальный Женский Педагогический университет; Институт информационных и вычислительных технологий, Алматы, Казахстан,
E-mail: omirlan.auelbek@gmail.com, https://orcid.org/0000-0002-2903-9086;
Е. Бостанов — сениор-лектор, Академия гражданской авиации, Алматы, Казахстан,

E-mail: bostanovernar0929@gmail.com, https://orcid.org/0000-0002-8753-0244;
Р. Беркутбаева — докторант 1-курса Казахского Национального университета имени аль-Фараби; сениор-лектор, Академия гражданской авиации, Алматы, Казахстан,
E-mail: barr_0609@mail.ru, https://orcid.org/0000-0002-5915-1941;
А. Сейдилдаева — кандидат технических наук, ассоцированный профессор, Академия гражданской авиации, Алматы, Казахстан,
E-mail: oimautova_1966@mail.ru, https://orcid.org/0000-0002-0551-9552;
И. Мусабекова — педагог-мастер, Школа-гимназия №210, Алматы, Казахстан,
E-mail: Balauka_nurai@mail.ru, https://orcid.org/0000-0002-2406-7990.

Аннотация. Данная работа посвящена изучению методов распознавания и анализа продуктивности сельского хозяйства в Казахстане. В ходе исследования рассматривается применение искусственного интеллекта (ИИ) на основе данных, полученных с беспилотных летательных аппаратов (БПЛА), также известных как дроны (квадрокоптеры). Стремительное развитие технологий и рост потребности в эффективном управлении сельскохозяйственными ресурсами открывают новые возможности для использования БПЛА и ИИ в мониторинге и анализе состояния посевов. В рамках исследования рассматриваются современные технологии наблюдения за сельскохозяйственными угодьями, которые позволяют с высокой точностью и частотой собирать качественные изображения и другие данные. Цель исследования – разработка и внедрение системы, способной автоматически собирать, обрабатывать и интерпретировать данные о состоянии сельскохозяйственных земель. Беспилотные летательные аппараты (БПЛА) оснащены передовыми сенсорами, камерами и системами передачи данных, что позволяет получать детализированные изображения сельскохозяйственных угодий. Эти изображения обрабатываются с применением методов машинного обучения и нейронных сетей, что помогает выявить ключевые факторы, влияющие на урожайность сельскохозяйственной продукции. В работе проводится анализ эффективности различных методов обработки больших данных, полученных с БПЛА, а также рассматривается разработка моделей, учитывающих климатические и агротехнические факторы, влияющие на продуктивность сельского хозяйства. В результате исследования планируется разработка комплексной системы, способной значительно повысить эффективность управления сельскохозяйственными ресурсами и укрепить устойчивость аграрного сектора Казахстана к изменениям внешних условий. Применение этой комплексной системы, разработанной в Казахстане, позволит существенно увеличить производительность и доходность, что, в свою очередь, окажет положительное влияние на развитие устойчивого сельского хозяйства в регионе.

Ключевые слова: искусственный интеллект, беспилотные летательные аппараты, сельское хозяйство, продуктивность, OpenCV, InceptionV3, интеграция технологий

Introduction. Agriculture is one of the key sectors of Kazakhstan's economics, ensuring the country's food security and a significant contribution to its economic development. In the context of global climate change and population growth, the agricultural sector faces the task of increasing production efficiency and resilience to external challenges. In this regard, the introduction of innovative technologies for monitoring and analyzing yields is of particular relevance. The use of unmanned aerial vehicles (UAVs) is beneficial in photographing agricultural lands in difficult physical, geographical and soil-climatic conditions, which can only be controlled from the air. Despite certain disadvantages, in the near future it is possible to predict the expansion of the functionality of unmanned aerial vehicles and an increase in the number of tasks that will be solved in agricultural production using UAVs. They become indispensable assistants to agronomists and farmers. UAVs are equipped with various sensors and cameras that allow to obtain detailed images and other data necessary for analyzing the condition of crops during the sowing and harvesting campaign, in choosing the proper time for harvest and detecting plant diseases, assessing damage from pests and predicting yields.

AI data collection is just the first step to improve agricultural efficiency. Machine learning and deep learning allow you to automatically recognize crops, assess their condition, and accurately predict yields. The aim of the work is to develop a yield analysis system in Kazakhstan based on data from drones and AI, taking into account the specifics of the country's agricultural sector. The introduction of such technologies will improve resource management, increase agricultural sustainability, and help avoid a food crisis.

Drones improve crop quality by identifying infected areas and spot-treating them with pesticides and fertilizers, including working at night. They use multispectral systems to accurately monitor plants and the environment. Thanks to the development of aviation and digital technologies, drones are becoming an important tool in agriculture for rapid and high-quality survey of territories. In the next decade, agriculture will become the largest consumer of unmanned services.

Literature review. In recent years, the use of UAVs and AI has become an important part of innovation in agriculture. These technologies make it possible to improve significantly the monitoring and analysis of the state of crops, which is especially important for Kazakhstan with its extensive agricultural lands and diverse climatic conditions. The review covers the main researches and achievements in the field of UAV and AI applications for yield recognition and analysis.

UAVs have found wide application in agriculture due to their ability to collect high-precision data over large areas with minimal cost. Works such as research by (Zhang, et.al., 2012) demonstrate the effectiveness of using UAVs to obtain high-quality images of crops, which allows monitoring the state of crops in real time. In Kazakhstan, according to researches such as the work of (Abdrakhman, et al., 2022), UAVs are actively used to monitor grain crops and assess their condition in various climatic zones.

AI, in particular machine learning and deep learning, provides powerful tools for analyzing data obtained from UAVs. Research by Liu, has shown that deep learning algorithms are capable of recognizing various types of crops with high accuracy and determining their condition. Works of (Kadyrov, et al., 2018) demonstrate the successful use of AI for yield forecasting and identifying signs of plant diseases based on data obtained from UAVs.

Modern machine learning methods such as neural networks are used to analyze big data. Research works by (Kamilaris, et.al., 2018) highlights the importance of using convolutional neural networks (CNN) to process crop images obtained from UAVs. In Kazakhstani studies, such as the work of (Omarov, et al., 2022), the effectiveness of using these methods for analyzing the state of crops and forecasting yields is noted.

The use of UAVs and AI in agriculture in Kazakhstan has a high potential. Research shows that these technologies increase productivity and contribute to the sustainable development of the agricultural sector.

Materials and methods. The multi-purpose UAVs equipped with high-precision data acquisition equipment including multispectral and hyperspectral cameras, as well as thermal imagers used in the given research. Multispectral cameras (RedEdge-MX, Parrot Sequoia) and hyperspectral cameras (Headwall Nano-Hyperspec) were used to obtain detailed images and data on the state of crops. Powerful servers and workstations for processing big data, equipped with NVIDIA Tesla and RTX graphics processors (GPUs) to accelerate computing in the process of learning machine learning models. Specialized programs for data processing and analysis were used, including QGIS for geospatial data processing and Python libraries (TensorFlow, Keras, PyTorch) for the development and training of machine learning models.

To plan drone flights, the terrain, weather and time of day were taken into account using automated programs. The fields were regularly (weekly) filmed with multi- and hyperspectral cameras during the growing season. Image correction methods and segmentation algorithms were used to accurately align and identify various plant sites and conditions.

Development and training of machine learning models include:

- algorithm selection: study of various machine learning algorithms, including convolutional neural networks (CNN), recurrent neural networks (RNN) and hybrid models combining elements of CNN and RNN;

- model training: dividing data into training and test sets, configuring hyperparameters of models and GPU-based training to speed up the process;

- data augmentation: applying data augmentation techniques to increase the size of the training set and improve the overall performance of models.

Data analysis and interpretation includes:

- assessment of the condition of crops: the use of trained models for automatic recognition of plant conditions, detection of diseases and determination of growth stages;

- yield forecasting: using time series of data and recurrent neural networks to predict yields based on data collected from UAVs.

Integration of AI and UAVs into Agricultural Processes in Kazakhstan.

For the successful integration of AI and UAVs into agriculture in Kazakhstan, it is necessary:

- education and training: specialists should be trained to work with AI and UAVs;
- investments in technology: purchase and implementation of modern equipment;
- software development: creation of specialized applications for crop analysis and monitoring;
- pilot projects: developing pilot projects to test and adapt technologies in real-world conditions.

Drones with high-quality cameras and sensors, as well as AI platforms for information processing, were used to collect data on the state of crops and soil in Kazakhstan. The drones collected multispectral and thermal imaging data during different periods of crop growth. Artificial intelligence created accurate field maps, identified problem areas, and predicted yields based on historical and climatic data. The analysis made it possible to develop recommendations for the targeted application of fertilizers and pesticides, reducing their consumption and minimizing the environmental impact. Regular monitoring provided an assessment of the effectiveness of these technologies during the season. The AI and UAVs using efficiency was assessed by such indicators as improving plant health, reducing the cost of fertilizers and pesticides, increasing yields and improving product quality. In addition, there were held:

- Interviews with local farmers and representatives of agricultural enterprises were held to assess the perception and readiness to introduce new technologies.
- The economic benefits of using AI and UAVs were analyzed, including cost reduction, increased productivity and improved product quality.

Results. The results of the study showed that the application of these technologies contributes to the effectiveness of agricultural production, improving product quality and reducing negative impact on the environment.

Program Analysis for Leaf Classification Using Inceptionv3 Mode

The study is designed to analyze the state of plant leaves using the pre-trained InceptionV3 model. The program loads leaf images, processes them, performs classification using a machine learning model and visualizes the results as images and a bar graphs.

Results and Interpretation

- Image display: The program displays each source image with a header indicating the predicted class and confidence level. This helps to visually assess how well the model prediction matches the actual image.
- Bar chart: The chart shows the confidence levels for each prediction, making it easy to compare results between different leaf images.

The program demonstrates a basic approach to analyzing the state of plant leaves using a pre-trained machine learning model and OpenCV library. Visualization of results as images and bar charts (Fig. 1-8), allows to evaluate the model predictions and compare the condition of different leaves.

1/1 ________________________________ 1s 1s/step
1/1 ________________________________ 0s 167ms/step
1/1 ________________________________ 0s 218ms/step

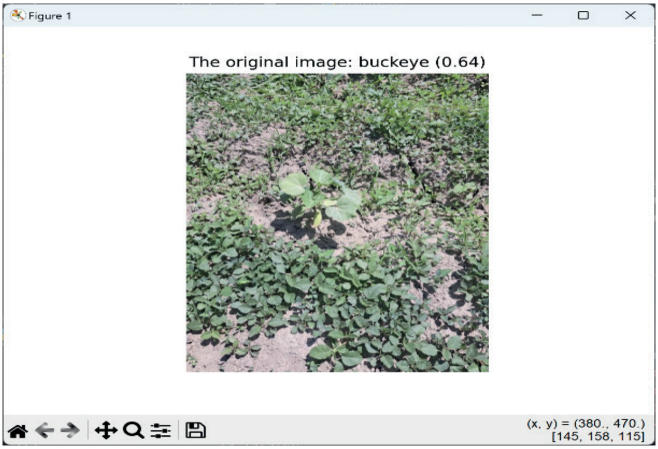

Fig. 1 – Condition of plant leaves No.1

The image was captured by the drone (quadcopter). It shows a plant identified as "horse chestnut" with a confidence level of 0.64. The plant is surrounded by other vegetation and soil.

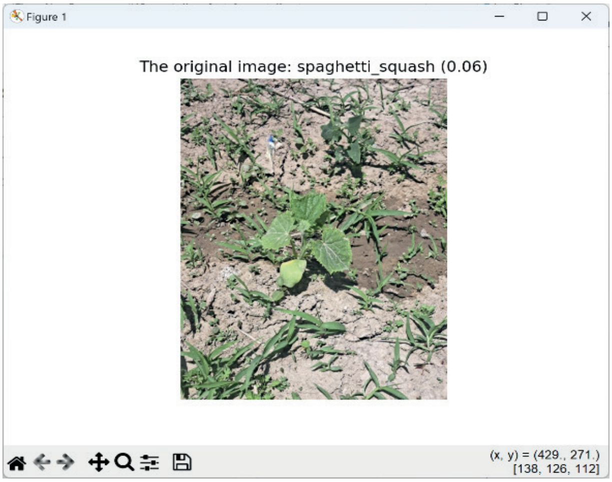

Fig. 2 – Condition of plant leaves No.2

The next image (Fig. 2) was also taken by drone and shows groups of weeds Spaghetti squash or vegetable spaghetti is a group of varieties of Cucurbita pepo subsp. They are available in a variety of shapes, sizes and colors including ivory, yellow and orange, and orange contains the highest amount of carotene.

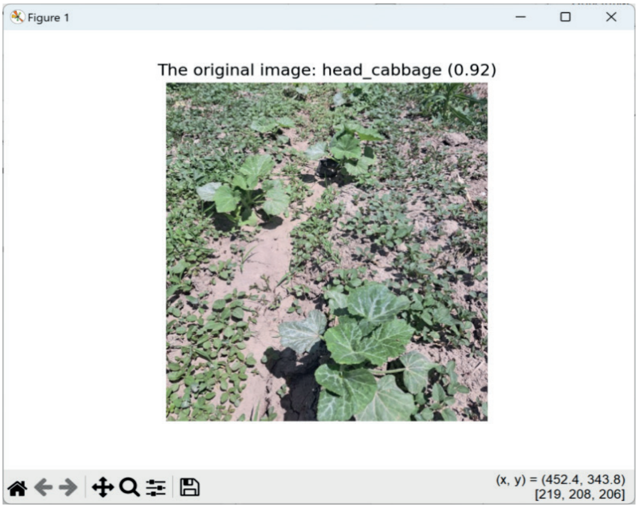

Fig. 3 – Condition of plant leaves No.3

The third image (Fig.3) shows a plant identified as “cabbage” with a high confidence level of 0.92. The plant is growing in a field with vegetation and soil similar to that shown in the previous image.

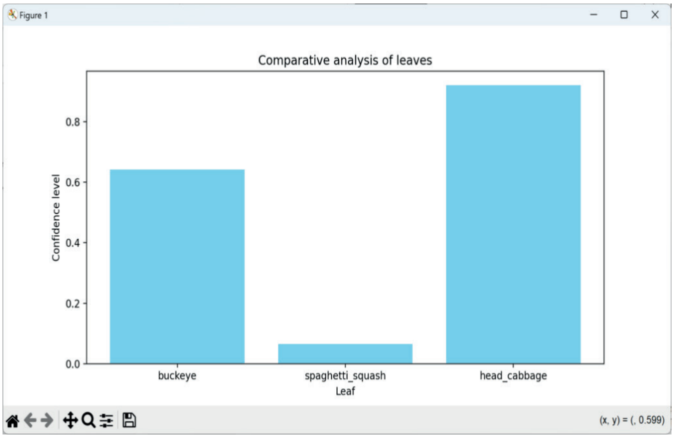

Fig. 4 – Diagram of comparative analysis of leaves No.1, No.2, No.3

The bar chart shows a comparative analysis of confidence levels in identifying different leaf types. There are three columns, each representing a different type of leaf. Horse chestnut: confidence level is approximately 0.64. Spaghetti squash: very low confidence level, close to 0. Cabbage: high confidence level, approximately 0.92. The table visually highlights the high confidence level of identification of cabbage leaves compared to the other two species.

1/1 ________________________________ 1s 1s/step

Results for leaf 1:

1. head_cabbage: 0.86
2. artichoke: 0.03
3. pot: 0.02
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 267ms/step
Results for leaf 2:
1. buckeye: 0.75
2. jackfruit: 0.05
3. acorn: 0.02
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 172ms/step
Results for leaf 3:
1. buckeye: 0.18
2. custard_apple: 0.16
3. capuchin: 0.07
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 165ms/step
Results for leaf 4:
1. buckeye: 0.33
2. volcano: 0.18
3. spider_monkey: 0.05
1/1 ━━━━━━━━━━━━━━━━━━━━ 0s 187ms/step

The results show the predictions of the pre-trained InceptionV3 model for four leaf images. The model predicts which categories the images belong to with a certain confidence level. However, since InceptionV3 was trained on a large ImageNet dataset that includes many categories unrelated to plant leaves, the results may be strange and may not match the expected categories for analyzing plant condition.

Explanation of Results

For each leaf, the model predicts three categories with the highest confidence level. The results and their interpretation are presented below:

Fig. 5 – Condition of plant leaves No.4

Figure 5 shows a plant growing in a field with vegetation and soil similar to those shown in the previous image.

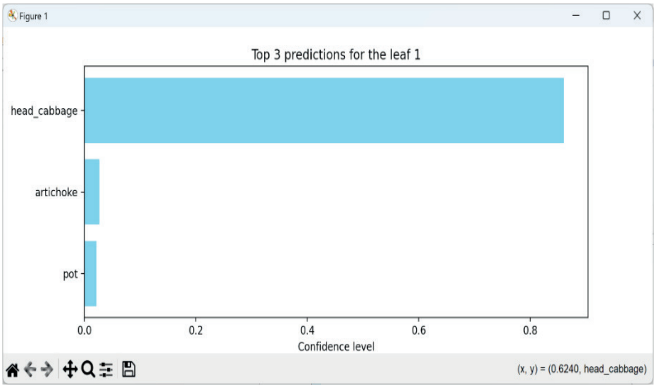

Fig. 6 – Diagram of confidence level of leaves No.4

The given diagram (Fig.6) shows the confidence level, which is approximately 0.85:

1. Leaf 1:

- head_cabbage: 0.86 (86% confidence)
- artichoke: 0.03 (3% confidence)
- pot: 0.02 (2% confidence)

The most likely category as predicted by the model is cabbage with a confidence level of 86%. This shows that the model reads the image as a cabbage.

The model is less confident in its prediction for this leaf, and the top categories have relatively low confidence levels.

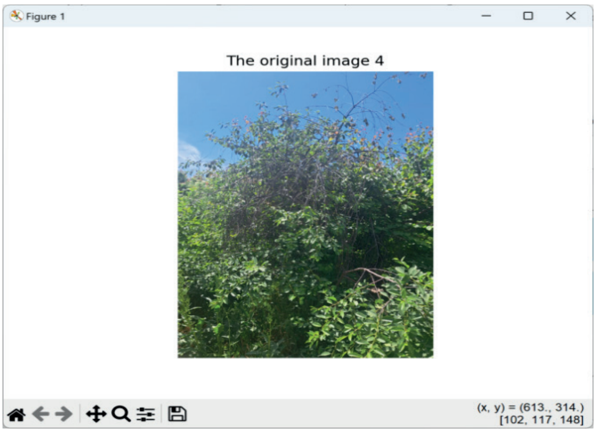

Fig. 7 – Condition of cherry leaves No.5

Here, the model is most confident that the image resembles a horse chestnut, with 35% confidence.

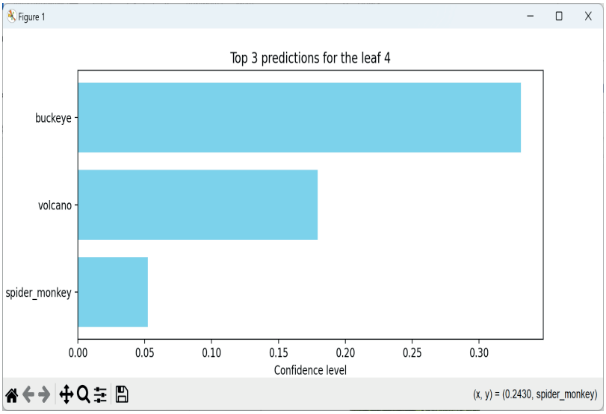

Fig. 8 – Diagaram of confidence level of leaves No.5

4. Leaf 4:
- buckeye: 0.33 (33% confidence)
- volcano: 0.18 (18% confidence)
- spider monkey: 0.05 (5% confidence)

The most likely category is horse chestnut with 33% confidence.

Why are the results so strange?

The InceptionV3 model was trained on the huge ImageNet dataset, which contains thousands of different categories, many of which are unrelated to plants. This results in the model being able to predict categories that have nothing to do with actual plant diseases or conditions.

How to Improve Results?

1. Training a specialized model: accurate analysis of plant leaf condition requires a specialized model trained on a dataset containing images of leaves with different diseases and their conditions;

2. Using pre-trained models for plants: there are specialized models such as PlantVillage that can be used to recognize plant diseases;

3. Data augmentation: using data augmentation techniques to improve the quality and diversity of the training dataset.

Confidence, in the context of machine learning and image classification in particular, is a numerical value that reflects confidence level the model has in the correctness of its prediction. Confidence is expressed as a number between 0 and 1, where 1 indicates absolute confidence in the correctness of prediction and 0 indicates no confidence.

Explanation of Confidence in Image Classification

When a machine learning model as a neural network makes a prediction, it assigns to each possible class a probability that reflects how confident the model is that the image belongs to the certain class. These probabilities add up to 1, and the most likely class is taken as the result of prediction.

For example, if the model classifies a leaf image and produces the following probabilities:

- Class A: 0.70 (70% confidence)
- Class B: 0.20 (20% confidence)
- Class C: 0.10 (10% confidence)

This means that the model considers that with 70% probability the image belongs to class A, with 20% probability to class B and with 10% probability to class C. In this case, the result of classification will be class A.

How to Interpret Confidence

1. High confidence: if the model's confidence in prediction is high (close to 1), it means that the model is confident in its prediction. In the example, 0.86 for "head_cabbage" means that the model is 86% confident that the image is a cabbage.

2. Low confidence: low confidence (close to 0) means that the model is not confident in its prediction. In the case where all probabilities are low and there is no single dominant class, it may indicate that the model does not recognize the image with sufficient accuracy.

Example of Using the Confidence Level

Let's consider an example with real data that was provided:

```plaintext
Results for leaf 1:
1. head_cabbage: 0.86
2. artichoke: 0.03
3. pot: 0.02
```

- The model has 86% confidence that the image is a cabbage.
- The model has very low confidence that it is an artichoke or a pot (3% and 2% respectively).

For this leaf, we can consider that the image most likely shows a cabbage based on the high confidence level.

Conclusion: Confidence level is an important issue in classification as it helps to assess the accuracy of the model's prediction. Understanding this issue allows for better interpretation of results and make informed decisions based on them.

The next stage of the study is to analyze the concentration of plant yields.

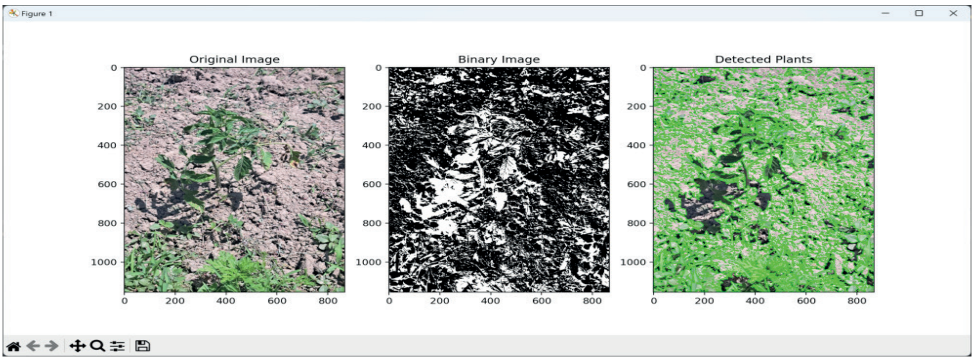

Fig. 9 – Photos of plants in a field
(original image, binary image, detected plants)

The image in Figure 9 represents the results of photo treatment of plants in the field. It consists of three parts:

1. Original Image: source image showing field with plants. There is a ground and plants growing on it, which are used as a starting point for further processing.

2. Binary Image: result of converting the original image into a binary image using thresholding:

- in binary image, each pixel is either black (value 0) or white (value 255). The black pixels represent the background, and the white pixels represent the plants;
- the goal of this step is to select plants from the background for further analysis.

3. Detected Plants: An image of the original field with overlaid contours found in the binary image. Green contours show the detected areas that the program interpreted as plants. They allow to visually assess the accuracy of the plant detection algorithm.

Fig. 10 – Photos of plants in the field
(original image, binary image, detected plants)

The image (Fig.10) shows the processing results of seven photos of plants in the field. The images are in three columns: original images, binary images and images with detected plants.

Column 1: Original Image

- Bushes or plants growing in the field. Leaves and stems of plants;
- Similar to the first image, but with a different part of the field. The ground and growing plants;
- Section of a field with dense plants. Large leaves;
- Trees or tall bushes with dense foliage;
- Trees or shrubs against a clear sky;
- Similar to the first image with bushes growing in a field and ground;
- A number of plants in the field with visible ground and small plants.

Column 2: Binary Image

- Thresholding has converted the image to a black and white image, where the white areas represent the plants and the black ones represent the background;
- Converted similarly to the first image, highlighting the plants with white areas on a black background;
- A binary image of dense plants with many white areas;
- Tall bushes or trees also converted to black and white to highlight the vegetation;
- Processing of trees or bushes, with clearly visible white areas on a black background;
- Similar to the first image, with plants highlighted with white areas;
- A number of plants highlighted in white on a black background.

Column 3: Detected Plants

- An image with a number of plants outlined with green lines.

These images show the process of photo processing to determine plant concentrations. The binary images help to highlight plant areas, which are then mapped with contours in the original images. This allows a visual assessment of how well the algorithm has recognized plants, which is important for yield analysis.

Research Process and Method for Analyzing Plant Images

The aim of the research is an automatic analysis of plant concentration in a field, which can help in assessing the condition of crops and making plant care decisions.

The study includes the use of computer vision and image processing techniques for segmentation and analysis of vegetation in field photographs.

1. Image Processing

Images obtained from drones are processed using the normalized difference vegetation index method (NDVI): $= \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$

where NIR is the intensity of reflected near-infrared light and RED is the intensity of reflected red light.

2. Machine Learning for Crop Classification

Machine learning and logistic regression algorithms were used to classify crops:

$$P(y = 1|x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n)}}$$

where x is a vector of input features, β is a vector of model weights.

3. Deep Learning for Image Segmentation

Convolutional neural networks (CNNs) are used for more accurate segmentation and recognition of objects in images. For example, the activation function in a neural network:

$$a^{(l)} = f(z^{(l)}) = f\left(\sum_{i=1}^{n} w\, a^{(l-1)} + b\right)$$

where

$a^{(l)}$ is activation at layer l, w are weights, b is displacement, f is nonlinear activation function (e.g., ReLU).

4. Regression for Yield Estimation

Linear regression is used for yield prediction:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon$$

where Y is the predicted yield, X is a vector of input features (e.g., NDVI scores, weather data, and other factors), β is the model coefficients, ε is a random error.

5. Clustering for Pattern Analysis

Clustering techniques is applied to analyze patterns and identify zones with different productivity:

$$J = \sum_{i=1}^{n} \sum_{x_j \epsilon C_i} \left\| x_j - \mu_i \right\|$$

where k is the number of clusters, C_i is cluster i, μ_i is cluster center i, x_j is data point.

6. Exact Error Estimation Methods

Mean square error (MSE) is used to estimate model accuracy and analyze errors:

$$\mathrm{MSE} = \frac{1}{n} \sum_{i=1}^{n} \left(Y_i + \hat{Y}_i\right)^2$$

where Y_i is actual value, $\hat{Y}_i$ is predicted value, n is a number of observations.

To build a mathematical model for recognizing and analyzing agricultural yields in Kazakhstan based on UAV data using AI, the following key components can be considered:

1. Data Collection

UAVs are equipped with a variety of sensors and cameras (RGB, multispectral, hyperspectral, thermal imaging) to collect field data. These data include:

- high quality images of field surfaces,
- plant spectral characteristics,
- temperature data.

2.Preliminary Data Processing

The collected data needs to be processed for further analysis. It includes:

- Image calibration: correction of distortions (Fig.11) caused by UAV movement and weather conditions.

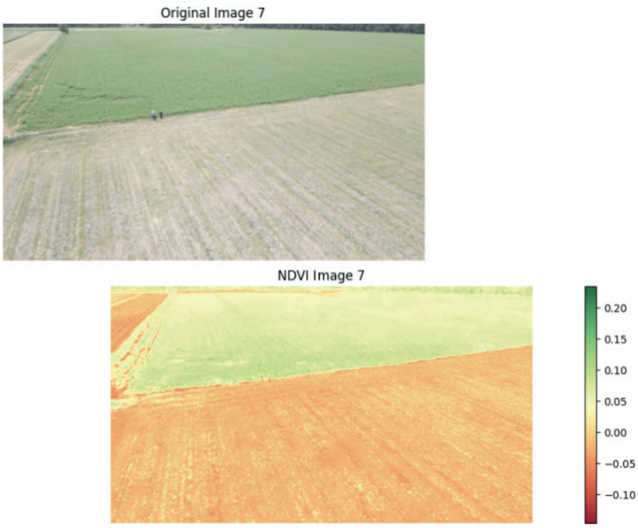

Fig. 11 – Distorted field image

Calibration: $I_{calibrated} = \frac{I_{raw} - I_{dark}}{I_{white} + I_{dark}}$

where:

Orthotransformation: image transformation to create orthophotos.

Orthotransformation:

x'=Hx

where: *x'* and are coordinates of the point before and after transformation, H is homography matrix.

- Mosaicking: combining multiple images into a single image to get a complete view of the field.

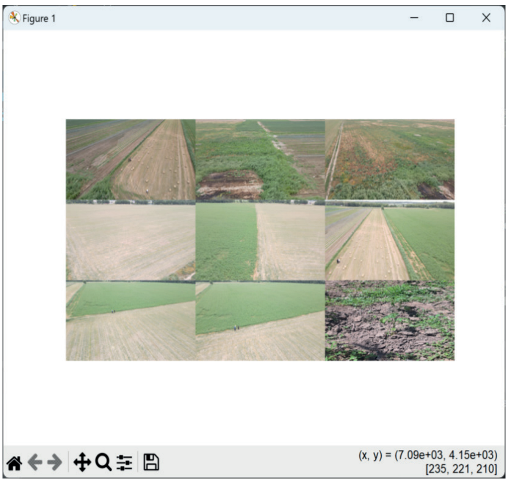

Fig. 12 – Field image in one whole

Combine multiple images into one (Fig.12):

$$I_{mosaic} = f(I_1, I_2, \dots, I_n)$$

where:

- $I_1, I_2, \dots, I_n$ - are separate images.

3. Data Analysis and Feature Extraction

From the processed data, key features are extracted that can be used to estimate crop yields (Fig.13):

- NDVI (Normalized Difference Vegetation Index):

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}},$$

where NIR и RED are reflectance values in the near infrared and red spectral ranges.

- GNDVI (Green Normalized Difference Vegetation Index):

$$\text{GNDVI} = \frac{\text{NIR} - \text{GREEN}}{\text{NIR} + \text{GREEN}},$$

where GREEN are reflectance values in green spectral range.

- SAVI (Soil-Adjusted Vegetation Index): $\text{SAVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED} + L}(1 + L)$,

где L - коэффициент, учитывающий влияние почвы.

Fig. 13 – Image of field

4. Building a Machine Learning Model

A machine learning model is used to predict crop yield. One approach is to use regression or neural networks.

An example of a linear regression model:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon$$

where:

- Y is predicted yield value,
- $X_1, X_2, \dots X_n$ are features extracted from data (NDVI, GNDVI, SAVI indices),
- $\beta_0, \beta_1, \dots, \beta_n$ are model parameters,
- ε is model error.

5. Training and Testing the Model

A part of the data (training set) is used to train the model, and another part of the data (test set) is used to check the quality of the model. The process includes, as shown in Fig.14:

Data split: 80% for training, 20% for testing.

Model training: minimizing prediction error.

Model evaluation: using quality metrics (RMSE, MAE)

6. Interpretation of Results and Forecasting

Once the model is trained and tested, it is used to predict crop yields on new data collected from UAVs. The results can be visualized as yield maps, allowing farmers to make informed decisions.

Final mathematical model:

Input data: images and spectral data from the UAVs.

Features: NDVI, GNDVI, SAVI and etc.

Model: Linear regression or neural network.

Output: Predicted yield.

This model allows to analyze crop conditions, predict yields, and optimize agricultural operations.

To describe the mathematical model for recognizing and analyzing agricultural yields based on UAV data using AI, several key formulas and equations can be identified:

Application of model for predicting yields on new data

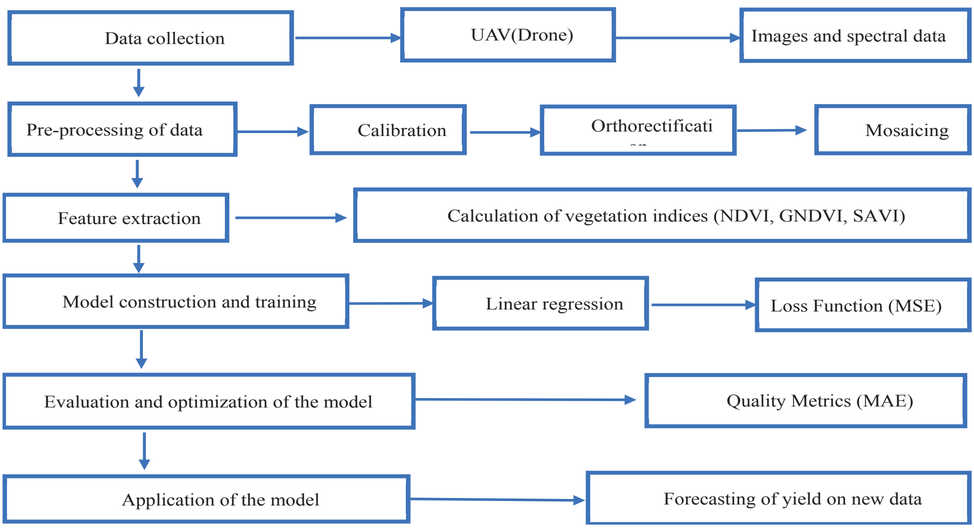

Fig. 14 – Process scheme

The research shows how image processing techniques can be used to automatically analyze field vegetation. This program can be run in PyCharm by installing the necessary libraries, for example using the command `pip install opencv-python numpy scikit-learn matplotlib`.

Discussion. Modern technologies are opening up new opportunities for agriculture, especially in the field of yield monitoring and analysis. In Kazakhstan, with its vast farmlands, the use of drones in combination with AI is becoming increasingly relevant. UAVs collect high-quality data on the state of fields using various sensors. Artificial intelligence processes this data, detecting plant diseases, determining moisture levels and predicting yields with high accuracy.

Advantages of using AI and UAVs in agriculture in Kazakhstan

1. Increase Yields: accurate and timely data allows farmers to make informed decisions about field management, which can significantly increase yields.
2. Reduced Costs: automation of monitoring and analysis processes reduces labor and resource costs.
3. Early Problem Detection: AI can quickly identify problems such as plant diseases or pests, allowing early action to be taken and crop losses to be prevented.
4. Optimized Resource Use: data obtained from UAVs helps optimize fertilizer and water use, leading to more sustainable farming.

Conclusion. The use of UAVs and AI for yield analysis in Kazakhstan opens up new opportunities for improving agricultural efficiency. The study developed methods for monitoring fields using drones and deep learning algorithms to accurately recognize the state of crops and identify problems at an early stage. AI helps predict yields, optimize crops, fertilizers, and irrigation, which reduces costs and increases profitability. The introduction of these technologies contributes to the digitalization of the agricultural sector and the strengthening of the country's food security. Further development requires continued research and adaptation of solutions to the conditions of Kazakhstan.

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