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Review

Review of Some Applications of Unmanned Aerial Vehicles Technology in the Resource-Rich Country

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Abstract: The use of unmanned aerial vehicles (UAVs) in various spheres of human activity is a promising direction for countries with very different types of economies. This statement refers to resource-rich economies as well. The peculiarities of such countries are associated with the dependence on resource prices since their economies present low diversification. Therefore, the employment of new technologies is one of the ways of increasing the sustainability of such economy development. In this context, the use of UAVs is a prospect direction, since they are relatively cheap, reliable, and their use does not require a high-tech background. The most common use of UAVs is associated with various types of monitoring tasks. In addition, UAVs can be used for organizing communication, search, cargo delivery, field processing, etc. Using additional elements of artificial intelligence (AI) together with UAVs helps to solve the problems in automatic or semi-automatic mode. Such UAV is named intelligent unmanned aerial vehicle technology (IUAVT), and its employment allows increasing the UAV-based technology efficiency. However, in order to adapt IUAVT in the sectors of economy, it is necessary to overcome a range of limitations. The research is devoted to the analysis of opportunities and obstacles to the adaptation of IUAVT in the economy. The possible economic effect is estimated for Kazakhstan as one of the resource-rich countries. The review consists of three main parts. The first part describes the IUAVT application areas and the tasks it can solve. The following areas of application are considered: precision agriculture, the hazardous geophysical processes monitoring, environmental pollution monitoring, exploration of minerals, wild animals monitoring, technical and engineering structures monitoring, and traffic monitoring. The economic potential is estimated by the areas of application of IUAVT in Kazakhstan. The second part contains the review of the technical, legal, and software-algorithmic limitations of IUAVT and modern approaches aimed at overcoming these limitations. The third part—discussion—comprises the consideration of the impact of these limitations and unsolved tasks of the IUAVT employment in the areas of activity under consideration, and assessment of the overall economic effect.

Keywords: intelligent unmanned aerial vehicle technology; precision agriculture; mineral exploration; monitoring; machine learning

1. Introduction

New technologies are a mandatory component of successful economic justification when using traditional and new sectors of economy, causing an increase in production and productivity. These technologies are connected not only with extraction, processing, and production, but also with data collection, processing, analysis, and application of new management methods.

This study comprises the review of the possible use and benefits of utilizing the unmanned aerial vehicles (UAVs) for such a resource-rich country such as Kazakhstan.

The state of Kazakhstan's national economy is heavily dependent on extracted minerals, like in other countries with similar economy. However, the explored reserves are depleting. Sustainable development of the economy requires the transition to new methods and technologies of management, involving other significant riches, which Kazakhstan has (agricultural products, animal husbandry, new deposits of minerals, human resources, etc.) in the economic turnover. In particular, in [1], it is noted that there is a global increase in demand for organic, environmentally friendly products, but, at the same time, there is a lag in the level of labor productivity in sectors of the economy of Kazakhstan. For example, in comparison to countries such as Australia and Canada, there is a delay of 12–15 times in agriculture, and 5–10 times in mining, and 2–4 times in manufacturing. The insufficient spread of modern technologies, high levels of deterioration, and the low technological level of fixed assets resulted in a decline in gross fixed capital formation from 30% of GDP in 2007 to 23.3% in 2016; this constrained the growth in productivity. The state program "Digital Kazakhstan" [2] helps to accelerate the economy's pace of development in the Republic of Kazakhstan, improve the quality of life of the population via the use of digital technologies in the medium term, and create conditions for the transition of the economy of Kazakhstan to a fundamentally new development path, ensuring the creation of the digital economy of the future in the long run. Nevertheless, the development and/or use of specific technical implementations (appropriate technologies, methods, and algorithms) is not a subject of such programs. Technical implementations should be studied and developed for the most effective solution of each applied problem, which requires processing the different types of data.

Data processing is one of principal aspects of the technological development of the economy of each country [3,4]. There are many studies which show that hardware and software products in data processing can be used for different applications in economy. Computing resources cannot be considered as a critical obstacle to data processing tasks either. There is also an option of using resources of supercomputers or graphic processors in combination with machine learning methods applied in practice [5].

At the same time, successes in the field of agricultural production, animal husbandry, industry, and urban management are usually associated with the collection and practical application of large amounts of data, including spatially distributed resources and objects for the purpose of monitoring and process control. In many of these tasks, data collection is associated with the analysis of terrain [6–8]. These data can be collected using stationary systems, platforms with low mobility (for example, using cars), and several types of highly mobile platforms (spacecraft, aerial photography, unmanned aerial vehicles (UAVs)). Among the listed technologies, UAVs have very serious advantages in obtaining data of a small and partly medium scale in terms of efficiency, cost, and resolution [9] (see Appendix A Table A1).

The use of such data is relevant when engineers, agronomists, livestock keepers, and others specialists deal with spatially distributed natural or technical systems. These systems include agriculture, prospecting and extracting the minerals, geo-ecological systems, technical and architectural structures, animal husbandry, transport, etc.

UAVs management and application of the potential of large volumes of collected data is implemented using the artificial intelligence technologies [5,10].

In this regard, the set of solutions combining artificial intelligence systems and UAV-based platforms will be called intelligent unmanned aerial vehicle technology (IUAVT) [11].

IUAVT has impressive market prospects: USD 127 billion for key industries [12] (see Figure 1).

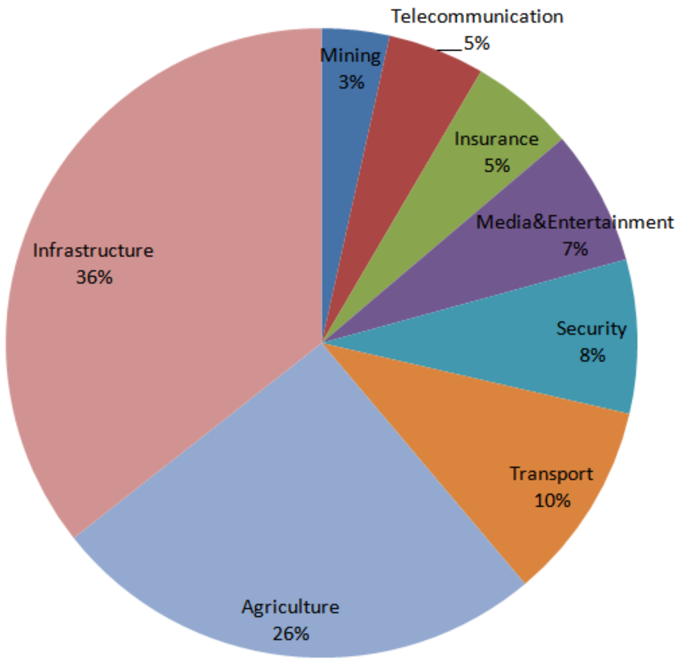

Figure 1. Market prospects of using UAVs. Source: Generated by the authors.

Nevertheless, despite the good economic prospects, there are also limitations, including preventing the widespread use of IUAVT in sectors of economy. Along with the technical limitations of UAVs, there are also unsolved problems in the field of data processing related to the fact that the data, collected with UAVs employment, demonstrate the classical features of Big Data with additional unique features [13].

This paper considers the economic prospects and technological restrictions for the use of IUAVT in the following fields:

- Precision agriculture (PA);
- Monitoring hazardous geophysical processes (MoHGP);
- Environmental pollution monitoring (MoEP);
- Exploration of minerals (EoM);
- Monitoring of wild animal life (MoWAL);
- Monitoring of technical and engineering structures (MoTES);
- Traffic monitoring (TrM).

The article details and expands the review started in [11], which describes the possibilities of using UAVs for solving the problems in the above listed areas. This article provides a brief structured information about the advantages and limitations of IUAVT for these applications. The applications related to PA, EoM, and MoWAL are described in detail.

Unlike other review works, for example [6,14,15], this research provides:

1. The list of UAVs tasks and applications for each area under consideration;
2. The evaluation of possible economic effect of the use of IUAVT, exemplified by one of the countries with a resource-oriented economy;
3. The main limitations associated with the data processing tasks and possible approaches to overcome these limitations based on recent research.

The article includes three main sections.

Section 1 is devoted to the analysis of the possibilities and limitations of using IUAVT in the areas listed above. Using the example of Kazakhstan, the possible economic effects for each field of application were assessed.

Section 2 discusses some technical, legal, software and algorithmic limitations of IUAVT, and possible ways of overcoming them.

Section 3 structures the identified limitations and tasks, the solution of which could facilitate the use of UAVs in the areas of activity under consideration.

In conclusion, the discussion is summarized.

2. Prerequisites for Using the UAVs in Some Spheres of Economy

2.1. Precision Agriculture (PA)

Precision agriculture is a fundamental component of the third wave of modern agricultural revolutions. The first agricultural revolution took place during the strengthening the mechanization from 1900 to 1930. Throughout this period, each farmer produced enough food to feed about 26 people. In the 1990s, there was the Green Revolution with new genetic modification methods, which resulted in each farmer can feed about 155 people. The world population is expected to reach 9.6 billion by 2050 [16], and to meet demand, food production must double from current levels. Precision agriculture is a system of crop productivity management based on complex aerospace, information, and communication technologies [17]. It provides irrigation and fertilization only for those fields that need it and chemical treatment for only diseased plants. This involves carrying out all agro-technical activities at the optimum time, depending on the specific conditions, etc., which allows obtaining savings of 10% to 50% [18]. Precision agriculture involves multiple elements and three main steps; the order of applying them is presented in Figure 2:

- Collecting comprehensive information on the farm, field, culture, and region;
- Analysis of the received information to plan agro-technological events and the development of solutions;
- Implementation of decision-holding various agro-technological events (application of fertilizers, herbicides, biophages).

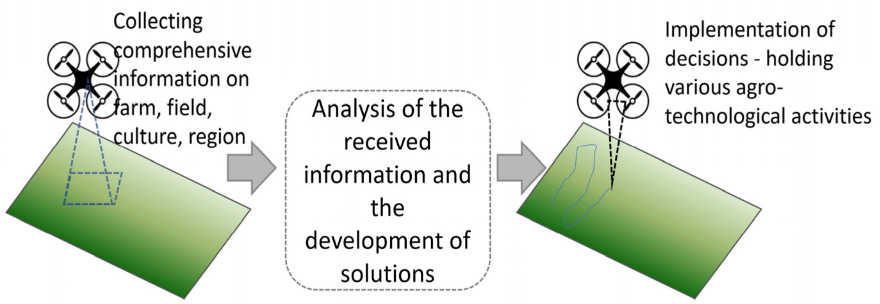

Figure 2. IUAVT as a component of precision agriculture. Source: Generated by the authors.

UAVs make it possible to use the potential of precision agriculture at full scale, not only at the stage of information gathering (the creation of accurate field maps with all their characteristics and features, determination of soil moisture, identification of pests [19], etc.), but also at the stage of implementation of decisions (for example, spot treatment with pesticides) [20] (see Figure 3). The figure shows the main agricultural activities on the cultivation of crops during the year (left) and the possible participation of UAVS in solving the tasks of PA (right).

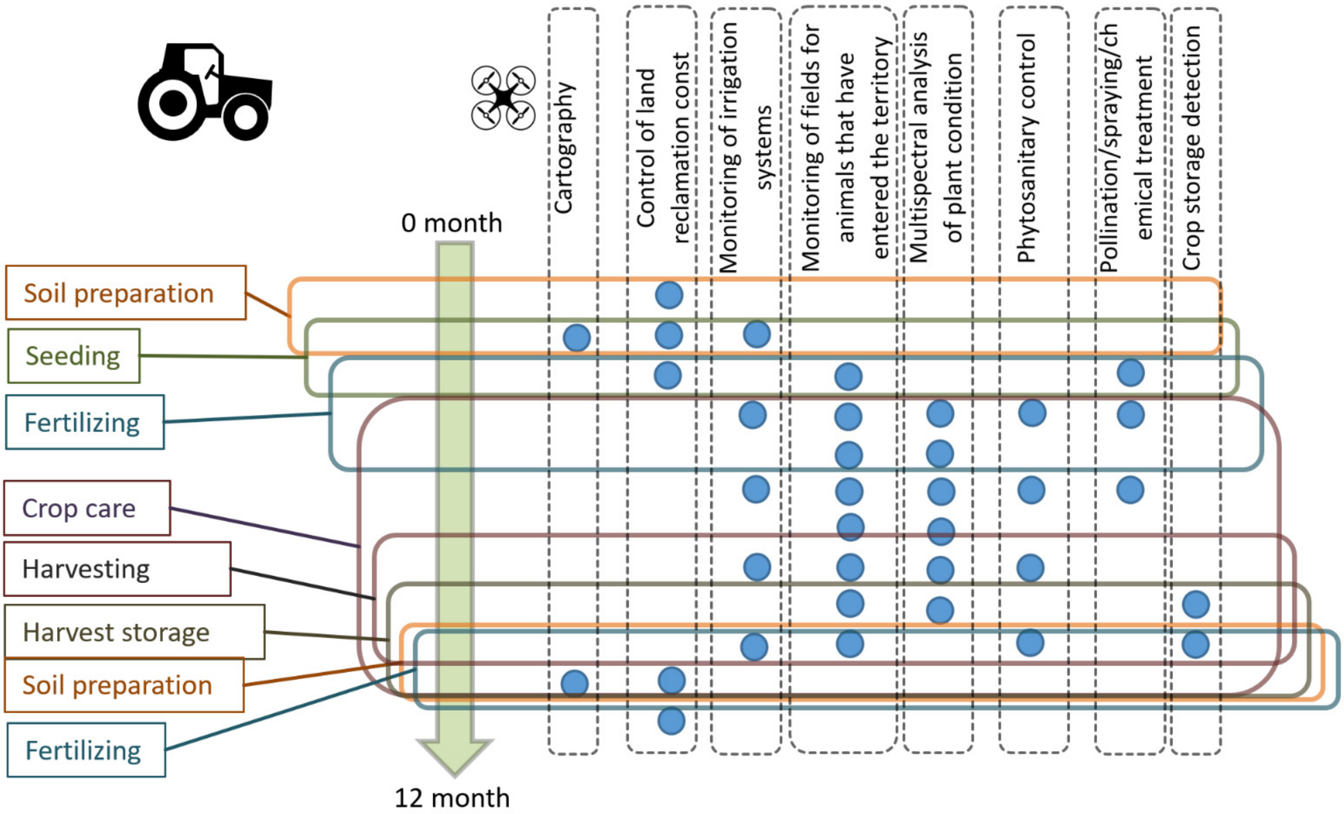

Figure 3. Periods of agrotechnical activities of precision farming and possible use of UAVs. Source: Generated by the authors.

The UAV can be equipped with different sensors, but most often they use GPS, a multi/hyperspectral camera, a humidity sensor, and a barometer [20]. In particular, it is important to have a camera covering the visible and near-infrared (NIR) range, since multispectral camera recording is used to determine the normalized difference vegetation index (NDVI); it has become one of the most reliable tools for easy and rapid remote assessment of plant and crop conditions since 1973.

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{Red})/(\mathrm{NIR} + \mathrm{Red})$$

To this day, the NDVI is the most common vegetation index used in agriculture.

NDVI allows agronomists and farmers to see fading crops in the field two weeks before the human eye can detect them. Diseased plants can be identified more quickly in the infrared range than with the unaided eye, so farmers can identify potential problems, such as diseases, pests, fungi, or arid zones, and solve the problems faster and without serious consequences.

Kazakhstan implements the precision agriculture on test sites. These test sites demonstrate 20–40% savings and a significant increase in the yield [21,22]. Nevertheless, there are no complex solutions with a wide use of mobile data collection platforms in the market of Kazakhstan. It creates the certain lag with the global trends. As a result, the competitiveness of agro-industrial complex of the Republic of Kazakhstan is significantly reduced [23]. At the same time, the application of new methods based on UAV suggests a substantial increase in yields and efficiency.

The results will have a significant impact on the development of the domestic market for agricultural UAVs, and can also be used for the development of agricultural drones' solutions abroad.

Internationally, the expected volume of the market for agricultural drones will be USD 4.8 billion by 2024, and the USA will continue keeping the main market share [24]. The main sources of growth will be: increasing venture capital financing, awareness of the benefits of agricultural UAVs, and software solutions for field research and data analysis.

By extrapolating this amount by the size of the population and the income level in Kazakhstan, it is possible to assume the formation of the agricultural UAV market of several tens of millions of dollars.

The advantage of application of precision agriculture models for the main crops of Kazakhstan can be estimated based on the data [25,26]. Table 1 shows generalized data on the current yield of the main crops grown in the Republic of Kazakhstan in comparison with the expected yield. According to [26], the introduction of precision agriculture leads to yield improvements from 42 to 80% for different crops.

Table 1. Comparison of current and expected crop values.

Agricultural Crops	Current Yield (2020), Centners per Hectare	Current Gross Harvest (2020) Million Tons	Current Crop Value, Million Dollars	Expected Yield When Using PA, Centners per Hectare	Expected Gross Yield When Using PA, Million Tons	Expected Crop Value When Using PA, Million Dollars
Cereals (excluding wheat) and legumes	12.8	5.6	761.15	21.6	9.5	1286.35
Wheat	11.8	14.4	2985.16	16.8	20	4238.93
Potato	206.7	4	1882.17	293.5	5.7	2672.68
Oilseed crops	9.5	1.8	188.76	13.5	2.6	268.04
Sunflower seeds	11.3	0.8	427.05	16.1	1.2	606.41
Vegetables of open and closed ground	265.9	4.3	5089.54	377.6	6.1	7227.14
Sugar beet	323.2	0.5	491.8	581.8	0.9	885.23
Cotton	25.9	0.33	99.34	36.8	0.46	141.05
Total		31.8	11924.97		46.8	17325.84

The prerequisites of employing IUAVT is low productivity in the field and growing demand for the organic products [1]. With the widespread integration of precise agriculture methods in the Republic of Kazakhstan, the expected profit increased is USD 5.4 billion. Here, 6% or USD 324 million, according to data [27], will be associated with the application of agricultural drones, without taking into account market the features of grain sales.

To implement the precision agriculture systems, it is necessary to develop the models and methods of decision support systems using machine learning algorithms which are based on processing the heterogeneous data obtained with the use of UAVs. It is needed to develop models and methods of decision support using machine learning based on processing the heterogeneous data obtained with the use of UAVs, and to develop methods for UAV group control to perform plant protection and fertilization tasks. Another issue is solving the computer vision problems for processing multi-spectral images from low-flying platforms (see Appendix A Table A2).

2.2. Monitoring of Environmental Pollution (MoEP)

Environmental pollution as a result of industrial development, mining, and urban growth is a serious problem. Environmental pollution affects human health [28], agriculture [29], the climate system, and the hydrological cycle [30]. Fast-growing cities face the atmospheric pollution problems [31]. Polluted air, water, and soil increase risk of coronary heart disease, lung cancer, cerebrovascular disease, chronic obstructive pulmonary disease (COPD), and respiratory infections, resulting in morbidity and mortality.

One of the promising practices for collecting data related to environmental pollution is using UAVs, equipped with cameras of various spectral ranges, a set of sensors, as well as spectrometric and gamma-radiometric equipment [32]. Existing examples show the possibilities of using UAVs to assess the radiation situation in the areas, dangerous for humans [33], for example, radiation mapping [34] and examining forests near Chernobyl [35]. In addition, UAV-based complexes are used for the detection of volatile organic substances (VOC) emitted as a result of emergencies [36] and for monitoring air pollution [37].

The scheme in Figure 4 shows the main tasks of environmental control (left) [38] and the way that UAVs can help in solving these tasks.

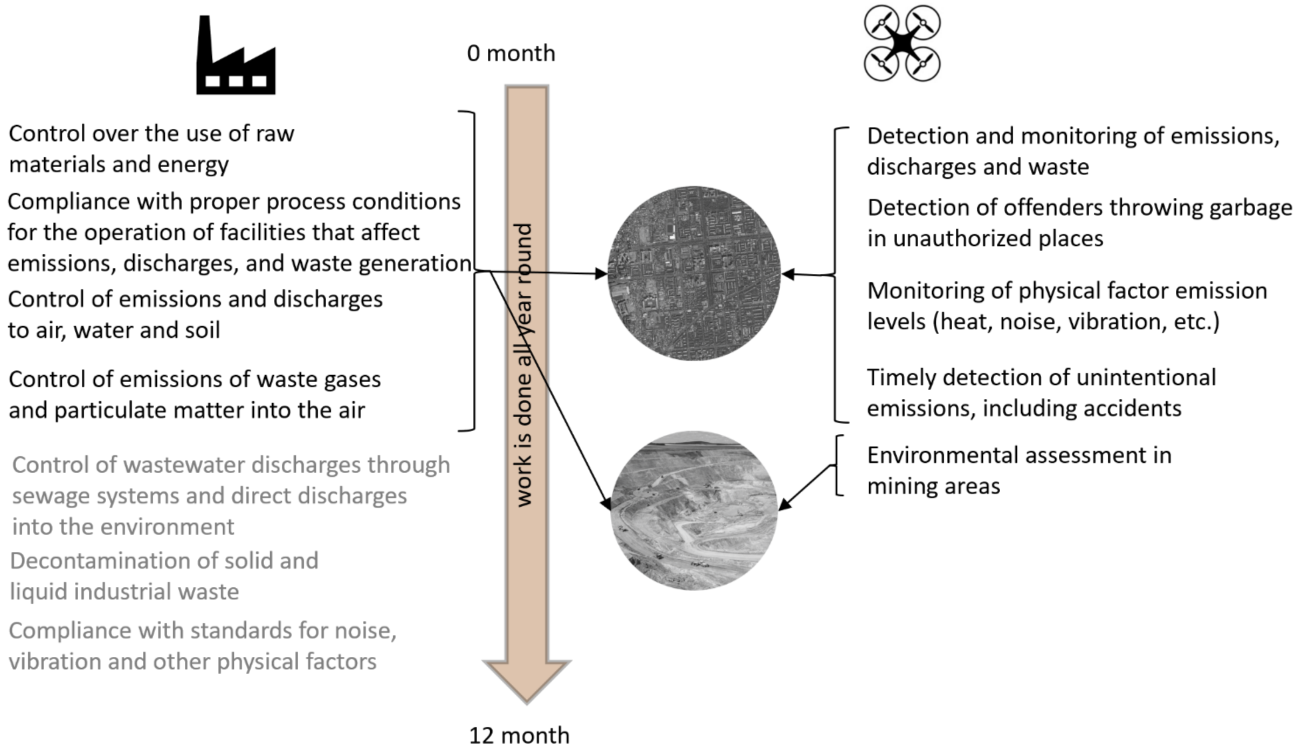

Figure 4. Environmental monitoring tasks and UAVs capabilities. Source: Generated by the authors.

Kazakhstan's environmental problems are associated with the growth of cities, the use of coal and oil for energy and heat generation, and the work of the extractive industry.

Intensive development of natural resources, often without regard for environmental impacts, inevitably leads to land and soil contamination. According to the land balance data for 1 November 2015, there are over 240 thousand hectares of disturbed lands in the Kazakhstan, where overburden and rock dumps, tailing ponds, ash dumps, coal and mining quarries, etc. are located. Most of these lands are located in Karaganda, Kostanay, Mangistau, Akmola, East Kazakhstan, and Turkestan regions [39].

It can be noted that the largest city of Kazakhstan, Almaty, has one of the highest levels of atmospheric pollution [31,40], which leads to a significant growth of chronic obstructive pulmonary disease, almost twice exceeding the average level in post-Soviet countries [41].

According to the World Bank estimates, polluted air increases healthcare costs in Kazakhstan by about USD 1 billion per year [42]. Reducing the concentration of the smallest PM2.5 dust particles by only 1 microgram will save about USD 56.7 million annually by reducing mortality and increasing the number of working days [43].

Payments for environmental emissions in Kazakhstan, which amounted to USD 216.7 million in 2017, are increasing annually by 8% according to the Organization for Economic Cooperation and Development [44].

The use of UAVs for the environmental monitoring tasks is conditioned by significant economic losses and a threat to public health [43]; it is expected that the use of UAVs will increase the intensity and quality of control over emissions into the atmosphere, which can reduce industrial environmental violations [37], reduce the number of smog days [45], and reduce greenhouse gas emissions into the atmosphere [46]. The estimated annual expenses are USD 1555 million.

It is necessary to develop the methods of operational control of hazardous substances emissions at the production facility and quality assessment of reclamation works based on heterogeneous data received from the UAV board. The following problems should be solved in this area: increasing flight time, payload, accuracy, and sensitivity of sensors; and data processing software, including computer vision systems (to assess the quality of remediation work) when performing crop protection and fertilization tasks. The evaluated economic effect of IUAVT employment is USD 87.9 million (see Appendix A Table A3).

2.3. Exploration of Minerals (EoM)

In the minerals' exploration sphere, due to the gradual depletion of the existing field resources [47], it is necessary to apply new methods that intensify the processes of geological exploration. This task is quite acute in Kazakhstan, thereby the President of the Republic instructed to develop a program of geological exploration [48]. The concept of the program was recently proposed in [49]. In recent years, the use of UAVs in the mining industry is rapidly expanding, changing the entire industry. The leader in this field is the Canadian company known as Pioneer Aerial Surveys [50]. Its main spheres of UAV application are as follows [51]:

- Mapping;
- 3D modeling;
- Conducting geophysical research.

One of the main advantages of using UAVs compared to the airborne surveys or traditional field surveys is the significantly lower cost of exploration, especially for remote regions with poor infrastructure.

At the same time, the use of drones is possible at all stages of the field development: during prospecting, development [52], and reclamation. The use of the UAVs becomes useful for geological applications due to its low operating costs and ease of use.

The period of geological exploration and mining can average up to 50 years, they are divided into stages or phases. The first phase is regional geological studies, making the geological maps of small scales, accompanied by regional geological and geophysical studies. A large area of several hundred km is usually investigated at this stage. The photogrammetric, aeromagnetic, gamma-spectrometric, and thermometric surveys can be performed with the use of UAVs, thereby it is possible to carry out part of geological exploration over a large area more economically and efficiently.

The next phase is the stage of exploration and evaluation of resources in a large area of sites with increased concentrations of useful components. An aeromagnetic survey can also be used in the areas of ore occurrence; this survey can identify ore or non-metallic objects, magnet-susceptible or not, radioactive or not, and further several wells will be drilled and several ditches will be dug.

In the third phase, the deposits and an assessment of mineral reserves and resources can already be identified for all the performed studies. At this stage, the main types of drilling are carried out according to the certain network, and the geochemical and other types of sampling are taken directly from the object. At this stage, the use of UAVs is not provided.

At the last stage (the stage of development of mineral deposits), as well as after the end of production, UAVs can be used to assess radioactive and other types of man-made environmental pollution.

The stages of exploration and mining operations and the possibilities of using the UAVs are shown in Figure 5. The figure was created based on the sources [53–56].

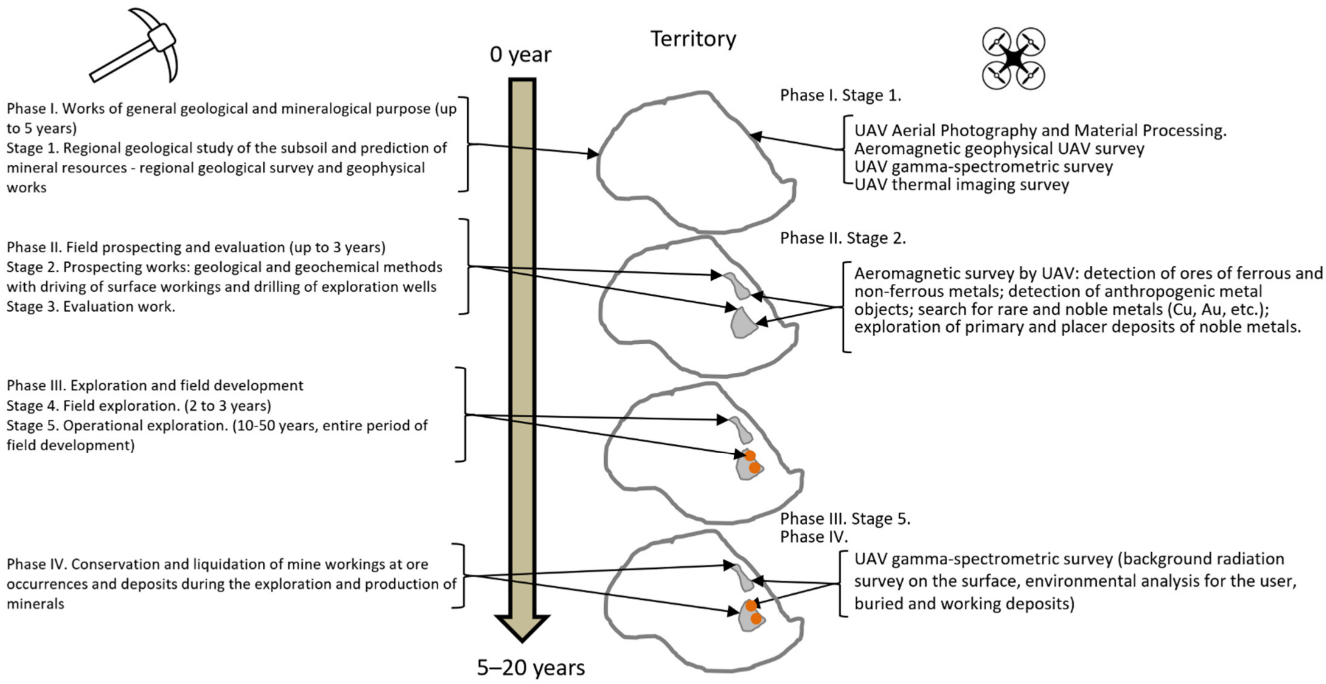

Figure 5. The use of UAV at various stages of geological exploration and mining. Source: Generated by the authors.

Magnetic and hyperspectral studies are of particular interest for mineral exploration, and groups of authors have published studies of magnetic data collected by the UAVs for such applications [57,58]. Magnetic measurements play an important role in mineral exploration, as magnetization in rocks is mainly related to magnetite and other iron minerals that can be used in mapping and exploration [59]. Currently, magnetic imaging is limited to mapping iron-containing minerals, such as hematite, jarosite, and goethite, which also have spectral characteristic features in the visible and near-infrared range.

Hyperspectral imaging (HSI) is a powerful method of exploration and mapping in areas where the rock surface is well exposed, and where geological bodies and minerals composition can be estimated by the spectral characteristics of the electromagnetic spectrum in the visual and infrared range [60]. The system can also identify vegetation features that can be used as indicators of mineralization (i.e., different vegetation types that correlate with major rock types [61]). Other potential applications include rare earth element mapping and mine tailings monitoring [62].

When searching for deposits, it is necessary to analyze a large amount of data: space images, soil and groundwater samples, presence of minerals-indicators, geophysical survey data, and many others. It is difficult for a person to process such a large amount of information. In particular, at the stage of exploration, identification of potentially prospective sites of ore, oil, and gas can occur after determining the correlation of field and well survey data; laboratory analysis of samples; and data recorded by drone sensors for ore, oil, and gas bearing and low potential sited. This problem has many parameters and hidden dependencies; it cannot be formalized and accurately solved by classical methods, but approximate solution can be obtained by machine learning methods. Algorithms such as artificial neural networks (ANN), support vector machines (SVM), and convolutional neural networks (CNN) are most often used in exploration geophysics [63].

The set of sensors installed on the UAV is determined by the task, but most often it is a hyperspectral camera, magnetometer, and GPS [60]. Due to the limitations imposed on the weight and size of the equipment, a camera operating in the VNIR band (400–1100 nm), such as RICOLA, is usually installed as a hyperspectral camera [64]. The spectral characteristics in this range allow the detection of iron oxides (range 800–1000 nm) as well as rare earth elements (Nb, Ta, . . .) [65]. Data validation is performed by ground-based measurements, in particular, X-ray fluorescence analysis, X-ray diffraction analysis, and optical microscopy [47]. Apart from VNIR range cameras, a SWIR range camera (1400–3000 nm), e.g., SWIR 640 P-Series, can be installed if necessary [66]. In general, it is necessary to work in a variety of spectral ranges to find different groups of minerals [67]. Given the presence of large uranium deposits in Kazakhstan, it is also necessary to equip the drone with a radiometer.

The main problem of remote sensing with drones is the need to maintain accurately the height above the ground, bypassing the terrain elements. If this condition is not met, significant distortions to the data may occur, and a complex system of corrections should be developed and implemented [68]. In addition, the corrections for the atmospheric phenomena, illumination, surface inclination angle, etc. have to be made [69]. These issues require the development of the new methods of searching for minerals. These methods can be based on the employment of mobile platforms for collecting heterogeneous data, computer vision systems, and new search criteria identified by machine learning.

So far, the unsolved problem is the development of the criteria for the search for minerals using computer vision, machine learning and UAVs. For example, for oil and gas fields, the search criteria are powerful accumulations of sedimentary rocks limited by deep faults; the composition of rocks is mainly carbonate with traces of bituminosity. For copper-porphyry copper deposits, the most important factor of the regional forecast is the substrate in which ore-magmatic systems are located. They should be tectonic zones and terranes composed of oceanic and island-arc melanocratic formations and metasomatic changes at the boundary of the magmatic body and the host rocks. The possibility of using highly mobile platforms and artificial intelligence methods for reliable identification of search criteria requires further research.

The countries of the world spend huge sums of money for exploration works, but the discovered fields do not pay off these expenses. According to MinEx Consulting [70], USD 140 billion was spent between 2005 and 2014, while the value of discovered mineral resources was USD 93 billion only. The technologies developed under the program will reduce exploration costs, which may result in significant savings on a global scale.

The use of unmanned technologies, combined with artificial intelligence techniques, will speed up geological exploration on large areas. For example, on an area of 10,000 square km, a comparative calculation of the cost of the traditional ground-based method (using motor vehicles) with manual geochemical sampling (USD 335,000) and the use of UAVs equipped with a hyperspectral camera and compact magnetometer (USD 68,000) shows almost five-fold advantage of using UAVs for some types of geological exploration. Two main sedimentary basins have been identified in Southern Kazakhstan with the total area of 248,000 square km: the Shu-Sarysu basin (168,000 square km) and the South-Torgay basin (80,000 square km) [71]. Consequently, the application of the described technology can result in savings of about USD 6 million for the territory of Southern Kazakhstan only.

In accordance with the program [72], it is necessary to study about 5.5% of the territory of Republic (149,000 square km) and to increase the degree of geological and geophysical exploration of sedimentary basins (900,000 square km [73]). The costs of such work using traditional methods of geological exploration will amount to about USD 42 million. The costs of these works with employment of IUAVT can amount to about USD 8.5 million.

In total, for the territory of Kazakhstan, savings in geological exploration with the use of UAVs and machine learning methods may amount to more than USD 18 million compared to the traditional methods. At the same time, the increase in labor productivity will amount to more than 300%. We would like to note that this assessment concerns only the part of necessary work. We also assume that the use of a hyperspectral camera could reduce sampling for laboratory studies. At the same time, some types of deposits require sampling, laboratory studies and well drilling.

The use of IUAVT for solving the tasks of minerals exploration has some prerequisites, the main of them are significant exploration costs that currently do not provide return [70] and the concept of the State program of geological exploration for 2021–2025 in Kazakhstan [72]. The estimated annual expenses are USD 41 million.

It is necessary to develop the methods of mineral exploration based on the application of highly mobile platforms for the collection of heterogeneous data, computer vision systems, and new search criteria identified by machine learning. The following problems should be solved in this area: increased flight time; payload; accuracy and sensitivity of sensors; data processing software, including computer vision; and control systems. The evaluated economic effect of IUAVT employment is USD 33 million (see Appendix A Table A4).

2.4. Monitoring of Wild Animal Life (MoWAL)

Kazakhstan is not only rich in minerals, but also in biological resources, one of which is wild animals. Considering the nature management, there is a need for transition from extensive methods of hunting to their intensification. At present, the country has all the prerequisites for the introduction of "green" technologies for hunting activities. This implies a combination of different uses of wildlife and its protection, including habitats and hunting grounds, increasing their productivity, reproduction, and game ranching. Experience of a number of countries (USA, Canada, Germany, Czech Republic, Sweden, Finland, etc.) shows that such hunting management allows obtaining its products in quantities comparable to the corresponding animal industries. For example, in Sweden, with an area 6 times less than the area of the Republic of Kazakhstan and three times more population density, the population of moose alone is 400 thousand, and the annual production volume is about 100 thousand heads [74]. For comparison, a limit of 78 heads has been allocated in the Republic of Kazakhstan in 2015 (according to the Committee for Forestry of Wildlife of the Ministry of Agriculture of the Republic of Kazakhstan).

One of the ways of sustainable use of animals assigned to hunting sites is through economic assessment of their cost and productivity of hunting grounds. It is difficult to justify the amount of investment in some measures for the reproduction, protection, and sustainable use of animal resources without such estimation. This assessment should be based, first of all, on knowledge of productivity of hunting grounds and number of animals included in hunting sites. This, in turn, should become the basis for determining the economic indicators of natural resources. All these factors serve as a basis for the development of payment standards for the use of wildlife and hunting grounds. The solution of this problem is one of the priorities of the world community in the field of sustainable natural resources management.

According to the International Convention on Biodiversity Conservation (Rio de Janeiro 1992, [75]), ratified by the Cabinet of Ministers of the Republic of Kazakhstan in 1995, each country involved in the convention, on the one hand, independently determines the principles and methods of sustainable use of biodiversity in its territory (in accordance with the convention and domestic legislation), and, at the same time, is responsible for the conservation of natural resources. In the Republic of Kazakhstan, these principles are laid down in the Constitution, the Environmental Code, and, in respect of wildlife, in the Law on Protection, Reproduction, and Use of Wildlife (2004) and relevant regulations. They also define the procedure for monitoring, cadaster, and accounting of animal resources related to hunting sites. At the same time, these documents do not define the participants of the monitoring, and the available methods of accounting are not adapted to hunting farms and specially protected natural areas. In order to eliminate this contradiction, it is necessary to monitor the number of wildlife representatives in a given area and to develop decision support systems for management and maintenance of biological and landscape diversity of unique natural ecosystems and their monitoring.

Collecting field zoogeographic data is a rather time-consuming process, mainly dependent not on the observer but on the representative of the animal world. It is impossible to calculate directly the population of commercial ungulates of mountain ecosystems of Kazakhstan by ground methods. However, it is possible to estimate roughly the number of animals, for example, boars, by indirect decoding signs. Such signs for them are trails, beds, and gusts. Data on the density of wild boar trails, obtained at different times of the year, allow determining the preferences of these animals in different periods foraging and staying on the territory of the reserve and outside its borders, depending on the hunting season.

Thus, the program should develop models and methods for operational monitoring, assessment and forecasting of biological and economic productivity of commercially exploited ungulate species.

Figure 6 shows the tasks of the huntsman [76] (left) and the possible use of UAVs to solve them (right). The data from the UAVs make it possible to determine the distribution ranges and the number of individuals [77]. UAVs can be used to control pollution in wild nature [78]. The employment of a multispectral and thermal camera enhances the capabilities of the method. Thus, UAVs equipped with an infrared camera are used to combat poachers [79]. The work on searching for wild animals can be reduced by several times with the use of a thermal imaging camera [80].

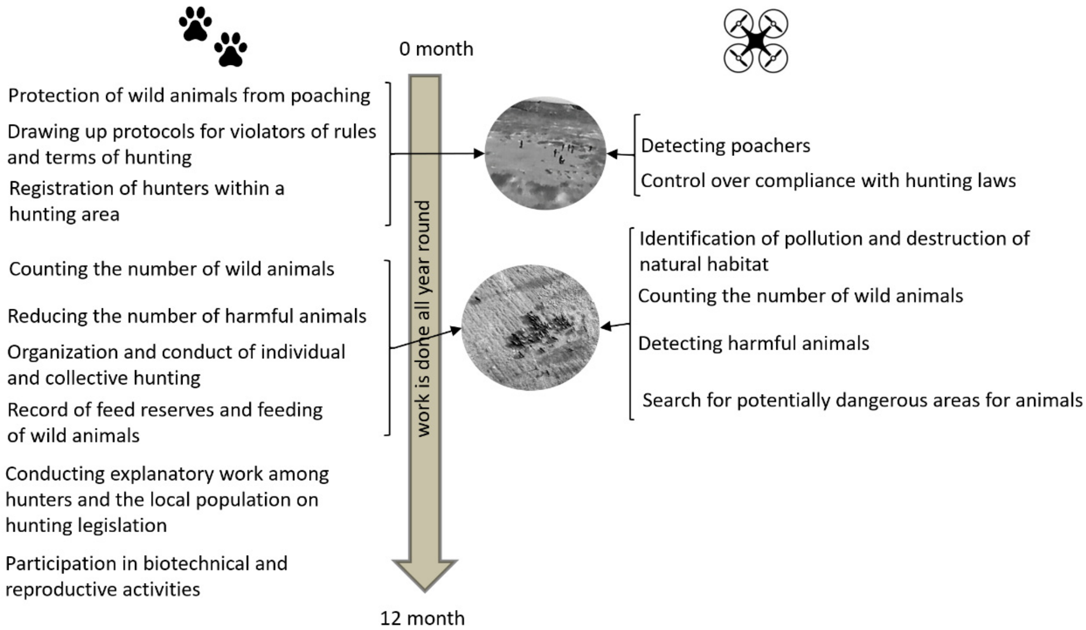

Figure 6. Monitoring of wild animal life. Source: Generated by the authors.

Comparative analysis of the cost of monitoring shows that aerial photography carried out once a quarter for 50 hunting grounds of Turkestan region with the total area of 80 thousand square km will be approximately twice as expensive (about USD 2.8 million) as compared to UAV (USD 1.4 million); these amounts are shown even without taking into account a number of unique features of the combined UAV platform and artificial intelligence system (for example a weaker impact on the ecosystem and the ability to perform operational monitoring). According to [80,81], IUAVT allows significant savings in animal monitoring.

It is necessary to develop models and methods for operational monitoring, assessment, and forecasting of biological and economic productivity of commercially exploited ungulate species. The areas of research and development are increased flight time; payload; accuracy and sensitivity of sensors; data processing software, including computer vision; and control systems. In general, savings from UAV technology and machine learning, related to all hunting grounds in Kazakhstan (702) with the area of 1,100,000 square km, are estimated at about USD 18 million per year (see Appendix A Table A5).

2.5. Monitoring of the Hazardous Geophysical Processes (MoHGP)

Geological and geophysical processes underground and on the surface can lead to catastrophes and natural disasters. Natural and man-made disasters in densely populated areas lead to deep social upheavals. They are considered to be one of the serious destabilizing factors [81,82]. Monitoring in order to identify the sources and to assess the consequences of catastrophic events and possible assistance to victims is the purpose of using UAVs [83]. The examples of this kind are as follows: the tasks of mapping the displacement of landslides (Italy, Tessin) [84,85], the organization of communications in the affected areas [85], and the delivery of small goods [86]. Possible monitoring tasks (left) and the use of UAVs (right) are shown in Figure 7 (the Figure is based on [83,87–89]).

The use of UAVs for monitoring the development of hazardous geological and geophysical processes is economically profitable. According to approximate estimates given in [11], the possible savings from preventing the consequences of annual floods in Kazakhstan can amount to up to USD 10 million per year.

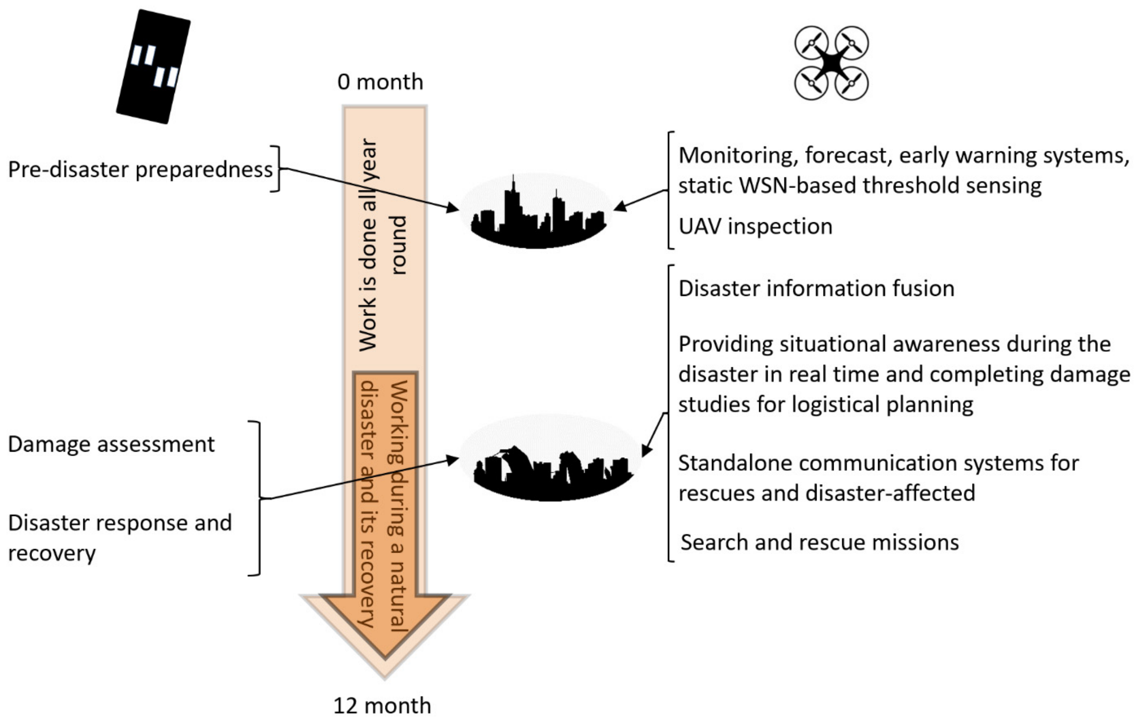

Figure 7. IUAVT in the disaster process control. Source: Generated by the authors.

The main prerequisites of using IUAVT for monitoring hazardous geophysical processes are as follows: destabilizing factors [82,89], significant economic losses, threats to life, and health of the population [81,90]. The estimated annual expenses are USD 200 million.

It is necessary to realize the possibility of prevention of emergencies, and to develop methods of forecasting and operative monitoring of dangerous geophysical processes and changes of engineering constructions with the application of a UAV and data mining tools. The following scientific and technical problems should be solved: development of methods for recognition and classification of images in this subject area. The evaluated economic effect of IUAVT employment is USD 10 million (see Appendix A Table A6).

2.6. Monitoring of Technical and Engineering Structures (MoTES)

The new industrial revolution, Industry 4.0 [91], is based on the paradigm of the industrial Internet of Things (IIoT). IIoT provides a new type of business model [92]. A key element of these models is collecting and processing the data throughout the entire life cycle of a product or structure.

IIoT application areas are as follows: transportation systems and vehicles, machinery, construction, houses, firefighting equipment, agricultural systems, mining and related equipment, medical devices, and personal products, etc. [93].

UAVs are used for monitoring, for 3D models construction, for the detection and assessment of damages, etc. [94]. Figure 8 based on [95,96] illustrates usage of UAVs for tasks of such type.

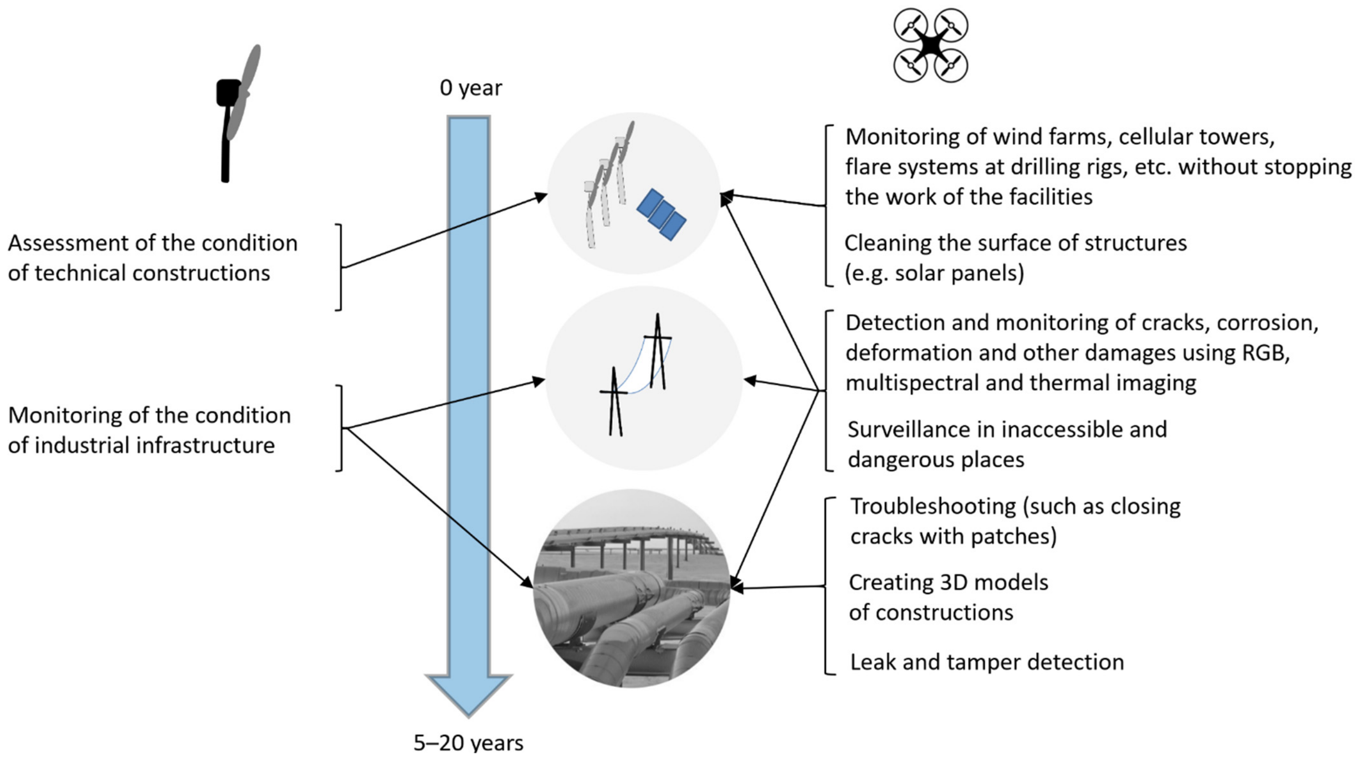

Figure 8. Using UAVs for monitoring of technical and engineering structures. Source: Generated by the authors.

UAVs allow getting quickly the collections of 3D images, including ones from hard-to-reach places [97]. The obtained images are classified using deep learning, for example, to assess the condition of the wings of wind turbines [98]. The use of noise sensors makes it possible to detect the increasing destruction [99]. UAVs additionally equipped with an infrared camera can be used for monitoring of vast areas of photovoltaic stations [100]. Re-equipment with additional ultrasonic and laser scanners allows the use of UAVs for monitoring of the steel structures [101]. Along with the advantages of such use of UAVs, there are also disadvantages among which are flight restrictions, weather dependence, and weight restricting equipment.

The assessment of the economic effect of the use of UAVs for air patrolling pipelines in Kazakhstan is given in [11], and its volume is about USD 7.9 million per year.

The main prerequisites of using IUAVT for monitoring of technical and engineering structures are the necessity to collect information on the condition of machinery and facilities, especially in hard-to-reach places for the implementation of tasks [97–101].

It is necessary to develop methods for monitoring engineering structures using computer vision systems and machine learning to identify and prevent violations in their work and to predict their condition. Scientific and technical problems, such as the development of software for machine vision, image classification, and indoor flight control applications, should be solved in this area. The evaluated economic effect of IUAVT employment is USD 10 million (see Appendix A Table A7).

2.7. Traffic Monitoring (TrM)

The main expectations from IUVT in traffic management tasks are an assessment of the traffic situation, rapid reaching the traffic accident site, and the possible delivery of first-aid kits to victims waiting for ambulances. Rapid response reduces the risk of traffic jams and additional costs.

In addition, data collection is required for solving the problem of traffic optimization [14]. The main tasks of traffic optimization and the possible participation of UAVs in this process are shown in Figure 9. The figure is based on the sources [102–107].

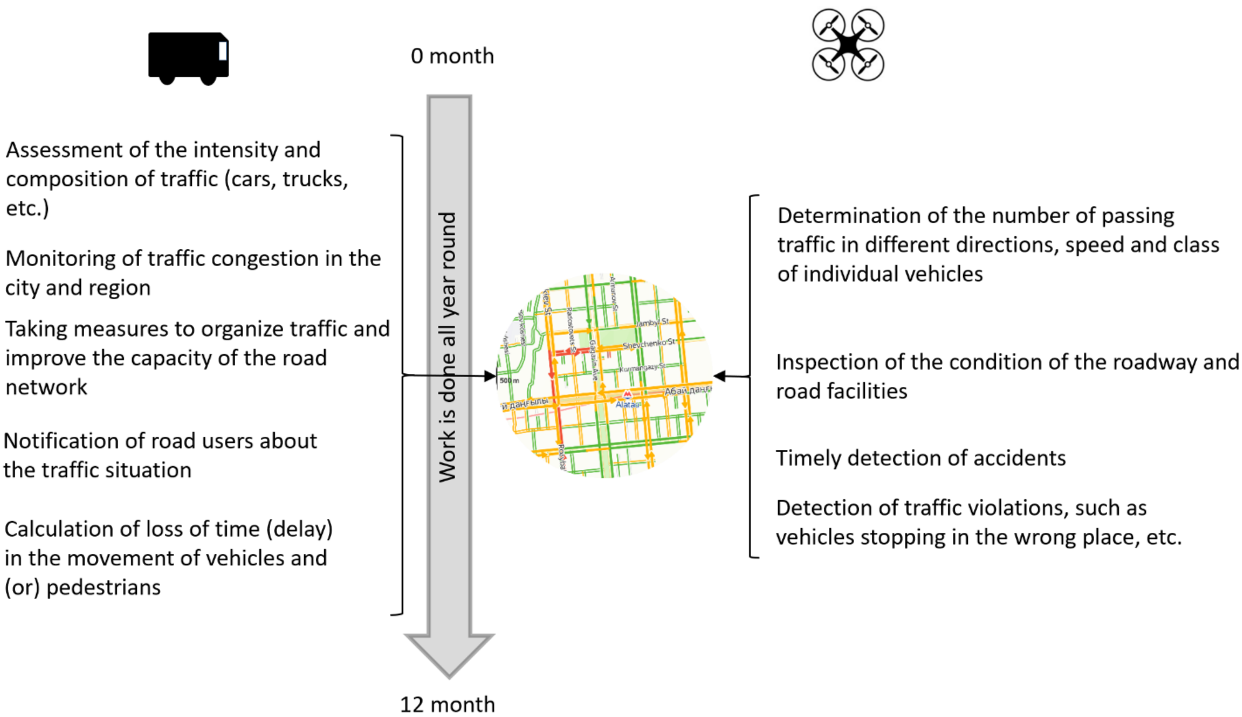

Figure 9. Traffic monitoring. Source: Generated by the authors.

The advantages and limitations of using UAVs in the task of traffic monitoring are summarized in Table 2.

Table 2. Pros and cons of UAV applications in traffic monitoring processes.

Tasks to be Solved	Advantages	Limitations
Assessment of the situation, delivery of small loads (first-aid kits), notification of road users, monitoring of road and pedestrian traffic, search and tracking of potentially dangerous road users, organization of communication.	Mobility and independence from communications, urgency and high speed, data availability for research purposes, organization of communication if necessary.	Limited flight time, weather dependence, limited payload, limitations in solving computational problems on board of the UAVs, legal restrictions on the use of UAVs in urban conditions.

The main prerequisites of using IUAVT for traffic monitoring are significant economic losses and a threat to public health [108,109]. The economic losses from traffic obstacles and accidents in Kazakhstan are estimated at about USD 3.3 billion per year [108,109]. Reducing these losses due to using UAVs by at least 2% gives an economic effect in the amount of about USD 66,000 thousand [11]. The estimated annual expenses are USD 3304 million.

It is necessary to study and develop a system of operational road monitoring, tracking the potentially dangerous road users and traffic forecasting. The following scientific and technical problems should be solved: increasing the flight time, increasing the computational power of on-board processors, and solving the problems of processing large video data streams outside the UAV. The evaluated economic effect of IUAVT employment is USD 66 million (see Appendix A Table A8).

3. Limitations in the Process of IUAVT Adaptation in the Sectors of Economy

Although the literature presents the solutions for the use of UAVs in various industries [14], however, at present, IUAVT still has a number of limitations: **technical** ones (limited battery capacity, flight time, payload, sensor sensitivity, dependence on weather conditions, etc.), **legal** ones (the impossibility of some use cases within the city), and **software-algorithmic** limitations in planning, flight management, and data processing.

The technical limitations listed above affect the different extents of performing the tasks with UAVs usage. When solving tasks outside the populated areas, the limited battery capacity and flight time can significantly complicate the use of UAVs for MoWAL, EoM, and MoHGP. A number of tasks of PA, MoEP, and MoTES require the use of special sensors and cameras, as well as motion control in a closed space and in the absence of a GPS signal.

Legal restrictions are related to the fact that, in many countries, the use of UAVs is legally restricted, especially within the cities. For example, according to the existing legislation of the UAV [110]:

1. During take-off and landing, it cannot be closer than 50 m horizontally from any person (except for the person operating an unmanned aerial vehicle), another vehicle, building or structure;
2. During the flight, it cannot be closer than 100 m horizontally from any person (except for the person operating the unmanned aerial vehicle), another vehicle, building, or structure;
3. In all cases, closer than 150 m horizontally from a mass gathering of people and (or) vehicles;
4. In restricted and dangerous flight zones, or flight restriction zones.

Additional restrictions are imposed on the use of heavy UAVs.

Software and algorithmic limitations include restrictions in data processing and limitations of software tools and algorithms for UAV control and flight planning.

Data processing. The data collected by UAVs in a wide spectral range differ in features characteristic of Big Data [111]: they are heterogeneous, often incomplete, have a large volume, and change quickly. In other words, "sUAS data are classified as Big". However, they have additional unique features: multi-dimensionality, high resolution in space and time, significant amounts of the data obtained from a small area, etc. [13]. The peculiarities of these data cause the appearance of specific processing problems, which are addressed by the efforts of the scientific community. The main, but not the only, task of processing data received from the UAV is image processing tasks.

Image processing includes the tasks of identification (cv1), verification (cv2), recognition (cv3), and determination (cv4) of the visible characteristics of an object (speed, size, distance, etc.). The most successful algorithm for solving cv1 and cv3 problems is the YOLO algorithm [112], which uses a convolutional network to identify the boundaries of an object "in one pass". The cv2 problem is often solved using Siamese networks [113], when two images are processed by two identical pre-trained networks. The obtained results (image vectors) are compared using a triplet loss function, which can be implemented as a triplet embedding distance [114] or a triplet of probabilistic embeddings [115]. The quality of solving cv1-4 problems depends on the subject area and data sets (data set –DS). To configure deep neural networks, sets of labeled images with ImageNet [116], Open Images [117], COCO Dataset [118], and FaceNet are widely used. However, the existing DS and deep network architectures do not take into account the peculiarities of the IUAVT solved tasks. Only recently, to solve the specific problems arising from the features of the data received from the UAV:

1. **Data sets are being developed for training deep networks, taking into account the peculiarities of the use of UAVs.** For example, [119] describes data sets (nature, fields, hills, forests, roads), including synthetic ones [120];
2. **New deep network architectures** are being developed to solve the problems of processing images obtained from UAVs. For example, [121] discusses methods for solving

problems (cv3) and (cv4) using deep neural networks for processing data obtained from low-flying UAVs;

3. **Methods of processing multispectral data are being developed.** For example, in [122], methods of processing high-resolution multispectral data for analyzing the state of agricultural crops are considered;
4. **Flight planning and management.** Manual and semi-automatic control of individual UAVs is presented in a number of developments. Commercial software systems for manual and semi-automatic control of individual branded devices are presented by DroneDeploy [123], senseFly(eMotion) [124], Pix4D [125], and DJI (Terra) [126]. However, the software can only be used with devices of the corresponding manufacturer. The basic functionality of the commercial management systems is limited to the following tasks:
    - Allocation of an area within which the surface is monitored and, in some cases, inspection of buildings is performed;
    - Calculation of the optimal route to cover the territory. In most cases, the Zamboni method is used [127], that is, zigzag movement, which guarantees the energy-efficient coverage of the area;
    - Flight simulation (pre-launch test);
    - Receiving flight data (UAV status) in real time with the possibility of emergency termination of the flight, if necessary;
    - Processing (consolidation) of the collected material (the collected images form an overall picture of the inspected area, depending on the task).

It is difficult or impossible to use effectively the commercial software in a heterogeneous UAV fleet. There is open-source software: ArduPilot (MissionPlanner) [128], papparazi UAV [129], microkopter [130], Dronecode [131], LibrePilot [132], and OpenDroneMap [133]. Support for the first two systems was discontinued. The remaining systems do not yet have support for piloting many UAVs, with the exception of Dronecode. FlyMASTER application has been developed for the Dronecode PX4 flight control system, and it provides piloting of a variety of UAVs [134].

Along with the ordinary tasks of flying or surface treatment (available only for DJI), it is necessary to plan the optimal movement of the UAV to solve a variety of tasks. The following tasks of UAV flight optimization are highlighted in [135]: area coverage, search operations, routing for a set of locations, data gathering and recharging in a wireless sensor network (WSN), allocating communication links and computing power to mobile devices, and operational aspects of a self-organizing network of drones.

There is summarized list with highlighting the **following tasks of UAV flight control:**

- **Area coverage problem** must be solved for many UAVs applications (PA, MoEP, EoM, MoWAL, MoHGP, and TrM). Although the standard solution is to use the Zamboni algorithm [136], however, in many cases there needed the algorithms, which optimize the UAV route for specific applications. For example, in [137], the route is optimized for the application of fertilizers and pesticides, taking into account the regions exposed to stress and identified at the preliminary stage. The optimal routes are based on the traveling salesman problem algorithm and the Voronoi diagram. In [138], a model of mixed integer linear programming (MILP) was developed to solve the problems of UAV routing and planning charging stations for checking belt conveyors with a total length of about 120 km and containing 230 control points;
- **The search task** is often mentioned in the literature in connection with the search for victims in emergency zones. In a number of modern researches, the search algorithms are being developed to rescue victims using several UAVs. The most effective algorithm is considered to be the fish-inspired algorithm for multi-UAV missions (FIAM) [139], which surpassed its competitor layered search and rescue (LSAR) [140] in terms of the number of people rescued in similar accident scenarios. However, the special search algorithms are necessary for the effective execution of tasks such as EoM MoEP, MoWAL, MoHGP, MoTES, and TrM.

- **The task of organizing communication** in emergency zones with employment of UAVs is a part of a set of applications, including the early warning system, logistics, and data collection [141]. In relation to the applications described above, this task is primarily characteristic of MoHGP. A modern approach is to use a genetic algorithm (GA) with a steady-state population model (GAE) to find those optimal locations for the UAVs in order to maximize network coverage [142]. UAVs in such a situation can be quickly deployed as air base stations over the affected area, and provide communication with the victims;
- **The tasks of cargo delivery** with employment of UAVs are considered as an efficient option for solving logistics problems in the future. In particular, for the effective use of UAV resources, there proposed a method of delivery using flying assistants that are launched from the side of a truck (base) and fly only the "last mile", after which they return to the base at a new point in the shortest time [143]. The method increases the efficiency of multiple delivery in one region. The legal restrictions associated with the use of UAVs in an urban environment are proposed to be overcome in the future by the following way [144]: UAVs move along pre-prepared nodes at an acceptable height, without hindering the movement of future passenger drones and minimizing risks to the population. The task of cargo delivery can also be considered as part of the tasks solved within the framework of PA (application of fertilizers, herbicides, biophages), MoWAL (delivery of urgent goods), and MoTFS (delivery of spare parts and tools to repair zones).

4. Discussion

IUAVT is a rapidly developing and promising technology for a number of sectors of economy, as it was shown in Section 1. However, there are restrictions for its wider use, which depend on a specific industry. The results of the analysis of these limitations, depending on the industry of using IUAVT, are shown in Table 3. In the context of this work, it is necessary to highlight the limitations on data management and processing algorithms, which are most closely related to the artificial intelligence technologies.

Table 3. The influence of the limitations of the IUAVT technology on the solution of problems in the sectors of economy.

	Technical Limitations	Limitations of Data Processing Technology	Limitations of Control Algorithms	Legal Limitations
Precision agriculture (PA)		Image processing for agricultural applications	Flight control of a group of heterogeneous UAVs	
Monitoring of the environmental pollution (MoEP)	Limited battery capacity, load capacity and flight time			Usage in an urban environment
Exploration of minerals (EoM)	Limited battery capacity and flight time	The task of identifying the search signs of mineral deposits using UAVs has not been solved		
Monitoring of wild animal life (MoWAL)	Limited battery capacity and flight time		Flight control of a group of UAVs	
Monitoring of the hazardous geophysical processes (MoHGP)	Limited battery capacity and flight time; dependence on weather conditions		Flight control of a group of UAVs	Usage in an urban environment
Monitoring of technical and engineering structures (MoTES)	Dependence on weather conditions	Image and data processing for specific tasks of monitoring of technical structures	Flight control of a group of UAVs and flight control in the absence of GPS signals and indoors	Usage in an urban environment
Traffic monitoring (TrM)		Processing the large volumes of images	Flight control of a group of UAVs	Usage in an urban environment

The authors offer an analysis of the specific management and data processing tasks depending on the area of application (sectors of economy), presented in Table 4. According to this analysis, there can be identified the most popular research areas, which will contribute to more intensive development and use of IUAVT.

Table 4. Data management and processing tasks, requiring the employment of UAVs in sectors of economy.

		PA	MoEP	EoM	MoWAL	MoHGP	MoTES	TrM
Control tasks	Area coverage	+	+	+	+	+		+
	Search operations		+	+	+	+	+	+
	Unmanned aerial vehicle routing problem	+	+	+	+		+	
	Data gathering and recharging in a wireless sensor network (WSN)	+					+	
	Allocating communication links and computing power to mobile devices					+		
	Operational aspects of a self-organizing network of drones	+			+			+
	Communication organization					+		+
	Cargo delivery	+			+		+	
Data and image processing tasks	Creating data sets for training the computer vision systems	+		+	+		+	+
	Development of new or adaptation of the existing neural network architectures	+	+	+			+	
	Development of methods for processing the heterogeneous data coming from the UAV.	+		+		+	+	

The performed analysis allows the authors to suggest the following major areas of the future research:

1. In the field of flight control and planning:
    a. algorithms for planning the optimal routes for the heterogeneous groups of UAVs for solving specific tasks in the sectors of economy;
    b. improving the publicly available software for managing the groups of technically heterogeneous UAVs.
2. In the field of data processing and computer vision:
    c. data sets for training the computer vision systems corresponding to the applications;
    d. development of new or adaptation of the existing neural network architectures;
    e. development of the methods for processing the heterogeneous data coming from UAVs.

In the process of considering the tasks requiring the current solution for a wider industrial use of IUAVT, it is also necessary to take into account the assessment of the economic prospects by application areas, as presented in Figure 10. According to the calculations, the use of IUAVT in precision agriculture (58%), monitoring of the environmental pollution (15.9%), and traffic analysis (12%) is the most promising for Kazakhstan.

Figure 11 shows the structure of the gross national product of Kazakhstan [145]. Due to the resource nature of the economy, at least a quarter of the country's gross production is formed by industries related to mining.

Comparison of Figures 10 and 11 demonstrates that the greatest effect from the use of IUAVT is provided for industries related to the use of renewable resources (PA), transport, and ecology. At the same time, IUAVT can contribute to improving the efficiency of the mining industry.

The principal problems in control and data analysis for these applications are routing and development of neural network architectures and specific datasets. Therefore, these two problems should be considered and investigated with priority. The development of the appropriate algorithms for UAV routing, and elaboration of the acceptable neural network architectures will allow a significant economic effect. An economic effect summarizes the considered background of IUAVT application in different economic branches and limitations of their introductions and exploitations. The economic effect, as well as the main advantages and limitations for Kazakhstan, are shown in Table 5. The table summarizes the assessments obtained in Section 1.

Therefore, the introduction and use of IUAVT, taking into account overcoming the above-listed restrictions, will have a significant effect for Kazakhstan.

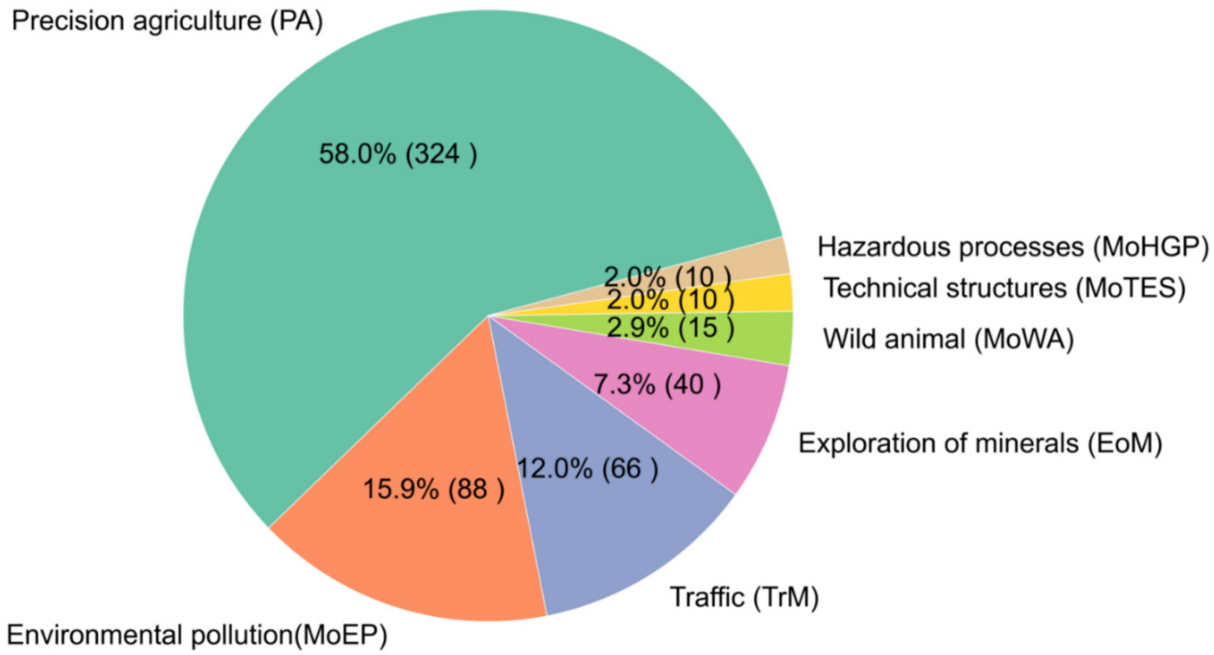

Figure 10. Comparative economic effect from the IUVAT applications. Source: Generated by the authors.

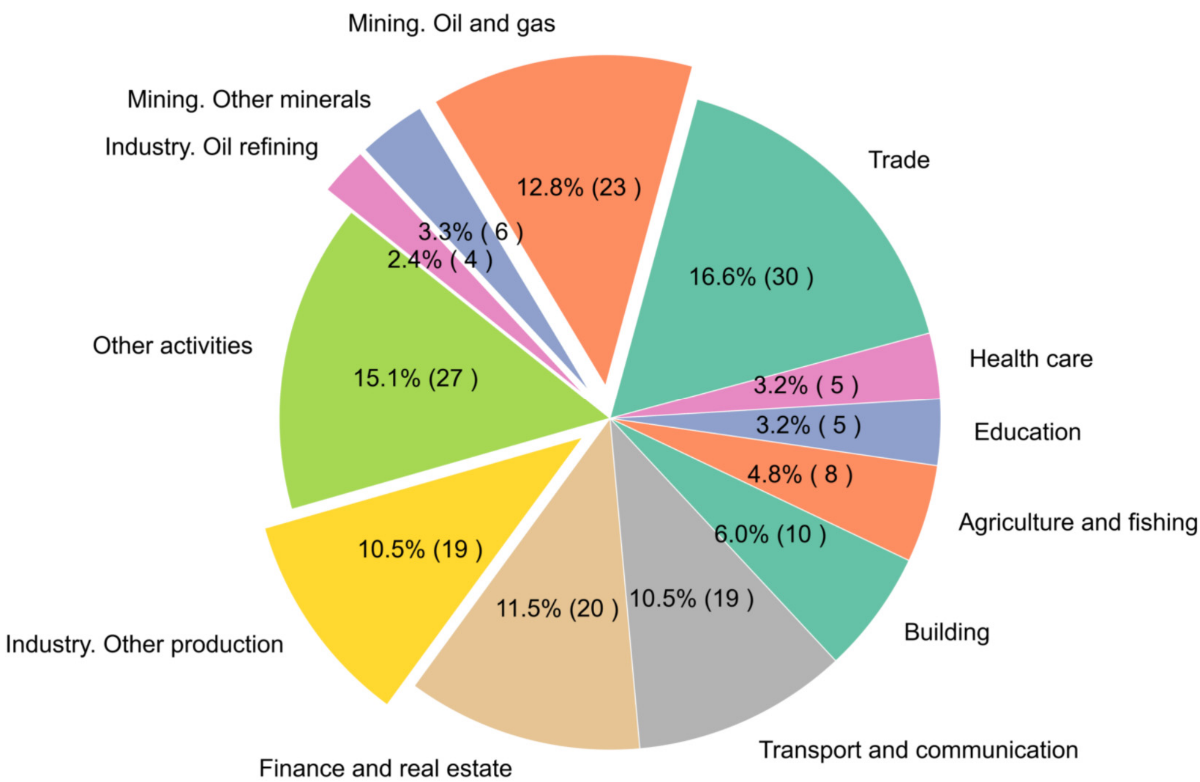

Figure 11. Structure of the GDP of Kazakhstan. Source: Generated by the authors.

By summarizing the above-described prerequisites, limitations, and the expected effect, it is possible to estimate approximately the economic potential of IUAVT in the production sectors of Kazakhstan in the amount of USD 570 million (see Table 5).

Table 5. Advantages and limitations of IUAVT.

Prerequisites	Advantages	Limitations	Annual Expenses in Millions of Dollars	Economic Potential of the Solution for the Republic of Kazakhstan, in Millions of Dollars
Low productivity, increased demand for environmentally friendly products, significant exploration costs, significant economic losses, threat to life and health, and the need to collect information on the status of equipment and structures (especially in hard-to-reach places).	Mobility and independence from communications, urgency and high speed, data availability for the research purposes, organization of communication if necessary.	Limited flight time, weather dependence, limited payload, limitations in solving the computational problems on board of the UAVs, legal restrictions on the use of UAVs in the urban conditions. Computer vision tasks for specific areas of UAV application, limited sensitivity of sensors, difficulties in controlling the flight outside the GPS range and indoors have not been solved.	5762	553

5. Conclusions

UAVs technology, combined with the intelligent flight planning and data processing methods, has promising prospects in various sectors of the economy. The main function of IUAVT involves monitoring the surrounding space and obtaining images, including multispectral ones, with subsequent processing using onboard and ground-based computing systems. In addition to monitoring, UAVs can solve the tasks of organizing communication, search, transportation, fertilization, as well as the application of herbicides and biophages, etc.

The economic effect of using UAVs depends on the degree of development of a particular industry in a particular country. The economic effect of the use of new technologies can be multiplicative for resource-oriented economies due to the relatively low degree of automation of non-extractive industries, for example, agriculture. The specific features of Kazakhstan associated with the pollution of the air basins of cities, the presence of significant risks of dangerous geological processes in the southern part of the country, environmental pollution due to mining, and the need for the development of the mining industry form the local peculiarities of using the IUAVT.

Although UAVs are mobile, relatively cheap, and efficient, this is not enough for widespread adaptation of IUAVT in the sectors of the economy. It is necessary to overcome a number of technical, legal, and software-algorithmic limitations.

The authors present some classification of data management and processing tasks that need to be solved in order to expand the scope of UAVs employment. It is applied primarily to the tasks of data processing and flight planning. The low flight altitude and the large data flow coming from the UAVs cause the specific problems of processing large volumes of hyperspectral data. The heterogeneity of the tasks and the technical characteristics of the UAVs initiate the search for new solutions in the field of flight planning and control of groups of vehicles. The efforts of the scientific community are aimed at solving these problems. There are solutions for planning optimal routes for UAV groups, for the development of the computer vision systems and the formation of the necessary infrastructure of available data sets for training the deep neural networks.

Nevertheless, some technical tasks still remain unsolved; they include, first of all, the task of increasing the duration of the flight, as well as a whole range of tasks of control and data processing for specific conditions of UAV use.

The expansion of the range and capabilities of publicly available UAVs management software, the development of algorithms for optimal flight planning, and, in general, the use of UAVs taking into account their reliability, the development of new data processing models, and the creation of the IUAVT open data infrastructure will ensure a wider application of this promising technology.

One of the subsequent tasks of the widespread introduction of drones is the task of assessing the reliability of both the drones and their fleets (several drones with a single control center). Currently, according to the expert's estimates, the reliability of the midprice class devices can be improved [146]. It is also necessary to take into account the task of replacing a failed drone; this task results in an analysis of the redundancy of the system, the type of which is closely interrelated with the economic conditions of using drones [147].

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Abbreviations

ANN	Artificial neural network
EoM	Environmental pollution monitoring
GH	Geological hazards
HSI	Hyper spectral and imaging system
IIoT	Industrial Internet of Things
IUAVT	Intelligent unmanned aerial vehicle technology
LSTM	Long short-term memory
MoEP	Environmental pollution monitoring
MoHGP	Monitoring hazardous geophysical processes
NDVI	Normalized Difference Vegetation Index
NIR	Near infrared range
PA	Precision agriculture
SVM	Support vector machine
MoTES	Monitoring of technical and engineering structures
TL	Transfer learning
TrM	Traffic monitoring
UAVs	Unmanned Aerial Vehicle
MoWAL	Monitoring of wild animal life

Appendix A. UAVs Application. Advantages and Limitations

Table A1. Applications of spatially distributed data acquisition systems.

Type of Machine	Radius of Action	Cost	Operativeness	Resolution	Main Limitations	Sources
Satellites	Unlimited	27 USD/km^2-Geo 44 USD/km^2-Geostereo	Up to 60 days Up to 100 days for stereo shooting (note 1)	0.46 m for panchromatic photographs, 1.86 m for multispectral.	Resolution, especially for multispectral photographs, minimum scale 1:10,000 (for panchromatic images). A more accessible view of Geo satellite images requires a digital elevation model obtained from other sources.	[148,149]
Airplanes and helicopters	150 km on average	Depends on the area: 2200 USD/km^2 with an area of 5 km^2, 30 USD/km^2 with an area of 750 km^2	5 days and more (note 2)	Up to 0.04 m	High cost of rent for flights, very high cost of shooting in case of small area	[9,150]
UAVs	On average 10 km	Depends on area: 750 USD/km^2 with an area of 5 km^2, 15 USD/km^2 with an area of 750 km^2	1 day	Up to 0.04 m	Limitations on payload weight and flight time, control requires a high-bandwidth communication channel. Weather dependent.	[149,151]

(1) The time taken to take the picture depends on weather conditions, priority, at what angle of deviation from the nadir shooting, what kind of pictures you want to get (Geo or GeoStereo). (2) Depends on the region, the infrastructure for flying. Flight authorization may be required (5 business days).

Table A2. IUAVT use for precision agriculture.

Main Prerequisites	Estimate of Lost Profits, Millions of Dollars	Research and Development Areas	Scientific and Technical Problems to be Solved	Evaluation of the Economic Effect, Millions of Dollars
Low productivity, growing demand for organic products [1]	5400	To realize precision agriculture systems, it is necessary to develop the models and methods of decision support systems using machine learning algorithms which are based on processing the heterogeneous data obtained with the use of UAVs.	It is needed to develop models and methods of decision support using machine learning based on processing the heterogeneous data obtained with the use of UAVs, to develop methods for UAV group control to perform plant protection and fertilization tasks. Solving computer vision problems for processing multi-spectral images from low-flying platforms.	324

Table A3. IUAVT use for the environmental monitoring tasks.

Main Prerequisites	Annual Expenses, Millions of Dollars	Research and Development Areas	Scientific and Technical Problems to Be Solved	Evaluation of the Economic Effect, Millions of Dollars
Significant economic losses, a threat to public health [43]	1555	It is necessary to develop the methods of operational control of hazardous substances emissions at the production facility and quality assessment of reclamation works based on heterogeneous data received from the UAV board.	Increasing flight time, payload, accuracy, and sensitivity of sensors, data processing software, including computer vision systems (to assess the quality of remediation work) when performing crop protection and fertilization tasks.	87.9

Table A4. IUAVT use for the task of minerals exploration.

Main Prerequisites	Annual Expenses, Millions of Dollars	Research and Development Areas	Scientific and Technical Problems to Be Solved	Evaluation of the Economic Effect, Millions of Dollars
Significant exploration costs that currently do not provide return [70]. Concept of the State program of geological exploration for 2021–2025 in Kazakhstan [72].	41	It is necessary to develop the methods of mineral exploration based on the application of highly mobile platforms for the collection of heterogeneous data, computer vision systems and new search criteria identified by machine learning.	Increased flight time, payload; accuracy and sensitivity of sensors; data processing software including computer vision; and control systems.	33

Table A5. IUAVT use for wildlife monitoring objectives.

Main Prerequisites	Estimate of Lost Profits, Millions of Dollars	Research and Development Areas	Evaluation of the Economic Effect, Millions of Dollars
Significant savings in animal monitoring [80,81].	It is necessary to develop models and methods for operational monitoring, assessment and forecasting of biological and economic productivity of commercially exploited ungulate species.	Increased flight time; payload; accuracy and sensitivity of sensors; data processing software, including computer vision; and control systems.	18

Table A6. IUAVT use for monitoring hazardous geophysical processes.

Main Prerequisites	Annual Expenses, Millions of Dollars	Research and Development Areas	Scientific and Technical Problems to Be Solved	Evaluation of the Economic Effect, Millions of Dollars
Destabilizing factor [82,89], significant economic losses, threat to life and health of the population [81,90]	200	To realize the possibility of prevention of emergencies, it is necessary to develop methods of forecasting and operative monitoring of dangerous geophysical processes and changes of engineering constructions with the application of a UAV and data mining tools.	Development of methods for recognition and classification of images in this subject area.	10

Table A7. IUAVT use for monitoring of technical and engineering structures.

Main Prerequisites	Research and Development Areas	Scientific and Technical Problems to Be Solved	Evaluation of the Economic Effect, Millions of Dollars
The necessity to collect information on the condition of machinery and facilities, especially in hard-to-reach places for the implementation of tasks. Industry 4.0 [97–101]	It is necessary to develop methods for monitoring engineering structures using computer vision systems and machine learning to identify and prevent violations in their work and to predict their condition.	Software for machine vision, image classification, and indoor flight control applications	10

Table A8. IUAVT use for traffic monitoring tasks.

Main Prerequisites	Annual expenses, Millions of Dollars	Research and Development Areas	Scientific and Technical Problems to Be Solved	Evaluation of the Economic Effect, Millions of Dollars
Significant economic losses, a threat to public health [108,109]	3304	A system of operational road monitoring, tracking the potentially dangerous road users and traffic forecasting should be developed.	Increasing the flight time, increasing the computational power of on-board processors, solving the problems of processing large video data streams outside the UAV.	66

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