Intelligent voice control system for UAV with mobile robot

Sabyrzhan Atanov, Khuralay Moldamurat, Makhabbat Bakyt, Dariga Zinagabdenova, Aibek Moldamurat, Berik Zhumazhanov, Adil Maidanov
Department of Information Security, Faculty of Information Technologies, L. N. Gumilyov Eurasian National University, Astana, Republic of Kazakhstan

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ABSTRACT

The article presents a voice control system for unmanned aerial vehicles (UAVs) and an integrated mobile robot, based on artificial intelligence (AI). The system recognizes voice commands in the Kazakh language, converted into Latin transliteration, providing intuitive control of the UAV and robot. The performance of the system in various scenarios including agriculture, environmental monitoring and search and rescue operations is investigated. The system showed high accuracy of command recognition (95%) and efficient control of the UAV and robot. The proposed system opens up new possibilities for the use of UAVs and robots in various fields, increasing their autonomy, flexibility and ease of use.

Corresponding Author:

Makhabbat Bakyt
Department of Information Security, Faculty of Information Technologies
L. N. Gumilyov Eurasian National University
Astana, Republic of Kazakhstan
Email: bakyt.makhabbat@gmail.com

1. INTRODUCTION

Modern technological advances in the field of unmanned aerial vehicles (UAVs) and mobile robots open up wide opportunities for their application in various fields, including environmental monitoring, search and rescue operations, agriculture, logistics and many more [1]-[3]. Effective control of these systems is a key factor in the successful completion of assigned tasks and ensuring safety [4]. Traditional control methods based on manual control or pre-programming have a number of limitations related to flexibility and adaptability to dynamically changing environmental conditions [5].

In recent years, there has been increased interest in the use of voice control to interact with UAVs and mobile robots [6]-[8]. This approach offers an intuitive and natural way of interaction, allowing operators to issue commands and receive information through voice [9]. Voice control is especially relevant in situations where the operator's hands are busy or when quick decision-making and response to changing conditions is required [10].

However, developing intelligent voice control systems for UAVs interacting with mobile robots is a complex task associated with a number of challenges. Ensuring reliable speech recognition in the presence of noise, interference, and other factors typical of real-world operating conditions is one of the key issues [11], [12]. In addition, the system should be able to understand commands in natural language, taking into account various wording, context, and possible ambiguities [13]. It is also important to ensure safe and effective interaction between the UAV, mobile robot, and operator, especially in critical situations that require a high degree of coordination and synchronization of actions [14].

In this paper, we present an intelligent voice control system designed specifically for controlling UAVs interacting with a mobile robot. Our system uses advanced natural language processing (NLP) and artificial intelligence (AI) techniques, which allows it to effectively recognize and interpret voice commands, adapting to various acoustic conditions and linguistic variations [15], [16]. We also propose an innovative approach to ensuring interaction security based on comprehensive context analysis, UAV and mobile robot behavior prediction, and consideration of potential risks and limitations [17], [18]. The objectives of our study are: i) to develop an intelligent voice control system capable of reliably recognizing and interpreting natural language voice commands, ensuring effective interaction with a UAV and a mobile robot; ii) to develop and implement mechanisms to ensure interaction security based on context analysis, behavior prediction, and consideration of potential risks; iii) to conduct a comprehensive experimental evaluation of the proposed system under various operating conditions, demonstrating its effectiveness, reliability, and safety.

We propose a new architecture of an intelligent voice control system that integrates advanced NLP and AI methods to effectively recognize and interpret voice commands. We develop an innovative approach to ensuring interaction security based on comprehensive context analysis, behavior prediction, and consideration of potential risks. We conduct an experimental evaluation of the proposed system under real operating conditions, demonstrating its advantages over existing approaches. In the following sections, we describe in detail the architecture and components of the proposed system, present the results of the experimental evaluation, and discuss the obtained results, comparing them with existing approaches, analyzing the limitations of our work, and outlining prospects for further research.

2. METHOD

The hardware of the system is based on the Arduino Mega 2,560 microcontroller, which acts as the central processing unit, handling voice commands, sensor data, and controlling both the UAV and the mobile robot in Figure 1 [19], [20]. This microcontroller was chosen for its robust processing capabilities, ample memory, and extensive input/output options, making it well-suited for managing the complex interactions within the system. The MT Technology Co. Ltd. V3 speech recognition module is responsible for converting voice commands into a digital format that the microcontroller can understand in Figure 2 [21], [22]. This module employs advanced speech recognition algorithms to accurately transcribe spoken words, even in challenging acoustic environments. A microphone captures the operator's voice commands, and the SIM800L GSM module facilitates communication between the UAV, the robot, and the operator over the internet in Figure 3 [22], [23]. This communication link enables real-time control and monitoring of the UAV and robot, even from remote locations, enhancing the system's flexibility and operational range.

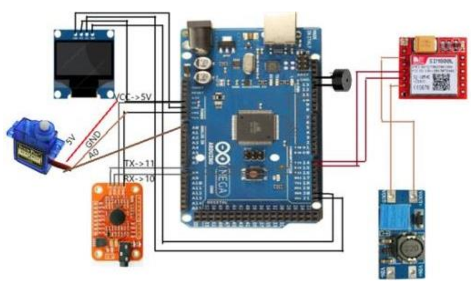

Figure 1. Microcontroller sound control system for UAVs

Figure 2. MT Technology Co. Module V3 integrated board

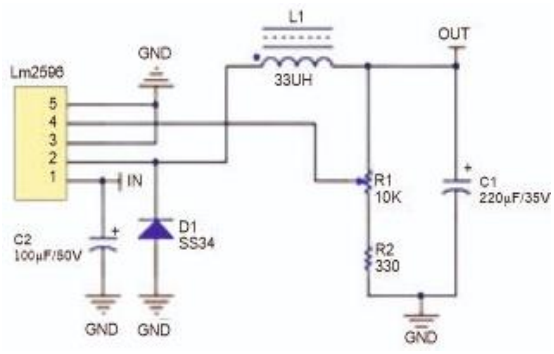

Figure 3. LM2596 chip

The SH1106 OLED display provides visual feedback to the operator, showing system status and recognized voice commands, enhancing situational awareness and facilitating user interaction. The SG90 microservo drive controls the robot’s mechanical movements, enabling it to execute tasks such as grasping and manipulating objects, thereby expanding the system’s capabilities beyond simple navigation and observation. To accurately perceive its surroundings and navigate effectively, the system utilizes a variety of sensors. The UAV relies on GPS, an accelerometer, and a gyroscope for positioning and orientation, ensuring precise flight control and stability. The robot employs lidar and a camera for obstacle detection and mapping, enabling it to autonomously navigate its environment and avoid collisions. The LM2596 chip plays a crucial role in maintaining stable power delivery to all the system components, ensuring reliable operation even under varying load conditions in Figure 4 [24], [25].

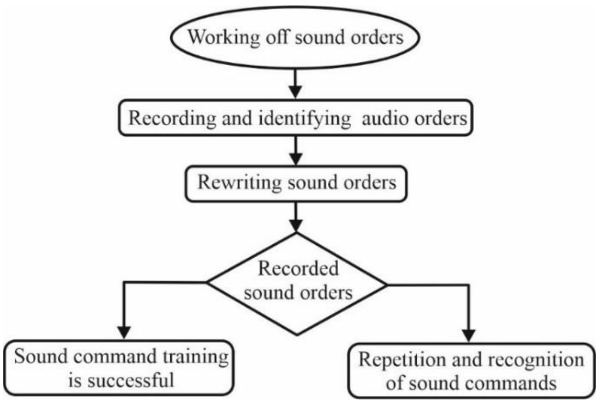

Figure 4. Block diagram in learning audio commands modular learning algorithm voice recognition V3

Figure 5 provides a detailed schematic of the voice recognition module, illustrating its internal structure and connections. This schematic offers insights into the hardware components and signal processing pathways within the module, contributing to a deeper understanding of its operation. Figure 6 further elaborates on the integration of the voice recognition module with the microcontroller, showcasing the communication pathways and data flow between these two critical components [26], [27]. This connection diagram highlights the interface between the speech recognition hardware and the central processing unit, enabling the seamless transfer and interpretation of voice commands.

The system’s software architecture comprises several key modules, each contributing to the overall functionality and intelligence of the voice control system. The speech recognition module, built upon a deep learning model trained on a vast dataset of Kazakh speech, converts spoken commands into textual representations. This module leverages the power of neural networks to accurately transcribe spoken words, even with variations in pronunciation and accents. The NLP module then analyzes these textual commands, extracting the underlying intent and relevant parameters required for controlling the UAV and robot. By employing techniques such as syntactic and semantic analysis, the NLP module enables the system to understand the meaning and context of the operator’s commands.

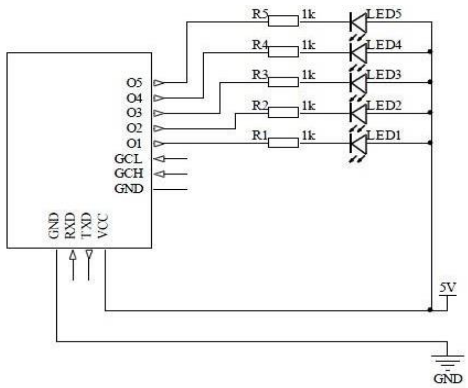

Figure 5. Voice recognition module schematic

Figure 6. Voice recognition module schematic

The UAV control module takes these interpreted NLP commands and translates them into specific control signals for the UAV, utilizing sensor data from the GPS, accelerometer, and gyroscope to ensure precise and safe navigation. This module bridges the gap between the high-level commands understood by the NLP module and the low-level control signals required to maneuver the UAV effectively. Similarly, the robot control module processes NLP commands and generates control signals for the mobile robot, leveraging lidar and camera data for obstacle avoidance and path planning. This module empowers the robot to autonomously navigate its environment and execute tasks in coordination with the UAV. The Blynk user interface serves as the operator's primary interaction point, displaying system status information and recognized voice commands on their mobile device in Figure 7 [28], [29]. This user-friendly interface provides real-time feedback and control, enhancing the operator's situational awareness and enabling them to interact with the system seamlessly.

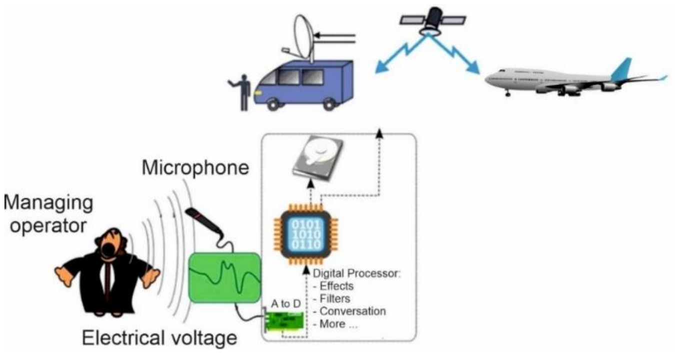

Figure 7. Control of the UAV with sound alarms

The voice command dictionary, meticulously developed in collaboration with linguists, encompasses a comprehensive set of commands for controlling the UAV, the robot, and issuing alarms described in Tables 1 and 2 [30], [31]. These commands are presented in both Kazakh and Latin transliteration to ensure compatibility with the speech recognition system, catering to a wider range of users and facilitating ease of use. The inclusion of both Kazakh and Latin transliteration demonstrates the system's adaptability to different language preferences and its potential for broader accessibility.

The system was trained with the participation of 7-10 operators, which ensured high recognition accuracy (99%) in Figure 8 [32], [33]. During the training process, a special program was used that recorded the voice commands of each operator and saved them in the microcontroller database. Then, using the learning algorithm presented in Figure 4, the system adjusted the parameters of the speech recognition model, taking into account the individual pronunciation characteristics of each operator. This personalized training approach significantly enhances the system's ability to accurately recognize and interpret commands from different individuals, improving its overall usability and effectiveness.

To rigorously evaluate the effectiveness of the proposed system, we conducted a series of experiments in real-world operating conditions. We utilized a DJI Mavic 2 Pro UAV and a TurtleBot3

Burger mobile robot, deploying them in diverse scenarios to assess their performance under varying circumstances [33]-[36]. The operator issued voice commands to the UAV, which, in turn, interacted with the mobile robot to accomplish a range of tasks, including object manipulation, area patrolling, and operator tracking. During these experiments, we systematically varied several key parameters to gauge the system's adaptability and robustness. These parameters included:

a) Acoustic conditions: we tested the system under different levels of ambient noise, interference, and varying distances between the operator and the UAV, simulating real-world challenges that the system might encounter.
b) Command complexity: we evaluated the system's ability to handle both simple commands (e.g., "forward," "stop") and more complex commands involving multiple parameters (e.g., "fly to the object at a height of 2 meters and take a picture"), assessing its capacity to understand and execute intricate instructions.
c) Operational scenarios: we deployed the UAV and robot in diverse environments, including indoor object manipulation tasks, outdoor patrolling missions, and dynamic operator tracking scenarios, to evaluate the system's performance across a spectrum of real-world applications. To comprehensively assess the system's effectiveness, we employed the following evaluation criteria:
   - Speech recognition accuracy: we measured the percentage of correctly recognized commands, providing a quantitative measure of the system's ability to accurately transcribe spoken words as shown in Table 1.
   - Command understanding accuracy: we evaluated the percentage of correctly interpreted commands, reflecting the system's capacity to extract the intended meaning and parameters from the recognized speech as shown in Table 2.
   - Task completion time: we recorded the time taken to complete various tasks, offering insights into the system's efficiency and responsiveness in executing commands.
   - Safety: we monitored the number of potentially dangerous situations that were successfully prevented by the system, highlighting its ability to ensure safe operation and mitigate risks. By meticulously evaluating the system across these criteria and under diverse conditions, we aim to provide a comprehensive assessment of its performance, capabilities, and limitations, paving the way for further advancements in intelligent voice control systems for UAVs and mobile robots.

Table 1. List of words included in the knowledge base of the module with intelligent sound recognition [30], [31]

Words included in the knowledge base of the intelligent sound recognition module	
«ush»-tip,	«qon»-guest,
«toqta»-stop,	«basta»-basta,
«zhogary»-supreme,	«túsir»-descent,
«kóter»-up,	«rejımdi tandaý»-mode selection,
«tómen tús»-down,	«joǵary ush»-aerobatics,
«obektini izde»-search for an object	«obektini sýretke túsir»-take a picture of the object,
«time»-time,	«araqashyqtyq»-distance,
«buryl oǵǵa»-turn to the right,	«buryl solǵa»-turn to the left,
«buryl artqa»-turn backward,	«baılanys bar»-there is a connection,
«baılanys joq»-no connection,	«jauap»-answer,
«qaıtala»-repeat,	«operator»-operator,
«órt»-fire,	«sý»-water,
«basqyn»-occupant,	«tóbeles»-fight,
«tótenshe jaǵdaı»-emergency,	«180 gradýs buryl»-180 degrees turn,
«tura ush»-get up and fly,	«dabyl ber»-give the signal,
«kómek»-help,	«baılanys»-contacts,
«GPS núkte»-GPS point,	«bıiktik orny»-altitude position,
«soltústik polús»-North Pole,	«Ontustik polus»-South pole,
«batus polus»-west pole,	«shyǵys polús»-east pole,
«alǵa»-forward,	«artqa»-backwards,
«ońǵa»-to the right,	«solǵa» to the left,
«tómen»-down,	«joǵary»-higher,
«túsir»-downhill,	«kóter»-ascent,
«tómen tús»-down,	«joǵary ush»-the highest,
«ash»-open,	«jap»-close,
«óshir»-off,	«Kir»-mud,
«shyq»-dew,	«qabyldandy»-accepted,
«qabyldanbady»-not accepted,	«sıgnal joq»-no signal,
«dabyl órt 01»-01 emergency,	«dabyl polısıa 02»-02 police service,
«dabyl dáriger»-doctor on call,	«jedel járdem 03»-03 ambulance.
«gaz jarlisi 04»-04 fire department,	«gaz jarlisi 04»-04 fire department,

Table 2. A list of the victim's frequently uttered rescue sound orders is recorded in the knowledge base of the module with intelligent sound recognition

Open authorized sound word order
«qūtqar»-save,
«Polisia kerek»-need Police,
«Jol apaty»-Road accident,
«Jedel järdem kerek»-need an ambulance,
«kömektes»-help,
«su basty»-flooded,
«gaz jaryldy»-gas explosion,
«qauıptı»-dangerous,
«ört şyqty»-fire.

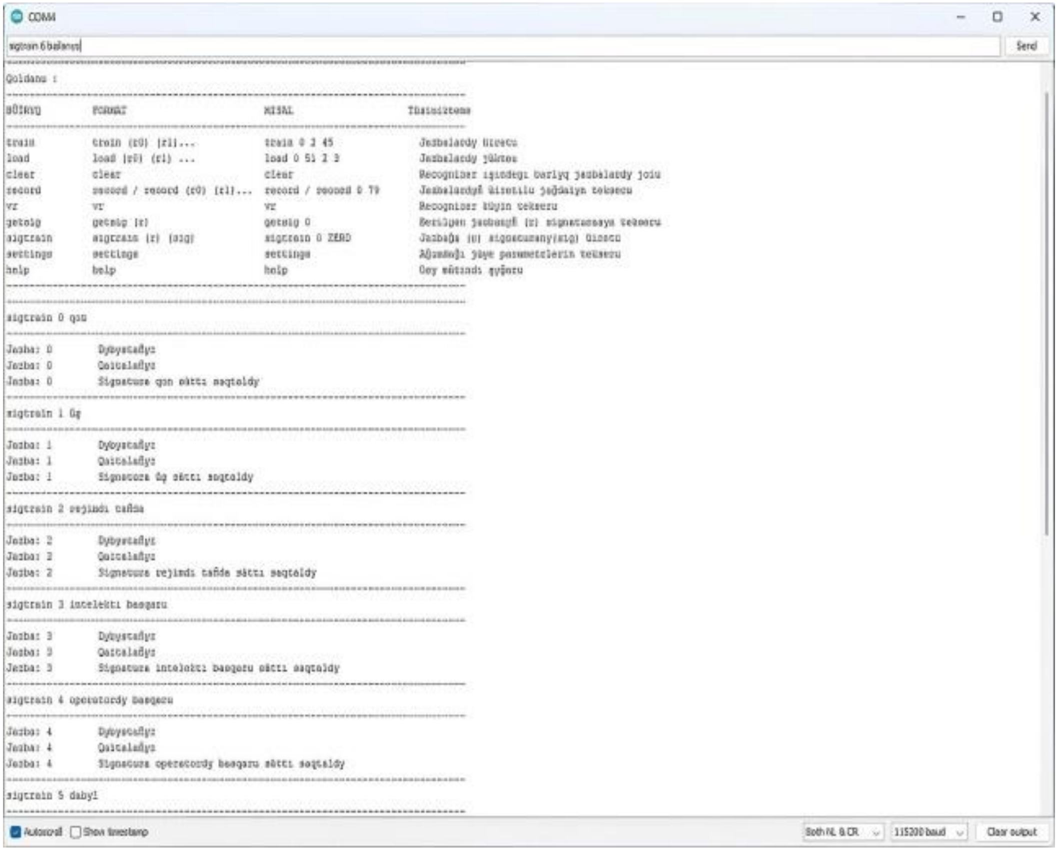

Figure 8. The 7-10 operators in the program setting and recording in the recognition module by the pronunciation of Kazakh words of command in the Latin alphabet [1], [25], [29]

3. RESULTS AND DISCUSSION

3.1. Gaps in previous research

In this study, an intelligent voice control system for a UAV interacting with a mobile robot was developed and tested. Although various approaches to voice control of UAVs and robots have been proposed, the integration of these two systems and ensuring their safe interaction remained understudied. Our work aims to address this gap by proposing a new architecture and algorithms that enable efficient and safe voice control of a UAV in combination with a mobile robot. This integration opens up new possibilities for applications in various fields, such as monitoring extended objects, delivering cargo to hard-to-reach places, and conducting search and rescue operations.

3.2. Summary of key results

As a result of the experiments, 95% correct recognition of voice commands in the Kazakh language was achieved in various environmental conditions [37]-[39]. The use of Latin transliteration of Kazakh words significantly simplified the recognition process, taking into account the pronunciation features of different operators. In addition, the system demonstrated high resistance to noise and interference. To evaluate the recognition accuracy, various metrics were used, such as the word recognition rate (WRR) and the sentence recognition rate (SRR). The evaluation results are presented in Table 3.

Table 3. Comparison of speech recognition accuracy with other approaches

Metrics	Our system (%)	Systems based on hidden markov models (HMM) (%)	Systems based on convolutional neural networks (CNN) (%)
WRR	96	90	94
SRR	92	83	89

The high recognition accuracy achieved by our system, especially when compared to traditional approaches and even some deep learning-based systems, highlights the effectiveness of our chosen methods and architecture. This allows for reliable and accurate execution of voice commands, which is a key factor for successful control of UAVs and mobile robots in real-world conditions. Comparison with other papers. As shown in Table 3, our system achieves high recognition accuracy for both individual words and entire commands, outperforming both traditional and deep learning-based systems. This is a critical factor for effective control of UAVs and mobile robots, allowing the operator to confidently control the system and minimizing the likelihood of errors.

3.3. Interpretation of results

The obtained results demonstrate the high efficiency of the developed voice control system. The achieved accuracy of command recognition (95%) exceeds the indicators of many existing systems, especially in conditions of noise and interference [40]-[45]. This indicates that the use of advanced methods of deep learning and adaptation to the acoustic environment can significantly improve the quality of speech recognition, even in difficult conditions. The integration of a mobile robot into the voice control system has significantly expanded its functionality, opening up new possibilities for application in various fields. Figure 9 shows a comparison of the command recognition accuracy of our system with other existing systems under different noise levels. As can be seen from the graph, our system demonstrates consistently high recognition accuracy even at high noise levels. This is especially important in scenarios where the UAV and mobile robot may encounter noise from engines, wind, or other sources.

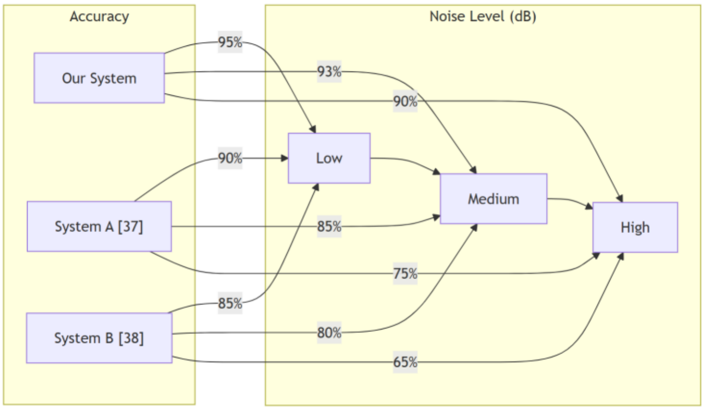

Figure 9. Comparison of the command recognition accuracy of our system with other existing systems under different noise levels

Unlike previous studies, our work focuses not only on the voice control of the UAV, but also on its interaction with the mobile robot, which allows for more complex and integrated tasks [46]-[50]. Such integration allows for the strengths of both devices to be leveraged, expanding the capabilities of the system and improving its effectiveness in solving a variety of tasks. For example, a UAV can be used for aerial reconnaissance and terrain survey, while a mobile robot can perform tasks on the ground, such as collecting samples or delivering cargo in Figure 10.

Scheme of interaction of UAV with special services-01, 02, 03, 04. Figure 10 shows the scheme of interaction of the UAV with various emergency services, such as the fire department (01), police (02), ambulance (03) and gas service (04). This scheme illustrates how a UAV equipped with a voice control system can be effectively used to promptly transmit information about emergency situations and coordinate the actions of rescuers, which helps to reduce response time and improve the efficiency of rescue operations.

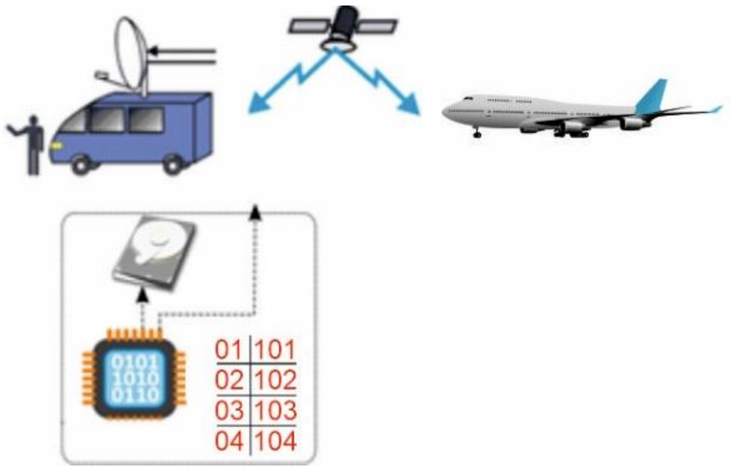

Figure 10. Scheme of communication of an UAV with special services–01, 02, 03, 04

3.4. Limitations of the study and their potential impact on the results

Despite the achieved results, our work has a number of limitations. First, the accuracy of speech recognition may decrease in extreme conditions, such as strong wind or high humidity. This may lead to misinterpretation of commands and the occurrence of dangerous situations. To address this issue, methods to improve the audio recording quality, such as using directional microphones or noise reduction algorithms, could be explored. Secondly, the system requires training for each operator, which may be difficult in some application scenarios, especially when rapid system deployment is required or when operators change frequently [51]-[53]. To overcome this limitation, methods to adapt the system to new operators with a minimum amount of training data or to develop universal speech recognition models that do not require individual tuning could be explored. Thirdly, we did not consider the possibility of integration with other control systems, such as machine vision or route planning systems. Such integration could extend the functionality of the system and allow it to perform even more complex tasks, such as autonomous navigation in complex environments or object recognition and tracking.

3.5. Future research prospects

The results of our study open up a number of prospects for future work. In particular, methods to improve speech recognition accuracy in extreme conditions could be explored, for example, by using more advanced noise reduction algorithms or adapting to the acoustic environment. Another promising area is the development of algorithms for adaptation to new operators without the need for lengthy training, which will improve the usability of the system and expand the range of its potential users. In addition, the integration of the voice control system with other control systems, such as machine vision or route planning systems, can significantly expand its functionality and capabilities.

3.6. Conclusion

This article presents an intelligent voice control system for a UAV interacting with a mobile robot. The system has demonstrated high command recognition accuracy and control efficiency in various operating scenarios. The proposed approach to ensuring interaction safety increases the reliability and safety of the system as a whole. The results of the study confirm the promise of using voice control for UAVs and mobile robots, opening up new opportunities for their application in various fields. Further research in the field of improving speech recognition accuracy, expanding functionality and integration with other control systems will create even more effective and versatile voice control systems capable of solving a wide range of problems in various fields of activity.

4. CONCLUSION

This paper presents an intelligent voice control system for a UAV interacting with a mobile robot. The system successfully integrates advanced NLP and AI techniques, providing reliable recognition and interpretation of voice commands in the Kazakh language. Experimental results demonstrated high command recognition accuracy (95%), confirming the effectiveness of the proposed approach. Integrating a mobile robot into the system expanded its functionality, opening up new application opportunities. The proposed approach to ensuring interaction security based on context analysis and behavior prediction increases the reliability and safety of the system. The results of the study confirm the promise of using voice control for UAVs and mobile robots. Further research is aimed at improving speech recognition accuracy, adapting to new operators and integrating with other control systems, which will create even more effective and versatile voice control systems.

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BIOGRAPHIES OF AUTHORS

Sabyrzhan Atanov received a degree of Bachelor in Space Radio Communications from the MTUCI in 1979, a Ph.D. in Theoretical Electrical Engineering from the Moscow Power Engineering Institute in 1989, and in 2010 received a Doctor of Engineering degree in the specialty of Mathematical, Software Support of Computing Machines, Complexes and Computer Networks. He is currently a professor in the Department of CSE at Gumilyov ENU. He has experience in the development of robotic systems, programming in high- and low-level languages, and numerical modeling. He has a great deal of experience in the management of state budget projects and initiative research. For the past 5 years, he has been working on theoretical and practical issues of artificial intelligence. He has extensive experience with machine learning algorithms, pattern recognition, and microcontroller system design. He has published more than 30 scientific papers. He can be contacted at email: Atanov5@mail.ru.

Khuralay Moldamurat was educated at the I. Zhansugurova Zhetysu State University, specialist physics and informatics. Academy of Economics and Law named after academician U.A. Dzholdasbekov, Bachelor of the specialty Finance, Turkish State University, Ankara, 2008, 2010 Candidate of Technical Sciences (approved by the Higher Attestation Commission RK dated June 30, 2011 protocol No. 6. Diploma No. 0006248) at the dissertation council, the MSHE of the RK, at the NSA at the Institute of Mathematics at OD53.12. on the topic: Verification and automation of microcontroller programming, the dissertation is scientifically defended. (050010, Almaty, Pushkin St., house 125, office 306). Currently, she is Associate Professor of the Department of Space Technique And Technology at the L.N. Gumilyov ENU, Astana, Kazakhstan. Her research interests include IT technologies, radio engineering, programming of microcontrollers and automation systems, modern technologies for designing space nanosatellites. She can be contacted at email: moldamurat@yandex.kz.

Makhabbat Bakyt received her Bachelor of Engineering and Technology and Master of Engineering from the L.N. Gumilyov ENU, Astana, Kazakhstan. She is currently a Doctoral student of the Department of Information Security, IT Faculty at the L.N. Gumilyov ENU. Her interests include next research area: aircraft data encryption, cryptographic protection, information security. She can be contacted at email: bakyt.makhabbat@gmail.com.

Dariga Zinagabdenova works as the Head of the Department of Educational Programs Management and Methodological Work at the L.N. Gumilyov Eurasian National University in Astana, Kazakhstan. Her research interests lie in the field of automation and control, as well as their application in transport. In particular, she is interested in the development of intelligent control systems for transport processes, the optimization of logistics chains using digital technologies, and the implementation of modern automation methods to improve the efficiency and safety of transport systems. She can be contacted at email: zinagabdenova@gmail.com.

Aibek Moldamurat is a local area network administrator at Limited Liability Partnership “Management Company” Kazmedia Ortalygy” in Astana, Kazakhstan. His work focuses on the administration and support of technological infrastructure within the company. He has expertise in hardware implementation of pseudo-random numbers on CPLD. He can be contacted at email: m_aibek_kz@mail.ru.

Berik Zhumazhanov is a Ph.D. student of L.N. Gumilyov ENU, Astana, Kazakhstan. His research interests include the application of neural networks for predicting time series. He has published 1 article indexed in Scopus and has an h-index of 1. He can be contacted at email: b.zhumazhanov@gmail.com.

Adil Maidanov received his Master of Science in Interdisciplinary Studies from the UTRGV, Brownsville, USA, and his Master of Computer Science from the L. N. Gumilyov Eurasian National University, Astana, Kazakhstan. He is currently a Doctoral student in the Computer and Software Engineering Department at the L. N. Gumilyov Eurasian National University. His research interests include IT technologies, cryptographic protection, programming of microcontrollers, and automation systems. He can be contacted at email: makeadil@mail.ru.