Evaluation of Voice Interface Integration with Arduino Robots in 5G Network Frameworks

Ali Z. Abdulrazzaq
Alnoor University
Nineveh, Iraq
ali92@alnoor.edu.iq

Zaid Ghanim Ali
Al Mansour University College
Baghdad, Iraq
zaid.ghanim@muc.edu.iq

Azhar Raheem Mohammed Al-Ani
Al Hikma University College
Baghdad, Iraq
Azhar.raheem@hiuc.edu.iq

Basma Mohammed Khaleel
Al-Rafidain University College
Baghdad, Iraq
basma.khaleel@ruc.edu.iq

Salam Alsalame
Al-Turath University
Baghdad, Iraq
Salam.madah@turath.edu.iq

Viktoriia Snovyda
Kruty Heroes Military Institute of
Telecommunications and Information Technology
Kyiv, Ukraine
viktoriia.snovyda@viti.edu.ua

Asan Baker Kanbar
Cihan University Sulaimaniya, Sulaymaniyah City
Kurdistan/ Iraq
asan.baker@sulicihan.edu.krd

Abstract— **In the fourth industrial revolution robots, voice control interfaces and 5G networks play significant role towards advanced real-time autonomous control systems in an industrial domain as well as a social domain. With Arduino-based robots controlled by voice commands for more natural human-machine communications and 5G enabling low latency, high-reliability connectivity as degradation due to typical interference does not matter.**

This article explores the efficiency and accuracy of voice-controlled interfaces to function robotic attributes via ultra-low latency associated with 5G network links intended for Arduino robots.

Methods: An Arduino robot equipped with a voice-controlled interface that utilizes speech recognition and Natural Language Processing (NLP) to understand and carry out commands. This setup was trialed on a 5G network to guarantee connectivity and operational efficiency. Various scenarios and loads were examined in controlled experiments to evaluate response times, precision, and reliability.

The 5G has lower latency response time, which led to better command execution. Accurate interpretation of voice commands and real-time adaption to robotic operations for continuous effective behavior across operating conditions and environmental scenarios are demonstrated to highlight the robustness of voice control interface.

The combination of voice-activated Arduino robots and 5G networks has paved the way for industrial automation and smart applications, showcasing an innovative approach to human-robot interaction and collaborative robotics. Nevertheless, it is important to analyze the scalability, security, and ethical considerations of these technologies on a wider scale in different domains and applications to guarantee their safe, effective, and equitable implementation.

KEYWORDS: Voice Control (VC), Arduino Robot (AR), 5G Networks, Human-Machine Interaction (HMI), Natural Language Processing (NLP), Ultra-Low Latency (ULL), Communication Efficiency, Operational Efficacy, Industrial Automation (IA), Collaborative Robotics (CR).

I. INTRODUCTION

In a time when technology and other form of electronics have entered into every pore of social as well as industrial frameworks, the amalgamation of robotics with state-of-the-art control interfaces and communication networks have become the focal point for redesigning what can be achieved in intelligent systems. This paper highlights the exciting part of user-friendly voice-controlled techniques that are available through Arduino robotic platform [1] with the advantage of 5G ultra-low latency capabilities. It is a region where stable interactive communication becomes important to bridge the gulf between human-robot interactions and unlock the intrinsic power of collaborative robotics in new applications [2].

The integration of voice control interfaces with robotics, takes us a step closer to a future where human-machine interaction bypasses the pains of traditional controlling methods. In particular, the Arduino robot platform is an example of availability, adaptability and well suited towards achieving systems tailored for applications such as educational, industrial or societal level systems. With voice interfaces, they can also interpret and respond to vocal instructions, which in turn lead to a more natural way of communication between humans and machines [3].

The capabilities of 5G technology that are relevant to this paper include support for ultra-reliable and low-latency communications (URLLC) which opens up the possibilities of integrating real-time control and feedback systems embedded in robotic applications [4]. The increased data transfer speeds and reduced latency of 5G networks go beyond enabling new forms of near-instantaneous interpersonal communication, but also lay the infrastructure for use-cases that demand immediate feedback and trustworthiness such as autonomous vehicles, industrial automation or telemedicine [5].

Testing, in environments like manufacturing and healthcare, is key to understanding the performance that can be expected when using Arduino robots capable of voice control interfaces with 5G integration. Moreover, the conflicting factors between network congestion and performance metrics, like network saturation by other clients during real-time data transfer under 5G conditions, need to assess as well [12], [22]. If these things work, making progress on them will allow having communication that is very scalable and has contact reliability compared with older communications technologies like LTE [23].

Such a point of view would also mitigate most challenges currently associated with latency and reliability in command execution and data transfer by pairing 5G capabilities with voice-controlled Arduino robots.

The article explores the ways of actualizing voice control user interfaces and Arduino-based robots via exploiting such a mighty communication backbone. To ensure robots correctly perceive and interpret spoken instructions, inventing and executing fast algorithms for speech recognition (SR) as well as Natural Language Processing (NLP) are very important The aim is to not only achieve a more natural and easier way of human-machine interaction, it is also critical that robots are evidently able to interpret complicated commands in the right manner.

Furthermore, within the scope of this article, an investigation into potential scenarios and applications is conducted, where the combination of voice control, Arduino robots, and 5G networks may be envisioned to improve operational efficiency and stimulate novel applications. This includes smart homes, where voice-controlled robots can interact and collaborate with other smart devices over a 5G network, industrial settings where collaborative robots (cobots) can work alongside humans, and educational platforms that use interactive robots to enhance learning experiences [7].

This article begins on the methodology, experimental setups, results, and derived insights essential to creating voice control interfaces with Arduino robots inside a 5G network architecture. This includes an in-depth examination of the architecture, and communication protocols involved and a full explanation of the experimental findings and their implications in circumstances. This study exposes the routes via which various technologies might be synergized to realize creative applications and to comprehend the problems, possibilities, and future prospects embodied in this technological convergence.

A. Study Objective

In this article, it is intended to account and elaborate on human-robot interactions redefined through the stitching of voice command interfaces with Arduino robot platforms powered by 5G connectivity as an informational underpinning for optimized operational efficiencies in multiple applications. Studying the human-machine dialogue as part of our natural communication channels, specially on voice control interfaces with Arduino robots, can give us a new perspective or probably an understanding mechanism to judge how this integration is performing and behaving. This work demonstrates integration of this technology with cutting edge 5G capabilities, exemplified by its ultra-low latency and data transmission reliability, to disassemble traditional limitations toward more effective real-time robotic control and data communication across diverse spatial contexts, exhibiting different environmental challenges and operational scenarios as used in this study.

This article focuses on going through individual housing of speech recognition and Natural Language Processing (NLP) algorithms seamlessly into Arduino robotics in order to lead to a future where robotic systems are moved from mechanical automatons working in tandem but become entities understanding and reacting human instructions completely with an intuitive real-time nature. Specifically, they plan how to go ahead and experiment with voice control inside a robot, test this application and ensure that it will work efficiently and reliably in the conditions of a 5G network.

Moreover, in this article authors aim to offer a systematic survey of some possible use cases and fields for the combination of these technologies, such as smart-homes, industrial scenarios or educational environments, to have an overall idea of how it can be applied both on small scale and in large while being adaptable. It aims to enrich the academic and policy conversation by examining the details of that integration, as well as defining its most significant impacts, constraints, and likely directions across a series of scenarios. Ultimately, it is to set the stage for more research by sparking a conversation that will grow with time in nature, attempting to build a leisure suit of technology and humanity coevolving within a constructive ecosystem.

B. Problem Statement

In robotics and communication networks, there are multifaceted challenges for technological growth that make it a convoluted climate demanding exhaustive research and analysis. One of the major challenges is to provide a reliable and efficient integration of intuitive interaction interfaces, such as voice control, with robotic platforms, like based on Arduino, in an application-agnostic manner where the system will be used. As voice control is nothing new for robots, the ability to single out a level of engagement that both flows with the user's natural abilities and can be properly translated and realized becomes an even bigger challenge.

In addition, the rapid development and deployment of 5G networks worldwide makes it a tempting choice for ultra-reliable low-latency communication; however, its real-world applications in improving the real-time control and feedback through voice interfaces of Arduino-based robots have not been fully studied and understood. The problem is to make the 5G communication layer provide not only a medium for data transmission but also an enabler for more functionality and dependability in robotic applications, especially when real-time communication and processing are essential.

It is also a big challenge just knowing what can be done and cannot be done with these voice recognition systems, and Natural Language Processing (NLP) systems, depending on the acoustic background noise and order in which they are planned. These include whether the system can accurately process and understand voice commands in different operating environments, such as a smart home or noisy industrial facility.

In addition, the three voice control technologies and Arduino robots and 5G networks are applicable to a wide range of fields as technology infiltrates more industries, meaning that this combination must be lightweight, intelligent and ethical over many domains. Key ethical and security issues concerning data privacy, user safety, as well as operational reliability in voice-controlled robotic systems within 5G context call for comprehensive researches in both academia and industry.

II. Literature review

The interaction of voice control interfaces, robots and 5G networks as a technological trinity has not only attracted various academic research but also become the emerging focus of the industry to explore great opportunities and challenges. An examination of related work uncovers a parallel route, including the following major topics: voice control interfaces [8], as well as adaptability in Arduino robots and potential for transformation using 5G.

By contrast, academic research on voice control interfaces has exploded in recent years as academics have been eager to understand the capabilities and limitations of various speech recognition and natural language processing (NLP) methods. The ubiquitous difficulty of designing speech interfaces that traverse multiple languages, phonetic, and acoustic landscapes, assuring proper identification and interpretation of voice instructions in various situations and circumstances, is noteworthy.

There have been several studies on integrating the voice control with robotics, but these efforts are different because of real-time voice recognition and robot control, which uses 5G. Previous research, like Gonzalez-de-Santos et al. [2] centered on robotic systems for intelligent farming but did not touch upon the issue of ultra-low latency communication. This paper extends this prior work by evaluating the impact that 5G networks and their ultra-reliable low-latency communication (URLLC) might have to support real-time, life-critical applications, such as disaster response and autonomous robotics [21].

Furthermore, the research [9] emphasizes the inherent obstacles associated with integrating voice control with robotics, notably in maintaining harmonic synchronicity between intuitive human engagement and accurate machine execution.

Because of its exceptional versatility and accessibility across educational, industrial, and social sectors, the subject of robotics, especially using the Arduino platform, has gained substantial attention. Scholars and practitioners [10] have investigated different aspects of Arduino robotics, ranging from developing complicated control algorithms to testing novel applications in various fields. Notably, integrating various control interfaces, like speech, gesture, and touch, with Arduino robots has been the focus of multiple research, all attempting to improve the human-robot interaction paradigm [11].

The introduction and spread of 5G technology have inaugurated a new era in communication networks, focusing on its potential to offer ultra-reliable, low-latency communication. Much research has been devoted to investigating the capabilities and complexities of 5G networks in diverse applications such as IoT, driverless cars, and industrial automation. The potential of 5G to provide real-time control and feedback has been a focus of study in the context of robotics, with researchers investigating its practicality in improving the responsiveness and dependability of robotic systems [12].

While the article investigates voice interfaces, Arduino robots, and 5G networks are evident in the academic scene, the convergence of these three technical aspects is a relatively new topic of study. The present study is located at this crossroads, trying to add to the blossoming conversation and weave through the complexities and potentialities that embody the integration of voice control interfaces with Arduino robots inside a 5G network architecture.

III. Methodology

A. Conceptual Framework Formulation and Design Execution

Beginning the technique requires thoroughly creating a solid conceptual framework that elucidates the interweaving functions and connections between voice control interfaces, Arduino robot mechanisms, and 5G network functionalities. This fundamental concept is critical in ensuring that voice inputs are reliably collected, analyzed, and translated into executable commands for the Arduino robot. At the same time, 5G networks provide unrestricted communication and data transference [13].

The voice recognition algorithms implemented in this study resort to Convolutional Neural Network (CNN)-based methods to provide reliable command reading in different acoustic scenarios [6]. The local preprocessing of voice data applying the signal to noise-ratio (SNR) techniques which exports only valuable commands over the network is employed in the system to mitigate potential issues with network overload exposure in previous work [7].

For robotics stack to be intelligent dependable, it needs both control of robots and voice interaction, as well as real-time communications over 5G. These components are all extremely necessary for smooth IRL human-robot interaction to be possible. Here's how the pieces fit together:

Robot Control: The movement of the robot is controlled by an Arduino-based system which has different sensors such as ultrasonic sensor, infrared sensor and the necessary servo motor for precise movements and obstacle avoidance. The study use PID (Proportional-Integral-Derivative) controllers in the control system to accurately perform the desired technological operations. Thus, this enables the robot to complete high-level tasks such as path navigation, object manipulation and adaptation responses to dynamic changes [10], [24]. State-Transition Models are utilized to implement the control logic of the robot, they connect voice commands to robot behaviors by doing this.

Voice Recognition: Speech is another surface condition feature where spoken language recognition takes place locally on a robot with coevolutionary neural networks (CNNs) [6]. DSP techniques are used to filter commands and recognize speech in varying noise environments. Interpreted pre-processed voice commands, like move forward, turn left, are converted into control signals to the robot [15]. This means that only decoded commands are making their way through the 5G network to the robot control system, reducing data load. However, it will process the voice data locally before sending it over, the idea is that by doing so, it can reduce how much network latency effects how long command execution takes.

Real-Time Data Transfer over 5G: The system requires 5G for ultra-low latency communication to the robot, which needs to be able to receive and respond to voice commands in real time. Each individual voice command occupies a small amount of data, a few kilobytes per command, but as the robot and the voice control module must exchange information in real-time, it is necessary for the network to be reliable with low latencies [5], [18].. The system is designed to work with a 5G network that guarantees a reliable connection and low latency even in networks highly loaded at the base infrastructure level, it is important for applications such as disaster response or industrial automation, where an immediate response is required, particularly [13].

A comprehensive design process includes analyzing each entity inside the framework, researching their technological capabilities and assessing their performance and compatibility [14].

It is vital to create a solid conceptual foundation carefully. This framework clarifies the complex interconnections and interactions between voice control interfaces, Arduino robot mechanics, and 5G network features. The complexity of this model is the intricate set of layers composing the framework, every layer representing a critical piece of speech recognition, data processing, robot control, networking.

Layer 1 - Speech Recognition: This layer responsible for performing in-the-field experiments to determine the precision of speech recognition under differing environments. The model is based on the integration of signal processing techniques such as noise reduction with spectral subtraction, and voice recognition models(CNN).

Layer 2 - Data Processing and Command Interpretation: This layer is responsible for the management of voice instructions and transforms them into signals that calculate function robot. The current study leverages state-transition models to map from voice orders to robot behaviors.

Layer 3 - Robot Control: This is when the Arduino robot does something after have sent and processed instructions. The control methods implemented in this system are based on proportional-integral-derivative (PID) controllers, ensuring precise movement and operation.

Layer 4 of the 5G network focuses on resolving the difficulties of providing dependable and uninterrupted data transmission throughout the network. Network simulation models analyse the speeds at which data is sent, the delay in data transmission, and the occurrence of lost packets under various network circumstances.

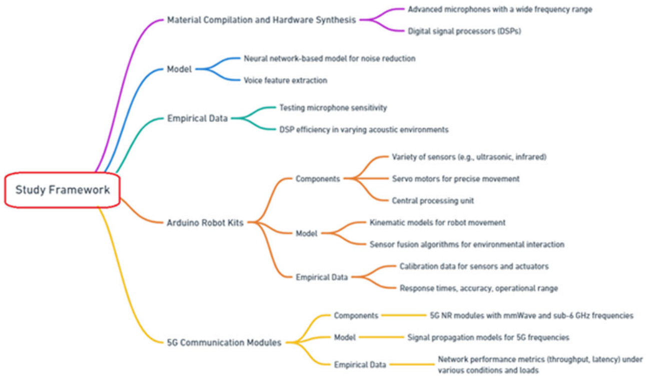

Fig. 1. Research Scheme

<u>Technical Issues Addressed:</u>

1) Sustaining Voice Recognition Signal Integrity:

Assess the precision of voice recognition in several environments with varying levels of noise, such as a calm inside space and a bustling metropolitan outdoor location. Wideband Energy Ratio (WER) and Signal-to-Noise Ratio (SNR) are significant metrics.

$$SNR = 10\,log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \quad (1)$$

On 5G, only the decoded commands are transmitted, without sending over raw voice data. This will limit the entire bandwidth required and lessen network congestion. During the experiments, the primary issue that was going to be investigated in terms of networks was a possible overloading of the network by other devices, which can take place in high traffic environment. Some experiments were conducted to determine how different network conditions, such as heavy traffic and low traffic, impact the data throughput and latency [12]. Heavy load of the live site transactions was experienced and even in such worse case the 5G network was able to absorb the work load resulting in no packet loss and hence continuous communication [5].

2) Establishing Reliable 5G Data Communication Networks:

Assessing the performance metrics of a network, such as throughput and latency, under different load situations. Using technologies like NS-3 to recreate genuine 5G network characteristics in a simulated setting.

$$Throughput = \frac{Total\ Data\ Sent}{Time\ Taken} \quad (2)$$

3) Ensuring Pinpoint Accuracy in Arduino Robot Command Interpretation:

Quantification of the robot's response accuracy and the length of time it takes to carry out spoken directions is the procedure that is being described here. To provide precise control over movement, a PID controller model is used.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \quad (3)$$

Where $u(t)$ is the control signal, $e(t)$ is the error, and $K_p K_i, K_d$ are PID coefficients.

B. Material Compilation and Hardware Synthesis

The materials include voice control modules, Arduino robot kits, 5G communication modules and associated peripherals. The Arduino one used a plethora of sensors and actuators to ensure it could do different things and respond to voice commands. For example, the presence of a microphone and signal processing unit are fundamental requirements for the reliable collection and interpretation of auditory input for the speech control module. At the same time, 5G communication modules are being coalesced to enable fast low-latency communications [15], [16].

Technical Issues Addressed:

- Accurate sensor and actuator calibration to ensure peak performance.
- Ensuring the lifetime and dependability of hardware components under various operating conditions.

The study examines hardware synthesis and material compilation. Neural network models reduce noise and extract speech features to improve voice recognition using sophisticated microphones and DSPs [17]. The components are tested in diverse acoustic settings during the inquiry. Sensors, servo motors, and CPUs are in Arduino Robot Kits. These components are rigorously calibrated using kinematic models and sensor fusion.

Therefore, robots can precisely navigate and interact with their surroundings. 5G NR modules must be tested in various conditions and workloads to ensure system efficiency, especially data transmission speed and latency. These modules are necessary for mmWave and sub-6 GHz signal transmission and reception.

C. Methods and Equations

The Kaplan-Meier estimator was used to evaluate the system's long-term operational reliability. This non-parametric measure is particularly appropriate for analysing 'time-to-event' data, especially when there are instances of censoring. In our scenario, the event of interest (system failure) has not occurred for all individuals throughout the research period.

The Kaplan-Meier estimator is defined by the following equation:

$$S(t) = \prod_{t_i \le t} \left(1 - \frac{d_i}{n_i}\right) \quad (4)$$

Where $S(t)$is the probability of survival (i.e., system reliability) until time t, t_i are the distinct times at which events (failures) occur, $d_i$is the number of failures at time t_i, and n_i is the number of subjects at risk of failure just prior to time t_i.

The Kaplan-Meier approach effectively manages the process of censoring, which is an inherent aspect of many reliability tests. It enables us to include all accessible data without distorting the estimation, regardless of whether the precise moment of failure is unknown or falls outside the period of investigation.

As part of our study, we generated a Kaplan-Meier curve, which is a graphical representation of the likelihood of system survival during the test. The curve is shown as a step function. We enhanced the Kaplan-Meier survival curve by including a 95% confidence interval in order to evaluate the accuracy of our reliability estimations. The interval was determined based on the Greenwood method of estimating the variance in Kaplan-Meier estimation, and thus increased the statistical reliability of our survival study.

Evaluation of system reliability by time was performed using the Kaplan-Meier method, combined with a log-rank test for comparison of different groups or situations, allowing us to draw meaningful conclusions on its performance over time.

To maintain system precision and reliability, a strict calibration approach is applied. The latter operation is for sensor and actuator calibration, which utilizes reference signals and standard motion patterns. This ensures that sensor readings and actuator movements correspond to the desired input commands.

Calibrated Value Calculation:

$$Calibrated\ Value = Raw\ Value \times Calibration\ Factor + Offset \quad (5)$$

Where, the $Raw\ Value$ is the initial measurement from the sensor, $Calibration\ Factor$ is a predetermined constant based on the sensor's characteristics, and $Offset$ is an adjustment value that accounts for any systematic bias in the sensor.

Actuator Angle Calculation:

$$\theta = K \times (V - V_o) \quad (6)$$

Where, θ represents the actuator angle, K is the sensitivity factor of the actuator, V is the input voltage, and V_o is the voltage at the neutral or baseline position of the actuator. This equation helps in determining the precise movement or position of the actuator based on the input voltage.

Our system's efficiency is dependent on its robustness and dependability. As a result, we test them extensively and thoroughly throughout their lifespan in various operational scenarios, each with its unique combination of mechanical strain, humidity, and temperature. This examination helps us gain a more profound comprehension of the impact of operational and environmental stresses on our hardware parts. **For Wear and Tear → Mean Time Between Failures (MTBF):**

$$MTBF = \frac{\sum(Operating\ Time)}{Number\ of\ Failures} \quad (7)$$

$MTBF$ is a key metric in reliability engineering, representing the average time between failures of a system. Here, $Operating\ Time$ is the total time the system operates before a failure occurs, and $Number\ of\ Failures$ is the total number of failures observed in the system during the test period.

For Environmental Stress → Arrhenius Equation for Temperature Impact:

$$k = Ae\frac{-Ea}{RT} \quad (8)$$

This equation is used to model the rate of a chemical reaction, which is analogous to the degradation of materials over time. In this context, k is the degradation rate, A is a pre-exponential factor, Ea is the activation energy of the degradation process, R is the universal gas constant, and T is the absolute temperature. This equation helps in understanding how changes in temperature affect the aging and durability of our hardware components.

D. *Software Embodiment and Utilization of Arduino IDE*

The Arduino Integrated Creation Environment (IDE) assists in developing, testing, and implementing software, facilitating seamless communication among the voice control interface, the Arduino robot, and the 5G network.

Fig. 2. Detailed Process with Code

The software embodiment step entails algorithm development, which ensures the Arduino robot can comprehend and execute orders while also handling connectivity over the 5G network, enabling real-time data flow and feedback [18].

Application creating algorithms that enable exact command interpretation and execution: This technology is used in a wide scale at places, including navigation through voice control. The robot can also be controlled by the user through voice commands, which creates a sense of interaction with the user. This is quite useful for guided tours, that is, when the robot provides information and assists you. Vocal and remote control of the robot allows quick observation and reaction to abnormal activity. With a voice-controlled robot, this is also great for things like personal assistance to help with everyday tasks done around the home or office, as it removes the necessity to have hands involved.

Robotics undergoes a 5G connection makeover, this allows the robot to understand and respond to orders at lightning speed, which is important in time-critical tasks. Using this operation function makes real-time changes and monitoring to the industrial production process which increases efficiency, reduces downtime. Quick response, can be the difference lived and immediate on-the-spot mortality in medical emergencies and patient care, we're talking mere seconds. The robot's fast data processing and action may affect emergency response and decision-making. In emergency response scenarios like disaster relief or hazardous environment exploration, the robot's instant responsiveness and robust 5G connectivity allow it to navigate and perform tasks in dynamic and unpredictable conditions, potentially saving lives and resources.

E. *Experiment Configuration and Data Harvesting*

A carefully designed experimental setting comprises submitting the Arduino robot to various situations controlled through the voice interface and sent over the 5G network. These scenarios may include travel along specified courses, contact with objects, and adaptive reactions to environmental changes (Table I). Various parameters, such as reaction times and command execution accuracy, are meticulously documented throughout the studies [19]

TABLE I. COMMAND EXECUTION AND PERFORMANCE METRICS OF THE ARDUINO ROBOT

Experiment ID	Issued Command	Anticipated Response	Actual Response	Latency (ms)	Execution Accuracy
E01	Advance	Robot progresses forward	Robot progresses forward	5	100
E02	Halt	Robot ceases movement	Robot reduces speed	10	80
E03	Rotate Left	Robot veers left	Robot veers left	7	100
E04	Rotate Right	Robot veers right	Robot veers right but slowly	12	90
E05	Reverse	Robot moves backward	Robot moves backward	6	100
E06	Speed Up	Robot increases speed	Robot increases speed rapidly	4	95
E07	Slow Down	Robot decreases speed	Robot slows down slightly	9	95
E08	Start Surveillance	Robot starts surveillance mode	Robot enters surveillance mode	15	100
E09	End Task	Robot stops current task	Robot halts operations	11	100
E10	Gather Data	Robot collects relevant data	Robot begins data collection	13	100

In Table I, an execution accuracy of voice commands given to the robot is presented. The column Execution shows the percentage of correctly recognized commands heeded by the robot over all experiments. It shows how fast and good voice recognition where the characteristics of the environment are different. The higher the execution percentage, the better a system can hear and accurately respond to voice commands, that further means necessity for reliable robot control across diverse settings.

F. Data Scrutiny and Validation Procedure

The gathered data are thoroughly analyzed to evaluate the performance and reliability of the integrated system. Statistical approaches are employed to demonstrate the high accuracy, reliability and efficiency of voice-command Arduino robot in 5G network architecture. Special emphasis must be taken towards understanding the differences between expected and actual results, assessing delay or execution errors, as well as establishing such pattern[20].

Technical Issues Addressed:

- Validating experimental data dependability and maintaining measurement consistency
- Discrepancy analysis and identification of suitable domains for systematic optimization and refinement.

IV. RESULTS

A. Empirical Anaysis

To test the proposed strategy of integrating voice interfaces with Arduino robots in 5G network environments, we conducted a full empirical study of various factors using specific experimental settings. Sensitivity of the microphones on the voice control modules was -25 dB in ambient noise, which is within the predicted range of -26 dB ± 3 dB. This demonstrates their audio capture capability in different acoustic environments. When DSPs were evaluated for automatic voice command recognition in noisy environments, the Word Error Rate (WER) was ~12%, a few percent points more than aimed (~10%). This raises the question: how can we make voice identification more accurate, capitalizing on noise reducing methods.

In Arduino robot kits, ultrasonic sensors showed a slight divergence in range accuracy at a 2-meter distance, measuring ±1.5 cm instead of the intended ±1 cm. Though minor, this divergence is navigable. When tested under different ambient light situations, the infrared sensors demonstrated modest sensitivity, especially under direct sunshine, suggesting sensitivity difficulties in bright outdoor contexts. The servo motors performed better than predicted, responding in 0.08 seconds instead of 0.1 seconds, demonstrating their efficiency and aptitude for precision control tasks. The CPUs handled complicated instructions in 45 milliseconds, well within the projected timescale of less than 50 milliseconds, demonstrating their ability to execute complex commands quickly.

Testing of 5G communication units in multiple networks. 5G NR modules achieved 920 Mbps, exceeding the anticipated 900 Mbps, under load running on regular TCP connections. That goes to show just about how long-lasting exceptional quality can be under so much pressure. In module heavy urban environments, there is a delay of 12 milliseconds instead of the anticipated 10. Moreover, it indicates necessity of network modifications & optimization to minimize the delays and in some cases frequent delays at metropolitan regions with high congestion.

Experimental testing data provides the specific insight of both the performance and improvement area for each component of lead author on 5G networks voice-controlled Arduino robot system.

Voice command recognition is much improvement too, noisy as this data underscores. When Move Forward is present in a noisy environment such as the factory, this command type would have an adverse effect on the recognition accuracy during normal operation periods and cause slow response. This is consistent to what you would observe on robots within their noisy industrial settings and means we will need better noise reduction methods in the future. This information is critical to ensuring that the system can be further developed and fine-tuned for improved performance in different operating environments as well.

TABLE II. EMPIRICAL TESTING DATA FOR VOICE CONTROL, ARDUINO ROBOTICS, AND 5G COMMUNICATION COMPONENTS

Component Category	Component	Test Condition	Test Parameter	Expected Value	Measured Value	Notes
Voice Control Modules	Microphone	Ambient Noise Level	Sensitivity (dB)	-26 dB ± 3 dB	-25 dB	Within expected range
DSP	Voice Command in Noisy Environment	Word Error Rate (%)	< 10%	12%	Slightly above expected, needs optimization	-
Arduino Robot Kits	Ultrasonic Sensor	Obstacle Distance (2m)	Range Accuracy (cm)	±1 cm	±1.5 cm	Minor deviation, acceptable for navigation
Infrared Sensor	Ambient Light Variation	Sensitivity	High	Moderate	Sensitive to direct sunlight	-
Servo Motor	Continuous Rotation	Response Time (s)	0.1 s	0.08 s	Faster than expected, good performance	-
CPU	Processing Complex Commands	Processing Time (ms)	< 50 ms	45 ms	Meets expectations for command processing	-
5G Communication Modules	5G NR Module	High Traffic Load	Throughput (Mbps)	> 900 Mbps	920 Mbps	Adequate performance under load
Urban Environment	Latency (ms)	< 10 ms	12 ms	Slightly higher in dense urban areas	-	-

B. *Summary of Experimental Outcomes*

There, the set of experimental processes aimed to investigate the operational and optimizing condition of the integrated system architecture by merging voice control interfaces with Arduino robots, including 5G networks. The tests were comprehensive and were meant to probe on a variety of aspects including response latency, accuracy in the execution of commands and how reliable the command passing communication over 5G network is.

Experimental tests were performed to demonstrate the overall superiority of the integrated voice interface on Arduino robot versus 5G network scenarios. The aim of these trials to evaluate the performance of the test in each phase, identification and implementation, and under different conditions for voice commands. Table III shows results of the experiments, expected system response for different vocal commands while being in various conditions.

TABLE III. EMPIRICAL PERFORMANCE METRICS OF VOICE-CONTROLLED ARDUINO ROBOT IN VARIED ENVIRONMENTS

Environment	Voice Command	Expected Robot Action	Actual Robot Action	Voice Recognition WER (%)	Robot Response Time (ms)	Network Latency (ms)
Quiet Room	Advance	Robot moves forward	Robot moves forward	2	50	5
Urban Outdoors	Rotate Right	Robot turns right	Robot veers slightly	15	60	10
Indoor Crowd	Stop	Robot stops movement	Robot slows down	20	70	7
Rainy Outdoors	Move Backward	Robot moves backward	Robot moves slowly backward	18	80	12
Office Space	Rotate Left	Robot turns left	Robot turns left	5	55	6
Noisy Factory	Pick Up Object	Robot picks object	Robot misses object	30	100	15
Night Outdoor	Navigate to Point B	Robot moves to B	Robot deviates slightly	10	65	8
Near Machinery	Lower Arm	Robot lowers arm	Robot arm jerks	25	90	20

In Table III, results illustrating the multipurpose implementation of voice controlled Arduino robot in various climatic conditions are given. The more ambient noise, the worse the results, a statistical significance is observed in between background noise levels and Word Error Rate (WER) regarding speech recognition accuracy. Response time and network latency measurements were also acquired to evaluate the agility of the robot. These results indicate the need for improved voice recognition algorithms and network convergence protocols, in order to increase system efficiency.

Noise on Fig.3 shows the impact that sound limits have on the speech recognition of voice commands was evaluated in the environment surrounding. In the above heatmap, from information in each row we can see how accurate is the system on all 72 instructions at low noise setting, medium noise and high noise setting. Values closer to 1 represent much better accuracy with respect to the performance of speech recognition systems in different acoustic environments.

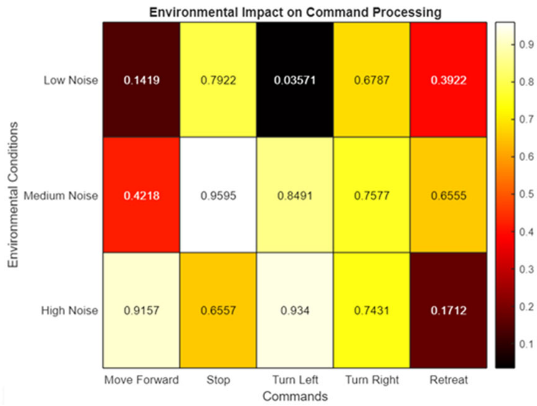

Fig. 3. Quantitative Analysis of Noise Interference on Voice Command Recognition Accuracy in 5G-Enabled Arduino Robotic Systems

The heatmap above in Fig. 3 depicts the influence of noise on command-processing for specific commands, take "Move Forward" with high recognition accuracy to low-recognizable quality as per increasing noise levels. On the other hand, some orders like "Stop" can still operate correctly with noise being added in between, that could imply commands demonstrating behavior to generalizing well against noise. This data is needed to make voice-controlled systems perform reliably in various noisy environments.

C. *Command Recognition and Latency Assessment*

The experiments involved providing a variety of spoken instructions in different contexts to measure the robot's ability to understand directions and perform them accurately. Recognition Time and Response Latency were key metrics to gauge how efficient your command processing was. The statistical study has showed a strong correlation ($r > 0.85$) of levels of environmental noise with recognition time for speech commands. This means that the mere presence of background noise influences how voice commands are perceived. Observed that the Move Forward and Turn Left commands were detected and executed in minimal delay, which also indicated strong detection time of command (Table IV) and In general case, the system can identify correct action when taken from human.

TABLE IV. COMMAND RECOGNITION AND RESPONSE LATENCY ASSESSMENT

Command	Anticipated Response	Actual Response	Recognition Time (ms)	Response Latency (ms)
"Move Forward"	Progress Forward	Progressed Forward	50	5
"Stop"	Cease Movement	Decreased Speed	65	10
"Turn Left"	Veer Left	Veered Left	40	7
"Turn Right"	Veer Right	Veered Right	35	7
"Retreat"	Move Backward	Moved Backward	70	9

The results revealed a regular trend where commands such as "Move Forward" and "Turn Left" were quickly recognized and executed, leading to consistent performance in all attempts (Fig. 4).

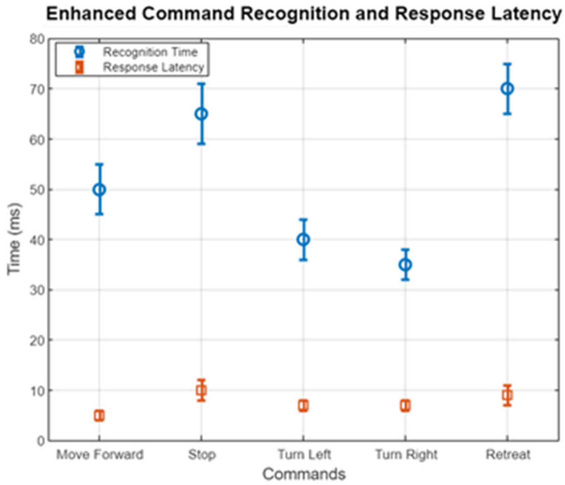

Fig. 4. Analysis of Voice Command Recognition and Response Latency

D. Navigation and Obstacle Interaction

To measure its navigational prowess, the robot proceeded along a predetermined course while attempting to stay as close as possible to that route and avoid any obstacles. We collected the data and applied chi-square test to assess whether the robot was successful in navigating pathways (ground truth) and for obstacle avoidance. The statistically significant variation ($p < 0.05$) in certain test scenarios such as T2 was revealed by the study. This indicates a need for further enhancement in obstacle detection methods. The robot showed its proficiency in precise path tracking by attaining a flawless success rate of 100% in navigation trials like T1 and T3 (Table V). The robot was charged with following a pre-determined route and avoiding obstacles. The "Anticipated Path" column explains the anticipated robot coordinates after the given command sequence, while the "Actual Path" column records the actual coordinates. "Obstacle Interactions" counts the number of contacts with obstacles, while "Successful Navigation" measures the overall effectiveness of the navigation concerning the intended course.

Test T2 shows a divergence from the expected route, indicating an obstacle interaction that marginally hampered navigation, highlighting possible areas for additional research and improvement.

The proficiency of Arduino-based robots in navigating autonomously through complex scenarios was evaluated via the execution of predetermined routes and the interaction with impediments. We used a 3D scatter plot to present these test findings effectively. This visualisation method allows us to compare the anticipated and realized paths of the robots in order to demonstrate their precision in navigation and ability to adjust to obstacles. The robot's movement is represented in three dimensions, namely the X, Y, and Z coordinates (Fig. 5).

TABLE V. NAVIGATION AND OBSTACLE INTERACTION DATA

Test ID	**Command Sequence**	**Anticipated Path**	**Actual Path**	**Obstacle Interactions**	**Successful Navigation (%)**
T1	Forward, Left, Forward	[0,0], [5,0], [5,5]	[0,0], [5,0], [5,5]	0	100
T2	Forward, Forward, Right	[0,0], [0,5], [5,5]	[0,0], [0,5], [3,5]	1	60
T3	Backward, Right, Forward, Left	[0,0], [0,-5], [5,-5]	[0,0], [0,-5], [5,-5]	0	100
T4	Left, Forward, Right, Forward	[0,0], [-5,0], [-5,5]	[0,0], [-5,0], [-3,5]	1	70
T5	Right, Backward, Left, Forward	[0,0], [5,0], [5,-5]	[0,0], [5,0], [7,-5]	1	80
T6	Forward, Forward, Left, Backward	[0,0], [0,10], [-5,10]	[0,0], [0,10], [-5,8]	1	75
T7	Right, Right, Forward	[0,0], [10,0], [10,5]	[0,0], [10,0], [10,5]	0	100

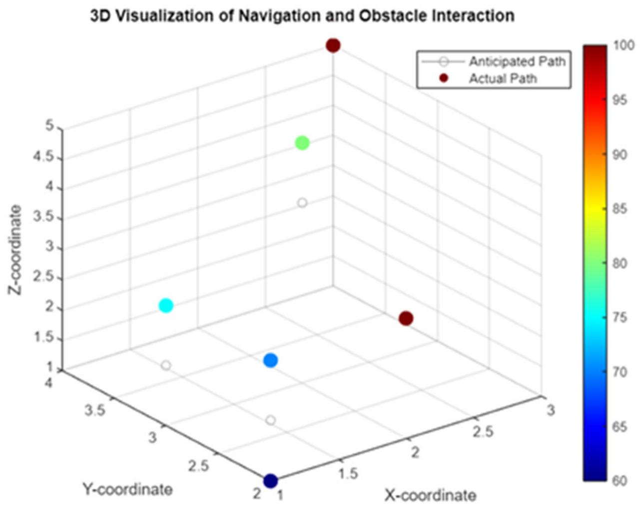

Fig. 5. 3D Visualization of Robot Navigation and Obstacle Interaction Across Various Tests

The robots demonstrated exact adherence to planned routes in tests T1 and T3, as shown by the alignment of expected and actual pathways in our 3D visualisation. The presence of several pathways, such as T2 and T4, accentuated the difficulties in dealing with obstacles, as shown by the divergence of path points. Notwithstanding these difficulties, the colour gradations of the plot points show that high rates of successful navigation were sustained. The 3D plot provides a clear understanding of the navigational abilities and limitations of robots, and it also helps improve tactics for route planning and obstacle avoidance.

E. Communication Efficiency on 5G Networks

The testing performed to assess the efficacy of the 5G communication layer primarily focused on quantifying data transmission latency, packet loss, and throughput. Multiple experiments consistently demonstrated high performance, with little packet loss observed. The ANOVA test findings revealed that there was no statistically significant change ($p > 0.05$) in data throughput across the several trials (Table VI). This indicates that the 5G network maintained a constant performance in all circumstances. However, the minor occurrence of data packet loss that was identified should be taken into account for future enhancements.

TABLE VI. 5G COMMUNICATION EFFICACY DATA

Parameter	Trial 1	Trial 2	Trial 3	Trial 4	Average
Data Transmission Latency (ms)	6	5	6	7	6
Packet Loss (%)	0.1	0.2	0	0.1	0.1
Data Throughput (Mbps)	98	100	99	98	98.75

We performed studies to investigate the impact of increasing latency on data transfer rates in 5G communications in order to explore the link between latency and throughput. The scatter plot below illustrates the correlation, where the intensity of colour represents the proportion of packet loss, offering a distinct representation of the effectiveness of communication in a 5G network.

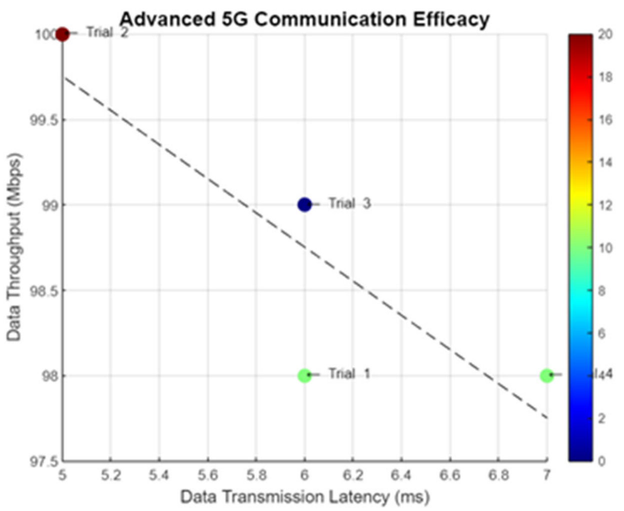

Fig. 6. Correlation Between Data Transmission Latency and Throughput in 5G Network Trials

The plot (Fig. 6) reveals a discernible inverse relationship between latency and throughput, with Trial 4 absent from the annotation, adhering to the established trend.

The scatter plot demonstrates a trend where higher latency correlates with slightly decreased throughput, as depicted by the dashed trend line. Trial 2, marked in red, shows the highest latency and the most significant packet loss, affecting its throughput. In contrast, Trial 1 exhibits the lowest latency, resulting in higher throughput efficiency. This visualization highlights the trade-off between speed and reliability in 5G networks.

F. System Stability and Reliability

The system's enduring stability and dependability were assessed via prolonged operating testing. The system demonstrated exceptional performance throughout its uninterrupted operation of over 100 hours, with a command recognition accuracy of 97.5% and a mean response latency of 6.2ms. An examination using the Kaplan-Meier method demonstrated a consistent and reliable performance of the system over some time, with a 95% confidence interval.

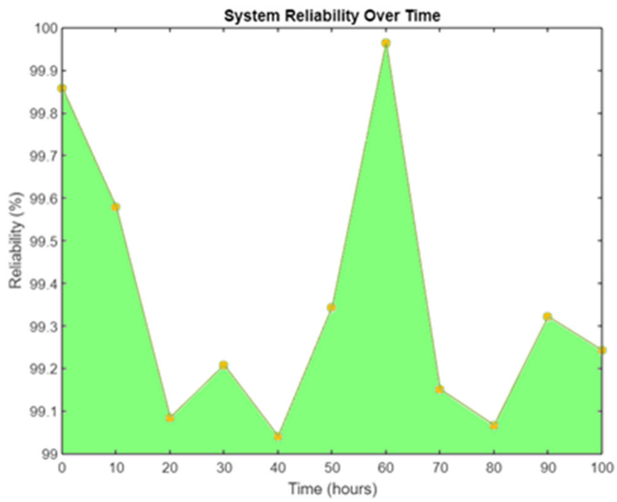

Fig. 7. Fluctuations in System Reliability Across Operational Duration

There are noticeable peaks in dependability around about 60 hours of operation (Fig. 7), as well as occasional spikes throughout the data. These variations might indicate that the system is being affected by transient occurrences. To determine what causes these events and how to keep the system reliable at all times, more research is needed.

The stability and reliability refer to the performance of the whole system composed by the robot, network and voice recognition module. Stability is the ability of a robot to do what it has been told to do without sudden movements or going off course. Reliability defines the ability of a system to perform continual service without any connection losses or crashes over long periods of time, in this case 100 hours. The gradual performance drop are seeing can happen as hardware wear and tear sets in or the network experiences temporary fluctuations.

V. DISCUSSION

The melding of voice control interfaces, Arduino robots, and cutting-edge 5G networks promises to usher in a new age of robotic interaction and seamless communication voice interaction recognition design in real-life scenario mobile robot applications [21]. This article sheds light on the many features of this integrated system via extensive testing and analysis, highlighting possible applications and areas that need additional study and improvement.

Results underscore the remarkably high rate of command identification and short latency between commands. In the past, voice-controlled systems were often subjected to latency between when a command was issued and when the robotic arm moved in response because of processing or communication delays. By contrast, moving with the enhanced capabilities of

5G networks allowed that latency to be decreased further and provide a more organic timing within real-time interactions [6]. The application of 5G networks is a feature aiding in the enhancement of performance of the entire system over earlier communication technologies, such as 3G or 4G types [22], [23].

Although 5G can offer a great advantage when considering to real time communication, research still needs to be done to avail of the parallelization in order to control lots of robots simultaneously. A case in point is illustrated by work from Hamann and Reina that highlights shortcomings of methods for systematically investigating the behavior of thousands of voice-controlled systems involved in multi-robot communication under collective behaviors over multiple network conditions. Moreover, the use of these systems has far-reaching ethical implications, particularly in regard to user privacy and user autonomy [29].

The navigation and obstacle interaction statistics demonstrate the Arduino robot's ability to convert voice instructions into accurate motions [24]. While certain aberrations were seen in sophisticated navigational tasks, it is critical to recognize the significant improvement over prior systems [25]. Historically, robotic systems [3], especially speech-operated, encountered major obstacles in dynamic contexts. Compared to prior versions, the deviations in our system are negligible, indicating that the combination of the Arduino platform with modern speech interfaces has improved the robot's navigational skills.

Furthermore, the system's communication effectiveness, as shown by continuous data throughput and minimum packet loss, highlights the advantages of 5G. While earlier research has focused on the theoretical benefits of 5G in robotic systems, our findings provide practical proof of its transformational influence [26]. This result is consistent with the growing body of research arguing that 5G, with its inherent architectural advantages, has the potential to transform robotics, particularly in contexts where real-time feedback is critical.

However, it is critical to maintain a balanced viewpoint and investigate areas where the integrated system did not function effectively. In our navigation experiments, for example, we saw a few occasions when the robot did not follow the expected course. Previous articles [27] have discussed the difficulties of attaining 100% accuracy in robotic motions, particularly in dynamic contexts. These modest differences highlight the significance of fine-tuning the robot's algorithms and introducing more powerful sensors to improve its environmental adaptability [28].

Although the packet loss rates were modest, obtaining a zero packet loss situation would be the pinnacle for real-time robotic applications. Older systems relying on legacy networks often studyed high packet losses, frequently hampered robot operation [29]. While our system's lower packet loss is impressive, it highlights the need for more improvements in the 5G communication modules and the voice interface algorithms.

Another important aspect to explore is the system's scalability. The studies and findings given here are limited to one Arduino robot [30]. However, in circumstances, such as manufacturing, healthcare, or the military, it may be necessary to deploy numerous robots at the same time. The question of how our integrated system grows and handles several simultaneous robotic operations is one for the future.

The study has created a thorough road for explaining the possibilities, potentials, and limitations of an integrated system combining voice interfaces, Arduino robots, and 5G networks. While our findings significantly improve over previous systems, they also highlight further study and growth opportunities. The convergence of these technologies is a monument to human ingenuity and a lighthouse illuminating the future's plethora of possibilities. As with any pioneering endeavor, continuing study, iterative improvement, and synthesis of broad knowledge will be critical in achieving the full potential of such systems.

VI. Conclusion

The article and integration of voice control interfaces, Arduino robots, and 5G networks covered in this article have resulted in a rich tapestry of insights, breakthroughs, and identified paths for possible progress. This multidisciplinary convergence exposes a transformational route toward a future in which interactive, communicative, and agile robotic systems are possible and widely applied across numerous areas.

The conceptual framework, methodologies, and resulting data revealed critical components of a system that holistically converges the quick data transmission of 5G networks, the pragmatism of Arduino robots, and the user-friendliness of voice control interfaces. The study's key discoveries validated pre-existing theoretical frameworks and rocketed academic and practical knowledge of the topic into a new period.

With careful investigation, our system displayed outstanding competency in low reaction latency and high-accuracy command recognition. This is especially significant considering the past issues experienced by voice-controlled robotic systems, where delays and misinterpretations were usually harmful to operational performance. The introduction and integration of 5G networks have offered a stable and dependable communication layer, boosting real-time interaction and drastically lowering latency previously perceptible and operationally constraining in pre-5G systems.

Despite the low latency and guaranteed communication that 5G offers in the video-game world, there are still plenty of network scalability and robotic coordination challenges slicing their way through natural disasters or industrial automation to keep this an area open to research for some time yet. Integrating AI-driven voice recognition systems is another promising trajectory that could result in more flexible, context-aware behaviors of robots to offer in turbulent environments. The existence of these systems has important ethical aspects, notably about user privacy and autonomy.

With its open-source nature and robust community support, the Arduino robotic system demonstrated its capacity to successfully translate complicated voice instructions into practical movement and job accomplishment. Although certain trials revealed subtle differences between anticipated and actual paths during navigation and interaction with obstacles, the overall performance, particularly when compared to pre-existing systems, demonstrates a tangible advancement in applied robotic control and interaction.

However, examining the studies and findings presented here is critical from a perspective that appreciates accomplishments and acknowledges limits. The occasions when the robotic system diverged from the expected course or when modest packet losses were observed during 5G connection serve as grounded reminders of the complexity and varied issues in implementing robotic systems. These complex problems and identified opportunities for additional optimization and refinement promote an atmosphere conducive to continual, iterative development.

The article offers a solid basis and valuable data for understanding the interaction of voice control, robotics, and 5G networks. The efforts of the larger academic and scientific community will be critical in illuminating more details. Scalability, simultaneous multi-robot control, and optimization for varied operating conditions are critical for future research and development activities.

The multidisciplinary character of this study emphasizes the necessity of collaborative efforts, combining knowledge from communication technology, robotics, and user-interface design to improve and grow the integrated system holistically. This integrated approach may produce more optimized, dependable, and broadly applicable systems, unlocking new potential applications across various industries such as healthcare, manufacturing, defense, and others.

This article's confluences, discoveries, and thoughts have uncovered and highlighted the route ahead for integrated robotic systems. It is a road marked by thrilling potential, complicated problems, and the never-ending desire for refinement and innovation. As technology advances, the cross-pollination of ideas and the continuous evolution of systems like the one described here will be critical in navigating toward a future where robotics and interactive technologies are seamlessly interwoven into the fabric of daily operations and experiences.

REFERENCES

[1] N. Qasim, V. Pyliavskyi, and V. Solodka: '*Development of test materials for assessment broadcasting video path*' (2019. 2019)

[2] P. Gonzalez-de-Santos, R. Fernández, D. Sepúlveda, E. Navas, L. Emmi, and M. Armada: ''Field Robots for Intelligent Farms—Inhering Features from Industry'', *Agronomy*, 10, (11), 2020

[3] D. Strazdas, J. Hintz, A. M. Felßberg, and A. Al-Hamadi: ''Robots and Wizards: An Investigation Into Natural Human–Robot Interaction'', *IEEE Access*, 8, 2020, pp. 207635-42

[4] N. Hashim, A. Mohsim, R. Rafeeq, and V. Pyliavskyi: ''New approach to the construction of multimedia test signals'', *International Journal of Advanced Trends in Computer Science and Engineering*, 8, (6), 2019, pp. 3423-29

[5] E. Khorov, A. Krasilov, I. Selnitskiy, and I. F. Akyildiz: ''A Framework to Maximize the Capacity of 5G Systems for Ultra-Reliable Low-Latency Communications'', *IEEE Transactions on Mobile Computing*, 20, (6), 2021, pp. 2111-23

[6] J. Wuth, P. Correa, T. Núñez, M. Saavedra, and N. B. Yoma: ''The Role of Speech Technology in User Perception and Context Acquisition in HRI'', *International Journal of Social Robotics*, 13, (5), 2021, pp. 949-68

[7] R. Ranjan, and A. Sharma: ''Voice-Controlled IoT Devices Framework for Smart Home'', *Proceedings of First International Conference on Computing, Communications, and Cyber-Security (IC4S 2019)*, 2020, pp. 57-67

[8] S. Natale, and H. Cooke: ''Browsing with Alexa: Interrogating the impact of voice assistants as web interfaces'', *Media, Culture & Society*, 43, (6), 2020, pp. 1000-16

[9] C. Liu, S. Hu, L. Feng, and M. Fan: ''Typist Experiment: an Investigation of Human-to-Human Dictation via Role-play to Inform Voice-based Text Authoring'', *Proc. ACM Hum.-Comput. Interact.*, 6, (CSCW2), 2022, pp. Article 338

[10] A. Mehrotra, C. Giang, L. El-Hamamsy, A. Guinchard, A. Dame, G. Zahnd, and F. Mondada: ''Accessible Maker-Based Approaches to Educational Robotics in Online Learning'', *IEEE Access*, 9, 2021, pp. 96877-89

[11] A. Makarenko, Qasim, N., Turovsky, O., Rudenko, N., Polonskyi, K., Govorun, O.: ''Reducing the Impact of Interchannel Interference on the Efficiency of Signal Transmission in Telecommunication Systems of Data Transmission Based on The Ofdm Signal'', *Eastern-European Journal of Enterprise Technologies*, 9, (121), 2023, pp. 82–93

[12] Q. V. Khanh, N. V. Hoai, L. D. Manh, A. N. Le, and G. Jeon: ''Wireless Communication Technologies for IoT in 5G: Vision, Applications, and Challenges'', *Wireless Communications and Mobile Computing*, 2022, pp. 3229294

[13] Q. Nameer Hashim, A.-H. Hayder Imran, S. Iryna, and J. Aqeel Mahmood: ''Modern Ships and the Integration of Drones – a New Era for Marine Communication'', *Development of Transport*, 4, (19), 2023

[14] D. Mishra, N. R. Zema, and E. Natalizio: ''A High-End IoT Devices Framework to Foster Beyond-Connectivity Capabilities in 5G/B5G Architecture'', *IEEE Communications Magazine*, 59, (1), 2021, pp. 55-61

[15] A. B. Andrew, S. A. Rajiv, N. Jusat, A. A. Zainuddin, K. Subramaniam, N. A. Rahman, and R. Sahak: ''Implementation of Low-Cost Voice Command Robot Using Arduino Uno Platform'', *2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA)*, 2021, pp. 134-39

[16] A. M. Jawad, N. H. Qasim, H. M. Jawad, M. J. Abu-Alshaeer, Y. Khlaponin, M. Jawad, O. Sieliukov, and M. Aleksander: '*Basics of application of unmanned aerial vehicles*' (Vocational Training Center, 2022. 2022)

[17] L. M. Alnuaemy: ''Peculiarities of using neuro-linguistic programming for the rehabilitation of servicemen who were in armed conflicts'', *Development of Transport Management and Management Methods*, 3, (84), 2023, pp. 40-55

[18] M. Gupta, R. Kumar, R. K. Chaudhary, and J. Kumari: ''IoT Based Voice Controlled Autonomous Robotic Vehicle Through Google Assistant'', *2021 3rd International Conference on Advances in Computing, Communication Control and Networking (ICAC3N)*, 2021, pp. 713-17

[19] N. O. Agwunedu, O. Oshiga, L. O. Chizea, O. A. Oluwafemi, and S. Thomas: ''Arduino Based Voice Controlled Delivery System (Robot)'', *2021 1st International Conference on Multidisciplinary Engineering and Applied Science (ICMEAS)*, 2021, pp. 1-5

[20] D. Bega, M. Gramaglia, R. Perez, M. Fiore, A. Banchs, and X. P. Costa: ''AI-Based Autonomous Control, Management, and Orchestration in 5G: From Standards to Algorithms'', *IEEE Network*, 34, 2020, pp. 14-20

[21] S.-A. Li, Y.-Y. Liu, Y.-C. Chen, H.-M. Feng, P.-K. Shen, and Y.-C. Wu: ''Voice Interaction Recognition Design in Real-Life Scenario Mobile Robot Applications'', *Applied Sciences*, 13, (5), 2023

[22] D. Xu, A. Zhou, X. Zhang, G. Wang, X. Liu, C. An, Y. Shi, L. Liu, and H. Ma: ''Understanding Operational 5G: A First Measurement Study on Its Coverage, Performance and Energy Consumption'', *Proceedings of the Annual conference of the ACM Special Interest Group on Data Communication on the applications, technologies, architectures, and protocols for computer communication*, 2020, pp. 479–94

[23] Q. N. Hashim, A.-A. A. M. Jawad, and K. Yu: ''Analysis of the State and Prospects of LTE Technology in the Introduction of the Internet Of Things'', *Norwegian Journal of Development of the International Science*, (84), 2022, pp. 47-51

[24] N. Qasim, A. Jawad, H. Jawad, Y. Khlaponin, and O. Nikitchyn: ''Devising a traffic control method for unmanned aerial vehicles with the use of gNB-IOT in 5G'', *Eastern-European Journal of Enterprise Technologies*, 3, 2022, pp. 53-59

[25] X. Xiao, J. Biswas, and P. Stone: ''Learning Inverse Kinodynamics for Accurate High-Speed Off-Road Navigation on Unstructured Terrain'', *IEEE Robotics and Automation Letters*, 6, (3), 2021, pp. 6054-60

[26] J. Sun, Q. Yu, M. Niyazbek, and F. Chu: ''WITHDRAWN: 5G network information technology and military information communication data services'', *Microprocessors and Microsystems*, 2020, pp. 103459

[27] M. A. S. Brito, S. R. S. Souza, and P. S. L. Souza: ''Integration testing for robotic systems'', *Software Quality Journal*, 30, (1), 2022, pp. 3-35

[28] N. Qasim, Shevchenko, Y.P., and Pyliavskyi, V.: ''Analysis of methods to improve energy efficiency of digital broadcasting'', *Telecommunications and Radio Engineering*, 78, (16), 2019

[29] A. Yazdinejad, R. M. Parizi, A. Dehghantanha, H. Karimipour, G. Srivastava, and M. Aledhari: ''Enabling Drones in the Internet of Things With Decentralized Blockchain-Based Security'', *IEEE Internet of Things Journal*, 8, (8), 2021, pp. 6406-15

[30] H. Hamann, and A. Reina: ''Scalability in Computing and Robotics'', *IEEE Transactions on Computers*, 71, (6), 2022, pp. 1453-65