ANALYSIS OF THE INTEGRATION OF AMRS WITH LIDAR TECHNOLOGY AND 5G CONNECTIVITY IN HOSPITAL ENVIRONMENTS.

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Abstract

The integration of Autonomous Mobile Robots (AMRs) with LiDAR technology and 5G connectivity presents a transformative potential for hospital environments. This study evaluates the performance of these technologies in addressing critical metrics such as latency, throughput, reliability, and reaction time, emphasizing their application in automating logistical tasks like transporting medical materials. The results demonstrate that 5G networks outperform WiFi in terms of low latency, high throughput, and performance consistency, making them ideal for real-time applications. Furthermore, LiDAR enhances AMR navigation by providing precise, three-dimensional mapping in dynamic environments. Despite the promising technical advancements, challenges remain, including infrastructure costs, interoperability, and cybersecurity concerns. The findings underline the need for multidisciplinary approaches to overcome these barriers and pave the way for innovative healthcare solutions. This research contributes to the growing knowledge of Industry 4.0 applications in the healthcare sector, aiming to enhance efficiency, safety, and quality in patient care.

Keywords

Autonomous Mobile Robots (AMRs); LiDAR Technology; 5G Connectivity; Hospital Automation; Industry 4.0

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1. INTRODUCTION

The technological evolution associated with the Fourth Industrial Revolution has the potential to radically transform working patterns in the most diverse sectors of human activity. In the healthcare sector, where the demand for professionals is growing steadily as populations age, the integration of these advanced technologies, such as Autonomous Mobile Robots (AMRs), LiDAR and 5G connectivity, could be one of the key components in balancing outpatient and hospital operations in terms of the demands of efficiency and effectiveness (SAHU et al., 2024) and (GUSTAVSSON, 2021). In complex environments such as hospitals, where precision, safety and efficiency are essential, these technologies can offer significant support for routine tasks, while relieving healthcare staff of repetitive and potentially risky activities, such as the transportation of medicines and laboratory samples. Automation at this level not only promises efficiency gains, but can also promote safer environments for professionals and patients, (WEI, 2023) and (GIUFFRIDA & MARTINA, 2023)

AMRs, equipped with LiDAR sensors, can navigate autonomously and adaptively in any environment with dynamic flow and complex geometry, adjusting to changes in the environment, such as hospitals and outpatient clinics, in real time. This capability is crucial, because dynamic environments require precise navigation to avoid accidents and ensure tasks are completed in a timely manner. LiDAR Sensors bring the ability to create three-dimensional maps that facilitate safe and efficient navigation, safely anticipating and avoiding obstacles.

Compared to other detection technologies, such as cameras, LiDAR sensors perform better in low light conditions and can map objects in 360 degrees around them. This set-up therefore makes autonomous operation possible because it reduces the need to exchange lengthy data packets related to image interpretation, because it helps to reduce response times, data packet losses and, above all, the cost of network and computing infrastructure. This favors the progress of the development and implementation of this technology in situations of budgetary constraint.

In this context, 5G Indoor connectivity is key to making the operation of AMRs more efficient in dynamic environments, such as hospitals, because it enables low-latency communication in the networks where they are inserted and the ability to transact extensive data packets securely. These attributes are prerequisites for ensuring that interactions between devices and control systems are fast and reliable (SIDDIQI & JOUNG, 2019) and (SEFATI & SIMONA).

In indoor environments where there is 5G infrastructure, data is transmitted practically in real time. This gives AMRs the ability to respond almost immediately to commands and avoid dynamic obstacles: flow of people and objects, reconfiguration of environments, changes in routes, etc. This agility is fundamental to the operation of outpatient clinics and hospitals, because serious events can arise due to delays in communication, or accidents on the way, which delay delivery, for example, the delivery of a medicine.

It is important to remember that operating AMRs at this level in hospital environments is far from being possible, but we are taking the structural learning steps here to make this a possible alternative soon, as an alternative to lowering the cost of their operations by automating the repetitive work of healthcare professionals (AKBARZADEH & HANI, 2022) and (KHAN & MIR, 2023).

Research Problem and Objective.

Despite the high technological and implementation potential, the integration of AMRs, LiDAR and 5G Indoor into an effective solution for outpatient and hospital environments still has to face significant challenges: interoperability between systems, implementation costs and cybersecurity concerns (NOKIA, 2024) and (HERMANT et al., 2021).

Implementing 5G Indoor networks is complex, especially in terms of infrastructure and network management. In addition, it is necessary to ensure that sensitive data is rigorously protected, as 5G connectivity exposes this data to new security risks. Given this context, this study aims to assess the feasibility and effectiveness of integrating AMRs, LiDAR sensors and 5G Indoor connectivity to optimize efficiency and security in hospital environments, by understanding how the construction of these applications should be planned, structured and implemented based on an understanding of their key performance indicators.

Significance of the Study

The application of AMRs with LiDAR sensors and 5G connectivity has the potential to redefine the way routine tasks are carried out in hospitals, allowing healthcare professionals to focus on activities that require clinical skills. Automating routine and repetitive tasks can not only improve operational efficiency, but also minimize the risks inherent in human traffic in biologically contaminated areas: cross-contamination.

Enabling truly autonomous AMRs effectively is essential for this. In addition, previous studies clearly point out that the use of AMRs in hospital environments can increase productivity by reducing response times for the transportation of materials, (SAHU et al., 2024).

The relevance of LiDAR lies in its ability to provide accurate data for navigation and object detection in real time. According to Berman (2018), LiDAR excels in environments where high-resolution mapping is required, offering an advantage over cameras and ultrasound sensors in terms of accuracy and speed. In hospitals, this precision is essential to avoid collisions and ensure that the robot follows safe trajectories. In addition, LiDAR's ability to identify different surfaces and materials in low light conditions is a significant differentiator (GUSTAVSSON ET AL., 2021).

Challenges and Perspectives.

Integrating these technologies into a specific application has a specific set of challenges to overcome.

The implementation of 5G Indoor also requires a robust infrastructure and efficient network management, especially with regard to low latency and high reliability in the transmission of data packets, in order to control AMRs in real time. SHAFI et al. (2017) point out that the maximum potential for 5G Indoor applications in dynamic environments, such as hospitals, requires investment in infrastructure and security solutions to protect sensitive user data. To do this, it is necessary to accurately determine the demands of each application space. This need, along with the interoperability issues of control systems, AMRs and LiDAR sensors, requires full mastery of their control and performance variables, which is the aim of this work, so that strict, synchronous coordination and data protection are possible, (SAHFI et al., 2017).

Conclusion of the Introduction

This work aims to help drive the application of Industry 4.0 enabling technologies in dynamic environments, especially outpatient and hospital environments that urgently need solutions to optimize the work of healthcare professionals, by assessing the technical feasibility of integrating AMRs, LiDAR sensors and 5G connectivity.

2. THEORETICAL FRAMEWORK.

The integration of Autonomous Mobile Robots (AMRs) with LiDAR sensors and 5G connectivity in dynamic environments, such as outpatient and hospital settings, represents a convergence of emerging technologies in applications that have the potential to profoundly change routines and work processes in logistics. This includes healthcare environments and their internal logistics. In order to fully understand the challenges and current ways of solving this integration, it is essential to review the advances and solutions associated with each of its components and their joint application.

2.1 Autonomous Mobile Robots (AMRs).

The use of AMRs as logistical and maintenance aids in complex and dynamic environments has received increasing attention from the world's major automation companies, due to their inherent ability to perform repetitive, physical tasks without concern for ergonomics, and thus physically save human workers. In health care environments, these applications have a clear adherence to tasks such as transporting medicines, laboratory samples and medical equipment, as well as many other possible tasks that can be imagined (VAJJHALA & EAPPEN, 2023).

For this to become a reality, challenges such as navigation in dynamic environments and safe interaction with humans must be worked on and resolved before commercial applications can be discussed (CABANILLAS et al., 2023).

2.2 LiDAR Technology for Autonomous Navigation

LiDAR (Light Detection and Ranging) technology basically uses laser pulses to map the environment in three dimensions and has been well known for almost 50 years. This mapping capability allows AMRs to develop accurate navigation strategies, avoiding obstacles and making decisions in unexpected situations. In addition, as stated by (CHOE & CHUNG, 2024), LiDAR has advantages over cameras and ultrasound sensors, especially in low light conditions, and provides more accurate and precise data for autonomous navigation.

However, it is necessary to work on lower-cost alternatives to LiDAR sensing, since cutting-edge alternatives can be highly complex, require specific knowledge and cost a lot of money (FAWOLE & RAWAT, 2024).

2.3 5G Indoor Connectivity.

5G Indoor connectivity provides data communication solutions with high bandwidth and low latency, which are requirements for communication processes that demand high accuracy, quality and low response time, such as the application of AMRs in complex and dynamic environments (YAO et al., 2024). SAHU et al. (2024) indicate that 5G Indoor, due to its performance in these requirements, can support even advanced medical services, including telemedicine and remote patient monitoring. This feature can support the search for specific healthcare solutions.

However, the implementation of 5G Indoor in outpatient and hospital environments faces challenges related to infrastructure, data security and interoperability with existing systems, which must be explored to the limit of their key performance settings.

2.4 Integration of AMR, LiDAR and 5G: Opportunities and Challenges

The integration of Autonomous Mobile Robots (AMRs) equipped with LiDAR sensors and 5G connectivity in hospital environments represents a technological convergence with the potential to revolutionize healthcare operations. This synergy makes it possible to automate logistical tasks, such as the transportation of medicines and laboratory samples, as well as enabling rapid responses to emergency situations, (GEOURGIUS & SATAVA, 2021).

LiDAR sensors provide AMRs with the ability to map environments in three dimensions with high precision, facilitating autonomous navigation and obstacle detection in real time. This technology is especially effective in low-light conditions, where other sensors, such as cameras, can be limited. 5G Inddor connectivity, meanwhile, offers high bandwidth and low latency, allowing AMRs to communicate instantly with central systems and other connected devices. This real-time communication is crucial for the efficient coordination of hospital operations and the immediate response to critical events.

The synergy between AMRs, LiDAR and 5G results in safer and more efficient systems. AMRs' precise navigation reduces the risk of collisions and accidents, while real-time communication ensures that robots can react quickly to changes in the environment, such as the presence of patients or healthcare professionals in corridors. In addition, the automation of repetitive tasks frees up professionals to focus on activities that require clinical expertise, improving the quality of patient care.

However, integrating these technologies presents significant challenges. Implementing 5G networks in hospital environments requires substantial investment in infrastructure and ensuring reliable coverage in all critical areas. In addition, interoperability between AMRs, LiDAR sensors and existing hospital systems must be carefully planned to avoid incompatibilities and ensure smooth operation.

Cyber security is another key concern. The transmission of sensitive data, such as patient information and operational details, over 5G networks increases the attack surface for cybercriminals. Therefore, it is imperative to implement robust security measures, including advanced encryption, multi-factor authentication and continuous monitoring of networks, to protect against unauthorized access and ensure data integrity, (GEORGIU & SATAVA, 2021).

Application cases of this integration are already being explored in various hospitals around the world. For example, the Hospital das Clínicas of the USP Medical School has launched the OpenCare 5G project, which uses a private 5G network to test advanced connectivity in healthcare, including the operation of AMRs to transport medical materials, DELLOITE (2021) and another example is in China, where robots are used to disinfect environments and deliver supplies, minimizing the exposure of healthcare professionals to contaminated areas (ZHAO et al., 2022).

2.5 Applications of AMRs in Other Sectors

In addition to the health sector, AMRs have been applied in industries such as manufacturing and construction. DELGADO et al. (2019) analyze the use of AMRs in flexible manufacturing systems, highlighting improvements in production efficiency and flexibility. GHAFARIANHOSEINI et al. (2016) explore the application of autonomous robotic systems in the construction industry, emphasizing benefits such as greater precision and safety. These applications demonstrate the versatility of AMRs and provide valuable insights for their implementation in hospital environments.

2.6 Security and privacy challenges

The integration of AMRs, LiDAR and 5G into hospital environments raises significant security and privacy concerns. LOU et al. (2023) discuss the vulnerabilities introduced by the adoption of emerging technologies such as IoT and 5G in healthcare environments, including potential threats such as denial-of-service attacks and interception of sensitive data. The authors propose mitigation strategies, such as advanced encryption, multi-factor authentication and continuous network monitoring, to ensure the security of smart healthcare systems.

2.7 Future prospects

The ongoing evolution of AMR, LiDAR and 5G technologies points to a future where automation and advanced connectivity will play crucial roles in hospital environments. FANG et al. (2017) emphasize that while reducing latency in 5G networks presents significant technical challenges, it offers substantial opportunities for the development of innovative real-time applications. In addition, the integration of artificial intelligence and real-time data analysis can further enhance the performance of AMRs, making them more adaptable and efficient in dynamic environments, (PARVEZ et al., 2018).

2.8 Final considerations

The literature review shows that the integration of AMRs with LiDAR technology and 5G connectivity in hospital environments offers significant opportunities to improve operational efficiency and safety. However, challenges related to infrastructure, data security and interoperability need to be addressed for successful implementation. Future research should focus on developing integrated solutions that take into account the specificities of hospital environments and guarantee the reliability and security of the systems implemented.

3. METHODOLOGICAL PROPOSAL

The methodology developed for this study aims to evaluate the effectiveness of integrating Autonomous Mobile Robots (AMRs) with LiDAR technology and 5G connectivity in hospital environments, using rigorous metrics that reflect the specific demands of this context. The methodological steps were designed to address technical and operational challenges, ensuring that the results contribute to the practical implementation of AMRs in these critical environments.

3.1 Evaluation parameters

The parameters chosen include latency, response speed, reliability, execution time and throughput. These metrics were selected because of their relevance to the performance of AMRs in hospital tasks. Each of these metrics reflects different aspects of robot operation in 5G networks, aligning with the requirements of real-time communication and efficient automation.

Latency: This refers to the total time it takes for a data packet to travel from source to destination within the network. In hospital applications, where AMRs perform time-sensitive tasks such as delivering medicines and transporting materials, high latencies can compromise the effectiveness of the operation. To measure latency, the Iperf tool was used, which simulates network loads and assesses the impact in real time. The 5G network is evaluated by its ability to maintain latencies below 1 millisecond, which is essential for efficient navigation and autonomous decision-making.

Speed of Response: This metric measures the time it takes the AMR to process and execute a command received from the cloud. In hospital environments, where quick decisions can directly impact patient care, speed of response is crucial. Using the Wireshark tool, traffic data was captured to measure the efficiency of communication between AMRs and central systems, validating the impact of 5G in reducing delays.

Reliability: Assessing the ability of AMRs to operate continuously and predictably under different network and workload conditions is essential for the hospital environment. To this end, continuous monitoring systems were implemented using the Prometheus tool. This approach made it possible to identify bottlenecks and analyze performance patterns, ensuring stable robot operation even in adverse situations.

Execution Time: Represents the time required for the AMR to complete a task, from the initial command to completion. This metric is essential to ensure that robots not only operate quickly, but also consistently. The AMR's operating system has been configured to automatically record execution time, allowing for real-time adjustments to optimize its efficiency.

Throughput: This refers to the amount of data that can be transmitted between the AMR and the cloud in a given time interval. This metric is critical for applications that require the transmission of large volumes of data, such as navigation sensors and real-time monitoring. Once again, Iperf was used to test the capacity of the 5G network, guaranteeing reliable, high-speed communication.

3.2 Implementing the Methodology

The tests were conducted in a simulated environment that reflects the conditions of a modern hospital, including network interference, multiple connected devices and workload variations. For each metric, specific scenarios were defined that simulate real challenges faced by AMRs.

1. **Latency and Throughput:** Test scenarios included different distances between the AMR and the 5G access point, as well as simulations with high data traffic. These tests helped validate 5G's promise of high bandwidth and low latency under load conditions.
2. **Response speed:** Critical commands were simulated, such as route changes and response to unforeseen obstacles. Wireshark recorded the communication times, allowing adjustments to be made to improve efficiency.
3. **Reliability:** The performance of the AMRs was monitored continuously with Prometheus, allowing communication failures or performance drops to be identified before they became critical.
4. **Execution Time:** AMR tasks were timed to ensure consistency in operation times, assessing the impact of internal processing and network conditions.

3.4 Tools used

The choice of tools was strategic to ensure the accuracy and robustness of the tests. **Iperf** was essential for measuring latency and throughput, providing a detailed view of network performance. **Wireshark**, with its ability to analyze packets in real time, made it possible to evaluate the response speed of the AMRs. **Prometheus** was used to continuously monitor the robots, identifying anomalies and adjusting parameters to improve reliability.

In addition, the AMRs' operating system played a crucial role, automatically recording execution times and providing detailed reports for analysis. Integration with visualization platforms such as Grafana made it easier to interpret the data and make decisions based on metrics.

Connection to the 5G Network

The 5G network was the central element of this methodology, offering the necessary infrastructure to guarantee low latency, high communication speeds and support for multiple connected devices. The tests showed that 5G is capable of meeting the demands of AMRs in hospital environments, enabling efficient automation and improving the quality of care.

Conclusion

The methodological proposal presented in this study provides a robust approach to evaluating the integration of AMRs with LiDAR and 5G technology. The practical application of the tests in a simulated environment reflects real challenges, ensuring that the results are directly applicable to implementation in hospitals. The use of specific metrics and advanced tools allows for a detailed analysis of the performance of AMRs, contributing to their optimization and large-scale expansion. This methodology lays a solid foundation for future research and the advancement of hospital automation.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The experiments carried out in this research were designed to evaluate the performance of Autonomous Mobile Robots (AMRs) integrated with 5G and WiFi networks in hospital environments, considering the methodological parameters defined. The analysis focused on the latency, transfer rate, reaction time and reliability of the communication systems, using specific tools for data collection and processing.

4.1 Network latency

Latency, defined as the time required for a data packet to travel between the server and the AMR, was measured using the Round-Trip Time (RTT) formula. Ten consecutive tests were carried out, each sending 1000 packets of 128 bytes at an interval of 250 ms. The test environment included the edge server and the AMR on-board computer, both operating with 5G and WiFi networks. The graph in Figure 1 shows these results.

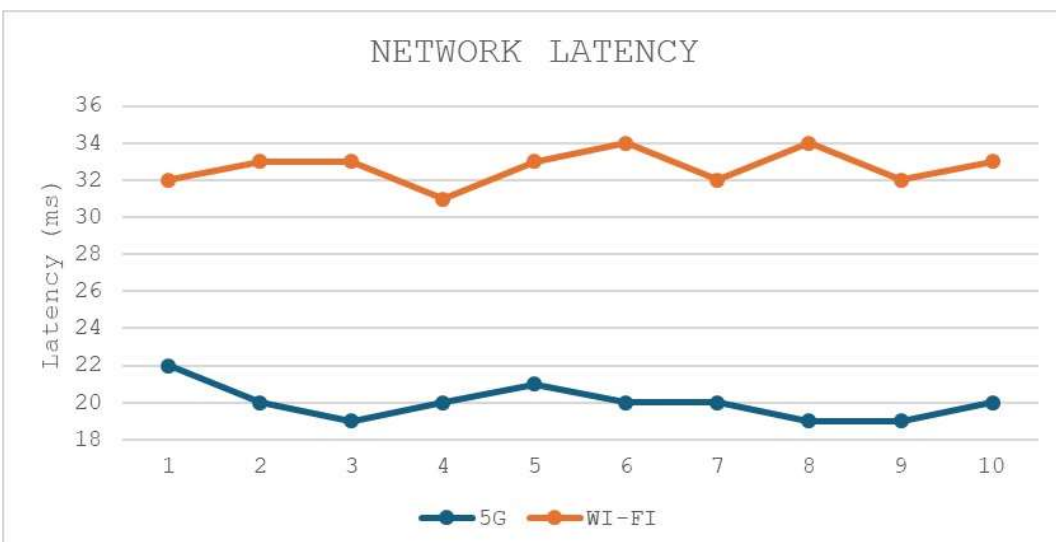

Figure 1 - Measured network latency results (ms), comparing 5G and WI-FI networks.

Results for 5G Network:

- **Average:** 19.92 ms
- **Median:** 19.91 ms
- **Standard Deviation:** 0.176 ms

Results for WiFi network:

- **Average:** 32.65 ms
- **Median:** 32.64 ms
- **Standard Deviation:** 0.89 ms

The analysis revealed that the 5G network offers significantly lower and more consistent latency compared to WiFi, with a coefficient of variation 3 times lower, highlighting its superiority for real-time applications such as navigation and mapping with the SLAM algorithm.

4.2 Transfer rate

The transfer rate, representing the amount of data exchanged between the server and the AMR per unit of time, was evaluated using the Iperf 3 tool. The experiment simulated high-demand scenarios, with 10 simultaneous flows and bandwidth limited to 100 Mbps. Figure 2 shows the results of the Throughput evaluation.

Figure 2 - Measured throughput results (mbps), comparing 5G and WI-FI networks.

Results for Uplink (Sent) in the 5G Network:

- **Average:** 95.12 Mbps
- **Standard Deviation:** 1.39 Mbps

Results for Uplink on the WiFi Network:

- **Average:** 46.58 Mbps
- **Standard Deviation:** 12.63 Mbps

Results for Downlink (Received) in the 5G Network:

- **Average:** 92.00 Mbps
- **Standard Deviation:** 1.04 Mbps

Results for Downlink in WiFi Network:

- **Average:** 41.72 Mbps
- **Standard Deviation:** 10.97 Mbps

The 5G network showed significantly higher transfer rates, with less variability, demonstrating greater stability and efficiency in supporting critical tasks, such as the transmission of maps generated by SLAM.

4.3 Reaction time

The system's reaction time was measured considering the interval between receiving an external stimulus, generated by a LIDAR sensor, and the AMR system sending the first speed command. The analysis compared 5G and WiFi networks. Figure 3 shows the Reaction Time results (ms), comparing %G and WI-FI networks.

Results for 5G Network:

- **Average:** 0.847 ms
- **Standard Deviation:** 0.046 ms

Results for WiFi network:

- **Average:** 0.841 ms
- **Standard Deviation:** 0.071 ms

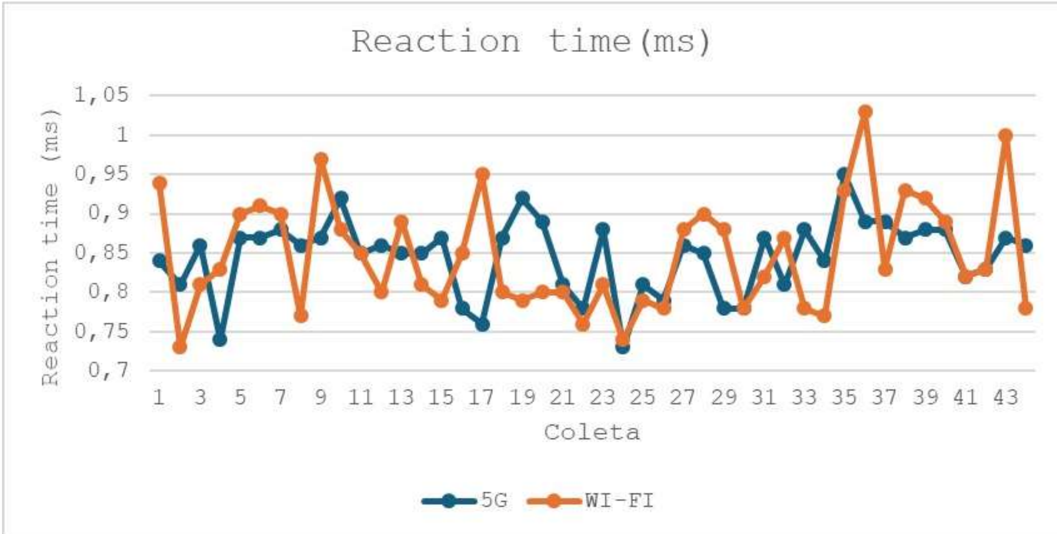

Figure 3 - Results of Reaction Time measurements (ms), comparing 5G and WI-FI networks.

Both networks showed reaction times below 1 ms, but the 5G network showed greater consistency, reflected in the lower standard deviation. This consistency is critical to avoid failures in navigation and collision avoidance tasks.

4.4 Reliability and Consistency

To assess reliability, Prometheus was used for continuous monitoring, focusing on the stability of AMR operations under different network conditions. The analysis indicated that the 5G network maintained a more predictable performance, even under high workloads.

5. DISCUSSION OF RESULTS

The experimental results presented in this study clearly demonstrate the benefits of integrating AMRs with 5G networks and LiDAR sensors in hospital environments. However, the challenges and implications of this integration need to be discussed in depth to provide a complete picture of feasibility and future opportunities.

Technical Superiority of the 5G Network

The tests confirmed the superiority of the 5G network in terms of latency, throughput and performance consistency. 5G's ability to operate with latencies below 1 ms is a significant differentiator for applications that require real-time responses, such as autonomous navigation and collision avoidance. In addition, the high transfer rate allows for the efficient transmission of data generated by LiDAR sensors, such as three-dimensional maps and obstacle information. This efficiency is critical in hospital environments, where delays can compromise the safety and effectiveness of operations.

On the other hand, the stability offered by the 5G network is particularly relevant in high-demand scenarios, where multiple devices need to operate simultaneously. The results indicate that while WiFi shows greater variability, especially under load, 5G maintains consistent performance. This characteristic makes 5G more suitable for supporting advanced automation in hospitals, especially in critical situations.

Practical Limitations of Implementation

Despite the technical advantages, implementing 5G networks in hospital environments presents significant challenges. The infrastructure needed to support 5G Indoor, such as dedicated PicoCell antennas and Network Core, requires substantial investment and rigorous planning. In addition, reliable coverage in critical areas of the hospital must be guaranteed to avoid communication failures.

Another challenge is interoperability. For AMRs to operate effectively, LiDAR sensors, central control systems and network infrastructure need to be perfectly synchronized. This requires clear integration standards and exhaustive testing to identify and resolve possible incompatibilities.

Data Security and Privacy

The adoption of 5G networks in hospital environments also raises cybersecurity concerns. The transmission of sensitive data, such as patient information and operational records, must be protected against unauthorized access. Strategies such as advanced encryption, multi-factor authentication and continuous network monitoring are indispensable for guaranteeing data integrity and confidentiality. In addition, the creation of robust security policies and regular training for technical staff are essential to mitigate risks.

Impact on Hospital Workflow

The introduction of AMRs integrated with 5G and LiDAR has the potential to profoundly transform the workflow in hospitals. By automating routine tasks such as transporting medicines and laboratory samples, these robots can free up healthcare professionals to focus on activities that require clinical expertise. This redistribution of tasks can result in a more efficient and safer working environment, reducing the risk of cross-contamination and improving the quality of patient care.

However, this transformation requires organizational restructuring. Hospital managers need to carefully plan how AMRs will be integrated into existing processes, considering factors such as maintenance, training and adapting professionals to the new technologies. Future studies should explore strategies to facilitate this transition and maximize the benefits of automation.

Scalability Potential and Global Adoption

The results of this study suggest that the integration of AMRs with LiDAR and 5G technology can be extended to areas other than hospitals, such as pharmaceutical distribution centers and home healthcare environments. However, the scalability of this solution depends on advances in the affordability of the technologies involved. Lower-cost LiDAR sensors and more accessible 5G networks are crucial to expanding the use of these systems in different contexts.

Future recommendations

Based on the challenges identified, some recommendations can be made for future research and practical implementation:

1. **Explore Infrastructure Alternatives:** Investigate the use of hybrid networks, combining 5G with high-density WiFi, to reduce costs and improve coverage in hospital environments.
2. **Focus on Interoperability Protocols:** Develop universal standards for integrating AMRs, sensors and 5G networks, facilitating implementation in different contexts.
3. **Developing Scalable Solutions:** Designing more affordable and compact LiDAR sensors, without compromising accuracy and reliability, to expand their use in critical applications.
4. **Cost-Benefit Studies:** Carry out detailed economic analyses to assess the return on investment in AMRs integrated with 5G and LiDAR, considering different sizes and types of hospitals.

Although this study has demonstrated the technical feasibility of integrating AMRs, LiDAR and 5G, the practical implementation of these technologies requires a multidisciplinary approach. From infrastructure issues to security concerns and organizational adaptation, there is a way to go before these solutions become standard in hospital environments. Even so, the results obtained here pave the way for future innovations, highlighting the transformative potential of these technologies in the healthcare sector.

6. CONCLUSION

This study explored the integration of Autonomous Mobile Robots (AMRs) with LiDAR sensors and 5G connectivity in hospital environments, analyzing their performance in critical metrics such as latency, throughput, reliability and reaction time. The results obtained demonstrated the transformative potential of these technologies in the healthcare sector, while highlighting significant challenges that need to be overcome for their practical implementation.

Advances and Contributions

The experiments conducted confirmed that 5G connectivity, compared to WiFi, offers substantial advantages in terms of stability and performance. Significantly lower latency and consistent reaction times make 5G the ideal choice for real-time applications such as autonomous navigation and the transportation of critical materials in hospitals. In addition, the high throughput seen on the 5G network allows AMRs to process and transmit complex LiDAR sensor data efficiently, ensuring accurate mapping and rapid responses to changes in the environment.

These advances not only strengthen the technical feasibility of this integration, but also point to opportunities for operational restructuring in hospital environments. Automating repetitive tasks with AMRs can free up human resources for activities that require clinical skills, improving overall efficiency and safety in patient care. The study thus contributes directly to advancing knowledge about the application of Industry 4.0 technologies in the healthcare sector.

Study limitations

Despite the promising results, this study has some limitations that need to be considered. Firstly, the experiments were carried out in a simulated environment, which, although it reproduces real conditions, may not fully capture the complexities of hospitals. Factors such as signal interference, density of connected devices and specific architectural configurations can impact the performance of AMRs and 5G networks in real scenarios.

In addition, issues of interoperability and cybersecurity were mainly addressed in terms of technical feasibility, but no specific solutions were implemented within the scope of this study. The protection of sensitive data and integration with existing hospital systems represent challenges that require more detailed investigations and multidisciplinary approaches.

Impact and Relevance for the Health Sector

The potential impact of this integration on the healthcare sector is significant. AMRs equipped with LiDAR sensors and 5G connectivity can revolutionize hospital logistics, providing greater agility and precision in the transport of medicines, laboratory samples and medical equipment. This automation not only reduces the risk of errors and delays, but also contributes to creating a safer environment by minimizing healthcare workers' exposure to contaminated areas.

In addition, the successful implementation of these technologies can serve as a model for other healthcare applications, such as remote patient monitoring, telemedicine and robotic assistance in clinical procedures. The development of integrated solutions that combine automation, advanced connectivity and artificial intelligence could set a new standard for efficiency and innovation in the sector.

Future recommendations

To maximize the impact and applicability of this research, some recommendations can be made:

1. **Studies in Real Environments:** Carry out experiments in operational hospitals to validate the findings of this study in more complex and dynamic scenarios.
2. **Exploring Hybrid Networks:** Investigating the integration of 5G networks with other communication technologies, such as high-density WiFi, to create more affordable and robust solutions.
3. **Deepening Cybersecurity:** Developing and implementing specific security protocols to protect sensitive data in healthcare applications.
4. **Economic and Feasibility Studies:** Evaluate the cost-benefit of implementing AMRs integrated with LiDAR and 5G, considering different scales and hospital contexts.

5. **Organizational Adaptation:** Investigate strategies to facilitate the adaptation of healthcare professionals to automation, including training and adjustments to workflows.

7. FINAL REFLECTION

The results obtained in this study show that the integration of AMRs, LiDAR sensors and 5G connectivity is a technologically viable and highly promising solution for hospital automation. However, the full realization of this potential requires coordinated efforts to overcome technical, economic and organizational challenges. Based on the findings presented, it is believed that this research contributes significantly to the advancement of knowledge in the field of healthcare automation and establishes a solid foundation for the development of future applications that will positively transform the sector.

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REFERENCES CITED.

CHEN, Simin et al. The Role of 5G in Healthcare. *IEEE Communications Magazine*, v. 58, n. 2, p. 84-90, 2020.

CHOE, J.; CHO, H.; CHUNG, Y. Performance Verification of Autonomous Driving LiDAR Sensors under Rainfall Conditions in Darkroom. *Sensors*, v. 24, n. 1, p. 14, 2024. DOI: 10.3390/s24010014.

DELOITTE. HC signs partnership with ecosystem of companies to test 5G technology. Available at: https://www.deloitte.com/br/pt/about/press-room/opencare-5g.html. Accessed on: Dec. 1, 2024.

FAWOLE, O. A.; RAWAT, D. B. Recent Advances in 3D Object Detection for Self-Driving Vehicles: A Survey. *AI*, v. 5, n. 3, p. 1255-1285, 2024. DOI: 10.3390/ai5030061.

GIUFFRIDA, L.; MASERA, G.; MARTINA, M. A Survey of Automotive Radar and Lidar Signal Processing and Architectures. *Chips*, v. 2, n. 4, p. 243-261, 2023. DOI: 10.3390/chips2040015.

GUSTAVSSON, Ulf et al. Implementation Challenges and Opportunities in Beyond-5G and 6G Communication. *IEEE Journal of Microwaves*, v. 1, p. 86-100, 2021. DOI: 10.1109/JMW.2020.3034648.

JAIN, Hemant et al. 5G Network Slice for Digital Real-Time Healthcare System Powered by Network Data Analytics. *Internet of Things and Cyber-Physical Systems*, v. 1, 2021. DOI: 10.1016/j.iotcps.2021.12.001.

LEE, M. -H.; LIU, I. -H.; HUANG, H. -C.; LI, J. -S. Cyber Security in a 5G-Based Smart Healthcare Network: A Base Station Case Study. *Engineering Proceedings*, v. 55, n. 1, p. 50, 2023. DOI: 10.3390/engproc2023055050.

PARVEZ, Imtiaz et al. A Survey on Low Latency Towards 5G: RAN, Core Network and Caching Solutions. *IEEE Communications Surveys & Tutorials*, 2018.

SAHU, Vinay et al. Challenges and Opportunities of 5G Network: A Review of Research and Development. *American Journal of Electrical and Computer Engineering*, v. 8, p. 11-20, 2024. DOI: 10.11648/j.ajece.20240801.12.

SHAFI, Mansoor et al. 5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment and Practice. *IEEE Journal on Selected Areas in Communications*, v. PP, n. 1, p. 1-1, 2017. DOI: 10.1109/JSAC.2017.2692307.

SIDDIQI, M. A.; YU, H.; JOUNG, J. 5G Ultra-Reliable Low-Latency Communication Implementation Challenges and Operational Issues with IoT Devices. *Electronics*, v. 8, n. 9, p. 981, 2019. DOI: 10.3390/electronics8090981.

SUFYAN, A. et al. From 5G to Beyond 5G: A Comprehensive Survey of Wireless Network Evolution, Challenges, and Promising Technologies. *Electronics*, v. 12, n. 10, p. 2200, 2023. DOI: 10.3390/electronics12102200.