Development of Cloud Based Robotic Application for Search and Rescue Operations in Disaster Management

[1]Akhil Raj Gaius Yallamelli, [2]Gulbir Singh, [3]Shaik.Reshma, [4]Vijay Kumar

[1]Amazon Web Services Inc, Seattle, USA.

[2]Department of Computer Science and Engineering, Graphic Era Hill University, Haldwani Campus, Nainital, Uttarakhand, India.

[3]Department of CSE, Santhiram Engineering College, Nandyal, Andhra Pradesh, India.

[4]Department of Physics, Graphic Era Hill University, Dehradun; Adjunct Professor, Graphic Era Deemed to be University, Dehradun, Uttarakhand, India.

[1]akhilrajyallamelli@ieee.org, [2]gulbir.rkgit@gmail.com, [3]reshma.cse@srecnandyal.edu.in, [4]vijaykumar@gehu.ac.in

Abstract

The proposed approach involves the integration of cloud computing and robotics with deep learning techniques for providing innovative solutions for search and rescue operations. They help to provide adaptive solutions in complex environments. Cloud computing helps in data storage and processing through adopting real-time decision-making and integration with the rescue teams. The accumulation of deep learning techniques with robotic systems helps in obtaining the ability to adapt to dynamic environments. This helps the robot to analyze and interpret huge amounts of data which involves sensor data and images. This helps in the identification of potential hazards by optimizing the navigation routes. The cloud-based robotic architecture is used to achieve multiple robotic units to exchange information through a communication protocol. This novel approach provides diverse solutions for Search and Rescue (SAR) operations. They also provide remote monitoring and control which leads to managing the robot with a centralized platform. Deep learning models help to improve accuracy through an iterative process. The situational awareness of the robot is obtained using the collaboration of advanced sensors and communication devices. This helps in increasing the automatic decision-making process. This helps to function the robots in lower visibility environments. Thus, the proposed methodology helps in reducing the impact of the disaster.

Keywords: Cloud computing, Robotics, Deep learning techniques, Search and Rescue operations, Autonomous decision-making.

1. Introduction

Disaster management is defined as the process of planning, arranging and coordinating measures to prevent and respond to adverse impacts of natural and man-made disasters. This leads to a reduction in the loss of life and property. This helps in improving the overall resilience of the community and infrastructure. The identification and evaluation of the potential hazards are done through various preventive measures [1]. Coordination between various services is important for the prevention and mitigation of dynamic situations. This involves a multi-disciplinary approach. This involves various advanced techniques and tools to solve the problem in an easier way. This includes the Internet of Things with artificial intelligence and the robotic applications [2]. The Internet of Things helps to integrate various devices into an Internet platform to communicate with various applications. Various examples of these devices involve sensors, actuators and Radio-Frequency Identification (RFID) tags. They are largely used in various applications such as education, healthcare and disaster management [3]. The IoT systems are implemented through various sets of data obtained from sensors. This is proceeded with cloud computing techniques. Cloud computing is an innovative model for obtaining on-demand network access to a shared pool of configurable computing resources. It handles resources based on a predefined service model which involves Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS) [4]. Another important factor in the search and rescue (SAR) operations involves mobile robot teams.

This involves cameras, infrared cameras, LiDAR and RADAR. This helps to generate 3D maps. Operating robots are used in situations with fire and smoke accidents where the GPS cannot able to activate [5]. The aid of artificial intelligence (AI) and computer vision plays an important role in SAR operations [6]. They help in the development of robots in various diverse platforms. Robotics provided various advancements in the past decades. They help in various applications and help to provide the solution for various real-world problems. The robots used in previous applications involve single robot which lacks in various hardware and performance constraints [7]. To overcome these issues, networking robotics are largely used in ongoing applications. This is referred to as the network of robots that are connected with both wired and wireless communication systems. Networked robots are used to overcome the constraints of standalone robots. The various robotic design involves Unmanned Aerial Vehicles (UAVs), Unmanned Ground vehicles (UGVs) and snake robots [8]. These developments and innovations must have a balance between innovation and regulatory frameworks. The proposed work focuses on the various constraints of robotic SAR operations. The various phases of emergency management involve mitigation, preparedness, response and recovery [10]. Thus, these robotic systems provide various advantages in disaster management system. They fit into various diverse places where humans can be unable to reach and rescue. The robotic systems are used for large-scale rescue operations whereas the drones are used for small-scale rescue operations.

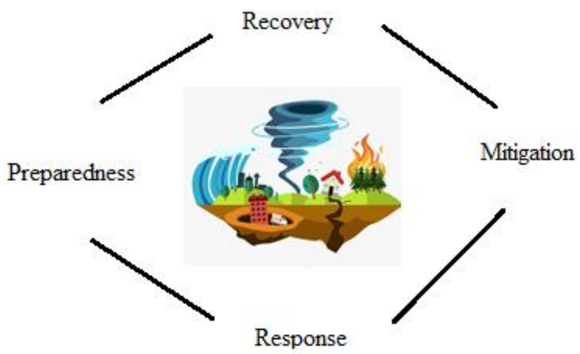

Figure 1. Four stages in emergency management

Figure 1 demonstrates the various stages involved in emergency management.

2. Proposed system

Disaster management is classified into four phases. Each stage involves various activists such as authorities, civilians, responders and advanced technology. The authorities play an important role in handling the situation through providing funding and regulatory frameworks. During the calamity, the first responders are used to handling complex situations using cloud robotics. The teleoperated robots are used to provide the rescue team with information about harsh environments. This also involves the haptic technology. These robots are designed to have higher mobility and robustness similar to a biological snake. They perform as a multi-agent system which includes various functions such as task sharing and distributed computing. They help to overcome the constraints in the existing robots. The snake robots are a combination of various drones and UGVs. Multiple actuators are necessary for the snake robot locomotion.

Thus, the development of a robot based on the biological characteristics of the snake helps in attaining a robust structure. Batteries and power cables are used as a source for robots. The locomotion phase is achieved using various levels of controllers. They are adapted to dynamic situations through the aid of deep learning techniques. These robots also help in providing food and basic needs to the trapped survivors in critical environments. This is achieved through the integration of locomotion and grasping. They help in updating the conditions of the rescuers through communication protocols. This involves the sensors and cameras attached to the robots. This helps in the identification of potential threats through providing informed decisions.

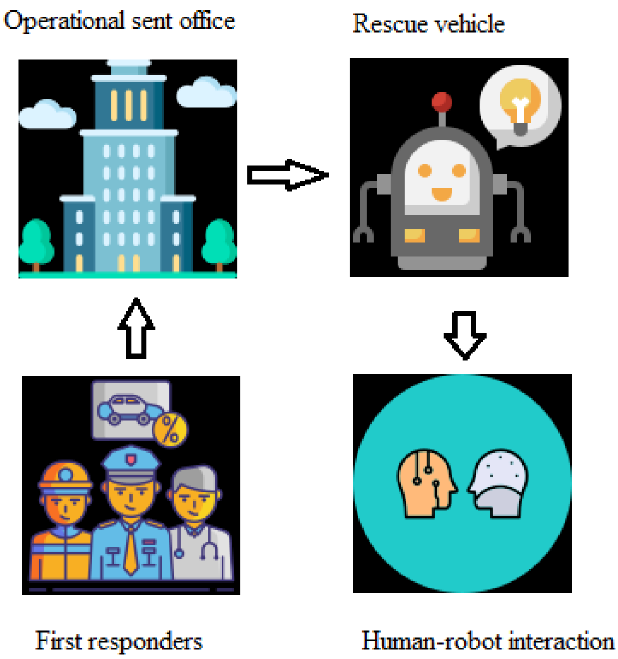

Figure 2. Various stages in the proposed system

Figure 2 represents the various stages in the proposed system in the SAR operations.

3. Role of the cloud in robotic Applications for SAR operations

Cloud robotics is defined as the automation system that is integrated with cloud infrastructure with various data for implementation and functioning. This involves sensing, memory and computation processes. The cloud robotics helps in obtaining increased storage space with speed. They are used for object recognition, speech recognition and computer vision. In simultaneous localization and mapping (SLAM), the robot itself cannot able to give rise to huge amounts of information [11]. Thus, cloud enables robots is used to huge amounts of information for further utilization.

They also help to access big data which involves global maps and object models [12]. They are used to solve the computational task through information sharing. They help to extract human knowledge through crowdsourcing. The various cloud computing services in recent period involves Amazon Web Services, Elastic Compute Cloud, Google Compute Engine and Microsoft Azure [13]. This integration provides an evolutionary phase with robotics that requires a specialized framework. The architecture of the cloud robotics is composed of two important parameters such as cloud infrastructure and bottom facility. The bottom facilities involve various kinds of robots such as unmanned ground vehicles, aerial robots and automated machinery. The cloud infrastructure is composed of very high-level performance and proxy servers. They include a huge database that can able to support the complex computation process [14]. The most familiar cloud robotics framework involves C2TAM.

They are developed for tracking and mapping processes. It provides a visual SLAM system dependent on the distributed network system. Since the onboard computers on the robot are relieved from various computations by providing internet connectivity [15]. This system can have the ability to access the map database. The stored maps can be used for other robots for vital applications. When overlap is found, the various robots can estimate the individual maps and integrate them together.

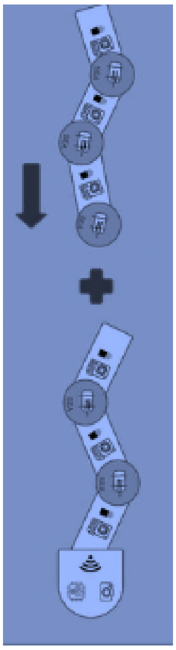

Figure 3. Structure of snake robots

Figure 3 demonstrates the structure of snake robots. To obtain standard applications in robotics technology, Rosbridge was developed. This is a simpler structural form with socket based programmatic access to the robotic interface through ROC [16]. This is done through Javascript. Rosjs is an infrastructure to adopt web services for robotic applications. They help in the development of controllers. They help in the development of robotic applications in the web browser. Various web tools are developed to increase the performance of the system through transmitting higher bandwidth. These tools are compared with standard ROS modules for transforming subscriptions. The complex robotic applications for the end users are done using software product lines [17]. This involves solving problems related to architectural design parameters.

The integration of robotic services with internet connectivity is done using RSi Research Cloud (RSi-Cloud). It is termed as a standardized communication protocol. This helps in the integration of various service components. This is also referred to as Robot Service Network Protocol (RSNP) [18]. This is used to develop a distributed service framework. In dynamic environments with communication constraints, the survivable cloud multi-robot (SCMR) is used. This is developed through a virtual ad hoc network. The software and hardware robotic systems are virtualized using RoboWeb systems. They are based on Simple Object Access Protocol (SOAP). In this proposed work, the architecture is based on IaaS which helps to handle the computing process. The authentication for accessing the robotic applications is obtained using Elliptic Curve Cryptography (ECC). Thus, the integration of cloud infrastructure in robotics plays a significant role in diverse applications.

4. Methodology

The proposed system initializes a cloud infrastructure that uses an image acquisition system process to control the functioning of robots based on the dynamic scenarios. The important objective of the proposed system is to provide a Cloud Enabled Robotics System. The Robot Operating System (ROS) is used as a robotic platform [19]. The proposed system involves the development of DAvinCi PaaS for robotic cloud applications. This helps in the collection of information from robots through the aid of ROC.

After the collection of data, it is processed using the Hadoop system. This is the distributed system designed for processing and saving large amounts of data with higher scalability. This involves two important divisions such as the Hadoop Distributed File System (HDFS) and the MapReduce programming model. The HDFS file system is used to classify large files into smaller systems of blocks. They are distributed across the nodes in the Hadoop cluster. This helps to enhance parallel processing with fault tolerance. The reliability of the system is achieved using the replication of data across various nodes. The parallel processing is done using MapReduce. The computation process is classified into map and reduce. The map phase is used for processing the data and the reduce phase is used for the evaluation of the results. This helps in the effective processing of huge amounts of information in the network. This involves various tools which involves Apache Spark for memory data processing. Apache HBase is used for handling real-time NoSQL databases. The obtained results are then forwarded to the robotic applications.

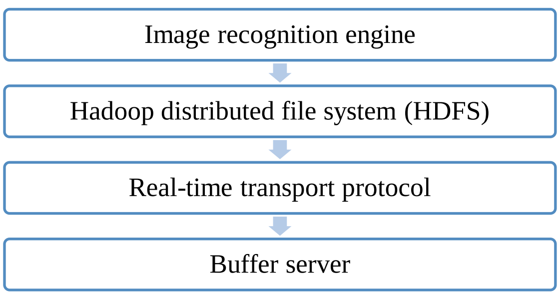

Figure 4. Development of cloud robot

Figure 4 demonstrates the development of cloud robots in visual platform.

1. Human-robot interaction

Robots are an important part of rescue operations. They are used for a wide range of applications which involve search, excavation, identification of victims and providing emergency medicines. Communication is an important constraint in the place of disaster [20]. In critical situations, humanoid robots are used to convey emotions through gaits. This helps in the designing of human-robot interaction. This is done using gait patterns through which the robots help to communicate with the victims. The hazardous situations are handled through gathering various information using sensors. They provide two-way communication for information exchange from disaster areas to the control centers to obtain effective SAR. They are based on teleoperation.

2. Snake robots

ACM R2 and ACM R3 are various forms of snake robots. They play a prominent role in search and rescue operations through their flexible performance parameters. These robots are highly flexible and designed to navigate in complex scenarios. This helps to access the collapsed buildings and harsh environments to save the victims. They are used for searching and visualizing the survivors. They serve as a valuable tool for accessing the damaged and affected victims.

3. Architectural design of snake robots

The snake robots are designed using a multi-joint system that helps to perform versatile movements. This helps in navigating with complex surrounding systems. They are integrated with sensors such as cameras, LiDAR and ultrasound sensors that help the sensors to obtain detailed information regarding the surrounding environments. Wireless communication is initiated for real-time data transfer between the snake robot and the control centre. The incorporation of edge computing helps in the reduction of latency in the decision-making techniques. Embedded systems and GPU accelerators are used in the onboard processing phase. Embedded system is the integration of hardware and software systems used for data processing techniques.

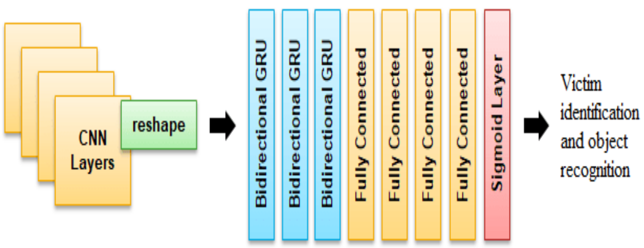

Figure 5. Role of DL in SAR operations

Figure 5 represents the role of deep learning in the SAR operations. The incorporation of GPU is done for improved processing of the deep learning techniques. The deep learning techniques are used for a wide range of applications which include object recognition, navigation and human detection.

The integration of cloud systems with deep learning provides efficient storage of data. This helps in obtaining relevant sources for distributed training of complex neural network models. These data are transferred to the centralized cloud servers based on multiple robots. The deep learning models are used to train and provide predictions in complex situations.

Deep learning helps in obtaining real-time processing and inference. The heavy computations are processed using the cloud servers. This helps the robots to perform complex tasks through adopting offloading computations to the cloud. These robots lead to continuous learning that helps the model to update with newer scenarios.

Deep learning model have the ability to change in dynamic situations and provides optimum solutions. This helps the collaborative robots in sharing information through the cloud systems. The deep learning is used to analyze and interpret the data from diverse robots. The human commands are understood through the aid of Natural language processing (NLP). They also involve facial and emotion recognition to analyze the situation of victims. Graphic user interface and augmented reality are used as user interface modules. Numerous security measures are implemented for data privacy. This includes data encryption and authentication processes. Adaptive learning plays a significant role in the development of robots with various performance metrics.

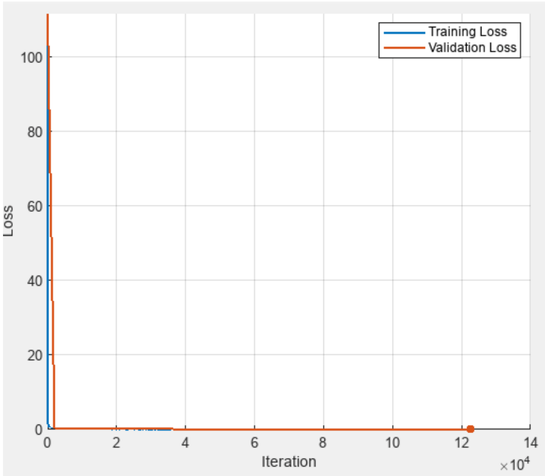

Figure 6. Numerous iterations involved in DL

Figure 6 demonstrates the various iterations involved in deep learning techniques to obtain optimum solutions.

4. Regulatory compliance

Regulatory compliance is defined as the robots must meet various standards such as safety standards, product safety regulations, FDA approval, cybersecurity compliance and intellectual property compliance.

5. Simulation result

The proposed system is implemented in MATLAB to evaluate the performance metrics as shown in figure 7.

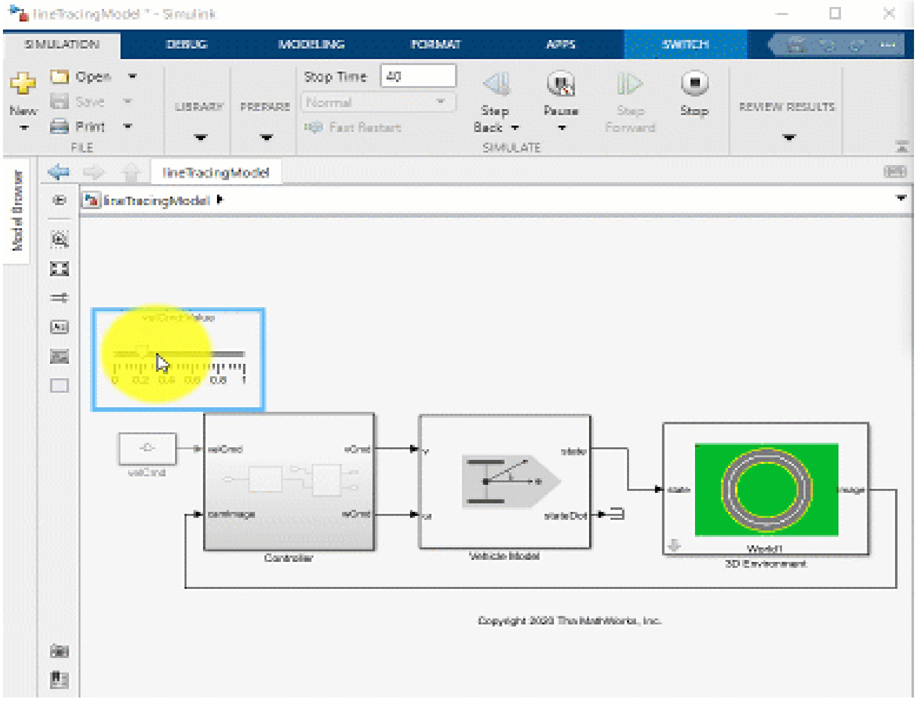

Figure 7. Performance analysis

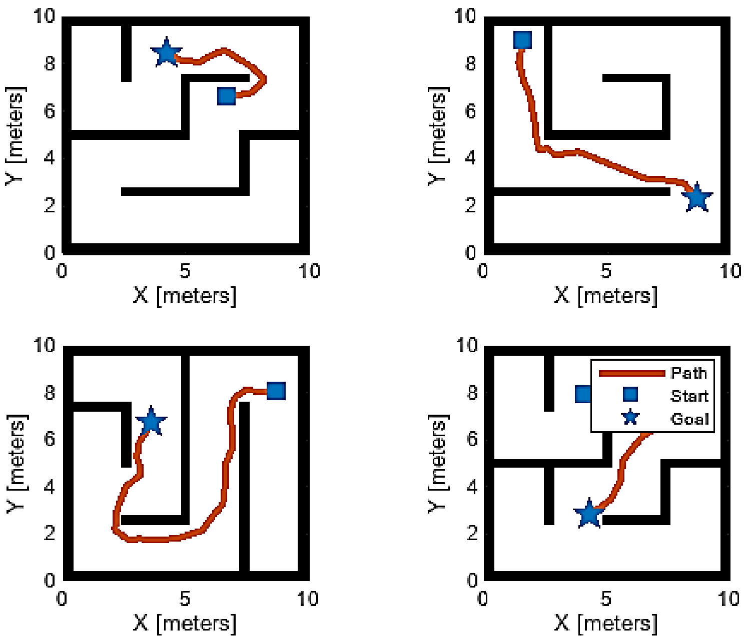

Figure 8. Detection of victims using robots

Figure 8 demonstrates the various paths in the detection of victims and objects through snake robots.

Way forward:

The applications of cloud robots are diverse in nature and involve various advantages as listed below.

- The cloud robots have the ability to offload heavy computational tasks to powerful cloud servers. This helps to perform complex calculations and simulations. This helps the robots to handle complex tasks.
- Cloud robots access a large amount of information storage in the cloud. This helps in generating sensor data with higher-resolution images. The storage of data helps in efficient data management.
- The role of deep learning helps in continuous improvement. This helps in the gradual increase of performance through analyzing the obtained real-time data. The cloud provides a scalable platform for the deployment of deep learning techniques.
- Software updates and security patches are obtained using real time updates provided by the cloud. They also help in easy sharing of information through enhanced communication systems. This helps in improving the overall efficiency of the systems.
- Cloud system helps in remote monitoring and control which helps in solving various troubleshooting issues. This infrastructure provides scalability in dynamic environments with improved access to information across globally. They tend to provide faster development cycles.

6. Conclusion

The development of a cloud-based robotic application for search and rescue operations is a significant advancement in providing innovative solutions for disaster management. The integration of cloud computing with robotic technologies increases efficiency and reliability in rescue missions during the most complicated situations. This helps in obtaining automatic decision-making techniques in dynamic environments. The cloud computing provides a centralized platform for data storage and analysis. This helps to maintain coordination between various teams involved in the search and rescue operations. The scalability of cloud computing techniques helps in enhancing the data volumes and integrating with the network of robotic devices. These techniques help to optimize the overall disaster response. Thus, the proposed cloud-based application helps improve accessibility of the dynamic situations.

References

1. Mehmood, S., & Qiao, B. (2021). 2D SLAM and Path Planning for Indoor Search and Rescue Using Multiple Mobile Robots. International Journal of Modern Research in Engineering and Technology (IJMRET) Www.Ijmret.Org, 6(4).
2. Staudinger, E., Zhang, S., Pohlmann, R., & Dammann, A. (2021). The Role of Time in a Robotic Swarm: A Joint View on Communications, Localization, and Sensing. IEEE Communications Magazine, 59(2). https://doi.org/10.1109/MCOM.001.2000593
3. Vanderhorst, H. R., Suresh, S., Renukappa, S., & Heesom, D. (2021). Strategic framework of Unmanned Aerial Systems integration in the disaster management public organisations of the Dominican Republic. International Journal of Disaster Risk Reduction, 56. https://doi.org/10.1016/j.ijdrr.2021.102088
4. Afrin, M., Jin, J., Rahman, A., Rahman, A., Wan, J., & Hossain, E. (2021). Resource Allocation and Service Provisioning in Multi-Agent Cloud Robotics: A Comprehensive Survey. In IEEE Communications Surveys and Tutorials (Vol. 23, Issue 2). https://doi.org/10.1109/COMST.2021.3061435

5. Freeman, M. R., Kashani, M. M., & Vardanega, P. J. (2021). Aerial robotic technologies for civil engineering: Established and emerging practice. In Journal of Unmanned Vehicle Systems (Vol. 9, Issue 2). https://doi.org/10.1139/juvs-2020-0019
6. Habibi Rad, M., Mojtahedi, M., & Ostwald, M. J. (2021). Industry 4.0, disaster risk management and infrastructure resilience: a systematic review and bibliometric analysis. In Buildings (Vol. 11, Issue 9). https://doi.org/10.3390/buildings11090411
7. Abid, S. K., Sulaiman, N., Chan, S. W., Nazir, U., Abid, M., Han, H., Ariza-Montes, A., & Vega-Muñoz, A. (2021). Toward an integrated disaster management approach: How artificial intelligence can boost disaster management. In Sustainability (Switzerland) (Vol. 13, Issue 22). https://doi.org/10.3390/su132212560
8. Lessi, C., Agapiou, G., Sophocleous, M., Chochliouros, I. P., Qiu, R., & Androulidakis, S. (2022). The Use of Robotics in Critical Use Cases: The 5G-ERA Project Solution. IFIP Advances in Information and Communication Technology, 652 IFIP. https://doi.org/10.1007/978-3-031-08341-9_13
9. Raparla, K., Modh, S., & Pandey, N. (2022). Emerging Technologies: A Paradigm Shift in SCM Application in Dairy Supply Chain 4.0. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4123896
10. Yamauchi, Y., Ambe, Y., Nagano, H., Konyo, M., Bando, Y., Ito, E., Arnold, S., Yamazaki, K., Itoyama, K., Okatani, T., Okuno, H. G., & Tadokoro, S. (2022). Development of a continuum robot enhanced with distributed sensors for search and rescue. ROBOMECH Journal, 9(1). https://doi.org/10.1186/s40648-022-00223-x
11. Staudinger, E., Pöhlmann, R., Dammann, A., & Zhang, S. (2023). Limits on Cooperative Positioning for a Robotic Swarm with Time of Flight Ranging over Two-Ray Ground Reflection Channel. Electronics (Switzerland), 12(9). https://doi.org/10.3390/electronics12092139
12. Häusermann, D., Bodry, S., Wiesemüller, F., Miriyev, A., Siegrist, S., Fu, F., Gaan, S., Koebel, M. M., Malfait, W. J., Zhao, S., & Kovač, M. (2023). FireDrone: Multi-Environment Thermally Agnostic Aerial Robot. Advanced Intelligent Systems, 5(9). https://doi.org/10.1002/aisy.202300101
13. Gupta, K., Singh, A., Yeduri, S. R., Srinivas, M. B., & Cenkeramaddi, L. R. (2023). Hand gestures recognition using edge computing system based on vision transformer and lightweight CNN. Journal of Ambient Intelligence and Humanized Computing, 14(3). https://doi.org/10.1007/s12652-022-04506-4
14. Thakur, A., Sahoo, S., Mukherjee, A., & Halder, R. (2023). Making Robotic Swarms Trustful: A Blockchain-Based Perspective. Journal of Computing and Information Science in Engineering, 23(6). https://doi.org/10.1115/1.4062326
15. Li, W., Zhang, X., Huang, B., Chen, Y., Zhang, R., & Balamurugan, S. (2022). Research on the Control Method of Unmanned Helicopter Under the Background of Artificial Intelligence. Journal of Interconnection Networks, 22. https://doi.org/10.1142/S0219265921430192
16. Wu, M. (2023). Robotics Applications in Natural Hazards. Highlights in Science, Engineering and Technology, 43. https://doi.org/10.54097/hset.v43i.7429
17. Kirubakaran, B., & Hosek, J. (2023). Optimizing Tethered UAV Deployment for On-Demand Connectivity in Disaster Scenarios. IEEE Vehicular Technology Conference, 2023-June. https://doi.org/10.1109/VTC2023-Spring57618.2023.10199492
18. G.V Chalapathi Rao, Kandhyanam Mahesh, & Maheshwaram Shiva. (2023). Gradient Based Routing Protocol For Modular Robotics. International Journal of Engineering

Technology and Management Sciences, 7(3). https://doi.org/10.46647/ijetms.2023.v07i03.030
19. Matukumalli, V., Naga Sasidhar Maddi, S., Krishna Angirekula, K., Reddy Pulicherla, V., Senthil kumar, A. M., Maridurai, T., … Kasinathan, D. (2021). Augment reality chatbot using cloud. Materials Today: Proceedings, 46, 4254–4257. doi:10.1016/j.matpr.2021.03.058.
20. Enireddy, V., Finney Daniel shadrach, S., Shobha rani, P., Anitha, R., Vallinayagam, S., Maridurai, T., … Balakrishnan, E. (2021). Prediction of human diseases using optimized clustering techniques. Materials Today: Proceedings, 46, 4258–4264. doi:10.1016/j.matpr.2021.03.068.