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Review

Remote Big Data Management Tools, Sensing and Computing Technologies, and Visual Perception and Environment Mapping Algorithms in the Internet of Robotic Things

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Abstract: The purpose of our systematic review was to inspect the recently published research on Internet of Robotic Things (IoRT) and harmonize the assimilations it articulates on remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms. The research problems were whether robotic manufacturing processes and industrial wireless sensor networks shape IoRT and lead to improved product quality by use of remote big data management tools, whether IoRT devices communicate autonomously regarding event modeling and forecasting by leveraging machine learning and clustering algorithms, sensing and computing technologies, and image processing tools, and whether smart connected objects, situational awareness algorithms, and edge computing technologies configure IoRT systems and cloud robotics in relation to distributed task coordination through visual perception and environment mapping algorithms. A Shiny app was harnessed for Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines to configure the flow diagram integrating evidence-based gathered and processed data (the search outcomes and screening procedures). A quantitative literature review of ProQuest, Scopus, and the Web of Science databases was carried out throughout June and October 2022, with search terms including "Internet of Robotic Things" + "remote big data management tools", "sensing and computing technologies", and "visual perception and environment mapping algorithms". Artificial intelligence and intelligent workflows by use of AMSTAR (Assessing the Methodological Quality of Systematic Reviews), Dedoose, DistillerSR, and SRDR (Systematic Review Data Repository) have been deployed as data extraction tools for literature collection, screening, and evaluation, for document flow monitoring, for inspecting qualitative and mixed methods research, and for establishing robust outcomes and correlations. For bibliometric mapping by use of data visualization, Dimensions AI was leveraged and with regards to layout algorithms, VOSviewer was harnessed.

Keywords: Internet of Robotic Things; remote big data management tools; sensing and computing technologies; visual perception and environment mapping algorithms

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1. Introduction

Internet of Robotic Things (IoRT) systems carry out assigned tasks through multipurpose environment monitoring systems, deep learning algorithms, and trajectory tracking tools [1–4] in relation to mobile control, coordinated operation, movement process, and performance evaluation. Cognitive artificial intelligence, wireless sensor and actuator networks, and remote big data management tools [5–8] are leveraged in object detection and recognition across remote and synthetic simulation environments. Autonomous cognitive systems enable process monitoring and diagnosis of production line management in intelligent connectivity infrastructures [9–12], considerably improving productivity. Cloud computing technologies, image recognition and ambient intelligence tools, and context awareness algorithms [13–16] can configure trajectory paths and detect events by continuous process monitoring and data collection. Sensor data fusion and analysis can be attained by dynamic actuators and environment mapping algorithms [17–20] as it pertains to monitoring events, controlling and manipulating objects, planning paths, and obstacle avoidance. Data acquisition and signal processing tools, convolutional neural networks, and obstacle avoidance algorithms [21–24] enable image and speech recognition processes. Computation-enabled robotic devices control and monitor connected objects and sensor networks [25–28] by use of computer vision and machine learning algorithms, artificial neural networks, and deep reinforcement learning tools. Data fusion and cloud computing technologies assist autonomous robotic systems through localization accuracy [29–32] with regards to multiple sound sources across ambient sensing environments and distributed sensor networks. Robotic knowledge sharing and computation task cooperation [33–36] require real-time complex data processing, motion coordination, and smart sensor devices. Image recognition algorithms and environment perception sensors [37–40] assist mobile autonomous robots in dynamic manufacturing environments.

Cloud computing machines, machine learning and remote sensing algorithms, and cyber-physical production systems [41–44] facilitate data transfer and object manipulation across intelligent simulation environments and smart factories [45–48] by integrating embedded IoRT-based sensors, thus optimizing productivity and efficiency. Data mining and context recognition tools enhance sensing and actuation capabilities of robotic networks [49–52] as autonomous agents. Smart devices, context aware systems, and artificial neural networks [53–56] further continuous sensing and contextual data monitoring [57–60] across the ambient environment and spatial surroundings. Robotic operating and autonomous control systems are pivotal in reconfigurable manufacturing processes [61–64] in Industry 4.0-based networked environments. Robot vision and navigation systems [65–68] harness sensor–actuator networks, semantic technologies, and cloud-based object tracking tools [69–72] in relation to predictive performance of navigation and mapping tasks. Massive computation capabilities, intelligent data processing tools, and plant maintenance scheduling [73–76] assist mobile robots and virtual machines in making autonomous decisions. Multi-agent and decision support systems, computer vision algorithms, and machine learning techniques [77–80] are pivotal in robotic comprehension of the surrounding environment. Cloud computing technologies and IoRT sensors [81–84] enhance decisional autonomy of robot swarms by tracking, monitoring, and manipulating objects.

The purpose of our systematic review was to inspect the recently published research on IoRT and harmonize the assimilations it articulates on ambient intelligence and context awareness tools [85–88], blockchain technologies [89–92], and path planning and computer vision algorithms [93–96]. Data gathered continuously by perception devices [97–100] across industrial robot systems and cloud computing infrastructure [101–104] diagnose and handle faults by use of visual perception and environment mapping algorithms. The actuality and originality of this research are articulated by addressing how IoRT systems leverage environment monitoring mechanisms [105–108] to aggregate sensor data and map networked processes [109–112] by use of decision and control algorithms. Robotic coordination mechanisms and cooperative actions [113–116] optimize object perception and tracking [117–120] in dynamic unknown environments. Our particular contribution is to clarify how data mining, fusion, and processing [121–124] assists sensor equipment through machine and deep learning algorithms. Visual perception and environment mapping algorithms, sensing and computing technologies, and deep neural networks [125–128] shape real-time 3D mapping of IoRT systems. Robotic navigation systems and virtual machines [129–132] can make autonomous decisions through remote big data management tools [133–135] in relation to collision-free motion and trajectory planning. Correspondence with published literature up to the present time comprise analyses on how blockchain technologies, cognitive decision-making algorithms, smart environment modeling and computational intelligence tools, and convolution neural networks [136–138] are instrumental in autonomous visual object detection [139–141] through decentralized data collection, transmission, and governance. The research problems concern whether IoRT systems can make decisions by captured image data [142–145] and object recognition processes [146–149], collaborative operation mechanisms [150–153], and multi-machine cooperation [154–156], completing assigned tasks flexibly [157–159].

Technical aspects covered by the inspected applied research include operations of IoRT-based context-aware systems in relation to distributed sensing units and 3D machine vision, based on data clustering and deep reinforcement learning algorithms, ambient intelligence and semantic sensor technologies, and object perception and manipulation tools in terms of process automation and coordination across smart robotic environments. As it will systematically be highlighted throughout the manuscript, in terms of taxonomy, IoRT systems and devices integrate cutting-edge technologies such as digital twin modeling, immersive extended reality, cloud and edge computing, distributed ledger, machine and deep learning, autonomous vehicle navigation, cyber-physical manufacturing, decision intelligence, visual and spatial analytics, and 3D virtual simulation.

Research Problem 1: Robotic manufacturing processes and industrial wireless sensor networks shape IoRT and lead to improved product quality by use of remote big data management tools.

Research Problem 2: IoRT devices communicate autonomously with regards to event modeling and forecasting by leveraging machine learning and clustering algorithms, sensing and computing technologies, and image processing tools.

Research Problem 3: Smart connected objects, situational awareness algorithms, and edge computing technologies configure IoRT systems and cloud robotics in relation to distributed task coordination through visual perception and environment mapping algorithms.

The manuscript is organized as follows: methodology (Section 2), remote big data management tools in IoRT (Section 3), sensing and computing technologies in IoRT (Section 4), visual perception and environment mapping algorithms in IoRT (Section 5), discussion (Section 6), conclusions (Section 7), specific contributions to the literature (Section 8), limitations and further directions of research (Section 9), and practical implications (Section 10).

2. Methodology

A Shiny app was harnessed for Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines to configure the flow diagram integrating evidence-based gathered and processed data (the search outcomes and screening procedures). A quantitative literature review of ProQuest, Scopus, and the Web of Science databases was carried out throughout June and October 2022, with search terms including "Internet of Robotic Things" + "remote big data management tools", "sensing and computing technologies", and "visual perception and environment mapping algorithms". As the inspected research was published between 2016 and 2022, only 404 sources conformed to the eligibility criteria. In total, 159 mainly empirical sources have been carefully chosen after eliminating out of scope full-text articles or without enough rigor or sufficient details (Tables 1 and 2). Artificial intelligence and intelligent workflows by use of AMSTAR (Assessing the Methodological Quality of Systematic Reviews), Dedoose, DistillerSR, and SRDR (Systematic Review Data Repository) have been deployed as data extraction tools for literature collection, screening, and evaluation, for document flow monitoring, and for inspecting qualitative and mixed methods research, and for establishing robust outcomes and correlations [160,161]. For bibliometric mapping by use of data visualization, Dimensions AI was leveraged and regarding layout algorithms, VOSviewer was harnessed (Figures 1–5).

Table 1. Topics and types of identified and selected scientific products.

Topic	Identified	Selected
Internet of Robotic Things and remote big data management tools	141	57
Internet of Robotic Things and sensing and computing technologies	137	53
Internet of Robotic Things and visual perception and environment mapping algorithms	126	49
Type of paper		
Original research	224	112
Review	88	47
Conference proceedings	67	0
Book	12	0
Editorial	13	0

Source: Processed by the authors. Some topics overlap.

Table 2. Synopsis of cumulative evidence concerning analyzed topics and descriptive outcomes (research findings).

Deep reinforcement learning and intelligent data processing tools, edge computing algorithms, and data analytics technologies articulate IoRT in relation to smart objects and devices. Robotic and sensor devices leverage IoT techniques and remote big data management tools across data fusion and context-aware systems in collaborative industrial environments.	[1–8]
IoRT leverages computer vision and data processing algorithms, image acquisition devices, and distributed intelligence tools for object recognition, manipulation, and control. Remote sensing technologies, context-aware systems, and data processing algorithms configure task scheduling and execution in smart IoRT environments.	[9–16]
Cloud computing technologies assist IoRT systems and virtual machines in terms of connectivity and scalability. IoRT devices leverage connected sensors, cloud computing and wireless technologies, and machine learning algorithms for real-time data collection as regards device control and diagnostics.	[17–24]
Collaborative autonomous multi-robot systems perform tasks in flexible industrial environments by use of image processing and data acquisition tools, computer vision and object recognition algorithms, and robotic guidance technologies. Object detection, localization, mapping, and avoidance through smart sensing tools model and design IoRT systems.	[25–32]
Context-aware and semantic IoRT systems monitor events, manipulate connected objects, and fuse sensor data by leveraging action modeling and distributed intelligence tools. IoRT-based monitored and mobile edge computing environments integrate sensor-based communication networks and fog computing technologies.	[33–40]
Blockchain-based IoRT systems and networks leverage cloud and computing technologies, data mining and remote sensing tools, and deep and machine learning algorithms in visual object detection and recognition. Mobile robot fleets collect data from unknown environments by use of actuated devices and motion control algorithms. IoRT devices and networked robotic systems exchange sensor data in relation to distributed computation resources changing contexts, and operating conditions.	[41–52]
Autonomous robots and mobile context awareness systems deploy sensor devices, machine learning algorithms, and convolutional neural networks as regards acoustic environment recognition. Connected IoRT mobile devices and collaborative robots gather and sense data from the surrounding environment across fog and cloud computing networks.	[53–60]

Table 2. *Cont.*

Image processing and visual modeling tools, edge surveillance and computing technologies, and deep neural networks optimize robotic agent behaviors in uncontrolled environments. Modeling and simulation tools, scheduling algorithms and decisions, and motion planning algorithms optimize cyber-physical and robotic systems.	[61–68]
Blockchain technologies and autonomous systems enhance IoRT device interconnection and networking. Cloud networked robotics and IoRT systems harness autonomous learning capabilities and deep learning techniques for object motion, detection, mapping, and tracking.	[69–76]
Autonomous cyber-physical systems leverage robot vision and obstacle detection technologies for fault diagnosis and prognosis accuracy, predictive maintenance, and perceptive control of the surrounding environment. Manufacturing technology automation across cyber-physical systems and IoRT-based networks improve autonomous mobile robot navigation in relation to object location and mapping.	[77–84]
IoRT harnesses edge computing and visualization techniques, simulation and forecasting tools, and industrial automation technologies to attain real-time autonomous navigation and interconnected production management. Interconnected products and processes in cyber-physical manufacturing systems develop on semantic and ontological modeling tools, real-time predictive analytics, and edge computing techniques across IoRT smart environments.	[85–92]
Data mining and processing tools, context awareness algorithms, and edge computing technologies shape cloud-based robotic cooperation systems. Inter-connected smart devices and cloud computing technologies optimize operational efficiency of IoRT-related products and services in relation to real-time data streaming.	[93–100]
Autonomous robotic and cyber-physical systems deploy data analytics and semantic technologies, computational and dynamic reconfiguration capabilities, and distributed intelligence tools. IoRT systems perform multi-machine tasks and enable coordinated and collaborative operations through real-time multipurpose monitoring and movement trajectory tools, convolutional neural networks, and path planning algorithms.	[101–108]
Sensor and actuator fusion, device controlling technologies, and context awareness algorithms optimize connectivity networks of IoRT edge devices. Spatial mapping algorithms, interconnected virtual devices, and navigation management tools configure networked IoRT cloud and swarm robotics in smart factory maintenance.	[109–116]
Local sensing and decentralized communication shape swarm and cloud robotics in terms of coordinated actions through trajectory monitoring of IoRT devices. Autonomous robotic systems harness cognitive decision algorithms, modeling and simulation technologies, and path planning and visual navigation tools for remote sensing performance.	[117–124]
Autonomous swarm robots deploy deep reinforcement learning techniques, computer vision algorithms, and imaging and sensing tools for path planning, collision avoidance, decision-making process, and task execution. IoRT-based collaborative autonomous fleets harness smart sensors and actuators, collect infrastructure data, and accomplish tasks efficiently under uncertain conditions in industrial environments.	[125–132]
IoRT devices deploy cloud computing technologies and data sensor fusion in environment and object perception and detection across dynamic operating systems. Data sharing capabilities, sensing and actuation technologies, and edge and cloud intelligence shape dynamically complex behavior of IoRT devices.	[129,133–138]

Table 2. *Cont.*

Collaborative IoRT technologies and multiple autonomous mobile robots require predictive maintenance tools throughout edge and cloud computing infrastructures. IoT-based robotic systems and connected devices can perform collaborative tasks by deploying remote sensing environment data in task allocation and collision avoidance.	[129,139–145]
Robotic monitoring capabilities develop on modeling and simulation tools, production operation and machine data, and sensing technology across industrial environments. Mobile navigation technologies, path planning and obstacle avoidance tools, deep neural networks, and machine learning clustering algorithms impact robotic perception and manipulation tasks.	[146–153]
Manufacturing machines and cloud and networked robotic systems operate autonomously, collecting, processing, and monitoring data accurately from remotely detected objects. Robotic cooperative behaviors and coordination mechanisms can accomplish tasks through collision-free and coordinated motion planning.	[154–159]

Citation correlations have covered how cognitive algorithms, real-time event analytics, and data visualization functionalities articulate robust interoperable and connectivity networks of IoRT digital twins. Autonomous robots carry out object perception and manipulation operations through collision-free trajectory tools in dynamic unstructured environments. Wireless network and multisensor fusion technologies assist in remote intelligent identification of objects and operations through image recognition and detection tools (Figure 1). Computer vision and data processing algorithms enhance mapping, path planning, and navigation operations of robotic autonomous systems. Behavior pattern clustering of multiple smart agents necessitates accuracy and performance of navigation systems attained by cooperative learning, collective decision making, data fusion mechanisms, and decentralized intelligence across big data infrastructures and blockchain and cloud computing networks. Mobile robotic devices consolidate communication networks by leveraging edge and fog computing technologies, decentralized data analytics, and visual perception tools (Figure 2). Sensing technologies, obstacle avoidance and path planning, and machine learning and object recognition algorithms typify mobile robot movements in terms of detection and tracking. Sensing systems can effectively monitor the surrounding dynamic environments, improving the autonomous navigation of swarm robots through visual and spatial intelligence, deep convolutional neural networks, and fault diagnosis algorithms. Smart manufacturing machines develop on production process modeling, industrial automation devices, and wireless sensor networks (Figure 3). Multi-robot cooperation requires sensor data sharing and processing for carrying out complex computational tasks. Object recognition and detection throughout the navigation process are pivotal in robotic coordination and cooperation as it pertains to collision-free trajectories and virtual path lines. Connected IoRT systems leverage neural network generated data for semantic context understanding in the operating environment, evaluating inaccuracies to reduce collision risks, and determining optimal routes (Figure 4).

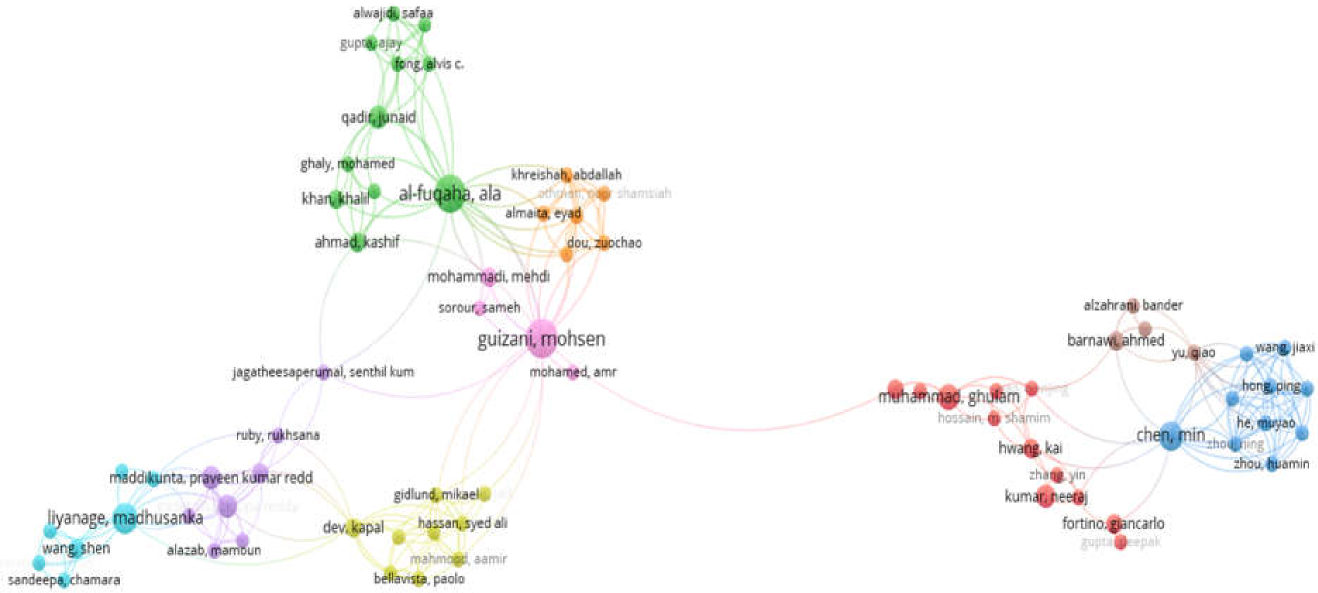

Figure 1. VOSviewer mapping of remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms in the Internet of Robotic Things regarding co-authorship.

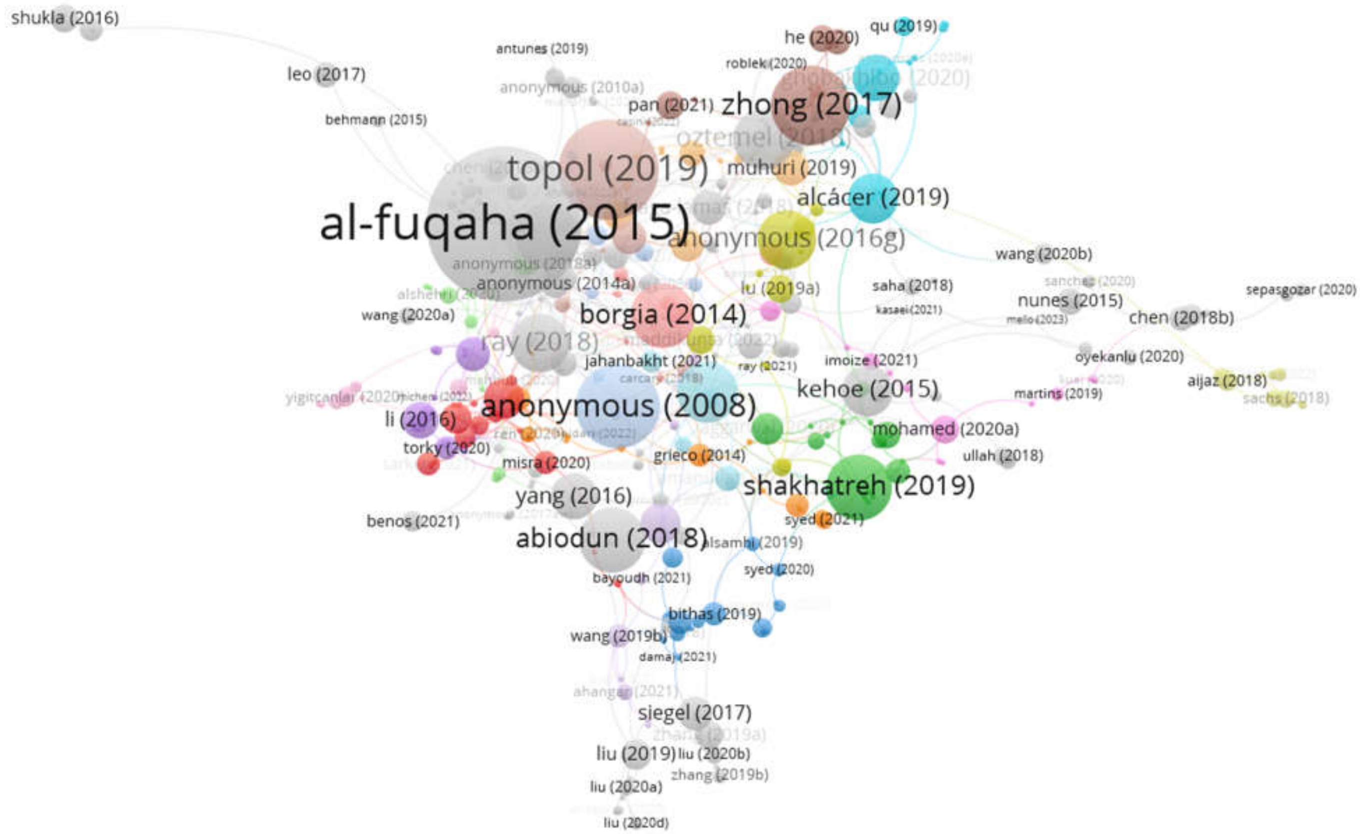

Figure 2. VOSviewer mapping of remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms in the Internet of Robotic Things regarding citation.

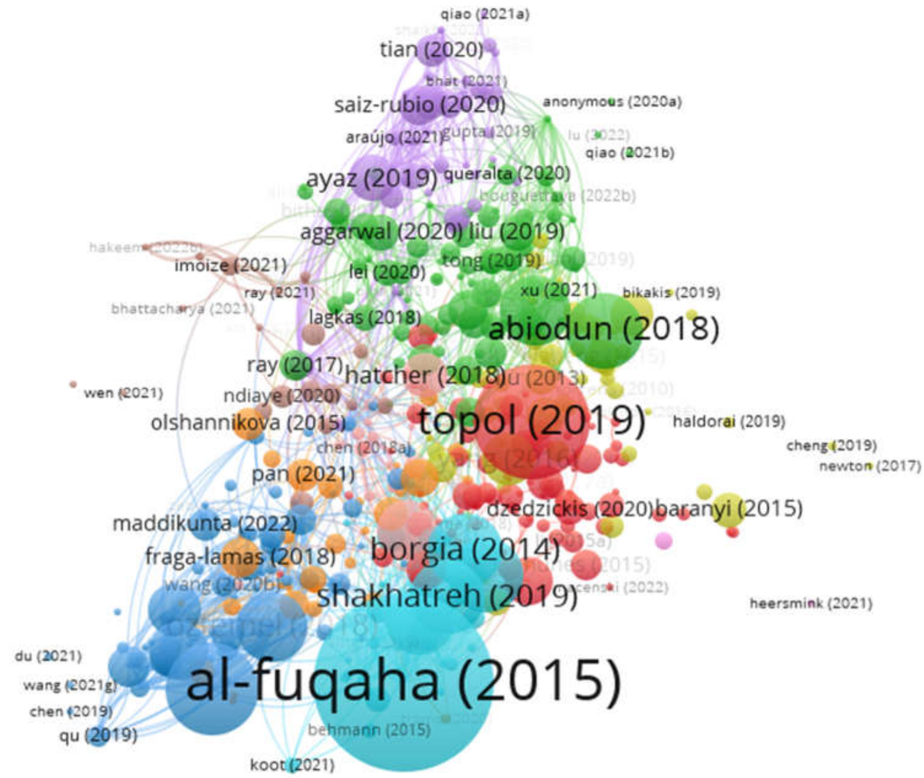

Figure 3. VOSviewer mapping of remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms in the Internet of Robotic Things regarding bibliographic coupling.

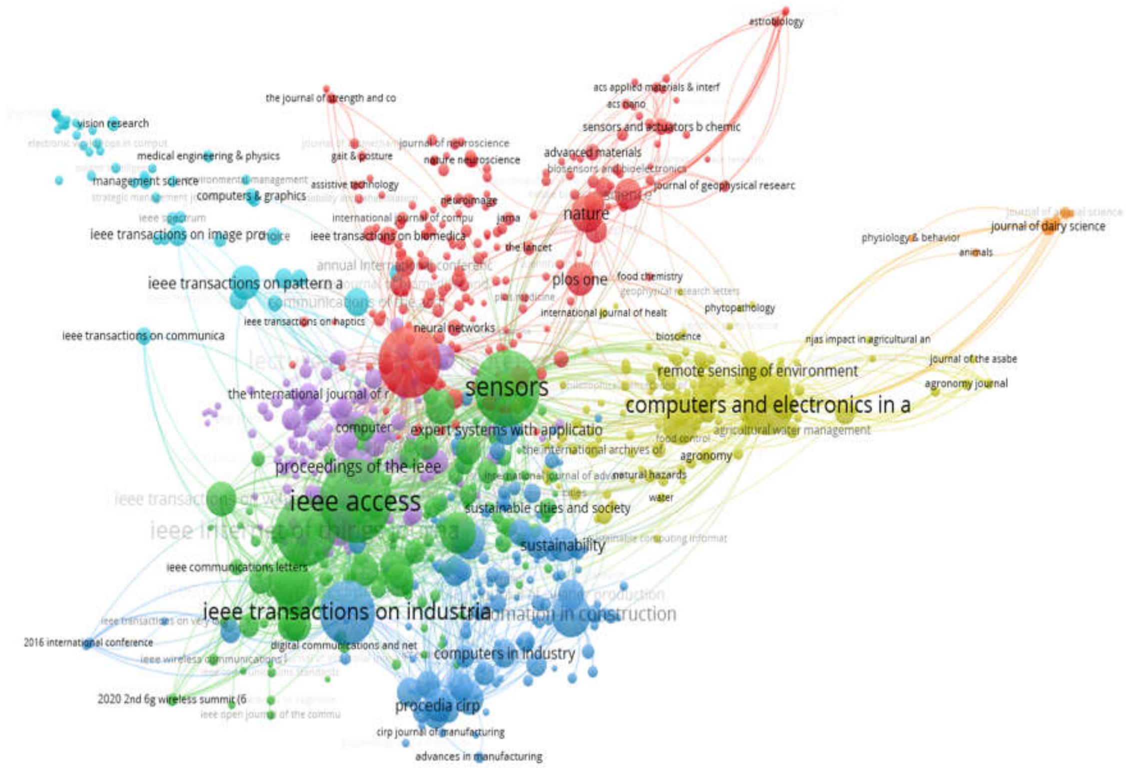

Figure 4. VOSviewer mapping of remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms in the Internet of Robotic Things regarding co-citation.

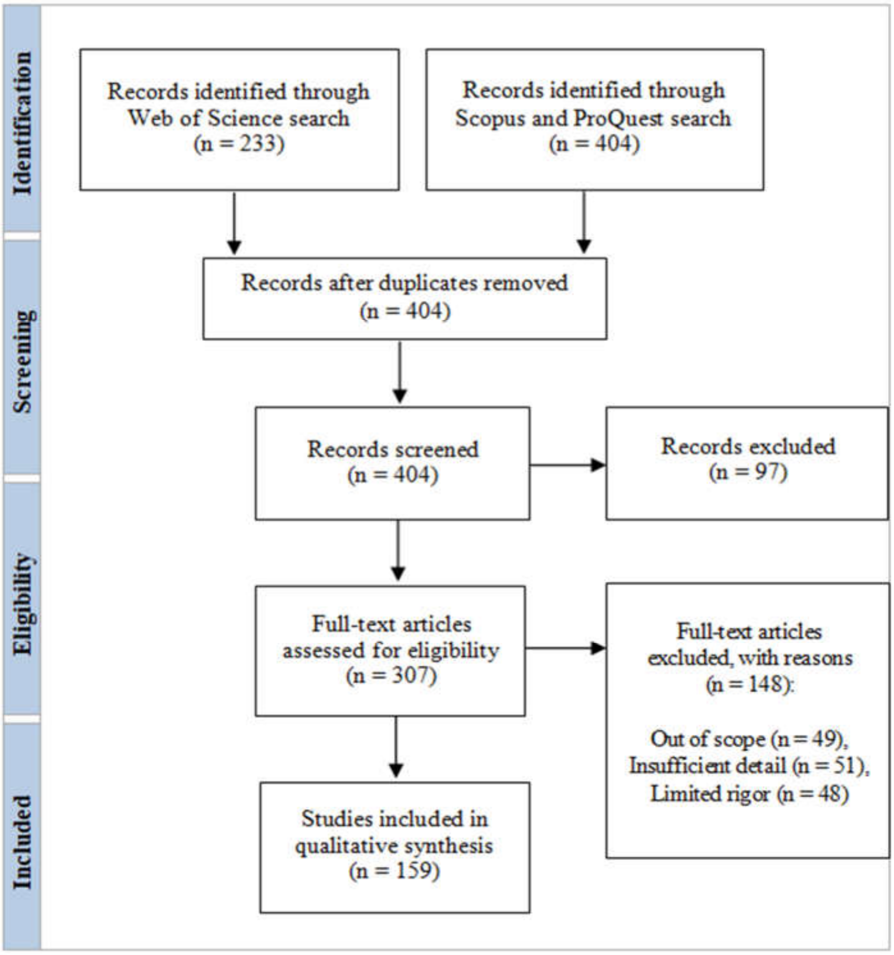

Figure 5. PRISMA flow diagram describing the search results and screening.

3. Remote Big Data Management Tools in the Internet of Robotic Things

Deep reinforcement learning and intelligent data processing tools, edge computing algorithms, and data analytics technologies articulate IoRT [1–4] in relation to smart objects and devices through autonomous operations. Cloud robotics collect real-time sensor data and harness deep neural networks and natural language processing tools for perception, monitoring, and decisions as it relates to object detection, recognition, and tracking. Autonomous robots, sensor technologies, and cyber-physical systems can be deployed in smart manufacturing tasks by use of real-time data and business process automation. Cloud robotics develops on language processing algorithms and systems, collecting real-time operational data. Smart devices, context aware systems, and artificial neural networks further continuous sensing and contextual data monitoring across the surrounding environment.

Robotic and sensor devices leverage IoT techniques and remote big data management tools across data fusion and context-aware systems [5–8] in collaborative industrial environments. Wireless network and multisensor fusion technologies assist in remote intelligent identification of objects and operations through image recognition and detection tools. Data fusion and cloud computing technologies, convolutional neural networks, and deep learning algorithms enable image and speech recognition processes. Data mining, fusion, and processing assist sensor equipment through cognitive decision-making algorithms. Speech and image recognition technologies, situational awareness algorithms, and natural language processing and mobile cloud computing tools assist mobile robotic devices and virtual machines in computation-intensive tasks.

IoRT leverages computer vision and data processing algorithms, image acquisition devices, and distributed intelligence tools [9–12] for object recognition, manipulation, and control. Machine intelligence and mobile robot technologies optimize image recognition accuracy and thus cloud-based production processes and tasks can be performed effectively. Mobile and wireless technologies assist autonomous swarm robots throughout smart and cloud manufacturing processes and remote big data management tools, improving operational efficiency. Cloud-based operational and industrial automation technologies require wireless data transmission across production plants, integrating smart manufacturing techniques and predictive maintenance tools. Natural language processing tools, data mining technologies, and machine learning algorithms can improve production management systems.

Remote sensing technologies, context-aware systems, and data processing algorithms [13–16] configure task scheduling and execution in smart IoRT environments. Sensor and actuator devices enable autonomous mobility for multi-robot systems and optimize task allocation, management, and execution through IoRT data streams. Machine learning algorithms, semantic interoperability, and sensor data assist multi-robot planning techniques. Robotic technologies execute data-driven tasks by use of fog and edge computing tools. Data mining and visualization tools, object recognition algorithms, and fog and edge computing technologies increase operational effectiveness of smart devices and sensors. Spatial data acquisition and processing tools optimize IoRT and virtual machine interoperability by use of connected devices and sensors. Decision-making capabilities of cloud and networked robotics integrate geospatial-temporal data through remote big data management tools.

Cloud computing technologies assist IoRT systems and virtual machines [17–20] in terms of connectivity and scalability. Autonomous and collaborative robots improve production workflow and manufacturing processes by use of data acquisition systems and digital twins in smart factories. Industry 4.0-based cognitive and cloud robotics develops on sensors and actuators across cyber-physical systems in manufacturing plants. Machine and deep learning techniques are pivotal in image classification and object recognition by use of synthetic data creation. Heterogeneous interconnected IoRT devices require mobile sensors and actuators. Robotic operating systems collaboratively perform tasks by use of smart interconnected devices and remote big data management tools.

IoRT devices leverage connected sensors, cloud computing and wireless technologies, and machine learning algorithms [21–24] for real-time data collection concerning device control and diagnostics. Sensor networks shape the interoperability of IoRT objects through remote big data management tools. Path planning and computer vision algorithms, blockchain technologies, and convolution neural networks shape real-time 3D mapping of IoRT systems. Sensors integrated across autonomous robotic systems and machine learning and image processing algorithms articulate the scalability of smart governance in manufacturing plants. Autonomous robotic systems track real-time data processing and interpretation continuously through sensor network management by integrating unsupervised learning techniques, data stream clustering algorithms, and data mining tools.

Collaborative autonomous multi-robot systems perform tasks in flexible industrial environments [25–28] through the use of image processing and data acquisition tools, computer vision and object recognition algorithms, and robotic guidance technologies. Robot vision and navigation systems are pivotal in reconfigurable manufacturing processes across intelligent simulation environments and smart factories. Industrial robots deploy cyber-physical production and autonomous manufacturing systems, cloud computing technologies, and visual tracking algorithms. Computer vision and data processing algorithms enhance mapping, path planning, and navigation operations of robotic autonomous systems. Cloud robotic technology and virtual machines deploy image recognition and path planning algorithms in production processes, multi-device collaborative monitoring, and control tasks. Robotic motion control and task management integrate big data processing technology across cloud computing environments through the use of remote big data management tools.

Object detection, localization, mapping, and avoidance through smart sensing tools [29–32] model and design IoRT systems. Decentralized robot motion control, distributed intelligence tools, and sensor data fusion are instrumental in multi-robot obstacle avoidance and dynamic mapping tasks. Sensor data fusion and analysis can be attained by dynamic actuators and environment mapping algorithms with regards to monitoring events, controlling and manipulating objects, planning paths, and obstacle avoidance. Multiple mobile robots can detect, track, and monitor obstacles across unstable control systems by data sharing. Sensors and actuators boost perceptual and interaction robotic capabilities in smart environments in terms of object localization, navigational behavior, and network-based cooperation. Embedded intelligent systems and wireless sensor networks optimize cooperative perception and behavior of mobile robots through remote big data management tools. Network robot systems autonomously navigate by harnessing mobile sensors and actuators.

Context-aware and semantic IoRT systems monitor events, manipulate connected objects, and fuse sensor data [33–36] by leveraging action modeling and distributed intelligence tools. Robotic navigation systems and virtual machines can make autonomous decisions through ambient intelligence and context awareness tools in relation to object perception and tracking. Networked robots and IoRT devices integrate virtual sensors and actuators for contextual knowledge, object localization, and data sharing. IoRT devices communicate autonomously as regards event modeling and forecasting by leveraging machine learning and clustering algorithms, computer vision technologies, and image processing tools. IoRT systems deploy remote sensing algorithms, data mining techniques, and artificial neural networks in relation to image capturing, acquisition, and processing. Sensor networks and computing devices operate as monitoring mechanisms of IoRT connected data by use of remote big data management tools.

IoRT-based monitored and mobile edge computing environments [37–40] integrate sensor-based communication networks and fog computing technologies. Robotic operating and autonomous control systems harness sensor–actuator networks, machine learning techniques, and context recognition tools in relation to predictive performance of navigation and mapping tasks. Localization and navigation systems map the environment and perform tasks through the use of actuating and sensing device capabilities in smart robotic environments. Mobile robots require wireless sensor networks and smart interconnected devices to perform navigation tasks. Automated algorithms can shape data visualization techniques and natural language processing and modeling tools in IoRT systems.

Blockchain-based IoRT systems and networks leverage cloud and computing technologies, data mining and remote sensing tools, and deep and machine learning algorithms [41–44] in visual object detection and recognition. Decision support systems articulate IoRT network performance through sensing connected and fog computing-based devices in terms of real-time data acquiring, managing, analysis, processing, and monitoring. Robotic systems can increase productivity under both uncertain conditions and controlling parameters and in a synthetic simulation environment by use of remote big data management tools. Behavior pattern clustering of multiple smart agents necessitates accuracy and performance of navigation systems attained by cooperative learning, collective decision making, data fusion mechanisms, and decentralized intelligence across big data infrastructures and blockchain and cloud computing networks.

Mobile robot fleets collect data from unknown environments through the use of actuated devices and motion control algorithms [45–48] through collaborative localization techniques. IoRT develops on machine and deep learning-based image processing and classification algorithms, computer vision control techniques, and convolutional neural networks. Robotic systems require spatial data for object detection, recognition, and classification accuracy, and perform tasks by use of 3D imaging techniques. Mobile sensors and actuators are pivotal in data visualization, acquisition, and analysis processes by autonomous agents, tracking robot localization, and navigation. Sensor data sharing and semantic technologies optimize robotic monitoring capabilities as regards obstacle avoidance and manipulation tasks.

IoRT devices and networked robotic systems exchange sensor data [49–52] in relation to distributed computation resources changing contexts and operating conditions. Mobile autonomous robots control and monitor connected objects and sensor networks through the use of cloud computing technologies and remote big data management tools. Cloud networked robots and virtual machines develop on big data analytics, image processing and location identification tools, and context-aware systems. Collaborative context-aware robotic networks disseminate environment data across IoRT processing units. Vision sensing technology, path planning and task scheduling algorithms, and collision-free tools shape cloud robotics in terms of autonomous task allocation and operational decisions in industrial automation. Motion sensing capabilities of mobile robots organize operations adequately by deploying path planning algorithms (Table 3).

Table 3. Synopsis of evidence relating to analyzed topics and descriptive outcomes (research findings).

Deep reinforcement learning and intelligent data processing tools, edge computing algorithms, and data analytics technologies articulate IoRT in relation to smart objects and devices. Robotic and sensor devices leverage IoT techniques and remote big data management tools across data fusion and context-aware systems in collaborative industrial environments.	[1–8]
IoRT leverages computer vision and data processing algorithms, image acquisition devices, and distributed intelligence tools for object recognition, manipulation, and control. Remote sensing technologies, context-aware systems, and data processing algorithms configure task scheduling and execution in smart IoRT environments.	[9–16]
Cloud computing technologies assist IoRT systems and virtual machines in terms of connectivity and scalability. IoRT devices leverage connected sensors, cloud computing and wireless technologies, and machine learning algorithms for real-time data collection as regards device control and diagnostics.	[17–24]
Collaborative autonomous multi-robot systems perform tasks in flexible industrial environments using image processing and data acquisition tools, computer vision and object recognition algorithms, and robotic guidance technologies. Object detection, localization, mapping, and avoidance through smart sensing tools model and design IoRT systems.	[25–32]
Context-aware and semantic IoRT systems monitor events, manipulate connected objects, and fuse sensor data by leveraging action modeling and distributed intelligence tools. IoRT-based monitored and mobile edge computing environments integrate sensor-based communication networks and fog computing technologies.	[33–40]
Blockchain-based IoRT systems and networks leverage cloud and computing technologies, data mining and remote sensing tools, and deep and machine learning algorithms in visual object detection and recognition. Mobile robot fleets collect data from unknown environments using actuated devices and motion control algorithms. IoRT devices and networked robotic systems exchange sensor data in relation to distributed computation resources changing contexts, and operating conditions.	[41–52]

4. Sensing and Computing Technologies in the Internet of Robotic Things

Autonomous robots and mobile context awareness systems deploy sensor devices, machine learning algorithms, and convolutional neural networks [53–56] as regards acoustic environment recognition. Immersive visualization and imaging-based navigation technologies boost situational awareness and expedite coherent, comprehensive, and intuitive decision-making and operational behavior of mobile robotic systems in unknown environments and situations. Sensor data and path planning algorithms increase productivity and optimize task performance and depth perception of mobile robotic systems across virtual and augmented operating environments in unstructured scenarios. Deep learning-based visual recognition technologies and sound recognition systems harness actuation and sensing mechanisms for mobile context awareness in terms of data processing and fusion. Multi-agent and decision support systems and machine learning and remote sensing algorithms assist robotic networks in making autonomous decisions.

Connected IoRT mobile devices and collaborative robots gather and sense data from the surrounding environment across fog and cloud computing networks [57–60] through computation and storage capabilities. Robotic operating systems can perform tasks autonomously by use of situational and contextual awareness capabilities in relation to interactive and collaborative tasks in smart environments. Robotic devices leverage distributed sensing and machine perception technologies, ambient intelligence, and deep learning techniques, integrating sensor data, cognitive decision-making processes, perceptual and sensing capabilities, and motion and path planning tools. Trajectory planning and obstacle detection tools, machine learning and motion control algorithms, and computer vision systems further robotic system performance for object manipulation tasks.

Image processing and visual modeling tools, edge surveillance and computing technologies, and deep neural networks [61–64] optimize robotic agent behaviors in uncontrolled environments. Collaborative and cognitive robotics develop on multi-sensor data fusion technology, object localization, recognition, and mapping tools, and autonomous navigation systems. Sensing technologies, obstacle avoidance and path planning, and machine learning and object recognition algorithms typify Mobile robot movements in terms of detection and tracking. Decision support agents make smart decisions by harnessing computer vision and image enhancement algorithms and geolocation data intelligence. Predictive geospatial modeling tools are instrumental in autonomous object detection, recognition, and classification by use of through sensing and computing technologies.

Modeling and simulation tools, scheduling algorithms and decisions, and motion planning algorithms [65–68] optimize cyber-physical and robotic systems, managing and completing task configuration and allocation. IoRT device management shapes cloud, collaborative, and cognitive robotics through predictive modeling and context awareness algorithms. Predictive maintenance and data processing tools, cloud processing capabilities, and sensor data and devices configure autonomous robotics, optimizing machine performance. Blockchain technologies, machine and deep learning algorithms, smart environment modeling and computational intelligence tools, and deep neural networks are instrumental in autonomous visual object detection through decentralized data collection, transmission, and governance. Data acquisition and signal processing tools assist autonomous robotic systems through localization accuracy as regards multiple sound sources across synthetic simulation environments and distributed sensor networks.

Blockchain technologies and autonomous systems enhance IoRT device interconnection and networking [69–72] by decentralized data sharing and decision processes, collaborative techniques, and machine learning algorithms. Object detection and manipulation can be attained through robotic environment recognition and mapping sensors in smart virtual environments. Computer vision and machine learning algorithms, image recognition and ambient intelligence tools, and smart sensor devices can configure trajectory paths and detect events by continuous process monitoring and data collection. Seamless data and sensor mobility and interoperability shape cooperative and synchronous robotic networks. Autonomous robots develop on convolutional neural networks, deep learning and object tracking algorithms, and computer vision capabilities in relation to navigation tasks across smart environment systems.

Cloud networked robotics and IoRT systems harness autonomous learning capabilities and deep learning techniques [73–76] for object motion, detection, mapping, and tracking. Wireless sensor networks, localization and navigation tools, and semantic technologies are integrated in IoRT. Real-time operating robotic systems, sensory equipment, and heterogeneous embedded devices enable swift data exchange. IoT-based robots develop on cloud computing, automation systems, and real-time computing processing tools. Sensing and actuation capabilities, computer vision algorithms, and semantic technologies are pivotal in robotic comprehension of the ambient environment and spatial surroundings. Sensors and actuators, semantic data, and 3D assembly operations shape cognitive and cloud robotics.

Sensor accuracy is instrumental in IoT-enabled robotic swarms in terms of performance and reliability. IoT sensors and devices enable real-time monitoring, coordination, and control of robot swarms and multi-robot systems.

Autonomous cyber-physical systems leverage robot vision and obstacle detection technologies [77–80] for fault diagnosis and prognosis accuracy, predictive maintenance, and perceptive control of the surrounding environment. IoRT requires sensing and computing technologies for space situational awareness in task execution. Real-time data collection and analysis optimize decision process operations of IoT-based autonomous robotic systems through advanced sensing techniques and intelligent control algorithms. Sensing systems can effectively monitor the surrounding dynamic environments, improving the autonomous navigation of swarm robots through visual and spatial intelligence, deep convolutional neural networks, and fault diagnosis algorithms. Swarm computing algorithms and machine learning techniques enable autonomous robots to handle visual data for automatic fault diagnosis and decision accuracy. Swarm robotic systems deploy machine intelligence and artificial neural networks in object detection and recognition.

Manufacturing technology automation across cyber-physical systems and IoRT-based networks [81–84] improve autonomous mobile robot navigation in relation to object location and mapping. Actuators and sensors optimize robotic navigation processes throughout IoT-based production systems by obstacle avoidance trajectory planning. Robotic manufacturing processes and industrial wireless sensor networks shape IoRT and lead to improved product quality. Cognitive robots develop on remote interaction sensors, virtual manufacturing modeling, and predictive maintenance tools, resulting in higher productivity, decreased downtime and machine failure, and scalable efficiency. IoRT can boost productivity in networked environments through robot trajectory planning, enhancing business modeling processes and driving economic growth.

IoRT harnesses edge computing and visualization techniques, simulation and forecasting tools, and industrial automation technologies [85–88] to attain real-time autonomous navigation and interconnected production management through distributed computing systems. Mobile robots integrate extended reality and blockchain technologies, simulation and forecasting tools, big data-driven computational processing power, and remote sensing algorithms to configure control decisions and data acquiring, processing, and sharing. Cloud computing machines, plant maintenance scheduling, and cyber-physical production systems facilitate data transfer and object manipulation in Industry 4.0-based networked environments by integrating embedded IoRT-based sensors, thus optimizing productivity and efficiency. Smart interconnected robots deploy speech and gesture recognition tools in collaborative manufacturing processes. Autonomous mobile robots increase productivity and optimize decentralized decisions by use of organizational digital capabilities, machine learning algorithms, blockchain technologies, and advanced analytics in relation to industrial data collection and manufacturing management systems.

Interconnected products and processes in cyber-physical manufacturing systems [89–92] develop on semantic and ontological modeling tools, real-time predictive analytics, and edge computing techniques across IoRT smart environments. Context modeling and automated detection tools, semantic sensor technologies and networks, and pattern-matching algorithms optimize the dynamic interoperability of production systems through edge-computing-based autonomous decisions. Semantic sensor data, object recognition algorithms, and machine learning techniques enable automated task allocation and distributed decision-making in interconnected organizations. Sensor networks and semantic technologies enhance IoRT-based products and processes in smart manufacturing environments.

Data mining and processing tools, context awareness algorithms, and edge computing technologies [93–96] shape cloud-based robotic cooperation systems. Networked cloud robotics is pivotal in computation-intensive collaborative tasks across dynamically changing environments. Robotic knowledge sharing and computation task cooperation require real-time complex data processing, motion coordination, and context awareness algorithms.

Semantic and cloud computing technologies assist robotic-task processing tools across heterogeneous environments through distributed decision-making. Networked robots share collected data and computational capabilities as regards cooperative tasks. Multi-robot cooperation requires sensor data sharing and processing for carrying out complex computational tasks. Robot task cooperation is instrumental in object localization and mapping through wireless networks.

Inter-connected smart devices and cloud computing technologies optimize operational efficiency of IoRT-related products and services [97–100] as regards real-time data streaming, boosting efficiency and productivity. Cognitive computing and modeling technologies monitor robotic systems and processes, shaping performance and competitiveness of IoRT smart products. Cloud imaging tools, distributed intelligence and machine learning algorithms, and big data analytics enhance operational efficiency of industrial robots across manufacturing enterprises and collaborative environments through location tracking and monitoring. Cloud-connected devices collect and analyze data, track and monitor manufacturing processes and industrial asset interconnection, and optimize product development operations (Table 4).

Table 4. Synopsis of evidence as regards analyzed topics and descriptive outcomes (research findings).

Autonomous robots and mobile context awareness systems deploy sensor devices, machine learning algorithms, and convolutional neural networks as regards acoustic environment recognition. Connected IoRT mobile devices and collaborative robots gather and sense data from the surrounding environment across fog and cloud computing networks.	[53–60]
Image processing and visual modeling tools, edge surveillance and computing technologies, and deep neural networks optimize robotic agent behaviors in uncontrolled environments. Modeling and simulation tools, scheduling algorithms and decisions, and motion planning algorithms optimize cyber-physical and robotic systems.	[61–68]
Blockchain technologies and autonomous systems enhance IoRT device interconnection and networking by decentralized data sharing and decision processes, collaborative techniques, and machine learning algorithms. Cloud networked robotics and IoRT systems harness autonomous learning capabilities and deep learning techniques for object motion, detection, mapping, and tracking.	[69–76]
Autonomous cyber-physical systems leverage robot vision and obstacle detection technologies for fault diagnosis and prognosis accuracy, predictive maintenance, and perceptive control of the surrounding environment. Manufacturing technology automation across cyber-physical systems and IoRT-based networks improve autonomous mobile robot navigation in relation to object location and mapping.	[77–84]
IoRT harnesses edge computing and visualization techniques, simulation and forecasting tools, and industrial automation technologies to attain real-time autonomous navigation and interconnected production management through distributed computing systems. Interconnected products and processes in cyber-physical manufacturing systems develop on semantic and ontological modeling tools, real-time predictive analytics, and edge computing techniques across IoRT smart environments.	[85–92]
Data mining and processing tools, context awareness algorithms, and edge computing technologies shape cloud-based robotic cooperation systems. Inter-connected smart devices and cloud computing technologies optimize operational efficiency of IoRT-related products and services as regards real-time data streaming, boosting efficiency and productivity.	[93–100]

5. Visual Perception and Environment Mapping Algorithms in the Internet of Robotic Things

Autonomous robotic and cyber-physical systems deploy data analytics and semantic technologies, computational and dynamic reconfiguration capabilities, and distributed intelligence tools [101–104], improving inventory allocation processes and business performance in IoRT environments. Smart connected objects, situational awareness algorithms, and edge computing technologies configure IoRT systems and cloud robotics in relation to distributed task coordination through visual perception and environment mapping algorithms. Intelligent data processing tools and IoRT sensors enhance decisional autonomy of robot swarms by tracking, monitoring, and manipulating objects. Cloud computing technologies, wireless sensor networks, and cognitive techniques assist IoRT systems and smart objects. Mobile, cognitive, and virtual robots integrate sensor data.

IoRT systems perform multi-machine tasks and enable coordinated and collaborative operations [105–108] through real-time multipurpose monitoring and movement trajectory tools, convolutional neural networks, and path planning algorithms. IoRT systems can make decisions by captured image data and object recognition processes, collaborative operation mechanisms, and multi-machine cooperation, completing assigned tasks flexibly. IoRT systems carry out the assigned tasks through multipurpose environment monitoring systems, obstacle avoidance algorithms, and trajectory tracking tools in relation to mobile control, coordinated operation, movement process, and performance evaluation.

Sensor and actuator fusion, device controlling technologies, and context awareness algorithms [109–112] optimize the connectivity networks of IoRT edge devices. Event sensing and actuating tools, edge computing technologies, and cloud data analytics improve asset performance and operational effectiveness. IoRT cloud analytics integrates interoperable controlling mechanisms, multiple smart sensors and actuators, and edge data processing tools. Cloud and fog computing technologies, machine learning algorithms, and event processing and visualization tools shape IoRT device connection by use of visual perception and environment mapping algorithms.

Spatial mapping algorithms, interconnected virtual devices, and navigation management tools [113–116] configure networked IoRT cloud and swarm robotics in smart factory maintenance. Collision avoidance algorithms, environment perception and mapping tools, and cloud computing technologies assist multi-robot systems in task coordination and performance. Data mining and cloud-based object tracking tools enhance massive computation capabilities of mobile robots and virtual machines as autonomous agents. Object recognition and detection throughout the navigation process are pivotal in robotic coordination and cooperation regarding collision-free trajectories and virtual path lines.

Local sensing and decentralized communication shape swarm and cloud robotics in terms of coordinated actions [117–120] through trajectory monitoring of IoRT devices. Mobile swarm robots and smart machines can share collected data and control signals, take coordinated decisions, and prevent collisions through wireless communication technologies, performing complex autonomous tasks effectively. By monitoring trajectories, communication network technologies ensure collision prevention in collaborative multi-robot environments. Robotic communication systems gather and process data intelligently from the surrounding environment, operating autonomously through the use of wireless sensor networks and visual perception and environment mapping algorithms. Artificial neural networks and machine and deep learning algorithms optimize collaborative robot communication pertaining to autonomous operations. Deep reinforcement learning tools assist robotic path tracking behavior and control systems through the use of crowd navigation algorithms. Multiple mobile and autonomous swarm robots require prediction accuracy with regards to path planning and obstacle localization, avoidance, and mapping by real-time data collection and processing. IoRT devices and multi-robot systems integrate cloud computing technologies and machine learning techniques.

Autonomous robotic systems harness cognitive decision algorithms, modeling and simulation technologies, and path planning and visual navigation tools for remote sensing performance [121–124] through real-time data acquisition and processing. Machine learning techniques articulate autonomous decision-making of smart agents in dynamic sensing and uncertain environments through object detection, recognition, and classification accuracy. Autonomous cognitive systems, wireless sensor and actuator networks, and deep reinforcement learning tools are leveraged in object detection and recognition across remote and ambient sensing environments.

Autonomous swarm robots deploy deep reinforcement learning techniques, computer vision algorithms, and imaging and sensing tools [125–128] for path planning, collision avoidance, decision-making process, and task execution by integrating cloud and sensor data. Image acquisition and processing tools, sensor fusion-based systems, and steering control algorithms enable accurate robot navigation across dynamic unstructured environments. Path planning and obstacle avoidance algorithms assist robotic technologies and automated decision systems in collecting accurate data concerning navigation operations through visual perception and environment mapping algorithms. Sensing and control systems enhance autonomous robotic technologies through data collection swiftness and accuracy.

IoRT-based collaborative autonomous fleets harness smart sensors and actuators, collect infrastructure data, and accomplish tasks efficiently under uncertain conditions in industrial environments [129–132] through interoperable perception and cognition algorithms. IoRT devices share data, recognize events, and react appropriately using intelligent connectivity in a smart decentralized network infrastructure. Autonomous robotic systems harness edge and cloud computing tools, swarm technologies, and machine intelligence in cognitive decision making in relation to complex operations. Autonomous and collaborative context-aware IoRT systems and cognitive robotic devices operate in dynamic industrial environments through coordination, mobility, sensing, and actuation functions that are pivotal in data exchange and processing. Data gathered continuously by perception devices across industrial robot systems and cloud computing infrastructure diagnose and handle faults using decision and control algorithms. Data processing algorithms typify cloud, collaborative, networked swarm, and cognitive robotics through autonomous operational processes, event monitoring, and sensor data fusion. IoRT systems perform tasks by completing the planned trajectories and manipulating objects with the help of sensing and actuating devices while inspecting the surrounding conditions. Autonomous IoRT fleets articulate collaborative behaviors to achieve shared goals by integrating data-centric edge computing technologies, supervisory control tools, and tactile interaction devices for artificial intelligence-inference processing in industrial operations and across connectivity networks.

IoRT devices deploy cloud computing technologies and data sensor fusion [129,133–135] in environment and object perception and detection across dynamic operating systems. Connected IoRT systems leverage neural network generated data for semantic context understanding in the operating environment, evaluating inaccuracies to reduce collision risks and determining optimal routes. IoRT operations can be attained by leveraging machine learning and cognitive decision-making capabilities, cooperative mobility systems and distributed computing networks. Perception sensors assist collaborative fleets of autonomous robotic systems and IoRT devices in simultaneous localization and mapping through visual perception and environment mapping algorithms. Decentralized data processing and knowledge exchange enable IoRT device connectivity by integrating swarm technologies, sensory-based robot control tools, and tactile feedback systems. Wireless communication technologies and intelligent connectivity networks shape cooperative multi-robot systems pertaining to cognitive decision-making processes, motion planning and coordination, and object recognition and manipulation. Mobile robotic devices consolidate communication networks by leveraging edge and fog computing technologies, decentralized data analytics, and visual perception tools. Edge processing algorithms, sensor fusion capabilities, and digital twin computation processes that configure the collaborative behaviors of IoRT devices.

Data sharing capabilities, sensing and actuation technologies, and edge and cloud intelligence [129,136–138] shape the dynamically complex behavior of IoRT devices. IoRT cognitive capabilities and distributed intelligence develop fog and edge computing technologies in smart interactive environments. The real-time performance of robotic swarm operations and multi-agent robotic systems integrate predictive maintenance and deep reinforcement learning tools. Predictive algorithms, data mining tools, and edge computing technologies are pivotal in context-aware IoRT autonomous systems with regards to cloud processing tasks and collaborative networks in industrial manufacturing. Cognitive algorithms, real-time event analytics, and data visualization functionalities articulate robust interoperable and connectivity networks of IoRT digital twins. Network intelligence enables collective tasks of swarm robotic devices and technologies. Machine learning data analytics impacts the IoRT system performance in decentralized cloud environments.

Collaborative IoRT technologies and multiple autonomous mobile robots [129,139–141] require predictive maintenance tools throughout edge and cloud computing infrastructures. Image recognition algorithms and environment perception sensors assist computation-enabled robotic devices in intelligent connectivity infrastructures. Robotic device capabilities integrate data sharing, storing, and processing by sensors and actuators across distributed interoperable environments. Collaborative autonomous systems and robotic devices deploy distributed intelligence and data processing tools. Swarm robotic algorithms and IoRT devices are leveraged in object movement and manipulation tasks, spatial cognition and computation, and condition diagnostics and monitoring. Collaborative autonomous robotic systems harness sensing and actuation devices across intelligent networked infrastructures. IoRT swarm technologies and cognitive systems require data mining tools and machine and deep learning algorithms.

IoT-based robotic systems and connected devices can perform collaborative tasks [142–145] by deploying remote sensing environment data in task allocation and collision avoidance through motion capture systems across unstructured contexts. Cloud networked and mobile autonomous robots integrate sensing and computing capabilities to execute coordinated operations in dynamic environments. Data visualization and analysis tools, path planning and data fusion algorithms, and machine intelligence assist robotic technologies and robot sensor networks in object detection and tracking. IoRT systems leverage environment monitoring mechanisms to aggregate sensor data and map networked processes using visual perception and environment mapping algorithms.

Robotic monitoring capabilities develop on modeling and simulation tools, production operation and machine data, and sensing technology [146–149] across industrial environments. Process planning and sensing technologies configure artificial intelligence-based machine performance and prognosis, impacting production system performance and modeling through real-time data analytics. Cognitive artificial intelligence enables process monitoring and diagnosis of production line management in dynamic manufacturing environments, considerably improving productivity. Computer vision technology is pivotal in situational awareness and machine condition monitoring, articulating real-time production scheduling in smart manufacturing management. Machine and deep learning algorithms can process massive volumes of manufacturing data in visual simulation environments with regards to fault detection and diagnosis. Smart manufacturing process monitoring and control can be achieved through distributed intelligence in relation to performance analysis, optimizing production systems. Artificial intelligence-based analytical tools can leverage sensor data in fault diagnosis in manufacturing plants.

Mobile navigation technologies, path planning and obstacle avoidance tools, deep neural networks, and machine learning clustering algorithms [150–153] impact robotic perception and manipulation tasks. Autonomous robots carry out object perception and manipulation operations through collision-free trajectory tools in dynamic unstructured environments. Cognitive robotics integrates visual perception and reinforcement learning technologies, motion planning and prediction algorithms, and trajectory planning and collision avoidance tools concerning object localization, perception, recognition, and mapping. Multiple robots can perform tasks autonomously through deep learning-based object and event detection and recognition.

Manufacturing machines and cloud and networked robotic systems [154–156] operate autonomously, collecting, processing, and monitoring data accurately from remotely detected objects by sensor technologies. Cloud-based manufacturing processes harness smart interconnected sensor devices, spatial mapping algorithms, and interactive simulation and virtual reality technologies in networked environments. Data-driven machines and factories integrate interconnected devices and sensors, distributed control systems, and data mining tools. Smart manufacturing machines develop on production process modeling, industrial automation devices, and wireless sensor networks.

Robotic cooperative behaviors and coordination mechanisms [157–159] can accomplish tasks through collision-free and coordinated motion planning. Autonomous robotic systems can handle coordinated and unpredictable tasks by leveraging swarm intelligence algorithms, modeling and simulation tools, and machine learning techniques. Collective, coordinated, and cooperative robotic behavior is pivotal in decentralized task allocation, assignment, and execution by object localization, mapping, and manipulation. Multi-robot control systems perceive and sense the surrounding environment for task performance, coordinated decisions, object handling, and collision avoidance. Robotic coordination mechanisms and cooperative actions optimize collision-free motion and trajectory planning in dynamic unknown environments. Deep reinforcement learning algorithms shape multi-robot task, motion planning, and object manipulation through cooperative multi-agent controls. Autonomous robotic behavior algorithms harness multi-sensor fusion technology in mobile navigation, task completion, route planning, and performance modeling (Table 5).

Table 5. Synopsis of evidence regarding analyzed topics and descriptive outcomes (research findings).

Autonomous robotic and cyber-physical systems deploy data analytics and semantic technologies, computational and dynamic reconfiguration capabilities, and distributed intelligence tools. IoRT systems perform multi-machine tasks and enable coordinated and collaborative operations through real-time multipurpose monitoring and movement trajectory tools, convolutional neural networks, and path planning algorithms.	[101–108]
Sensor and actuator fusion, device controlling technologies, and context awareness algorithms optimize connectivity networks of IoRT edge devices. Spatial mapping algorithms, interconnected virtual devices, and navigation management tools configure networked IoRT cloud and swarm robotics in smart factory maintenance.	[109–116]
Local sensing and decentralized communication shape swarm and cloud robotics in terms of coordinated actions through trajectory monitoring of IoRT devices. Autonomous robotic systems harness cognitive decision algorithms, modeling and simulation technologies, and path planning and visual navigation tools for remote sensing performance.	[117–124]
Autonomous swarm robots deploy deep reinforcement learning techniques, computer vision algorithms, and imaging and sensing tools for path planning, collision avoidance, decision-making process, and task execution by integrating cloud and sensor data. IoRT-based collaborative autonomous fleets harness smart sensors and actuators, collect infrastructure data, and accomplish tasks efficiently under uncertain conditions in industrial environments.	[125–132]
IoRT devices deploy cloud computing technologies and data sensor fusion in environment and object perception and detection across dynamic operating systems. Data sharing capabilities, sensing and actuation technologies, and edge and cloud intelligence shape dynamically complex behavior of IoRT devices.	[129,133–138]
Collaborative IoRT technologies and multiple autonomous mobile robots require predictive maintenance tools throughout edge and cloud computing infrastructures. IoT-based robotic systems and connected devices can perform collaborative tasks by deploying remote sensing environment data in task allocation and collision avoidance.	[129,139–145]

Table 5. *Cont.*

Robotic monitoring capabilities develop modeling and simulation tools, production operation and machine data, and sensing technology across industrial environments. Mobile navigation technologies, path planning and obstacle avoidance tools, deep neural networks, and machine learning clustering algorithms impact robotic perception and manipulation tasks.	[146–153]
Manufacturing machines and cloud and networked robotic systems operate autonomously, collecting, processing, and monitoring data accurately from remotely detected objects through sensor technologies. Robotic cooperative behaviors and coordination mechanisms can accomplish tasks through collision-free and coordinated motion planning.	[154–159]

6. Discussion

Autonomous IoRT fleets articulate collaborative behaviors to achieve shared goals by integrating data-centric edge computing technologies, supervisory control tools, and tactile interaction devices for artificial intelligence-inference processing in industrial operations and across connectivity networks. IoRT cognitive capabilities and distributed intelligence develop on fog and edge computing technologies in smart interactive environments. Collaborative autonomous robotic systems harness sensing and actuation devices across intelligent networked infrastructures. Machine and deep learning algorithms can process massive volumes of manufacturing data in visual simulation environments concerning fault detection and diagnosis. Data-driven machines and factories integrate interconnected devices and sensors, distributed control systems, and data mining tools. Deep reinforcement learning algorithms shape multi-robot task, motion planning, and object manipulation through cooperative multi-agent controls. Cloud robotics develops language processing algorithms and systems, collecting real-time operational data. Natural language processing tools, data mining technologies, and machine learning algorithms can improve production management systems. Robotic operating systems collaboratively perform tasks by use of smart interconnected devices and remote big data management tools. Multiple mobile robots can detect, track, and monitor obstacles across unstable control systems by data sharing.

IoRT systems deploy remote sensing algorithms, data mining techniques, and artificial neural networks in relation to image capturing, acquisition, and processing. Robotic systems require spatial data for object detection, recognition, and classification accuracy, and perform tasks using 3D imaging techniques. Sensor data and path planning algorithms increase productivity and optimize task performance and depth perception of mobile robotic systems across virtual and augmented operating environments in unstructured scenarios. Predictive maintenance and data processing tools, cloud processing capabilities, and sensor data and devices configure autonomous robotics, optimizing machine performance. Sensors and actuators, semantic data, and 3D assembly operations shape cognitive and cloud robotics. Semantic sensor data, object recognition algorithms, and machine learning techniques enable automated task allocation and distributed decision-making in interconnected organizations. Cloud computing technologies, wireless sensor networks, and cognitive techniques assist IoRT systems and smart objects. By monitoring trajectories, communication network technologies ensure collision prevention in collaborative multi-robot environments. Sensing and control systems enhance autonomous robotic technologies by data collection swiftness and accuracy. Perception sensors assist collaborative fleets of autonomous robotic systems and IoRT devices in simultaneous localization and mapping through visual perception and environment mapping algorithms.

Machine learning data analytics impacts the IoRT system performance in decentralized cloud environments. Data visualization and analysis tools, path planning and data fusion algorithms, and machine intelligence assist robotic technologies and robot sensor networks in object detection and tracking. Artificial intelligence-based analytical tools can leverage sensor data in fault diagnosis in manufacturing plants. Multi-robot control systems perceive and sense the surrounding environment for task performance, coordinated decisions, object handling, and collision avoidance. Autonomous robots, sensor technologies, and cyber-physical systems can be deployed in smart manufacturing tasks using real-time data and business process automation. Data mining and visualization tools, object recognition algorithms, and fog and edge computing technologies increase operational effectiveness of smart devices and sensors. Autonomous robotic systems track real-time data processing and interpretation continuously through sensor network management by integrating unsupervised learning techniques, data stream clustering algorithms, and data mining tools. Sensor networks and computing devices operate as monitoring mechanisms of IoRT connected data through the use of remote big data management tools. Mobile sensors and actuators are pivotal in data visualization, acquisition, and analysis processes by autonomous agents, tracking robot localization, and navigation. Collaborative and cognitive robotics develop multi-sensor data fusion technology, object localization, recognition, and mapping tools, and autonomous navigation systems.

Autonomous robots develop convolutional neural networks, deep learning and object tracking algorithms, and computer vision capabilities in relation to navigation tasks across smart environment systems. Swarm computing algorithms and machine learning techniques enable autonomous robots to handle visual data for automatic fault diagnosis and decision accuracy. Smart interconnected robots deploy speech and gesture recognition tools in collaborative manufacturing processes. Cloud imaging tools, distributed intelligence and machine learning algorithms, and big data analytics enhance operational efficiency of industrial robots across manufacturing enterprises and collaborative environments through location tracking and monitoring. Cloud and fog computing technologies, machine learning algorithms, and event processing and visualization tools shape IoRT device connection using visual perception and environment mapping algorithms. Path planning and obstacle avoidance algorithms assist robotic technologies and automated decision systems in collecting accurate data as it pertains to navigation operations through visual perception and environment mapping algorithms. IoRT systems perform tasks by completing the planned trajectories and manipulating objects with the help of sensing and actuating devices while inspecting the surrounding conditions. Edge processing algorithms, sensor fusion capabilities, and digital twin computation processes configure the collaborative behaviors of IoRT devices. Collaborative autonomous systems and robotic devices deploy distributed intelligence and data processing tools. Computer vision technology is pivotal in situational awareness and machine condition monitoring, articulating real-time production scheduling in smart manufacturing management.

Sensor networks shape the interoperability of IoRT objects through remote big data management tools. Predictive geospatial modeling tools are instrumental in autonomous object detection, recognition, and classification using through sensing and computing technologies. Network intelligence enables collective tasks of swarm robotic devices and technologies. Collective, coordinated, and cooperative robotic behavior is pivotal in decentralized task allocation, assignment, and execution by object localization, mapping, and manipulation. Robotic technologies execute data-driven tasks through the use of fog and edge computing tools. Vision sensing technology, path planning and task scheduling algorithms, and collision-free tools shape cloud robotics in terms of autonomous task allocation and operational decisions in industrial automation. Networked cloud robotics is pivotal in computation-intensive collaborative tasks across dynamically changing environments. Artificial neural networks and machine and deep learning algorithms optimize collaborative robot communication regarding autonomous operations. Smart manufacturing process monitoring and control can be achieved through distributed intelligence in relation to performance analysis, optimizing production systems. Sensors integrated across autonomous robotic systems and machine learning and image processing algorithms articulate the scalability of smart governance in manufacturing plants.

IoT-based robots develop on cloud computing, automation systems, and real-time computing processing tools. Robotic communication systems gather and process data intelligently from the surrounding environment, operating autonomously by use of wireless sensor networks and visual perception and environment mapping algorithms. Cloud networked and mobile autonomous robots integrate sensing and computing capabilities to execute coordinated operations in dynamic environments. Autonomous and collaborative robots improve production workflow and manufacturing processes through the use of data acquisition systems and digital twins in smart factories. Real-time data collection and analysis optimize decision process operations of IoT-based autonomous robotic systems through advanced sensing techniques and intelligent control algorithms. IoRT devices share data, recognize events, and react appropriately using intelligent connectivity in smart decentralized network infrastructure. Industry 4.0-based cognitive and cloud robotics develops on sensors and actuators across cyber-physical systems in manufacturing plants. Real-time operating robotic systems, sensory equipment, and heterogeneous embedded devices enable swift data exchange. Swarm robotic algorithms and IoRT devices are leveraged in object movement and manipulation tasks, spatial cognition and computation, and condition diagnostics and monitoring.

7. Conclusions

Significant research has elucidated how sensor and actuator devices enable autonomous mobility for multi-robot systems and optimize task allocation, management, and execution through IoRT data streams. Object detection and manipulation can be attained through robotic environment recognition and mapping sensors, optimizing product development operations. Cloud-connected devices collect and analyze data and track and monitor manufacturing processes and industrial asset interconnection. Cloud-based operational and industrial automation technologies require wireless data transmission across production plants in smart virtual environments. Machine learning algorithms, semantic interoperability, and sensor data assist multi-robot planning techniques, integrating smart manufacturing techniques and predictive maintenance tools. Localization and navigation systems map the environment and perform tasks through the use of actuating and sensing device capabilities in smart robotic environments.

Our systematic literature review investigates relevant published peer-reviewed sources in relation to how heterogeneous interconnected IoRT devices and cognitive computing and modeling technologies require mobile sensors and actuators for monitor robotic systems and processes. Sensor accuracy is instrumental in IoT-enabled robotic swarms in terms of performance and reliability by use of remote big data management tools. Event sensing and actuating tools, edge computing technologies, and cloud data analytics improve asset performance and operational effectiveness. Robotic systems can increase productivity under both uncertain conditions and controlling parameters and in a synthetic simulation environment, shaping performance and competitiveness of IoRT smart products. Robotic devices leverage distributed sensing and machine perception technologies, ambient intelligence, and deep learning techniques, integrating sensor data, cognitive decision-making processes, perceptual and sensing capabilities, and motion and path planning tools (Research Problem 1).

We show how networked robots and IoRT devices integrate virtual sensors and actuators for contextual knowledge, object localization, and data sharing, with deep reinforcement learning tools assisting robotic path tracking behavior and control systems by use of crowd navigation algorithms. Mobile swarm robots and smart machines can share collected data and control signals, take coordinated decisions, and prevent collisions through wireless communication technologies, performing complex autonomous tasks effectively. When developing remote interaction sensors, virtual manufacturing modeling, and predictive maintenance tools, decision support agents can make smart decisions by harnessing computer vision and image enhancement algorithms and geolocation data intelligence, resulting in higher productivity, decreased downtime and machine failure, and scalable efficiency. Cognitive robots and cloud-based manufacturing processes harness smart interconnected sensor devices, spatial mapping algorithms, and interactive simulation and virtual reality technologies in networked environments (Research Problem 2).

We indicate that decision support systems articulate IoRT network performance through sensing connected and fog computing-based devices in relation to industrial data collection and manufacturing management systems. Autonomous mobile robots increase productivity and optimize decentralized decisions through the use of organizational digital capabilities, machine learning algorithms, blockchain technologies, and advanced analytics in terms of real-time data acquiring, managing, analysis, processing, and monitoring. Multiple mobile and autonomous swarm robots require prediction accuracy with regards to path planning and obstacle localization, avoidance, and mapping by real-time data collection and processing. Mobile robots integrate extended reality and blockchain technologies, simulation and forecasting tools, big data-driven computational processing power, and remote sensing algorithms to configure control decisions and data acquiring, processing, and sharing. Mobile and wireless technologies assist autonomous swarm robots throughout smart and cloud manufacturing processes and remote big data management tools, improving operational efficiency (Research Problem 3).

The findings collected from the performed analyses clarify that IoRT device management shapes cloud, collaborative, and cognitive robotics through remote big data management tools in relation to complex operations. Robot task cooperation is instrumental in object localization and mapping through wireless networks. Autonomous robotic systems harness edge and cloud computing tools, swarm technologies, and machine intelligence in cognitive decision-making. Decentralized data processing and knowledge exchange enable IoRT device connectivity by integrating swarm technologies, sensory-based robot control tools, and tactile feedback systems. Actuators and sensors optimize the cooperative perception and behavior of mobile robots through predictive modeling and context awareness algorithms. Embedded intelligent systems and wireless sensor networks optimize robotic navigation processes throughout IoT-based production systems by obstacle avoidance trajectory planning.

8. Specific Contributions to the Literature

This systematic review puts forwards a hot emerging topic (that is, remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms in IoRT) that has not been investigated so far in the literature regarding how autonomous and collaborative context-aware IoRT systems and cognitive robotic devices operate in dynamic industrial environments. Wireless communication technologies and intelligent connectivity networks shape cooperative multi-robot systems as it pertains to object detection, recognition, and tracking. Autonomous robotic behavior algorithms harness multi-sensor fusion technology in mobile navigation, task completion, route planning, and performance modeling through coordination, mobility, sensing, and actuation functions that are pivotal in data exchange and processing. Cloud robotics collect real-time sensor data and harness deep neural networks and natural language processing tools for perception, monitoring, and decisions concerning cognitive decision-making processes, motion planning and coordination, and object recognition and manipulation. Decision-making capabilities of cloud and networked robotics integrate geospatial-temporal data through remote big data management tools. Robotic motion control and task management integrate big data processing technology across cloud computing environments by use of situational and contextual awareness capabilities, requiring data mining tools and machine and deep learning algorithms. Mobile multiple robots, IoRT swarm technologies, and cognitive systems require wireless sensor networks and smart interconnected devices to perform navigation tasks autonomously through deep learning-based object and event detection and recognition. IoRT develops on machine and deep learning-based image processing and classification algorithms, computer vision control techniques, and convolutional neural networks. Robotic operating systems can perform tasks autonomously through the use of remote big data management tools in relation to interactive and collaborative tasks in smart environments.

Our analyses specifically prove that wireless sensor networks, localization and navigation tools, and semantic technologies are integrated in IoRT devices and multi-robot systems. Decentralized robot motion control, distributed intelligence tools, and sensor data fusion are instrumental in multi-robot obstacle avoidance and dynamic mapping tasks by use of cloud computing technologies and machine learning techniques. Networked robots share collected data and computational capabilities as it relates to cooperative tasks. Machine and deep learning techniques are pivotal in image classification and object recognition by industrial robots that deploy cyber-physical production and autonomous manufacturing systems, cloud computing technologies, and visual tracking algorithms. Deep learning-based visual recognition technologies and sound recognition systems harness actuation and sensing mechanisms for mobile context awareness in terms of data processing and fusion. Automated algorithms can shape data visualization techniques and natural language processing and modeling tools in IoRT systems through interoperable controlling mechanisms, multiple smart sensors and actuators, and edge data processing tools. Robotic device capabilities and IoRT cloud analytics integrate data sharing, storing, and processing by sensors and actuators across distributed interoperable environments. Cloud networked robots and virtual machines develop on big data analytics, image processing and location identification tools, and context-aware systems by use of synthetic data creation.

9. Limitations and Further Directions of Research

As only ProQuest, Scopus, and the Web of Science sources published in scientific journals between 2016 and 2022 were analyzed, relevant sources on remote big data management tools, sensing and computing technologies, and visual perception and environment mapping algorithms in IoRT may have been omitted. Additional research should address how digital twin modeling, plant equipment real-time diagnosis, and cognitive data analytics configure IoRT systems and virtual machines. The scope of this systematic review does not advance blockchain-based IoRT systems and networks in terms of spatial data analytics, virtual mapping tools, and edge intelligence technologies. Practical consequences would be how spatial data visualization and decision support tools, immersive visualization systems, and augmented reality algorithms articulate blockchain-based IoRT devices and networked robotic systems. Academic implications of this paper mainly integrate the priority of bolstering up research on connected IoRT mobile devices and collaborative robots in relation to virtual twinning techniques, computational object instantiation, and automated simulation modeling. Future research should investigate how data fusion techniques, swarm intelligence algorithms, and virtual reality mapping assist cloud networked robotics and IoRT systems. Subsequent analyses should develop on how virtual manufacturing systems, spatial computing and predictive modeling algorithms, and visual surveillance tools optimize collaborative IoRT technologies and multiple autonomous mobile robots. Attention should be directed to how cyber-physical systems and IoRT-based networks integrate extended reality and cloud computing technologies, big geospatial data analytics, and visual recognition tools.

10. Practical Implications

Sensors and actuators boost perceptual and interaction robotic capabilities in smart environments in terms of object localization, navigational behavior, and network-based cooperation. Sensor data sharing and semantic technologies, in addition to spatial data acquisition and processing tools, optimize robotic monitoring capabilities with regards to obstacle avoidance and manipulation tasks. Trajectory planning and obstacle detection tools, machine learning and motion control algorithms, and computer vision systems further robotic system performance for object manipulation tasks, shaping cooperative and synchronous robotic networks. Swarm robotic systems, together with semantic and cloud computing technologies, deploy machine intelligence and artificial neural networks in object detection and recognition, assisting robotic-task processing tools across heterogeneous environments through distributed decision-making. Collision avoidance algorithms, environment perception and mapping tools, and cloud computing technologies assist multi-robot systems in task coordination and performance through seamless data and sensor mobility and interoperability. Image acquisition and processing tools, sensor fusion-based systems, and steering control algorithms enable accurate robot navigation across dynamic unstructured environments, optimizing IoRT and virtual machine interoperability. Predictive algorithms, data mining tools, and edge computing technologies are pivotal in context-aware IoRT autonomous systems concerning cloud processing tasks and collaborative networks in industrial manufacturing by use of connected devices and sensors.

Requiring sensing and computing technologies for space situational awareness in task execution, IoRT can boost productivity in networked environments through robot trajectory planning, enhancing business modeling processes, and driving economic growth. Data processing algorithms typify cloud, collaborative, networked swarm, and cognitive robotics through autonomous operational processes, event monitoring, and sensor data fusion. Cognitive robotics integrates visual perception and reinforcement learning technologies, motion planning and prediction algorithms, and trajectory planning and collision avoidance tools. Speech and image recognition technologies, situational awareness algorithms, and natural language processing and mobile cloud computing tools assist mobile robotic devices and virtual machines in computation-intensive tasks. Cloud robotic technology and virtual machines deploy image recognition and path planning algorithms in production processes, multi-device collaborative monitoring, and control tasks. Motion sensing capabilities of mobile, cognitive, and virtual robots organize operations adequately by deploying path planning algorithms as it pertains to object localization, perception, recognition, and mapping. Real-time performance of robotic swarm operations and multi-agent robotic systems integrates predictive maintenance and deep reinforcement learning tools. Autonomous robotic systems integrate sensor data and can handle coordinated and unpredictable tasks by leveraging swarm intelligence algorithms, modeling and simulation tools, and machine learning techniques.

Collaborative context-aware robotic networks disseminate environmental data across IoRT processing units, sensors, and devices. Context modeling and automated detection tools, semantic sensor technologies and networks, and pattern-matching algorithms optimize the dynamic interoperability of production systems by edge-computing-based autonomous decisions. Machine learning techniques articulate autonomous decision-making of smart agents in dynamic sensing and uncertain environments through real-time data analytics. Process planning and sensing technologies configure artificial intelligence-based machine performance and prognosis, impacting production system performance and modeling through object detection, recognition, and classification accuracy. Machine intelligence and mobile robot technologies optimize image recognition accuracy and, thus, cloud-based production processes and tasks can be performed effectively. Network robot systems autonomously navigate by harnessing mobile sensors and actuators, with IoRT operations being attained by leveraging machine learning and cognitive decision-making capabilities, cooperative mobility systems, and distributed computing networks. Immersive visualization and imaging-based navigation technologies boost situational awareness and expedite coherent, comprehensive, and intuitive decision-making and operational behavior of mobile robotic systems in unknown environments and situations. Sensor networks and semantic technologies enhance IoRT-based products and processes in smart manufacturing environments, enabling real-time monitoring, coordination, and control of robot swarms and multi-robot systems.

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