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OCCLUSION BASED COOPERATIVE TRANSPORT WITH A SWARM OF MINIATURE MOBILE ROBOTS.

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Abstract:

Swarm robotics is a generally new research territory propelled from organic framework, for example, insect. Swarm robotics is a part of multi-robot frameworks that grasp the thoughts of natural swarms like creepy crawly provinces, herds of feathered creatures and schools (gathering) of fish. In this self-get together robots are utilized to move to the material starting with one spot then onto the next by swarm intelligence (S.I). In swarm intelligence whether the remaining task at hand of a specific robot builds then it will speak with different ones with the assistance of systems and by utilizing the swarm intelligence the robots appropriate the outstanding burden among themselves for legitimate treatment of the material. This automated framework will be helpful in dangerous material taking care of, clearing minefields, secure a territory without putting life in danger. Additionally, the military, law implementation, touchy law transfer unit and private security firms could be profited by this framework. In the conventional strategy the robots are working exclusively however in this proposed framework, the multi-robot will team up with one another and functions as a gathering as opposed to single robots on the off chance that it is required. Swarm robot, with its self-gathering ability included top of completely self-governing robots, opens up new research recorded arranged between self reconfigurable and aggregate robots. The idea consolidates equipment adaptability found in selfreconfigurable robot with control flexibility found in disseminated control for aggregate robotics. In addition, we are supplanting the wheel development with the components since the wheel development is just constrained to the uniform territories however with assistance of Klann's mechanism the robot, can get to the harsh landscapes.

Swarm robotics involves multiple robots working together to achieve a common goal through decentralized control, scalability, and robustness. This swarm robots is used to cooperatively transport objects from one location to another. Each robot is equipped with sensors for object detection, obstacle avoidance, and communication modules for inter-robot coordination. The decentralized control system enables each robot to make local decisions while sharing information with other members of the swarm to ensure efficient pathfinding and load distribution. The system's scalability allows more robots to join or leave the group without compromising the overall performance, making it ideal for tasks where flexibility and adaptability are essential.

Key words : Swarm Robotics, Multi-robot system, Decentralized control, Distributed robotics, Self-organisation, Robot-to-Robot Communication, Collective intelligence, Wireless Sensor Networks.

1. INTRODUCTION

This paper describes a system whereby a swarm of small and inexpensive differential drive LEGO robots [3] cooperate autonomously to transport a relatively much larger object to a specific location. In this work, swarms of only seven robots or less were considered. A variety of cooperative transportation approaches in the literature were reviewed as part of this work. In [4] it is shown how lack of communication results in loss of control, especially if the group of robots is small. In [5] robots organise themselves at two sides of an object to be moved, and push in a perpendicular direction. In order to change direction of movement, the robots have to change formation and re organise themselves. The system is not completely autonomous as the robots move towards a leader that is teleoperated by a human to guide them along a desired trajectory. In [6], holonomic Scarab robots 'cage' the object, creating a bounded moveable area for the object to be transported. Scarabs are equipped with laser range finders, Wi-Fi connectivity and make use of two overhead cameras and LED targets for self and neighbour localisation to maintain formation. In [7] a Kilobot swarm moves the object by grasping it. Circular rings were mounted along the edges of the object to emulate grippers. In [8] a simulated S-bot swarm is proposed which also grasps the object to be transported. Robot formation shapes generated are non-deterministic; with the most efficient for transport being a caging-like formation whereby the robots surround the object. Formation generation, which is a research domain in its own right, is also a crucial requirement for the achievement of cooperative transportation. Reference [9] proposes a behaviour-based approach which generates different formation shapes but is unable to switch formation on the fly. Leader and neighbour referenced formations proved to be more feasible than unitcentre referencing, which heavily taxed the communicaton system. In [10] an algorithm is proposed which can easily change formation, but requires the shape to be composed of equilateral triangles. In [11], robots must be contiguous in order to coordinate and generate a formation, imposing restrictions on the formation shape. In this paper, an autonomous system was developed whereby one robot is designated as a leader of a team of robots, who leads the group so as to cooperatively move an object towards a target position set by the user. This approach was taken because a proper balance between leader based and distributed control is known to yield positive results [12]. The final objective of cooperative transportation requires various intermediate steps for its achievement. The robots need to generate a formation, recognise and navigate towards the object to be transported, recognise and locate neighbouring robot positions, control their motion and coordinate as a team in order to reach the set target. Hence in this work, two novel control algorithms were developed; one based on rigid formations, and a second one based on leader imitation. The rigid formation algorithm can generate any shape bounded only by the range of the communication system used. Adaptations to an algorithm for visual target tracking [14] were also performed. Finally, experimental implementation and validation on a physical set up were carried out in a research domain where work is commonly implemented in simulation only. Three cooperative transportation strategies were investigated: pushing, caging and grasping, in target destinations situated at front, left and right of the swarm's initial position. The robots only relied on Wi-Fi or Bluetooth for communication, and local sensors were limited to a webcam, gyro and wheel encoders.

Through this communication infrastructure, robots can still collaborate even if visually occluded by the object to be transported.

2. LITERATURE SURVEY

Swarm robotics involves multiple robots working together to achieve a common goal through decentralized control, scalability, and robustness. This swarm robots is used to cooperatively transport objects from one location to another. Each robot is equipped with sensors for object detection, obstacle avoidance, and communication modules for inter-robot coordination. The decentralized control system enables each robot to make local decisions while sharing information with other members of the swarm to ensure efficient pathfinding and load distribution. The system's scalability allows more robots to join or leave the group without compromising the overall performance, making it ideal for tasks where flexibility and adaptability are essential.

Development Of Robotic Arm Using Arduino UNO by Priyambada Mishra, Riki Patel, Trushit Upadhyaya, Arpan Desai In this paper they have used 4 servo motors to make joints of the robotic arm and the movement will be controlled with the help of potentiometer. The controller used is Arduino UNO. The analog inputting also of the Arduino' is give into the Potentiometer. The arm has been built by the Cardboard and individual parts are attached to the respective servomotors. The arm is specifically created topic and place lightweight objects. So low torque servos, with a rotation of 0 to 180 degrees have been used. Programming is done using Arduino.

Design of Robotic Arm with Gripper and End effector for spot welding' by Puran Singh, Anil Kumar, Mahesh
Vashishth According to the paper the robotic arm consists of 2 degrees of freedom is being made for the purpose of spot welding, gripper will be used in the arm. The end effect or consists of an arrangement of spargers and threaded shafts along with an AC motor. Aims considered while building the robotic arm are. To have a rigid structure. 2.Movement of parts to defined angles. 3.To attain consumption of power at optimum level.

Review on Object-Moving Robot Arm based on Color by Areepen Sengsalonga ,Nuryono Satya Wido do the objective of this finding is to make a manipulator which can sort objects on basis of colour using specific motors and photo diode sensors programmed with a Arduino Megaseries microcontroller. The light photo diode sensor can identify RGB colours. In this system the output of Arduino Mega 2560 is displayed on a LCD screen which is an indication of the observed colour. The first step of object moving processes by distinguishing the RGB colour. The grid Perofroboticarm will move topic objects based on colour, depending on the colour input given by the light photodiode sensor. Arduino Mega 2560 is a microcontroller that uses ATmega2560 which is installed in robotic arm having 54 digital VO ports segregated into different types. In this International Research Journal of Engineering and Technology (IRJET)e-ISSN:2395-0056 Volume:08 Issue:02|Feb2021 www.irjet.net p- ISSN: 2395-0072 O 2021, IRJET | Impact Factor value: 7.529 | ISO 9001:2008 Certified Journal| Page2124 paper colour sensor testing is also carried out, having at argent determine the ability of Photo diode sensor for distinguishing of colour. The resultant voltage from photodiode will be sent to ADC to process and show result on the LCD screen provided.

Modelling and Simulation of Robotic Arm Movement using Soft Computing by V. VK. Banga, Jasjit Kaur, R. Kumar, Y. Singh In this research paper the authors successfully built a4 degrees of freedom robotic armusing soft computing. They have formulated ways for controlled movement of robotic armand planning of trajectory with the help of Genetic Algorithms (GAs) and fuzzy logic (FL). As optimal movement is critical for efficient autonomous robots. This architecture is used to limit the issues related to the motion, friction And the settling time of different components in robotic arm. Genetic optimization is used to find the finest joint angles for this four d-o-f robotic system. This type of optimization replaces the long process of trial and error in search of better combination of joint angles, which are valid as per inverse kinematics for robotic arm movement. These logic models (Fuzzy logic) have been developed for the joint movement, friction and least settling time attributes as the fuzzy logic input.

Design and Development of a Self-Adaptive, Reconfigurable and Low-Cost Robotic Arm by
KemalOltunEvliyaoglu1, MeltemElitas Variety of tasks can be performed by a robotic arm when we do some changes in it, 1.e changing the number of links, it can be made self adaptable his aspects of a robotic arm is discussed by the author in this paper. The paper represents a basic robotic solution to fulfill different applications with the help of it.

Designand Implementation of Wireless Robotic Arm Modelus Flexand GyroSensorby Anughna N, Ranjitha V, Tanuja G The paper represents the author using accelerometers to collect information. The controller used is Arduino Atmega328. Human arm motion, fingers are located by flex, gyrosensors and signals are sent to Arduino ATmega328which in turn controls the servo motors and makes the movement of the arm possible. The programming of the Arduino was done with the help of embedded C language. The Flexand GyroSensors were placed near the fingers. Whenever the change is detected, the information by both the sensors is processed by the controller. The Future Scope of this paper includes using 5 Flex Sensors near the fingers and more Gyro for the ease of operation.

A Geometric Approach for Robotic Arm Kinematics with Hardware Design, Electrical Design, and Implementation by Kurt E. Clothier and Ying Shang In this paper, the author has taken a geometric approach in order opposition the robotic arm in an autonomous manner. Robot command model is the main controller for the robot. For additional hardware, there are foure-ports and it is built around atmega168 microcontroller. The number of sensors used externally to Robot Create are three. Two Sharp GP2D12 Range Finder sensors and one GP2D120 Range Finder sensor are used. An in fared be a is emitted from these sensors and the reflection angles are used to find the distance of the objects. Objects in the range of 10-80 cm are detected by GP2D12, whereas the objects as close as 4- 30cm are detected by GP2D120. Element Direct, In is the screen used in this project, it came with Display which was designed for the use with command module. For scanning in the front of the robot, there are two infrared range finders. A distance in millimeters' is received with the help of these sensors when anything blocks their line of sight, and hence we get the position of an object with the help of these distances.

3. PROPOSED METHODOLOGY

Advanced Proximity Sensors: Incorporate a combination of infrared, ultrasonic, or LIDAR sensors, which allow robots to detect occlusions more accurately. This enables better coordination as

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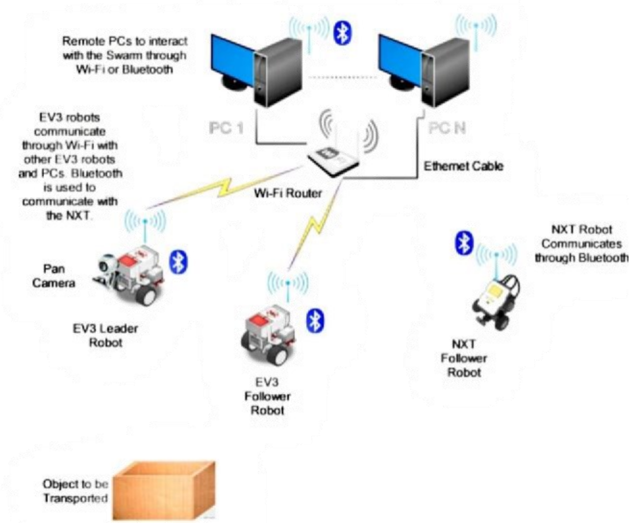
robots can more precisely determine the relative position of the object and other robots.
Some robots may be equipped with simple depth sensors to understand the shape and size of the object and surroundings, allowing the swarm to more effectively distribute force and avoid obstacles.
Self-Organizing Algorithms for Decentralized Role Allocation: Each robot assesses its position and chooses whether to push, pull, or reposition itself based on detected occlusions and the object's shape. This prevents congestion and optimizes force distribution across the swarm. Robots communicate their positions, directions, or required force vectors to each other. A central unit calculates paths or force requirements for each robot. Robots use sensors to detect forces applied to the object and adjust their movement accordingly. Each robot uses simple sensors to detect when its view of an object or another robot is blocked. This detection can trigger the robot to push or pull the object in a specific direction or to reposition itself. Instead of depending on communication with other robots, each robot uses local sensing (e.g., infrared or proximity sensors) to sense occlusions and coordinate movements.
Swarm robotics is an approach to multi-robot systems inspired by the collective behavior of social animals like ants, bees, and birds. Existing swarm robotic systems are used in various applications, including search and rescue, environmental monitoring, agriculture, and military operations. Here are some notable existing swarm robotic systems: A low-cost, small-scale swarm robot system designed for collective behavior research. Capable of self-organization, shape formation, and group movement. Used for studying decentralized algorithms.
Consists of three types of robots: foot-bots (ground movement), hand-bots (climbing and manipulation), and eye-bots (aerial surveillance). Designed for complex collaborative tasks, such as retrieving objects from shelves. Swarm robotics continues to evolve with advancements in AI, machine learning, and sensor technology, leading to more sophisticated and autonomous multirobot systems.



The physical and hardware setup consists of three Lego Mindstorms robots, including two Mindstorms EV3 and an NXT robot to form a swarm. Hence the swarm can be classified as heterogeneous. Each robot includes its embedded computer board, sensors and actuators. A remote computer for the user to interact with the swarm and a wireless router for inter-robot communication were used. The EV3 has a faster processor and more RAM than the NXT. In addition the EV3 also has built-in support for both Wi-Fi (through a USB dongle) and Bluetooth communication. The NXT only has built-in Bluetooth communication.
Swarm robotics is a field of multi-robot systems inspired by natural swarms like ants, bees, and birds. Swarm robots work together in a decentralized manner to achieve a common goal using local communication and simple rules. Here's how they work:

1. Decentralized Control

Unlike traditional robots with a central controller, swarm robots operate without a leader. Each robot makes decisions based on local information and interactions with nearby robots.

2. Simple Rules and Local Interactions

Each robot follows simple predefined rules, such as:

Moving towards or away from obstacles, Following or avoiding other robots, Cooperating in tasks like object transport
These local interactions create emergent behavior, allowing the swarm to accomplish complex tasks.
3.Communication Methods: Swarm robots communicate using various techniques: Infrared or Radio Signals: Short-range wireless communication to exchange data. Vision Sensors: Detecting other robots and surroundings. Swarm Intelligence Algorithms: Like particle swarm optimization (PSO) or ant colony optimization (ACO) for decision-making.

4. Distributed Sensing and Decision Making

Each robot collects data from the environment and shares it with nearby robots. Decisions are made collectively, making the swarm adaptable to changes and failures.

5. Self-Organization and Adaptability

Swarm robots adapt to their environment dynamically. If one robot fails, others can take over its task without affecting the overall mission.
Node MCU Development Kit/Board consist of ESP8266 wifi chip. ESP8266 chip has GPIO pins, serial communication protocol, etc. features on it.

ESP8266 is a low-cost Wi-Fi chip developed by Espressif Systems with TCP/IP protocol. For more information about ESP8266, you can refer ESP8266 WiFi Module.
The features of ESP8266 are extracted on Node MCU Development board. Node MCU (LUA based firmware) with Development board/kit that consist of ESP8266 (wifi enabled chip) chip combines Node MCU Development board which make it stand-alone device in IoT applications.

4. EXPERIMENTAL ANALYSIS

Three cooperative transport strategies were next evaluated. This included pushing, caging and grasping of an irregular, rectangular shaped cardboard box of size 90cm by 32cm. Rectangular objects are more challenging to transport . The centroid of the box was used as a reference point to measure performance accuracy of all three strategies. The pushing approach proved to be effective in transporting the object to target destinations situated at the front of the initial starting poses, but resulted in the robots losing control of the object when target destinations were situated at the left or right.

This occurred due to the large changes in heading demanded by the employed pose stabilisation algorithm. The pushing strategy imposes mobility restrictions such that the robots must constantly apply a force which is perpendicular to the object's surface, else a force which is perpendicular to the object's surface, else control is lost. This strategy achieved an average percentage error of –0.335% for destination targets situated 2800mm from the start position. The caging approach was based on 'conditional closure' as only three robots were available, and 'object closure' requires at least four robots. This approach was successful in moving the object to target destinations situated at the left, right and front of the robots' initial positions. An average percentage error of -1.98% was obtained over distances of 2800mm at the front and 3795mm at the sides. The grasping approach was also successful in moving the object to target destinations situated at the left, right and front of the robots' initial positions. Robots were placed inside 'grip rings' to emulate a gripper. An average percentage error of -0.42% was obtained in identical test conditions used for the caging approach. The grasping approach achieved more accurate results due to the more 'harmonious' and synchronised motion produced by the imitation algorithm, whereas in the caging approach each robot can be moving and applying a force in a different direction to move to the current target pose computed by the rigid formation algorithm. Thus the object is moved in the direction of the global resultant force, and a higher probability of wheel slippage is incurred. The grasping approach requires only two robots to perform the task, instead of three or four robots as required by caging. On the other hand the caging algorithm proved to be robust to faults and is suitable in unstructured environments whereby the object to be transported cannot be grasped. Both grasping and caging are free from motion restraints imposed by the pushing strategy. This freedom of movement is beneficial for navigating in dynamic real-world environments. In all three approaches, not all robots need to have knowledge of the final target location.

Fig Pushing approach

Fig The caging approach

Fig grasping approach

Swarm robotics is a generally new research territory propelled from organic framework, for example, insect. Swarm robotics is a part of multi-robot frameworks that grasp the thoughts of natural swarms like creepy crawly provinces, herds of feathered creatures and schools (gathering) of fish. In this self-get together robots are utilized to move to the material starting with one spot then onto the next by swarm intelligence (S.I). In swarm intelligence whether the remaining task at hand of a specific robot builds then it will speak with different ones with the assistance of systems and by utilizing the swarm intelligence the robots appropriate the outstanding burden among themselves for legitimate treatment of the material. This automated framework will be helpful in dangerous material taking care of, clearing minefields, secure a territory without putting life in danger. Additionally, the military, law implementation, touchy law transfer unit and private security firms could be profited by this framework. In the conventional strategy the robots are working exclusively however in this proposed framework, the multi-robot will team up with one another and functions as a gathering as opposed to single robots on the off chance that it is required. Swarm robot, with its self-gathering ability included top of completely self-governing robots, opens up new research recorded arranged between self reconfigurable and aggregate robots.

Applications:

1.Industrial & Manufacturing:

Automated Warehousing: Swarm robots optimize storage, retrieval, and sorting in warehouses (e.g., Amazon's Kiva robots).

Assembly Line Automation: Robots collaborate to assemble products with high efficiency and flexibility.

2. Agriculture & Farming:

Precision Farming: Swarm robots monitor soil conditions, plant seeds, and apply fertilizers or pesticides with precision.

Pollination: Small drones mimic bees to pollinate crops in areas with declining bee populations.

3. Search & Rescue:

Disaster Response: Swarm robots navigate through debris in earthquake or flood-hit areas to locate survivors.

Firefighting: Coordinated drones monitor and combat wildfires in realtime.

4. Military & Defence:

Surveillance & Reconnaissance: Swarm drones scout enemy territories and track movements.

Decoy & Disruption Tactics: Robot swarms can overwhelm enemy radar or communication systems.

5. Healthcare & Medical Assistance:

Nanorobotics: Microscopic robots assist in drug delivery, targeting cancer cells, or performing micro-surgeries.

Hospital Assistance: Autonomous robots transport medicines and equipment within hospitals.

6. Environmental Monitoring:

Air & Water Pollution Detection: Swarm robots measure pollution levels in oceans, lakes, and the atmosphere.

Wildlife Tracking & Conservation: Small robots track endangered species without disturbing their habitat.

7. Space Exploration:

Planetary Exploration: Swarm robots explore planets like Mars, working together to map terrain and search for resources. Asteroid Mining: Robots collaborate to extract valuable minerals from asteroids.

8. Construction & Infrastructure:

Autonomous Construction: Swarms of robots 3D-print structures, build bridges, or repair infrastructure.

Pipe & Tunnel Inspection: Small swarm robots inspect underground pipelines and tunnels for damages.

9. Transportation & Traffic Management:

Autonomous Vehicle Coordination: Swarm algorithms help selfdriving cars navigate efficiently.

Drone Delivery Systems: Swarm drones deliver packages in urban and remote areas.

10. Education & Research:

Robotics Learning Platforms: Universities and research institutions use swarm robots to study artificial intelligence, machine learning, and decentralized control.

The system can easily scale up or down by adding or removing robots without affecting overall performance.

1. Robustness & Fault Tolerance

If some robots fail, the rest of the swarm can continue operating without significant disruption.

2. Decentralized Control

No single point of failure since decisions are distributed across multiple robots.

3. Flexibility & Adaptability

Swarm robots can dynamically reconfigure themselves to complete different tasks.

4. Efficiency in Task Execution

Parallel task execution speeds up operations, improving efficiency.

5. Cost-Effectiveness

Using many small, simple robots can be more economical than a single complex robot.

6. Self-Organization

The swarm can automatically coordinate and form structures without external intervention.

7. Applications in Hazardous Environments

Swarm robots can be deployed in dangerous areas, such as disaster zones or space exploration, where human intervention is risky.

Swarms of robots are effective:

- They can perform tasks that one expensive robot cannot.
- Example: UAVs for surveillance. Swarms for robust:

Robots can be reused:

- Functionally specific agents can be used to solve different problems.

5. CONCLUSION

In conclusion, this work has given the itemized outline of flow swarm intelligence research and its applications in swarm robotics. Swarm robotics is an intriguing option in contrast to traditional ways to deal with robotics in view of certain properties of critical thinking systems, which comprises of flexible, robust, decentralized and self-organized. A few assignments might be unreasonably mind boggling for a solitary robot to perform. The speed is expanded when utilizing a few robots and it is simpler to structure a robot because of its straightforwardness. The correspondence between robots is diminished, due to the connections through the earth. This kind of arrangement swarm robotics offers, and swarm intelligence by and large, is the method for pushing ahead with regards to control of complex disseminated frameworks.

Swarm robotics is an emerging field inspired by the collective behavior of natural swarms, such as ants and bees. It leverages simple individual robots that work collaboratively to achieve complex tasks. Swarm robotics has demonstrated significant advantages, including scalability, robustness, flexibility, and adaptability. Applications in areas such as search and rescue, environmental monitoring, agriculture, and space exploration have shown promising results. Despite challenges related to communication, coordination, and energy efficiency, continuous advancements in artificial intelligence, machine learning, and hardware miniaturization are paving the way for more effective swarm robotic systems.

The robots are able to generate a formation, recognise and locate neighbouring robot positions, control their motion and coordinate as a team in order to move the object to a set target location. Simulation tests confirm that using the rigid formation algorithm, robots are able to generate any desired shape, and maintain it whilst the swarm is in motion, using a pose stabilisation algorithm of choice. Moreover robots can also change formation positions on the fly. Robots converge into formation using either leader referenced or neighbour-referenced target positions, with the latter offering a more distributed approach at the expense of longer convergence times. Similar results were obtained on a physical setup consisting of different Mindstorms platforms and other inexpensive parts, demonstrating that the system is effective in a heterogeneous environment. The pushing, caging and grasping cooperative transportation strategies were implemented and evaluated. The caging and grasping approaches provide increased freedom of movement over the pushing strategy. Grasping yielded slightly better results due to more synchronous motion. Future improvements include integrating inertial measurement units on board the robots, to investigate the efficacy of the system over longer distances.

Future Scope

- Enhanced Communication and Coordination – Advancements in wireless networks and AI-driven decision-making will improve realtime collaboration among swarm robots.

- Autonomous Swarm Intelligence – Future research will focus on developing more sophisticated algorithms that enable robots to selflearn and adapt to dynamic environments.

- Human-Swarm Interaction – Improving interfaces and control mechanisms to allow humans to effectively guide and collaborate with swarms.

- Miniaturization and Energy Efficiency – Development of smaller, more energy-efficient swarm robots for applications in nanotechnology and biomedical fields.

- Multi-Robot Cooperation – Integration of swarm robotics with other robotic systems, such as drones and autonomous vehicles, for largescale problem-solving.

- Security and Ethical Considerations – Addressing concerns related to data security, privacy, and ethical deployment in civilian and military applications.

- Industrial and Commercial Applications – Increased adoption in manufacturing, logistics, and smart cities for automation and efficiency improvement.

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