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Review

Uncrewed Ground Vehicles (UGVs) and Nature-Inspired Designed Robot DIGIT and SPOT: A Review

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Abstract: Researchers around the world are developing autonomous robot systems to assist humans with tedious, hazardous, complex, and time-consuming tasks. Today, autonomous robots are used for a variety of applications, ranging from delivering food to operating on patients. A robotic system can be operated with or without human assistance, depending on whether it is manned or unmanned. Additionally, the robot may be classified as an Unmanned Aerial Vehicle (UAV), Unmanned Surface Vehicle (USV), or Unmanned Ground Vehicle (UGV), depending on its operational conditions. An autonomous robot may be equipped with manipulators and advanced sensors, such as a LiDAR camera, which can collect 3D spatial data. The present study reviews recent research and development of unmanned ground vehicles, including two nature-inspired designed robots called SPOT and DIGIT and presents its technical data. In addition, this study introduces the challenges and applications of these robots. A novel type of comparison was made in this study between some UGVs, human and animal-inspired designed robots, where researchers were able to get an idea of different robot basic specifications that could be used to select these robots for future research. As a result of this study, two more studies will be conducted in the future.

Keywords: Unmanned Ground Vehicle, Humanoid Robot, DIGIT, Quadruped Robot, SPOT, Nature-Inspired Designed Robot, LiDAR

Introduction

Research on robotic advancement started after 1950. Table 1 illustrates the significant types of robotic research start times. Mobile robots and multi-robot are the sub-classes of the mobile robot; walking and humanoid robots are the sub-classes of biology-inspired robots. The last two types of robots are the sub-class of robot manipulation, such as robotic arms (Garcia *et al*., 2007).

Wheeled mobile robots are robots or vehicles that can operate without a human on board or by remote control to navigate environments for which they are designed (ground, air, water). Depending on the form and degree of control of the vehicle, the level and type of autonomy may vary, ranging from no automation to full automation (Rivera *et al*., 2019). Several robotic systems have demonstrated the capability to perform inspection tasks in environments that can be dangerous and difficult to reach, such as power plants (Rizia *et al*., 2020; 2022). The definition of the UGV can be written as a piece of mechanical equipment linked with different sensors. It can move on the ground surface for other purposes or missions without carrying a human being. In that branch, another type of robot can be operated with a long-distance signal, a teleoperated vehicle where navigational instruction comes from an external human operator (Gage, 1995). That type of robot is being used for various applications, including inspection, food delivery, cleaning, and different complex missions. It is about to demonstrate that it will significantly impact the change in human activity. The techniques used to operate a UGV are environment perception, object detection, camera sensor, and cloud control (Ni *et al*., 2021). Recently, scientists in robotic fields and manufacturers of UGVs have been using different types of updated sensors. For example, 3D LiDAR cameras are being used to collect three-dimensional data.

The development of autonomous robotic systems capable of moving across varied terrain has been a top goal for the industry. Most robots are big stationary objects, only capable of rotating one or two axes, primarily used in advanced manufacturing or assembly lines. Nature is said to be an excellent source of inspiration for research and design ideas. An animal-inspired robot: The four-legged robot can easily move a rough terrain faster than a wheeled vehicle. However, strictly mechanical movement cannot perform the same function as animals. To overcome this difficulty, the researcher uses advanced tools for uneven terrain, even for the movement of stairs (Gage, 1995).

A robot, called SPOT has that capability. The size of this robot is relatively small, about the size of a large dog. It is capable of moving throughout a building or a house seemed a token of the distant future. Also, it can move across varied terrain with its quadrupedal movement system and can work and operate in the same spaces as humans. This four-legged movement system allows it to traverse uneven surfaces and even climb stairs. As a bonus, this robotic system can be enhanced with a robotic arm to pick and place objects and even do advanced tasks such as opening doors. All of this is paired with a way for SPOT to remember and repeat task cycles so they can be done autonomously and the result is a highly adaptive system that can be used for any task.

Unmanned Ground Robot and Vehicles

Shakey was one of the extraordinary efforts to develop the mobile robot with the wheeled platform. That robot included an SDS-940, a TV camera, an ultrasonic range finder, and touch sensors. The research focus was mainly on developing a program for processing sensory data from the robot, storing information about the environment, and preparing the steps of motor actions to complete the task according to the environment. However, Shakey failed to achieve autonomous movement (Gage, 1995; Nilsson, 1969). The Stanford Cart project at the Stanford University AI Lab, led by Hans Moravec between 1973 and 1981, explored navigation and obstacle avoidance challenges using a vision system. The images were collected from nine positions with a TV camera. The system successfully made an obstacle-free travel to its destination using feature extraction and image correlation, but the system was too slow; the speed was up to 15 meters/minute (Gage, 1995; Moravec and Elfes, 1985).

The unmanned robot is the perfect tool to save the operation cost and human life for space inspection, research, and exploration. A study started in the early 1970s with NASA's support to develop UGV for exploring planetary surfaces, which began with the JPL Mars Rover. However, it was postponed in 1979 but resumed in 1986-87 for the potential 1996 plan. The primary goal was to travel over the Martian surface at a speed of 10 km per day and store the samples as per the instruction signaled by JPL mission control, but the system was partially autonomous (Gage, 1995).

Table 1: The evolution of robotics research involving mobile robots, nature-inspired robots, and robotic arms (Garcia *et al*., 2007)

Robot type	Sub-class	Year
Mobile Robot	Mobile robot	1968
	Multi-robot	1990
Nature-Inspired Robot	Walking robot	1968
	Humanoid robot	1972
Robot Manipulation	Industrial robot	1960
	Flexible automation	1990

Another form of UGV improvement known in the United States is IVHS, Intelligent Vehicle/Highway Systems, which involves enormous economic and technical issues. The environment is no longer more accessible but rather complex due to other vehicles operated by humans, signals, lanes, and safety issues. Dickmann's group based in Münich is considered a leader in autonomous driving on a live highway. VaMoRs-P, a vehicle, drove autonomously on a freeway near Paris in September 1994. It shows that heavy traffic conditions speed up to 130 km/h under different lighting conditions and light rainfall (Gage, 1995; Maurer *et al*., 1995).

AI has been used by research to develop the UGV or autonomous mobile robot since the late 1960s, but it still has many challenges (Gage, 1995). One of the significant advantages of the technological advancement of UGV is that with a bit of modification or without any changes, it is being applied to Unmanned Surface Vehicles. For example, a technology from a man-portable UGV has been transferred successfully to USV by SPAWAR Systems Center San Diego (Ebken *et al*., 2005).

Simulation is a great tool to forecast the system feasibility of a UGV. A study performed a waypoint navigation activity for a mobile robot using the GAZEBO simulator, which gives an idea of an outdoor environment with modeling by Solid works and a control system developed by MATLAB-Simulink (Rivera *et al*., 2019). For all-terrain UGV, Abad *et al*. (2018) developed an algorithm to improve navigation capabilities based on a quasistatic approach and a half-vehicle. The algorithm is based on a simple equation system compared to more complex equations-based algorithms to reduce the calculation time (Abad *et al*., 2018).

UGV has also been used to support farmers in performing automated tasks. One study used a UAV to collect data for a UGV path plan. Georeferenced images are taken from a vineyard with a UAV to create an autonomous path for the UGV by differentiating the vine rows and inter-row terrain (Zoto *et al*., 2019). UAV and the robotic arm can work with the UGV. Another research study simulated and tested using a

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UAV and UGV, where the arm picked the object from the UAV and placed it on the top of the UGV to deliver the objects (Arbanas *et al*., 2016).

Unmanned ground vehicles may have different equipment depending on the manufacturer and research needs. However, there are some general parts, sensors, platforms, control, and human-machine interface (Khurshid and Hong Bing-Rong, 2004; Nguyen-Huu *et al*., 2009). UGV has many components, but the essentials are the platform, sensors, control, and human-machine interface.

Platform: This part has a significant impact on the automation systems. Depending on the environment and surface type, this part defines the power and speed of the robotic system.

Sensors: Humans or living animals have different sensors that work for different purposes and situations. The robot also has different sensors depending on the purpose or the mission. For example, a camera works like the eyes. Image processing and machine learning have been widely used in different areas, including UGV (Garfo *et al*., 2020; Muktadir and Yi, 2021). A Thermal Infrared (TIR) camera is used for the autonomous movement of UGV, which supports day or night. For terrain mapping, pedestrian detection, and tree-trunk detection, the Jet Propulsion Laboratory has used TIR cameras with UGV. However, the daytime speed of a UGV may be different depending on the color camera and TIR due to the resolutions of the camera (Rankin *et al*., 2011). A study developed a system where a UGV can build a wall structure autonomously after understanding the environment and picking up the bricks based on a 3D LiDAR perception system (Lenz *et al*., 2020).

Control: The more innovative the control system, the more autonomous and intelligent the robot will be. The systems' scope is from a simple algorithm to the machine learning model. Nowadays, it is possible to collaborate with robots due to the advancement of control systems.

Human-machine interface: The robot may be controlled with a gamepad or android joystick, speech command, and a computer screen. Ali and Kabir (2021) developed a UGV and its manipulator, an Arduino-based, cost-effective, and serial manipulator. Also, it can be operated with a DualShock - 2 gamepad without using any wire communication (Ali and Kabir, 2021). It is possible to control advanced robots using the gamepad, such as SPOT and DIGIT.

A study created a regional map to categorize the wheeled UVGx worldwide by considering the region and company and further classified it into three groups considering the footprint size, large, medium, and small robots. Table 2 shows a brief (Vieira *et al*., 2022). It is recommended to check or contact the robot manufacturer's website to get updated information.

UGV with Manipulator

The robotic arm attached to a UGV helps the researcher achieve different project goals. For example, Fig. 1 shows that a robotic arm is picking up an object after detecting the circularity of that object from its arm camera. This type of arm may be installed in different UGVs. Depending on the purpose of the end effector or gripper, there may be unique challenges. For instance, the 3D printing system, a suitable gripper with a robotic arm, and a UGV may be replaced in a hot environment where humans are not comfortable working hand-picking. A novel eight Degrees of Freedom (DoF) UGV is attached with a collaborative robot arm named Agri.q02 was developed for the agricultural industry, working in an unorganized environment (Quaglia *et al*., 2019).

Some environments are not suitable for GPS; alternative solutions need UGV in that type of situation. One study developed a system to assemble the elementary bricks from that situation. For instance, detection, segmentation, part segmentation, and object tracking included a deep learning-based multi-task visual perception system. Also, a self-adjusting gripper was designed based on the electromagnetic principle to grip the object. However, the initial accuracy was only 63% from 50 cycles of brick assembly (Vohra and Behera, 2023). Research should consider energy consumption for the manipulator because most UGVs operate on battery power. One study simulated a 3-link UGV manipulator arm by executing typical missions. They found that the total energy savings are 70.9% after simplifying a problem from an n-DOF problem to n 1-DOF and adding energy-minimizing torsion springs (Brown and Ulsoy, 2017). On-track inspection and repair in case of dynamic DOF of joint of the robotic arm and UGV wheels have been investigated by Rahman *et al*. (2021). They developed an unmanned track inspection maintenance system by designing the RIRIS, known as the autonomous Robotic Inspection and Repair System, which can be used for railway maintenance work (Rahman *et al*., 2021).

Table 2: Regional Map and Classification of UGVs

Region	Manufacturer	Robot	Size
North America	Adept technology	Pioneer 3-AT	Medium
	Clear path	Jackal	Small
	Clear path	Husky	Large
	SMP robotics	S-Series	Large
	Robo - team	Probot	Large
Asia	Kuka	Youbot	Small
	Agilex robotics	Scout 2.0	Large
	Agilex robotics	Scout Mini	Medium
Europe	Kell ideas	Leo Rover	Small
	Eca group	Cobra MK2	Small
	Robotnik	Summit-XL	Medium
	Husarion	Rosbot	Small
	Husqvarna	Auto mower	Medium

UGV (Husky A200, JACKAL, Rosbot), SPOT, and DIGIT

This section will include some present research using the mentioned robots.

Husky A200

SLAM, Simultaneous localization, and mapping lie at the core of most cases for autonomous robotic applications. For example, one study developed the feature detection with the Millimeter-Wave (MMW) radar on the top of the Husky A200 and implemented a filter named the Probability Hypothesis Density (PHD) with the SLAM (Adams *et al*., 2014; Dissanayake *et al*., 2001). Another study was conducted to collect the data with an Xsens MTi-3 IMU and Velodyne VLP-16 LiDAR after installing the sensors on the top of the HUSKY A200 (Aybakan *et al*., 2019).

Some locations, such as underground mining and nuclear plants, are not safe places to work for humans. As a result, a UGV may be a suitable replacement or assistant for that job. Research has been done with a larger UGV, the Husky A200. The goal included adding a robotic arm and sensors. To command the behaviors adjusted by the controller, a LiDAR camera was used to track the husky's lateral, longitudinal, and yaw motion (Dekkata *et al*., 2022; Dekkata and Yi, 2019; Dekkata, 2018; 2020). It may be used for rescue operations and inspection. The research studied a Husky A200 robot named Alexander in the mining environment. Many sensors, including a 3D camera, have been used for getting three-dimensional information, reconstructed depth maps (range 1–3 m), and reconstructed colored point cloud maps. That study also shows that it can collect humidity and temperature data along the way (Grehl *et al*., 2015; Scheding *et al*., 1999). Figure 2, a Husky A200 in laboratory environments with some sensors attached.

A digital twin is also essential to check the system's feasibility and inspection or monitoring. In Fig. 3, a JACKAL robot digital twin shows the same action as physical movement. Also, it helps end-users to use the system quickly. Kong *et al*. (2020) presented a digital twin with a DT framework with a Husky A200 and UR5 robotic manipulator in real-time for the manipulator's position and joint angle changes.

JACKAL

The same manufacturer of Husky also makes the JACKAL. Its size is small compared to Husky and its speed is faster than Husky, but its payload capacity is lower. Wang proposed an approach to visualize points of cloud data to Octomap using an RGB-D camera and a UGV (JACKAL). To create the simulation environment, the author used the Gazebo. To operate Gazebo, Robot Operating System, ROS, needs to be installed, which requires the Ubuntu operating system.

Fig. 1: Sawyer picks up an object after detecting it from the camera

Fig. 2: Husky A200 equipped with LiDAR

To get the actual scenario, the author also installed an RGB-D camper in the simulation environment on the JACKAL and used Rviz to visualize, which demonstrates the robot's perception of its world (Koenig and Howard, 2004; Wang, 2020). As part of another study, Scout Bot was presented as a dialogue interface for physical and simulated robots that supports the collaborative exploration of environments with physical and simulated robots. It has been trained on human-robot dialogue by collecting from a Wizard-of-Oz experiment. Also, a UGV (JACKAL) was demonstrated with a simulated environment by ROS (Lukin *et al*., 2018).

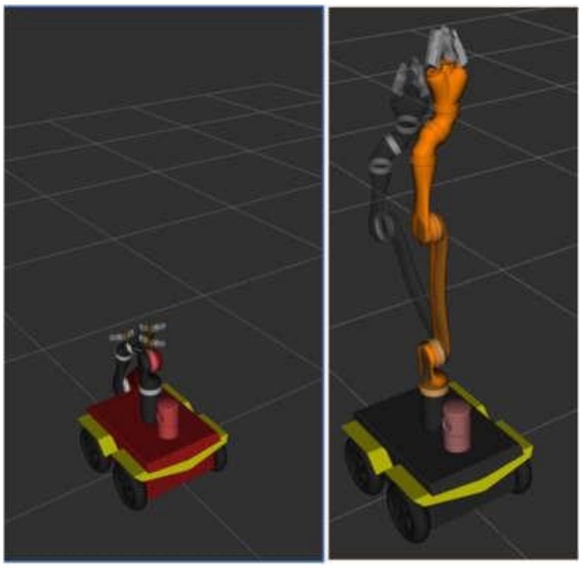

Fig. 3: Jackal with Kinova Gen2 equipped with LiDAR

In the robotics field, vigorous navigation is still an open research field for the UGV. One new low-cost approach involves the use of an odometer and monocular camera to perform robustly in low-light and occlusion conditions. As a result, this type of robot can robustly perform in low light and occlusion conditions. Two such robots, Miro and Jackal, have been used to trial more than 6000 meters of indoor and outdoor environments (Dall'Osto *et al*., 2020). Haofei *et al*. (2017) proposed a Model Predict Controller (MPC) for the Jackal robot to do the local navigation, which makes this UGV move at full speed in a static environment condition without collisions with the obstacles to solve an issue of ROS package for full speed Jackal. Figure 4 shows a JACKAL with a Kinova robotic arm.

Sometimes, a robot needs to navigate in a crowded or dense environment. A novel algorithm, Frozone, has been developed by Sathyamoorthy *et al*. (2020) to overcome the Freezing Robot Problem (FRP). This approach can predict the trajectories of pedestrians and constructs an FRP, where a robot could freeze to avoid a collision. A Jackal robot has been used among the human crowd, which can track and predict pedestrians' positions in the sensing range of the robot and can classify into two zones, potentially freezing and non-freezing, to demonstrate this approach. This approach can also avoid potentially freezing and navigate without any obstacles (Sathyamoorthy *et al*., 2020).

ROSbot PRO

ROSbot PRO is a low-cost mobile robot. A study experimented with their novel algorithm to overcome a local minimum avoidance problem while navigating. For maximum efficiency, the mobile robot should bypass the local minimum instead of jumping off it. The method allows the robot to choose a shorter path than the jumping technique, which may increase the efficiency of the robot and the end-user, for example, industries that use UGV. However, the experiment was done in a laboratory environment (Szczepanski *et al*., 2021). Figure 5 shows the ROSBot Pro with the LiDAR and RGBD cameras. In a research study, a new architecture was developed to provide autonomous navigation on Husarion's Rosbot PRO 2.0 while avoiding obstacles. Also, for testing purposes, that study tried out their work in a virtual world (Soto Pan, 2021).

A challenge of Reinforcement Learning (RL) is training real agents to operate the robot in a real-world environment. Kumar *et al.* (2019) developed a collection of open-access real-world environments named Off World Gym to solve RL's robotics issue. A Husarion Rosbot was also used for the experiment of the API interface, which shows the seamless transition between the real world and the simulation environment (Kumar *et al*., 2019).

Animal Inspired Designed Robot, SPOT

Researchers have been trying to control the movement of the UGV on various types of surfaces, including rough terrain, satisfying the need for smooth navigation with payloads for different purposes. A study designed and proposed a solution by developing a propulsion mechanism by increasing the adhesion of the wheel with the ground of a mobile robot (Gradetsky *et al*., 2018). Quadrupeds may be good options for a wheeled UGV to navigate uneven terrain. Quadrupeds are four-legged robots without wheels. However, one of the complex tasks for a quadruped robot with many joints, such as SPOT, is to stay balanced (Afsari *et al*., 2021). The field of robotics is constantly innovating and improving on designs. SPOT by Boston Dynamics leads the way with new capabilities and many uses for particle applications. It can open doors and walk up and down and second-to-none agility. The user-friendly interface has a touch screen with direct commands that allow SPOT to be controlled easily. The user is not required to participate in the complex dynamics of the various joint speeds and positions.

Accessories can be swapped out to customize SPOT's ability for specific uses. Figure 6 shows a SPOT with a robotic arm. SPOT can complete missions such as picking up, carrying payloads up to 14 kg, and delivering to a particular destination. The use of the fiducials allows the user to program SPOT to complete and save specific tasks repeatedly. SPOT can move laterally, vertically, and horizontally while climbing up and down stairs and operating on rough terrain thanks to its lightweight feature. It can also turn over while on its back and stand up on its own if ever tipped over. Most of the complex demands come pre-programmed for many commands such as walking, crawling, and sitting. When SPOT is in stand mode, a specific task cannot be completed until SPOT is removed from stand mode for safety reasons. The same goes for when SPOT is trying to pick up an object using the pick and place grab tool. The SPOT is a complicated but simple artificial intelligent quadruped (Afsari *et al*., 2021; Zhong *et al*., 2019; Zimmermann *et al*., 2021).

This robot can be modified for many different uses to be used in many different scenarios. It also has a variety of sensors that allow it to operate autonomously and be teleoperated by a person. Robots have always been used to perform repetitive tasks and to replace humans who work in dangerous environments. Due to the ongoing pandemic, the definition of dangerous environments has expanded to hospitals or in contact with individuals that might have an extremely contagious viral infection. In a study, the layout of the robot's operating area was controlled and unchanging. This was due to the precautions taken to ensure the safety and privacy of all the individuals involved. This means that the effectiveness of this robotic system cannot be directly applied to an actual hospital environment where there are a lot more variables. Still, it concludes that currently, SPOT can be used to safely collect health data right now if the paths are clear and don't change (Huang *et al*., 2020).

Another study uses the SPOT robot aimed to improve LiDAR technology by combining sub-maps into one large map based on segmented areas of the scanned environment. This reduced the amount of memory used and the amount of redundant data collection. The robot had a LiDAR camera mounted to it and, as it mapped the three-storied building that it was placed in, created submaps of individual rooms and then combined those submaps where there was redundancy.

It did this for each floor it was on and the result was a map of the entire building with each room marked off which was more accurate than previous iterations. This study showed the SPOT robot's capability to be used as a data collection device that can be used in areas where people live and work and can have minimal restrictions moving around. The LiDAR development gained in this experiment can allow for even more precise and accurate mapping of space and detection, which can be used by autonomous systems when exploring unknown and recently changed environments. The SPOT may be used as a system to collect data that can be used to solve problems while keeping individuals safe from unnecessary risks. This is mainly caused by the addition of sensors to the payload of SPOT, which adds to the functions that it already has. From this, we can see those future innovations will come from seeing this system as a blank canvas that engineers and innovators can use to paint a myriad of solutions to any engineering problem (Islam *et al*., 2020; 2021; Wang *et al*., 2021).

Fig. 4: JACKAL with three fingers robotic arm

Fig. 5: ROSbot PRO

Fig. 6: SPOT carrying an object with its gripper

The biggest development of the SPOT robot is the quadrupedal movement system and the ability to perform tasks autonomously. Numerous studies have been conducted, pushing this system to its limits and seeing where improvement can be made. These studies allow engineers and innovators to figure out how this robot can be used and applied to situations that require long uptimes and that uneven traverse surfaces. The study concerned long-term exploration using a SPOT robot to improve its capability in real-world exercises. This was done using hardware that increased its mapping and autonomous planning capabilities. This robot platform can be made more autonomous without human intervention by improving its autonomy. This increased independence will allow it to be more effective in uncertain situations, such as natural disasters (Bouman *et al*., 2020).

Another study compared the capabilities of the SPOT robot to another four-legged robotic platform developed by Ghost Robotics and a robot with a tread-based movement system. This report determined some difficulties in getting the two-legged robots to work together in areas where the sightlines are limited. The researchers also tested the capabilities of these three robots on various terrains. They found that there are some advantages of a quadruped movement system. Still, these systems were lacking in some areas compared to the tread robot, specifically on surfaces with unstable footholds. While this study suggested that the results should not be directly compared, it showed the limitations of the four-legged movement system of the SPOT robot and others like it, which means that this can be improved upon through either software or hardware improvements. The exciting part about this study was the collaborative aspect of it. The study linked the two robots to travel a tunnel autonomously using a linked sensor system. The paper does not indulge much in this attempt, except for the encountered challenges. However, this presents a path for study in the form of multi-robot collaboration (Tam *et al*., 2021).

Another path that can be explored further is human-robot collaboration. A study published in 2020 looked at the SPOT Robot working in a construction environment, assisting the people working there, and its limitations in this environment. This study had a SPOT robot and a humanoid robot controlled by an operator individually or simultaneously and had each robot perform a different task. The study showed that multi-robot collaboration could be possible using an interface to link the three with human intervention. While this study had the robots operate in a controlled environment that simulated an actual construction site and did not represent the constant flux of conditions and variables, it presented a compelling idea that can be expanded upon (Wallace *et al*., 2020).

With the complexity of the dynamics involved with SPOT, safety is of great concern. SPOT has safety measures to prevent damage to the robot or injury to humans. The manual emphasizes best safety practices and offers much detail. Online instructional videos walk through setting up SPOT properly and outline every safety procedure for any situation. A thorough walkthrough of each step is recommended for anyone planning to operate SPOT. Special soft padding is used in the lab. One note of long-term concern would be the health of the exposed joints of SPOT. The rubber padding sheds and the small pieces may contaminate the joints of SPOT, mainly when it performs a 'sit.' Whenever the user is finished with the SPOT, they must follow the proper steps to shutting down the SPOT and charge the battery after to avoid causing harm to the robot. After use, removing the battery of SPOT is recommended (Afsari *et al*., 2021; Zhong *et al*., 2019; Zimmermann *et al*., 2021).

Human-Inspired Designed Robot, DIGIT

The research on human-like robotics started a long time ago, as, at the end of the 15^{th} century, Leonardo Da Vinci developed a knight that could move its head, wave its arms and sit up. Hisashige Tanaka, a Japanese craftsman, created a toy that could serve tea, fire arrows, and paint in the 19^{th} century, and another Japanese innovator, Makoto Nishimura designed and created a robot in 1929 that could move its hands and head. Following the trend of fully autonomous robots, humanoid robotic research also started in the 20th century. In the 1970s, Waseda University created a humanoid robot, Wabot, known as the flagship of human-type robotic research. After that, several research projects started to develop. The same university developed Wabot 2 in 1980, which can play on an electronic keyboard and can move precisely with its CCD camera and five-finger hands. In 1986, HONDA's research on bipedal robots started and developed many models by developing steps by step, such as walking like a human, stair climbing, head, body, arms, and automatic movement. The updated model is ASIMO, which can walk and run-on uneven slopes and surfaces by avoiding obstacles (Durán and Thill, 2012). Korea's Advanced Institute of Science and Technology (KAIST) has started its development of a humanoid robot with the model KHR-1, a 21 DOF robot. They also developed KHR-2, KHR-3 (HUBO), Albert HUBO, FX-1, DRC-HUBO, and DRC-HUBO+

from the same lab named HUBO (Durán and Thill, 2012; Heo *et al*., 2018; Park *et al*., 2005). Until 2010, iCub; a robotic child, was the only robot that could crawl, developed by the Robot Cub. The height of that robot was 90 cm, the mass was less than 23 kg and the DOF was 53. One of the major objectives of that project was to develop the cognitive abilities of a human child of 2.5 years old. Furthermore, the researchers made everything open source, including design and software (Durán and Thill, 2012; Tsagarakis *et al*., 2007).

Boston Dynamics also developed a bipedal robot, PETMAN. The initial goal was to test the chemical protective equipment. It was tested with the treadmill and turntable to test the walking in the windy environment and the suit was prepared in such a way that it could sweat to examine the physiologic conditions. The updated Boston dynamics humanoid robot, ATLAS, uses 3D printed parts to reduce the weight of and world's most compact mobile hydraulic humanoid robot (Atlas, 2022; Nelson *et al*., 2012).

DIGIT is a great tool for multidisciplinary research areas, such as mapping (SLAM), Brain-Computer interface thru EEG, Human-machine interaction, Gait dynamics (rigid-body and multi-links dynamics) and modeling, sensing and control, Postural and neural systems (rehabilitation), Cyber-physical systems (exoskeleton). This bipedal robot is developed by agility robotics which is the descendant of another robot of agility robotics, Cassie. DIGIT has some updated sensors, including a LiDAR atop the torse, which helps to navigate an environment full of obstacles and helps to navigate on stairs (Hurst, 2019). Here is an example of a DIGIT in stand mode in a lab environment, as shown in Fig. 7. Figure 8 shows that the robot has a digital twin and a 3D object behind it, which helps it avoid obstacles.

Castillo *et al*. (2022) developed and successfully tested on DIGIT hierarchical and robust framework. They also test the feasibility of their method by transferring the simulation work to the DIGIT hardware and realizing walking gaits from an external disturbance force and different challenging terrains such as mulch, vinyl, and rubber (Castillo *et al*., 2021). One of the challenging terrains of a bipedal robot is the suitable surface in a dynamic environment, like trains and ships. A study experimented to calculate the pose and velocity of that kind of environment by introducing a Kalman filter and using different common sensors, RGB-D cameras, inertial measurement units, and joint encoders. A DIGIT robot and pitching treadmill were used for that study (Gao *et al*., 2022).

Fig. 7: DIGIT on a standing mood at the LAB

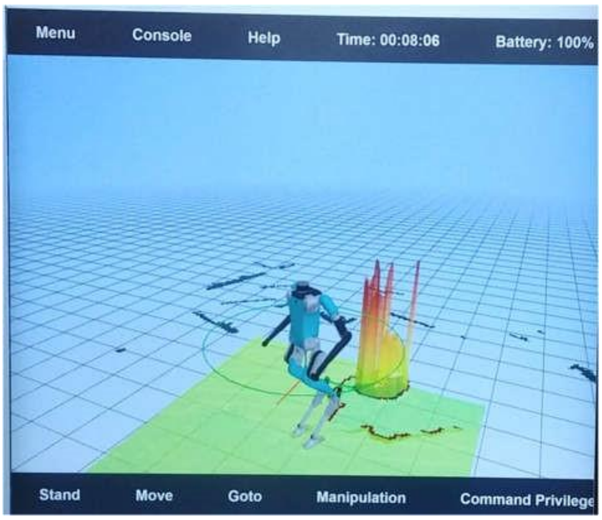

Fig. 8: Digital twin of DIGIT

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Summary

Table 3 shows some important technical information about Husky, Jackal, ROSbot PRO, DIGIT, and SPOT. For further updated information and development, it is recommended to visit the manufacturer's website.

The history of the robotic term, research, and use is not a long story and started from a story in the early 20th century. But the development and use of these tools are increasing rapidly in different fields, including agriculture, medicine, food delivery, food industry, automotive industry, aerospace industry, space exploration, and many more sectors. However, some people may think that robots might replace their jobs. But there is no doubt that tools save human life by doing risky jobs. There are many types of robots, in this study focused on Unmanned Ground Vehicles.

The UGV has been used in some recent research and development. More specifically, Husky, Jackal, and ROSbot UGV have been considered, a type of large, medium, and small size UGV, respectively. Finally, an animal-inspired design robot and a human-inspired design robot have been discussed. It may conclude from Table 3 that some critical parameters, depending on the user requirements, have many options to use for their research and task.

Husky can take more payloads (~165 lbs) compared to Jackal, ROSbot, DIGIT, and SPOT. For economic issues, ROSbot is better for the researcher of UGV. For the manipulation option and economic consideration, Jackal is cheaper than others. But for the speed and uneven surfaces, SPOT is the best. SPOT DOCK makes the robotic field more autonomous. SPOT can charge automatically after a certain mission and do a routine task repeatedly without human control with this charging station. The camera on all sides of this robot can see 360 degrees, images can be captured at any point and the images can be viewed directly from the controller. Legs instead of wheels give SPOT the ability to operate in rough terrain. One application considered is the inspection of a pipe. That may require a LiDAR camera to be installed to scan the pipe's interior. This is one example of many that demonstrate SPOT's versatility and ability to be customizable.

SPOT can be used in some places, like inspecting a large pipe where the surface environment is not dry and may contain moisture or water. SPOT has a place to install the payload capacity, where a 3D scanner is used to create a three-dimensional view for virtual inspection.

However, DIGIT can also move on stairs and navigate a map; for Human-Robot collaboration research, it is suitable to compare the other robots mentioned in Table 3. In the future, to overcome the complicated and time-consuming obstacles of a wheeled robot to research space surfaces, four-legged robots or bipedal robots can be used to explore the environment.

Finally, this study's outcome is to conduct the two types of research in the future. Firstly, CFD analysis. As the robot is designed to assist the human in harsh conditions and emergencies, such as in a hot or windy environment, CFD analysis will be performed to see how different windy conditions affect the dynamic conditions (SPOT and DIGIT) and temperature flow to keep the sensors safe in hot environments (Opoku *et al*., 2020; Uddin *et al*., 2020; Won *et al*., 2015; Yan *et al*., 2019). In addition, reducing carbon emissions will be achieved using renewable energy sources. These energy sources include wind and wave energy. To maintain and inspect that turbine regularly, a robot can be a great alternative (Opoku *et al*., 2022; Uddin *et al*., 2022).

Table 3: Basic technical data of different UGVs, DIGIT and SPOT (it is recommended to visit the manufacturer's website for updated information)

Robot model/ Name	Husky A200	JACKAL	ROSbot 2.0 PRO	SPOT	DIGIT
Robot type	Four-wheel robot	Four-wheel robot	Four-wheel robot	Quadruped robot	Humanoid robots
Manufacturer	CLEARPATH (https://clearpathrobotics. com/husky -unmanned ground-vehiclerobot/), Access on Dec 21.	CLEARPATH (https://clearpathrobo tics. com/jackalsmall-unmanned ground-vehicle/) , Access on Dec 21.	Husarion (https://husarion.co m/ manuals/rosbot/) Access on Jan 1, 22	Boston Dynamics (https://shop.bostondyna mics.com/SPOT?cclcl=e n_US&pid=aDl6g00000 0XdpaCAC), Access on Jan 1, 22	Agility Robotics (https://www.ag ilityrobotics.co m/robots#digit), Access on Feb 22, 22
Operation hour (Normal usage)	~3 h	~4 h	~1.5 h – 5 h	~1.5 h (average) (Without payload)	~2.5 h
Maximum speed	~1.0 m/s	~2.0 m/s	~1.0 m/s	~1.6 m/s	~1.5 m/s
Typical payload	Stereo cameras, LiDAR, GPS, IMUs, Manipulators.	Laser range finders, GPS, FLIR Blackfly camera, 3DM-GX325 IMU, SMART-7 RTK, LiDAR	RGBD cameras, LiDAR	LiDAR, and SPOT CAM, SPOT ARM and different sensors connect with payload options.	Not Available
Max payload	~165 lbs	~44 lbs	~22 lbs	~30.9 lbs	~11 lbs

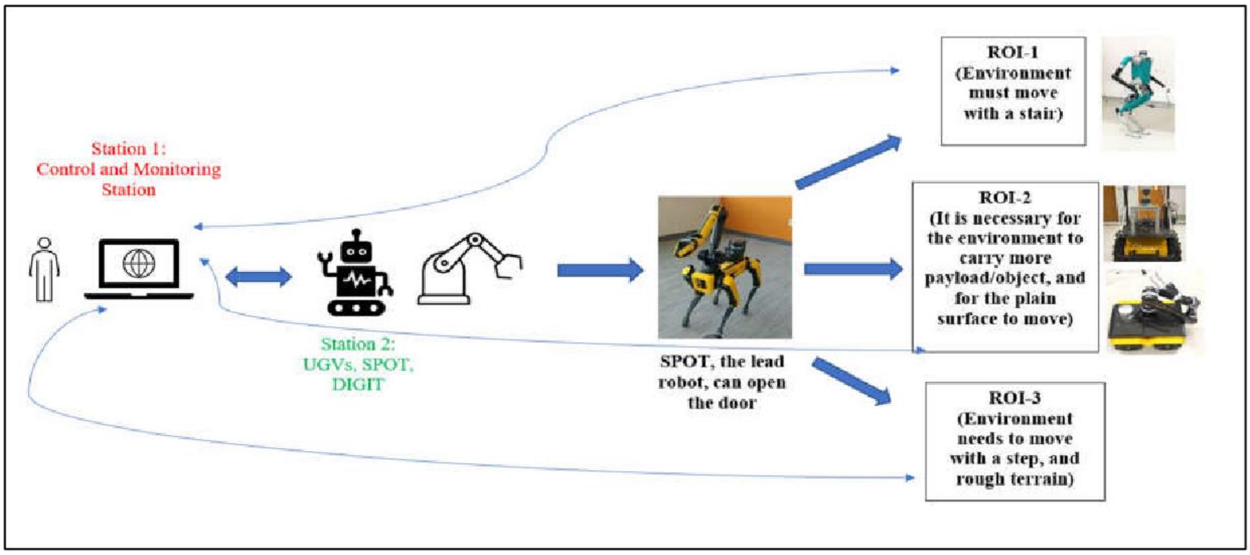

Fig. 9: A future novel research proposal that involves the communication between UGVs, SPOT, and DIGIT

Secondly, communication between robots assists the human operator. In the future, UGVs, DIGIT, and SPOT will be used to assist humans in a variety of situations. Figure 9 shows the schematic plan for the future study.

The first station will monitor and control the entire mission, while station 2 is a robot's docking station, where it will be able to communicate with other robots as the leader of the entire mission. Once the Region of Interest (RoI-1, 2, and 3) has been inspected, other robots will be sent based on the situation. Station 1 will be monitored at all times to capture the data and to monitor the robot's task by the human operator to ensure safety and prevent any bad situations.

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Author’s Contributions

MA Muktadir: Defined the manuscript topic, collected the data, reviewed it, and contributed to writing.

Sun Yi: Reviewed, proofread, and supervised the writing.

Sameer Hamoush: Reviewed and proofread the manuscript.

Selorm Garfo, Xingguang Li, Amanuel Abrdo Tereda and Richard McKee: Proofread and contributed to the writing.

Sai Charan Dekkata: Proofread and contributed to the writing of Husky A200 navigation and control.

Kamar Brown and Normal Klawah: Contributed to the writing.

Ethics

The corresponding author confirms that all the other authors have read and approved the manuscript and no ethical issues involved.

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