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Voyager, a ground mobile robotic platform for research development

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Abstract. This paper describes a mobile ground-based robotic platform named Voyager which was developed to support robotics research and replace the old mobile robotic platform, the Pioneer. A comparative analysis was done with three mobile robot: platforms Pioneer 3-DX, Clearpath Robotics Jackal, and SuperDroid Robots VIPR to determine the requirements for Voyager's development. The Voyager is currently equipped with a 3D LiDAR scanner, inertial measurement unit, and camera to allow for the onboard software to perform obstacle avoidance as well as avoid non-traversable terrain when driving outdoors. This universal platform has been used for developing new algorithms for path planning, obstacle avoidance, localisation, and mapping.

Voyager is a ground-based robot that was built and developed locally in South Africa at the Council for Scientific and Industrial Research (CSIR). The platform is aimed at ground-based robotic research, and is equipped with a multi-beam LiDAR sensor, an industrial-grade inertial measurement unit (IMU), and a camera as the base sensors for the system. Additional sensor payloads can be added to the system and interface through the externally supplied ethernet and USB ports.

Three existing mobile robotic platforms were investigated to compare to the design we developed, namely the Pioneer 3-DX, the Clearpath Robotics Jackal, and the SuperDroid Robots VIPR. The Pioneer 3-DX robot [1] was widely recognized as a popular [2] indoor reference platform for numerous research groups working in mobile intelligent platform research. It is a small customizable and upgradeable two-wheel differential drive [3] robot for research and education purposes. The robot comes standard with a front SONAR, wheel encoders, a microcontroller with ARCOS firmware, and the SDK advanced mobile robotics software development package [1]. This platform has been discontinued and is no longer supported.

The Clearpath Robotics Jackal is a small, fast skid-steer [4] platform for field robotics research intended to be used mainly in outdoor applications. It has an onboard i3 or i5 computer, Global Positioning System (GPS), and IMU [4]. It weighs 17 kg, has a maximum payload capability of 20 kg, and a maximum speed of 2 m/s [4]. The Jackal uses the Robot Operating System (ROS) Melodic drivers and provides power and communication interfaces for adding a wide variety of payloads for research and development [4].

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The SuperDroid Robots VIPR [5] is a configurable indoor autonomous platform. It includes an onboard NVIDIA Jetson AGX Xavier computer, a Hokuyo UST-10LX single beam scanning lidar, an Intel RealSense D435 depth camera, and a UM7 orientation sensor (IMU) [5]. It weighs 26 kg, has a max payload capability of 91 kg, and a maximum speed of 0.58 m/s. The VIPR comes with an established ROS Melodic environment [5].

Most academic research relating to mobile robots for education and research focuses on mobile robots for education at the secondary and undergraduate levels [6]. The focus is on small and low-cost platforms with very limited (if any) ability to add different sensor payloads.

This paper presents the following research contributions:

- Development of a local robotic platform.
- Designed to allow for research in mobile robotics.

In this paper the Methodology and Results will elaborate on the design Requirements, Comparison of Existing Systems, the Development Stages, and Testing. Finally, Section 3 contains the Conclusion of the research.

1 Methodology

This section outlines the engineering techniques used to develop the Voyager mobile robot platform. Section 2.1 gives a detailed description of the Requirements. Section 2.2 covers the Comparison of Existing Systems to the User Requirement Specification (URS) of Voyager. Section 2.3, Development Stages, expands on the Design, Development, and Final Design of the robot.

1.1 Requirements

The Centre had existing Pioneer robots which were used for mobile robotic research, but these robots are no longer supported. The Centre reviewed what was commercially available, see Section 2.2, and decided to develop its own mobile robots with improvements from the Pioneer robots.

From the review of the commercially available mobile robotic platforms and experience with the Pioneer robots, four fundamental design needs were clear:

1. Easily accessible, affordable, mobile robotic technology with local support both in hardware and software.
2. A robotic research platform for testing experimental software that has ROS2 integration, allows for onboard processing, has sensors for mapping, and has a good battery life.
3. A robotic platform that can drive indoors and outdoors on well-maintained tarred roads, pavements, and grass areas.
4. The robot needs to be able to be picked up by two people.

The following URS was derived from the four key design needs and broken down into performance specifications, payload specifications, and base sensors.

Performance Specifications:

- Minimum speed: being able to move 0.01 m/s.
- Maximum speed: 1 m/s.
- Rotational speed: 90 degrees/ s max (for the entire robot).
- Incline: 20 degrees max.

- Size: fit through a standard door 700mm wide.
- Long life between charges: 2 – 4 hrs.
- Operate indoors and outdoors on well-maintained tarred roads, pavements, and grass areas.
- Emergency stop capability.
- Remote controllable.
- Remote software emergency stop.
- Monitoring of motor temperatures and currents.
- Encoders on motors.
- Wi-Fi or other wireless communication: for remote data transfer during run time.
- Computing power: better than an 8th Gen Core i7 embedded board, mini-ITX form factor.
- Weigh less than 35 kg.

Payload Specifications:

- Payload connectors: Ethernet, two power outputs, and USB.
- Allow for a payload of up to 10 kg.
- Payload space for additional sensor and computing components.

Base Sensors:

- Camera.
- Multi-beam LiDAR.
- Industrial-grade IMU.

1.2 Comparison of Existing Systems: Pioneer, Jackal, and VIPR Compared to the Requirements of Voyager

Three Unmanned Guided Vehicles (UGVs) were reviewed to compare the user needs for a robotic research platform in South Africa. Table 1, shows a summary of the three UGVs reviewed. The requirements are from Section 2.1 and have been further broken down into key performance parameters for each requirement.

Table 1: Comparison of Pioneer, Jackal, and VIPR to the requirements specified for Voyager

Requirements	Key Performance Parameter	Existing UGV		
		Pioneer [1]	Jackal [4]	VIPR [5]
1	Support in South Africa for hardware and software.	No local support is available.	No local support is available.	No local support is available.
	Affordability	Cannot purchase anymore.	Range from mybot shop €17 492.95 to €22 995.00.	Start from $21 800.
2	ROS2 integration	No native ROS or ROS2 capabilities.	Only older ROS packages supported.	Only older ROS packages supported.

	Onboard processing PC	Only available as an optional add-on.	Has an onboard PC but only Core i3 or i5 processors.	Has an onboard PC but only Core i3 or i5.
	LiDAR and IMU for mapping	LiDAR and IMU only as optional add-on.	A 10-Meter 2D LiDAR and IMU are available as an add-on in the additional "Explorer" package.	Has a LiDAR but only 2D and a limited 10-meter range, no IMU provided.
	Battery Capacity	8-10 hours	4 hours	Not specified
3	Indoor driving	Intended for indoor operation only.	Indoor operation on rubber floors with this type of drivetrain is very difficult.	Intended for indoor operation only.
	Outdoor driving	Cannot operate outdoors.	Is an outdoor robot.	Cannot operate outdoors.
4	Weight	9kg	17kg	26.3kg

Concluding remarks relating to the review: Support in South Africa for hardware and software performance parameter 1 is not met for all three robots, and the Jackal and VIPR are relatively expensive for the South African market, Voyager's cost is estimated to be R300 000.00. LiDAR specifications are also limited despite the higher costs of the existing UGV's. The performance parameter 2 for ROS2 integration is also not met for all three robots. It was therefore decided that a local, low-cost UGV is needed in South Africa for research and development.

1.3 Development Stages

The development of the robotic platform involved starting with multiple concept designs. These designs were then reviewed and the concept that best met the requirements was prototyped to test aspects such as active vs passive steering as the robot needed to function both indoors and outdoors. The insights gained from this were then used to develop version 0 of the robot, for initial testing, from here iterative improvements were made to create versions 1 and 2 of the platform, which then lead to the final design presented in this paper.

1.3.1 Design Development

As part of the concept design phase, several concepts were developed and evaluated for their suitability. In terms of the drive kinematics, differential steering was chosen over Ackermann due to its smaller turning circle offering more manoeuvrability in tight spaces [7,8]. Differential steering was chosen over skid steering due to its advantage of lower power needs [7,8] and because skid steering can cause damage to surfaces, like carpets, and as such is not ideal for indoor use [7,8]. An initial prototype was developed to test active steering versus passive steering, this prototype can be seen in Fig**. 1**.

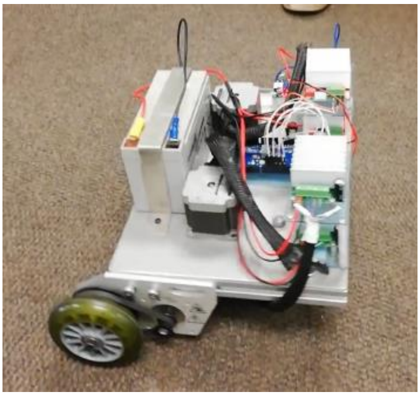

Fig. 1. Voyager initial prototype used to test steering methods.

To assess the differences between active and passive steering, the prototype was tested by having it drive on a paved surface. From visual inspections, the prototype with active steering was found to be more stable than the version with passive steering, as the version with passive steering would occasionally be affected by objects, such as stones, that were in its path. The improved stability of the active steering over the passive steering, as well as the project requirement for the robot to be able to drive outdoors, lead to the development of version 0 of the robot, which had active steering.

From version 0 to version 1, the focus was given to weight reduction, ease of manufacturing, and assembly. To reduce weight, the robot's size was reduced, and some components were replaced with smaller, more lightweight components, for instance, the active steering motors were changed to a smaller form factor of stepper motors with a reduction gearbox. Changes from version 0 to version 1 resulted in a weight reduction of at least 23%. The aesthetics of the robot were also improved by adding an exterior fiberglass shell. Fig. **2** depicts version 0 of the robot, undergoing steering tests on different surfaces. The three versions 1 robots that were constructed can be seen in Fig. **3**.

Fig. 2. Voyager version 0 undergoing active steering tests.

Fig. 3. Voyager version 1.

Having three fully built version 1 robots, it was decided to re-evaluate the benefits of active steering versus passive steering. One of the version 1 robots was converted to passive steering. The two robots (actively steered and passively steered) were then driven around the CSIR campus to compare their operation. The robots were driven over various terrains, such as rubber floors, tarred roads, grass, loose soil, and gravel. From these tests, it was found that, visually, both robots performed similarly, with the active steering only providing a marginal improvement in stability at times. Compared to passive steering, active steering was found to bring about certain disadvantages, such as increased system complexity, increased weight, increased power consumption, increased cost, and slower response times when performing certain functions, such as turning on the spot. It was therefore decided that the disadvantages of active steering outweighed its minor advantage. This led to version 2 of the robot being designed with passive steering.

Version 2 of the robot is currently being manufactured. Minor design changes based on component availability and learnings from using the three version 1 systems have been incorporated into version 2. Some of the custom components were replaced with commercial off-the-shelf (COTS) components to lower the cost and lead time of manufacturing the robot. Version 2 of the robot will be used by other research institutions as a base platform to implement their own research. A render of version 2 of the robot can be seen in Fig. **4**.

Fig. 4. Render of Voyager version 2.

1.3.2 Final Design

The latest design of the Voyager robot is version 2, which as mentioned in Section 1.3.1, is currently being manufactured. In terms of electronic design and functionality, the robot uses a single battery pack with a built-in battery management system. It has a charger that allows for the battery pack to be charged within the robot, while also keeping the robot powered (except for the motors). The robot provides its own Wi-Fi access point which allows researchers to connect to it and wirelessly transfer data from the robot or troubleshoot software. It has a payload connector that provides battery voltage, 12V, and 5V, allowing researchers to power varying types of payloads that they may require for their research. Panel-mounted HDMI, USB, and Ethernet connectors are provided at the top of the robot. This allows researchers to connect a screen, keyboard, and mouse to the robot's PC, giving them direct access to the internal computer when required. These panel mount connectors can also be used to connect different types of payloads to the robot’s PC. The base robot includes a LiDAR, IMU, and camera, allowing researchers to start developing mapping and localisation algorithms out of the box.

In terms of the mechanical design and functionality, the robot is driven by two brushless DC motors that independently control the two drive wheels, this in combination with the castor wheels gives the robot the ability to turn around any point on a line passing through the axis of the two drive wheels. The increased manoeuvrability is ideal for research in autonomous platforms. The robot is also supplied with four mounting points to attach a modular payload mount, thus enabling researchers to mount their own payloads on the platform. A labelled render of the latest version of the robot can be seen in Fig. **5**.

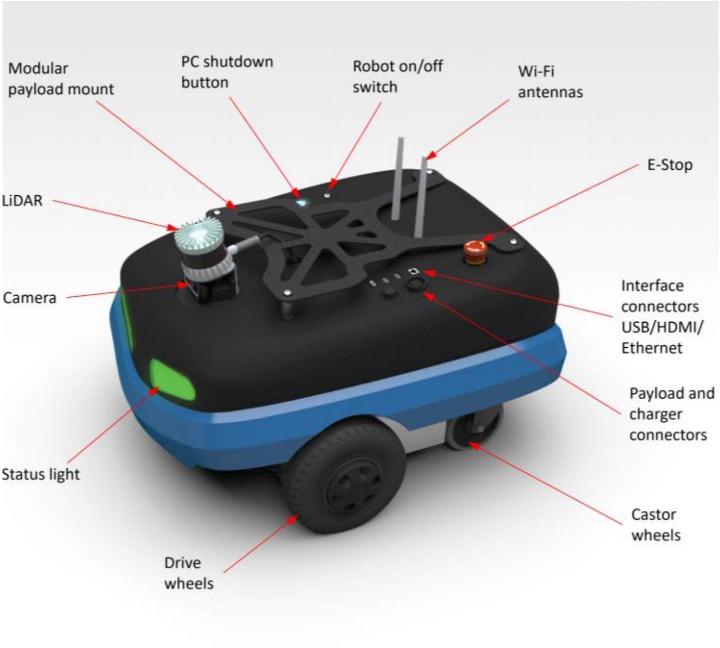

Fig. 5. Labelled render of Voyager version 2.

2 Results

This section outlines the testing done to determine if all the URS is met and to evaluate how the robot operates in a real-world environment. Section 2.1, Testing, covers the URS Tests and Sensor Tests.

2.1 Testing

In Section 2.4.1, User Requirements Specification Verification and Testing, the robot is tested against the URS to determine if the robot has been designed and manufactured to meet all the requirements. Section 2.4.2, Sensor Tests describes the sensor testing and overall testing of the Voyager robotic platform.

2.1.1 User Requirements Specification Verification and Testing

To determine if the Voyager robotic platform meets all the requirements, various tests were performed with the robot in the laboratory and outdoor environments.

To test the performance specifications of Voyager, different driving tests were done with the robot. To test the maximum and minimum speed of Voyager the robot was driven a known distance and the time it took to travel that distance was recorded. The calculated value was verified against the software speed calculation. The speed was software limited to 1 m/s to meet the requirement, however, if the software limit is removed it can reach a speed of 2.5 m/s. The minimum speed the robot can drive is 0.01 m/s, however, the motion of the robot is not smooth. The minimum recommended smooth speed is 0.03 m/s. To measure the robot's rotational speed the robot was rotated 90˚ and the time it took to rotate the 90˚ was recorded. The calculated value was also verified against the software rotational speed calculation. The rotational speed was software limited to 90˚ per second, however, if the software limit is removed it can reach a speed of 180˚ per second.

To determine if the platform can drive up the required incline of 20˚ the robot was driven up an incline with and without a payload of 18kg. The robot was first tested on a 10˚ incline, which it was capable of driving up. It was then tested on a 20˚ incline and the robot could drive up the incline in reverse but failed to do so while driving forward due to slippage. The robot has enough torque to drive up a 20 ˚ incline but the positioning of the drive wheels at the front of the robot causes the weight distribution of the platform to shift towards the castor wheels at the back, while the robot is driving forward on the incline, causing a reduction in traction at the drive wheels. When driving in reverse the opposite happens because the drive wheels are now at the bottom of the incline and will experience more traction. With an evenly distributed payload, no noticeable difference could be seen in slippage with or without the payload. A ramp was set up to test the maximum incline the robot can drive up on. The ramp was made from tread plate. The ramp started at 12˚ and was gradually increased to 18˚. All inclines below 18˚ were successfully traversed, at 18˚ the robot could drive up the incline in the forward direction, but it experienced some slip, especially at the start of the movement when the platform is accelerating. Fig. **6**, depicts the incline test done in the forward and reverse direction and the payload test to determine the maximum payload of the robot.

Fig. 6. From left to right, incline test, incline test in reverse, payload test.

The robot is also required to be able to drive through a standard door with a width of 700mm, thus the robot measures 600mm in width at the widest part. The weight of the robot without a payload is 33kg. The ability of the robot to drive on different terrain both indoors and outdoors was tested. The robot was driven outdoors on well-maintained tarred roads, pavements, and grass areas. Indoors the robot was driven on rubber floors, tiles, carpets, and wooden floors. The robot could drive on all the mentioned indoor and outdoor terrain.

To test the battery life of the platform, the robot was driven around and the amount of time it could drive around before requiring a recharge was recorded. After reaching 8 hours the battery was not fully drained, the test was ended as double the requirement time of 4 hours was reached.

For safety the robot is required to have an emergency stop capability. The robot has an emergency stop on the body of the robot and a remote software emergency stop using the red B button on the wireless game controller used to control the robot. It was verified that pressing the emergency stop on either the robot or the remote control resulted in the robot stopping, as intended.

The following electronics and sensors form part of the platform to satisfy the requirements. The robot's two drive motors are fitted with incremental encoders and temperature sensors and allow for current monitoring through the motor controller.

The robot provides its own Wi-Fi access point which allows researchers to connect to it and wirelessly transfer data from the robot or troubleshoot software. The computing power is provided by a Core i9-10900TE embedded PC with 32 GB of RAM in a mini-ITX form factor.

The robot is fitted with three base sensors, an Xsens MTi-630 IMU, Ouster OS0 32-beam LiDAR, and a C920 HD webcam.

To meet the payload requirements the platform was fitted with connectors accessible through the body of the robot comprised of a power connector providing, 12 V, 5 V, and battery voltage, one Ethernet, two USBs, and one HDMI connector. The payload connectors offer ease of use to connect a screen, mouse, and keypad for debugging or programming and allow for additional sensors to be connected via Ethernet or USB and the payload can be powered by the 12V, 5V, or battery voltage depending on the power requirements of the payload. The robot can carry a payload of at least 18 kg and this can also be carried up an incline of 20° in reverse or 18° in the forward direction. The final robot design has been designed to include a payload mounting plate that allows for a payload to be mounted easily on the robot.

2.1.2 Sensor Tests

The robotic platform supplies a base that can be used for a multitude of research applications, including mapping, vision systems, and other autonomous research activities. The base platform includes a multi-beam LiDAR for mapping and obstacle detection. For other research applications, custom payloads can be added. The robotic platform provides access to its built-in sensors through ROS2 [9] drivers. These sensors include a LiDAR, camera, IMU, battery state information, wheel encoders, and temperature sensors. The array of sensors provides a good basis for users to create their own algorithms and programs.

The Voyager platform also includes a 3D LiDAR-based SLAM package, lidarslam_ros2, for 3D mapping and localization. The LiDAR SLAM successfully generated 3D point-cloud maps in varying conditions and at very different scales. An example of a point-cloud map created inside the Centre for Robotics and Future Production (CRFP) laboratory by the robot during testing can be seen in Fig. **7**.

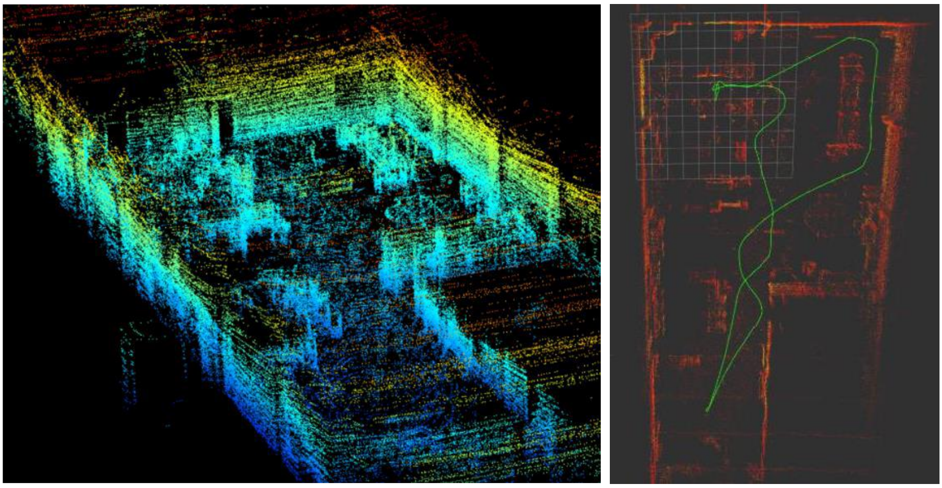

Fig. 7. A 3D point cloud of the CRFP lab (left) and a top view showing the robot path (right).

Voyager also successfully performed SLAM over a long distance in an outdoor environment. Voyager created a map while driving between two buildings on the CSIR campus over a total trip distance of approximately 900 m. Overlaying the generated map on a Google Earth image of the campus shows a very good alignment of the map features with the building features as shown in Fig. **8**. The map was generated only using the LiDAR SLAM without any global sensors such as GPS. The generated map also includes good detail of the features along the path such as the parking lot and the cars in it shown in Fig. **9**.

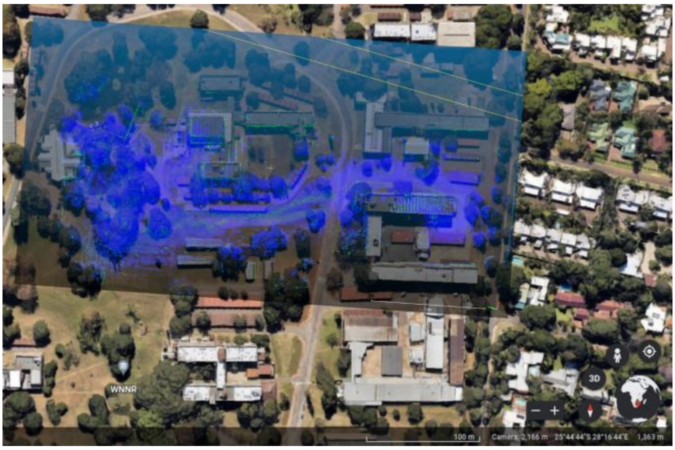

Fig. 8. Top view of the 3D map overlayed on a Google Earth view of the CSIR campus.

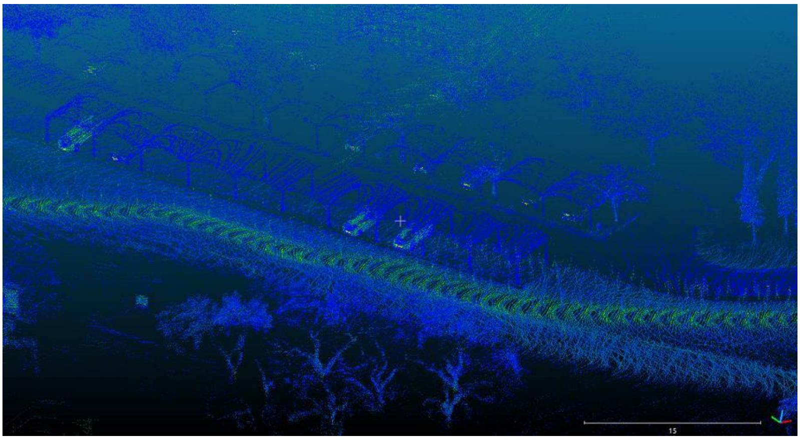

Fig. 9. 3D point cloud of the carports and the cars in the middle of the campus map.

3 Conclusion

The need for a local South African mobile robotic platform at the CSIR, that allowed for research and development, was achieved with the successful development of Voyager.

It can be concluded that the four key performance parameters and design needs are met. The robot is easily accessible and affordable for the local South African market and offers local support in both hardware and software. The robotic platform can be used to test experimental software with its sensors and onboard software already integrated. Voyager can be used as a test platform for path planning, obstacle avoidance, localisation, and mapping, in indoor environments as well as some outdoor environments, such as relatively short grass or well-maintained tarred roads and pavements. The platform is as lightweight as possible as through the different versions the weight was reduced by removing unnecessary components.

Voyager also met all the user requirements that the robot was required to meet. The following requirements outperformed the user requirements: battery life, maximum speed of the robot, rotational speed of the robot, and payload capacity of the robot.

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