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DEVELOPMENT OF A VOICE-CONTROLLED ROBOTIC VEHICLE TO ENHANCE HUMAN-ROBOT INTERACTION

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ABSTRACT

This paper focuses on enhancing the functionality of robotic machines for operation in challenging environments through the integration of voice commands. This will help in solving the problem of disabled persons who suffer from a variety of physical mobility challenges and make work easier for other people. The central objective is to improve human-robot interaction by employing a system composed of components such as the L293D motor driver, HC-05 Bluetooth module, Arduino Uno microcontroller, jumper wires, battery, and ultrasonic sensor. The robot's movement and control are orchestrated through a speaker, allowing it to respond to vocal instructions mimicking human speech frequencies. This interaction is facilitated by a Bluetooth module, establishing a connection between the microcontroller and Android devices for the reception of voice commands. The robotic vehicle incorporates an ultrasonic sensor to navigate and avoid collisions with obstacles. Voice commands were converted into text through a Google text application and transmitted to the microcontroller, guiding the robot based on user instructions. Several tests were conducted, including hardware assembly, voice command interpretation, voice command variability, Bluetooth distance, ultrasonic sensor reliability, and robustness tests in lighting and weather conditions. Results indicate a successful design, construction, and implementation of the voice-controlled robotic vehicle, meeting the project's primary objective. Noteworthy findings include the impact of environmental noise and accents on voice command detection and Bluetooth reliability over varying distances. The vehicle demonstrated excellent performance across diverse conditions, highlighting its potential contributions to the fields of robotics and human-machine interaction.

Keywords: Robotic Machines, Human-Robot Interaction, Voice Commands, Arduino Uno Microcontroller, Innovative Technology.

1. INTRODUCTION

The inception of the field of robotics can be traced back to the 1950s. Since then, more than six decades have passed, but the progress of robotics has been remarkable and unmatched. In the contemporary world, robots have become ubiquitous, finding applications across various domains, including healthcare, the military, education, and governance. Robotics has evolved into a versatile assistant for humanity, significantly simplifying and enhancing our lives [1]. It was actually impractical to control hardware utilizing speech until recent times [2]. The development of a voice-controlled robotic vehicle holds great promise and importance, especially for individuals with disabilities who are unable to operate a vehicle independently [2]. The implementation of a Bluetooth module (HC-05) establishes a link used for communication between the vehicle and human voice commands via an Android application. The Bluetooth system can receive human voice commands, converting them into encoded digital data for effective communication over a considerable range of meters from the vehicle. The receiver deciphers the data before forwarding it to the Arduino Uno to drive DC motors through the L293D motor driver [2].

Several communication interfaces, including USB, Wi-Fi, and Bluetooth, are available on Android devices and can be used to connect to the robot [3]. The application and use of a smart device or phone as the brain of a robot is already a very active research field with different and numerous open opportunities and promising essential possibilities. The potential of agricultural robotics and its broader implications was explored in [4]. Their study delved into the economic, ethical, and policy aspects of incorporating robots into agriculture. The research considered factors such as environmental impact, cultural context, and security implications, aspects often underrepresented in the existing agricultural robotics literature. To develop an unmanned lawnmower with obstacle detection and avoidance capabilities, the system employed modules for infrared and ultrasonic sensing positioned at the lawnmower's front to identify obstacles by utilising both light and sound waves. An Arduino microcontroller processed the sensor data, achieving an accuracy rate of 85% and a low probability of failure at 0.18% [5].

A system for wirelessly operating a robot remotely through an Android application was developed to display a live video feed captured by the robot's camera, with buttons for controlling the robot's movements. The research indicated minimal processing time for smartphone commands and high-quality video output at up to 15 frames per second [6]. An Android OS and a Raspberry Pi circuit board connected via Wi-Fi were used in designing an application to control a robotic hand using a smartphone. The robotic hand aimed to mimic human hand movements, and the Wi-Fi connection addressed issues related to delay and server problems encountered with internet-controlled techniques [7]. An AI-based autonomous voice-enabled robot with real-time object detection and collision avoidance using Arduino was designed [8], but the voice used did not introduce Nigeria's local languages, which were considered in this paper.

2. MATERIALS AND METHOD

The major components used in the this work include Arduino Uno microcontroller, HC-05 Bluetooth module, the L293D motor driver, jumper wires, battery, and ultrasonic sensor and the android application.

2.1. Arduino Components/Pins Used for The Project

With the Arduino Uno directly connected to the motor shield, the pins used in this project are;

i. Motor power supply terminal:
This terminal is where the battery are connected to power the robot vehicle's motors.

ii. Power supply selection jumper:
This jumper is used to ensure that the Arduino Uno is properly connected to the motor driver shield for power distribution.

iii. DC motor connector pins:
These are connectors for the DC motors. They allow you to connect the four motors to the Arduino.

iv. USB connector:

This is a USB port used for connecting the Arduino board to a computer. It can be used to load programs from the Arduino Integrated Development Environment (IDE) into the Arduino board, and it can also be used to power the board.

v. Analog input pins:

The ultrasonic sensor and the Bluetooth module of the voice-controlled robotic vehicle are connected to the analog input pins. These pins are used for receiving sensor data and other analog input signals.

2.2. Pins of the Bluetooth Module Used

The pins of the HC-05 used in this project are:

i. TXD pin: It functions as the Transmit Serial data pin, sending data wirelessly that is received by the Bluetooth module.
ii. RXD pin: This pin is responsible for serially receiving data. The data received here will be transmitted wirelessly by the Bluetooth module.
iii. GND pin: This is the ground pin, providing an electrical connection to the ground.
iv. VCC pin: It is used to supply power to the Bluetooth module, which can be either 5 V or 3.3 V, depending on the module's requirements.

2.3. Pairing the Smart Phone and the HC-05

1. Ensure that power is supplied to the Bluetooth module
2. Initiate a search for new Bluetooth devices from your mobile phone. During the search, you should be able to discover a device named "HC-05".
3. Click on connect and pair device. Enter the password as provided.

2.4. The pins used in the HC-SR04 ultrasonic sensor

i. VCC: The VCC pin powers the HC-SR04 ultrasonic sensor, linking to the Arduino to supply the requisite 5 volts.
ii. Trig (Trigger) Pin: This pin triggers the emission of ultrasonic pulses. A HIGH signal for 10 microseconds causes the sensor to release an ultrasonic signal.
iii. Echo Pin: This pin becomes high during the transmission of the ultrasonic signal and stays high until an echo is detected, at which point it reverts to low.
iv. GND (Ground): The Ground pin connects to the Arduino's ground, establishing the necessary circuit completion for the sensor.

2.5. Battery and Battery Holder

Four 3.7 V batteries connected in series were placed in a battery holder.

2.6. Block diagram of the robot vehicle

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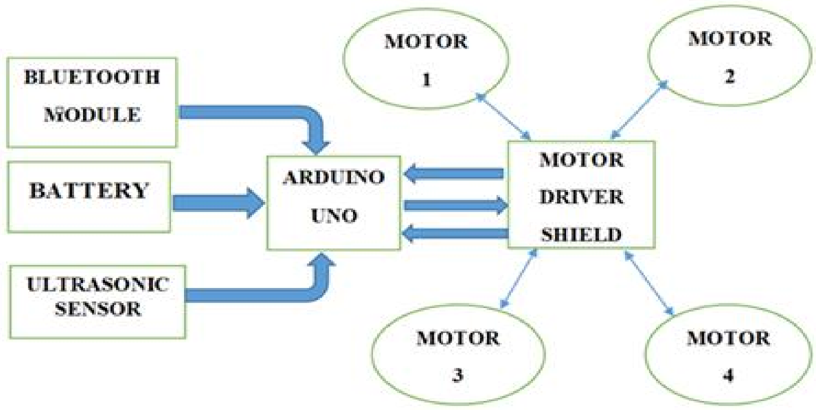

Figure 1: Block diagram of the robot vehicle

2.7. Flowchart of the project

Figure 2 shows and describes the flowchart of the voice controlled robotic vehicle.

Android application for the project

We created an android application called "VCRV app" that was used for this project. The application development environment utilized for creating this app is MIT App Inventor. MIT App Inventor is designed using various languages, including Java, Swift, Objective-C, Kawa, Scheme, and JavaScript. It employs a graphical user interface (GUI) that bears resemblance to programming languages like Scratch and StarLogo. The voice command was incorporated in the app created for the project using Google text to speech algorithm. Within this development environment, application development is divided into two distinct sections. One is the designer section and the other is the block section. Figure 3 is the final look of the developed application. That is, how it appears on the phone of the user.

2.8. Simulation of the Voice Controlled Robotic Vehicle

The simulation utilizes Proteus which is a powerful tool for the virtual prototyping and simulation. The robotic vehicle is modeled with necessary sensors, actuators, and motors, akin to its real-world counterpart. By integrating the voice recognition module within the simulation environment, the vehicle can effectively respond to voice commands based on pre-established control logic. Figure 4 shows the schematic capture of the simulation of the voice controlled robotic vehicle.

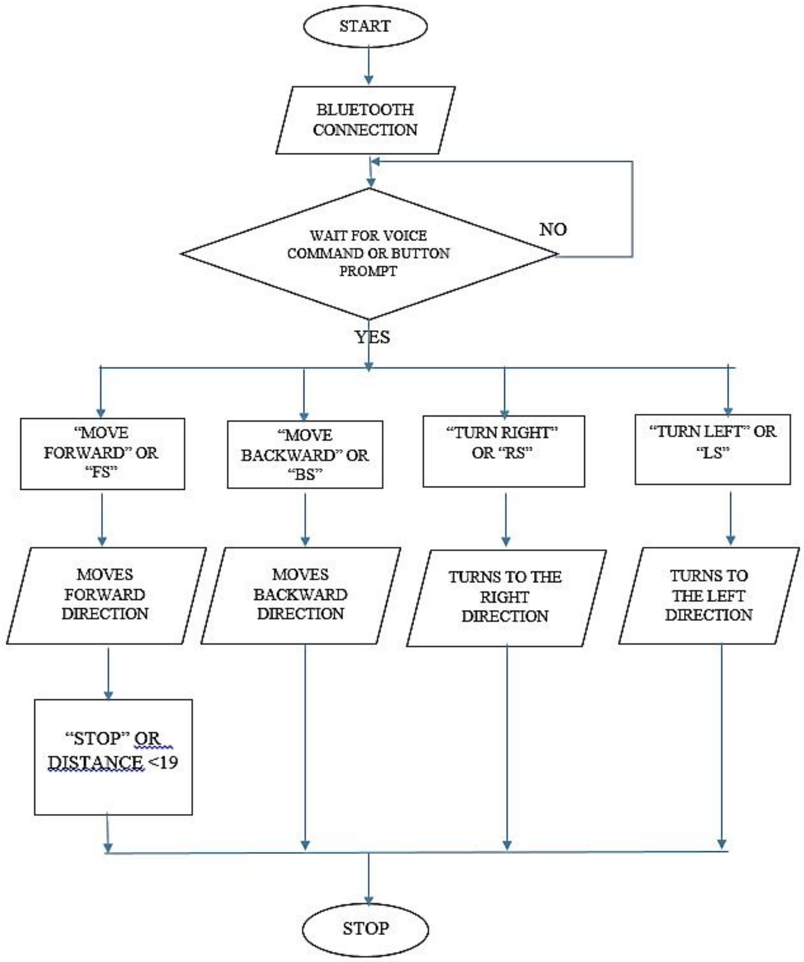

Figure 4: The schematic capture of the simulation of the voice controlled robotic vehicle

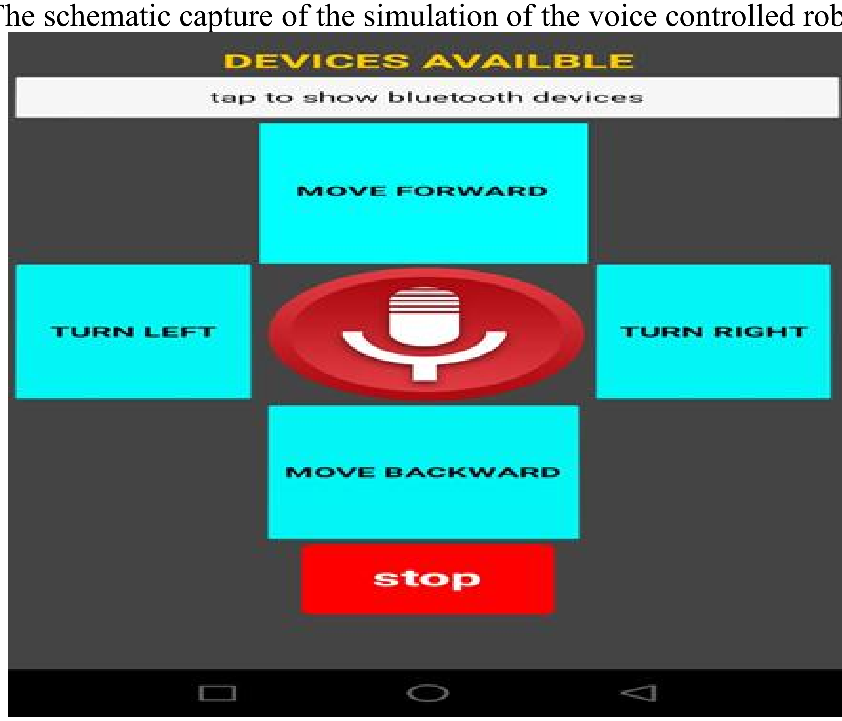

Figure 3: Final look at the working application in an android phone.

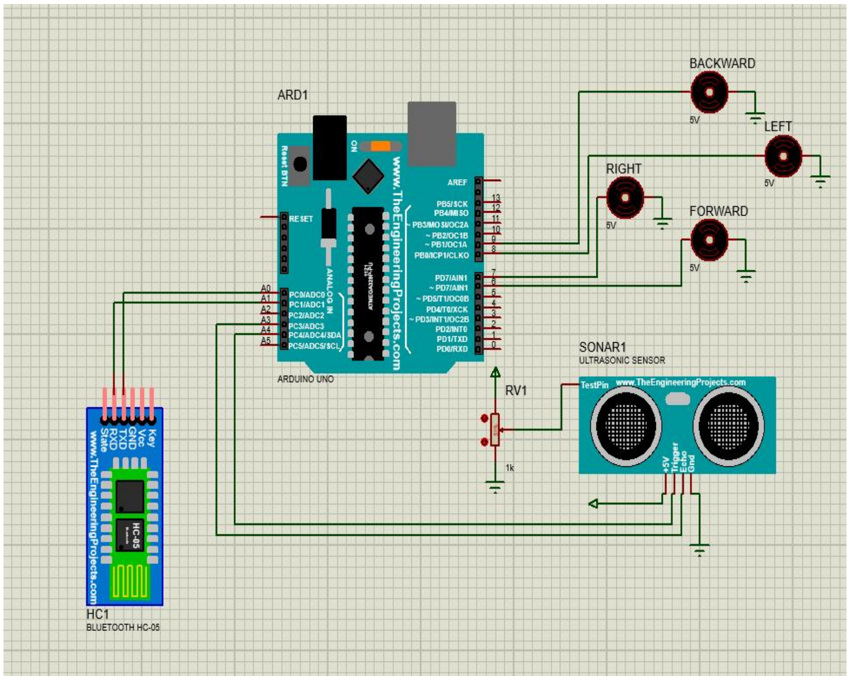

Figure 4: Schematic capture of the simulation

2.9. Hardware Implementation

The vehicle chassis implemented chassis is of 25.5 cm in length. It was ensured it has the right holes at the right places for the various connection of the vehicle components. The diameter of each rubber tyres used is 6.5 cm. Four batteries connected in series with each voltage of 3.7 volts were used and the whole components were operating properly. Figure 5 shows the fully connected voice controlled robotic vehicle.

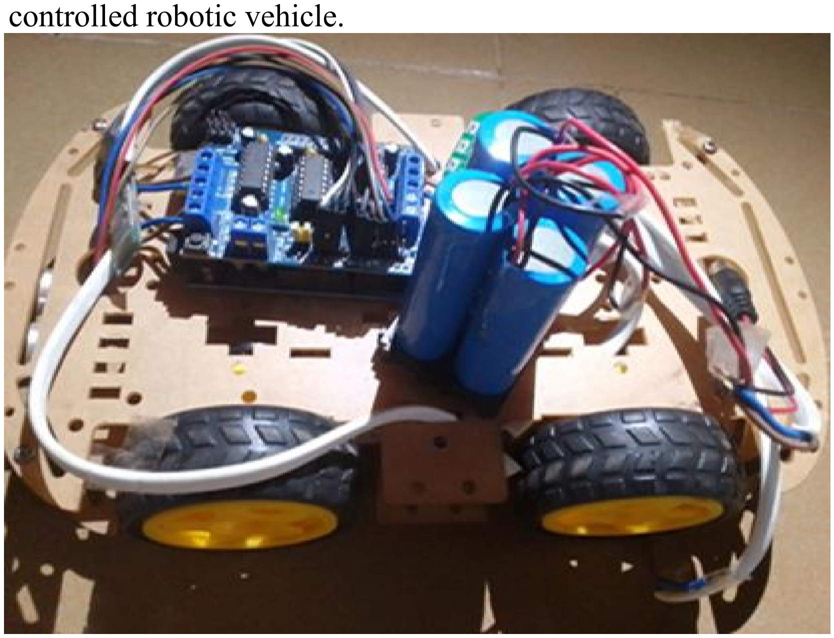
Figure 5: Fully interconnected voice controlled robotic vehicle

2.10. Tests Carried Out

Various tests comprising voice command interpretation, voice command variability, module reliability and robustness tests were carried out.

a. Voice command interpretation

To conduct the voice command interpretation test, the robotic vehicle was set up in three different environments. The various environment includes:

i. Environment 1: The first environment was a room with minimal background noise and interference.
ii. Environment 2: The second environment was a room with loud musical noise played by an mp3 player.
iii. Environment 3: The third environment was a room filled with 6 people making random statements at the top of their voices.

b. Voice command variability

In this test, six respondents were used, in which they used different accents to pronounce each voice commands twice.

c. Module reliability

This test include the Bluetooth distance test and ultrasonic sensor reliability tests

d. Robustness test

The various lighting conditions considered are;

i. Light condition 1: In an open space under the sunlight between 12:00 pm to 14:00 pm.
ii. Light condition 2: In a room with the light bulbs switched off.
iii. Light condition 3: In a room with the light bulbs switched on.

The various weather conditions considered are;

i. Weather condition 1: In a cool room that has, air conditioner set at 18 degree.
ii. Weather condition 2: In an open space under the sunlight at 15:00 pm.

3. RESULTS AND DISCUSSION

3.1 *Result of Voice Command Tests*

Table 1 shows the data collected which includes the response time, accuracy rate, and any error occurrences.

Table 1: Voice command interpretation tests in the various environments encountered.

Test environment	Error encountered	Response time	Number of attempts	Accuracy rate
Environment 1	Inconsistent Speech Volume.	<1 second	10	90%
Environment 2	1. Background Noise Interference 2. Distorted Audio 3. Inconsistent Speech Volume	<1 second	10	60%

Environment 3	1. Speech Overlapping 2. Background Noise Interference 3. Inconsistent Speech Volume 4. Speaker Variability	<1 second	10	20%

It is observed from Table 1 that the voice controlled robotic vehicle does excellently well in an environment with minimal background noise. It does averagely well in a room with musical background from a music player and it performs terribly in a room with noises from humans.
It was also observed that voice controlled robotic vehicle does not respond to other commands other than the exact defined commands, which are “move forward”, “move backward”, “turn left”, “turn right” and “stop”. This implies that unless the user knows the exact predefined words, the vehicle would be inoperable using the voice commands thereby increasing its security. Upon inputting an uncommon, unexpected or unregistered voice command to the voice controlled robotic vehicle, it does not give any response. Table 2 shows the voice command variability test carried out on the voice controlled robotic vehicle.

Table 3: Voice command variability test

User	Accent language	Number of attempts	Accuracy rate	Voice command error	Misinterpreted command
User 1	Yoruba	10	100%	Nil	Nil
User 2	Yoruba	10	87.5%	Turn right	Turn write
User 3	Igbo	10	100%	Nil	Nil
User 4	Igbo	10	100%	Nil	Nil
User 5	Hausa	10	50%	Move forward Stop	Move powered Stuff
User 6	Hausa	10	50%	Move forward Stop	Move powered Stuff

It was observed from Table 2 that although the same English words were pronounced using Yoruba, Igbo and Hausa accents, the voice controlled robotic vehicle did exhibit a good level of linguistic understanding. This means that the voice controlled robotic vehicle is user-friendly in understanding and accurately interpreting and executing a wide range of commands. This work compared favorably with the work of [8] and also tested the vehicle using three indigenous languages accents which [8] did not consider.

3.2 Bluetooth Distance Test Result

Table 3 shows the recordings made at each meter intervals.

Table 4: Bluetooth Distance Test Result

Distance range (meter)	Voice command given	Response time	Error encountered
0	"Move forward" "stop" "Move forward" "turn left" "turn right"	<1 second	No error encountered
8	"stop"	1 second	Delayed response
	"Move forward"	1 second	Delayed response
9	"stop"	2-3 seconds	Delayed response
9 < distance < 10	"Move forward"	2-3 seconds	Delayed response
10	"stop"	No response	Robotic vehicle not responding to voice commands
>10	"stop"	No response	Robotic vehicle not responding to voice commands

As indicated in Table 3, it can be noted that the voice-controlled robotic vehicle exhibits responsive behavior to commands up to a distance of approximately 8 meters. However, beyond a distance of 10 meters, the voice-controlled robotic vehicle ceases to acknowledge any commands. This shows that distance plays a huge factor in determining the reliability of the robotic vehicle.

3.3 Ultrasonic sensor reliability test result

Table 5: ultrasonic sensor reliability test

Object	Distance stopped (cm)
Wall	17.6 cm
Mirror	18.6 cm
Soft cloth	16 cm

From Table 4, the ultrasonic sensor was seen to have different response to the various objects used in the test. It was also observed that the ultrasonic sensor stops the vehicle from starting when there is an object in front of the ultrasonic sensor. It was also observed that the ultrasonic sensor stops the robotic vehicle only when the robotic vehicle is moving in the forward direction. The vehicle moves continuously in the forward direction when given a forward movement instruction until the stop button is hit or until an obstacle is detected nearby while moving in the forward direction. The backward and other direction moves only occur at limited distances until the button is pressed again. Ultrasonic sensors were not incorporated to the other sides because of cost as it is a prototype and about four (4) ultrasonic sensors would be needed totally for the full auto stopping implementation in all directions. This is a weakness of the vehicle.

3.4 Lighting Condition and Weather Test Results

Table 5 displays the outcomes of the examinations conducted under different lighting conditions while Table 6 displays the outcomes of the examinations conducted under different weather conditions.

Table 6: Result of the test carried out on the various lighting conditions

Lighting condition	Error encountered	Response time	Number of attempts	Accuracy rate
Light condition 1	None	<1 second	10	100%
Light condition 2	None	<1 second	10	100%
Light condition 3	None	<1 second	10	100%

From the Table 5, it is observed that the voice controlled robotic vehicle responds well to command excellently irrespective of the lighting condition of the environment, this implies that the voice controlled robotic vehicle has a stable condition or a stable response to voice commands in all lighting conditionsTable 7: Weather Conditions Test

Weather condition	Error encountered	Response time	Number of attempts	Accuracy rate
Weather condition 1	None	<1 second	10	100%
Weather condition 2	None	<1 second	10	100%

From Table 6, it is observed that the voice controlled robotic vehicle responds well to command excellently irrespective of the weather condition of the environment, this implies that the voice controlled robotic vehicle has a stable condition or a stable response to voice commands in all considered weather conditions. The hour of operation depends on the battery efficiency and capacity. The higher the ampere of the battery, the longer the hours usable from the battery for effective performance of the voice-controlled robotic vehicle. This is a limitation of the vehicle.

4. CONCLUSION

It can be concluded that the voice-controlled robotic vehicle has successfully been designed, constructed and implemented, addressing the primary objective of the project. This innovative technology has shown promising results. It also offers significant contributions to the field of robotics and human-machine interaction. Throughout the course of this project, comprehensive research and development were conducted, covering aspects such as hardware design, software development, and user interface design. Key findings and achievements include efficient voice-controlled operation, proactive obstacle handling, intuitive user interface, real-world applicability and versatile customization.

5. RECOMMENDATION

While the project has achieved several milestones, there is room for further improvements and enhancements. Recommendation for future works are; continuous improvement of voice algorithms, safety and redundancy, real-world applications, user feedback and cost optimization.

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