

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2024.0429000

Vega: A Chatbot Platform for Development of Internet of Things

HARITH AL-SAFI, (Fellow, IEEE), HARITH IBRAHIM, and Paul Steenson, (SeniorMember, IEEE)

School of Electronics and Electrical Engineering, University of Leeds, Leeds LS2 9JT, U.K

Corresponding author: Harith Al-Safi (e-mail: harith.alsafi@gmail.com).

This paragraph of the first footnote will contain support information, including sponsor and financial support acknowledgment. For example, "This work was supported in part by the U.S. Department of Commerce under Grant BS123456."

ABSTRACT Large language models (LLMs) have revolutionized natural language processing, yet their potential in Internet of Things (IoT) applications remains largely untapped. Traditional IoT interfaces often require specialized knowledge, creating barriers for non-technical users. We present a modular system that leverages LLMs to enable intuitive, natural language control of IoT devices, specifically a Raspberry Pi (RPi) connected to various sensors and devices. Our solution comprises three key components: a physical circuit with input and output devices, an RPi integrating Control Server, and a web application integrating LLM logic. Users interact with the system through natural language commands, which the LLM interprets to call appropriate commands for the RPi. The RPi executes these instructions on the connected circuit, with outcomes communicated back to the user via LLM-generated responses. We empirically evaluate our system's performance across a range of task complexities and user scenarios, demonstrating its ability to handle complex, conditional logic without additional RPi-level coding. Our findings reveal that LLM-driven IoT control can effectively bridge the gap between complex device functionality and user-friendly interaction. We discuss the system's scalability, exploring its potential applications in diverse settings such as smart homes, industrial monitoring, and educational environments. By enabling natural language interaction with IoT devices, our approach not only enhances accessibility for non-technical users but also opens new avenues for creative and intelligent IoT applications. This research contributes to the growing body of work on interactive intelligent systems for IoT, offering insights into the design and implementation of LLM-integrated IoT interfaces.

INDEX TERMS Enter key words or phrases in alphabetical order, separated by commas. Autocorrelation, beamforming, communications technology, dictionary learning, feedback, fMRI, mmWave, multipath, system design, multipath, slight fault, underlubrication fault.

I. INTRODUCTION

THE evolution of large language models (LLM's) has led to rapid development in the realm of intelligent systems. However, the application of LLM's hasn't been thoroughly explored in internet of things (IoT) and embedded systems (ESys). Traditionally, the development of IoT systems that seamlessly adapt to the user's need and tasks poses a considerable challenge. Leveraging the capabilities of LLMs presents an opportunity to address this challenge and bridge the gap between technical intricacies and user accessibility. see 2

II. BACKGROUND AND RELATED WORK

- A. PROGPROMPT
- B. TOD4IR
- C. CASIT

III. METHODOLOGY

A. OVERALL ARCHITECTURE

A

B. PHYSICAL CIRCUIT DESIGN

C. RASPBERRY PI DESIGN

D. WEB APP DESIGN

IV. EXPERIMENT AND RESULTS

- A. COMPLEX COMMANDS
- B. AUTOMATED EVALUATION
- C. RESULT ANALYSIS
- D. REAL LIFE APPLICABILITY

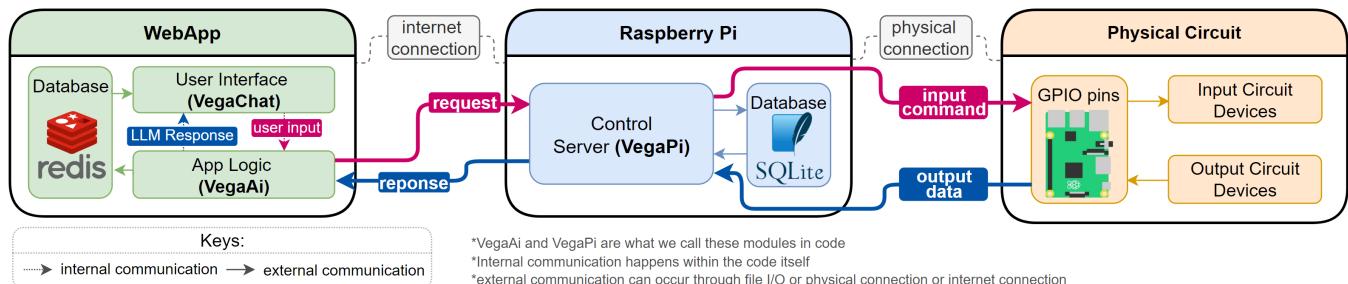


FIGURE 1. The overall architecture of the system.

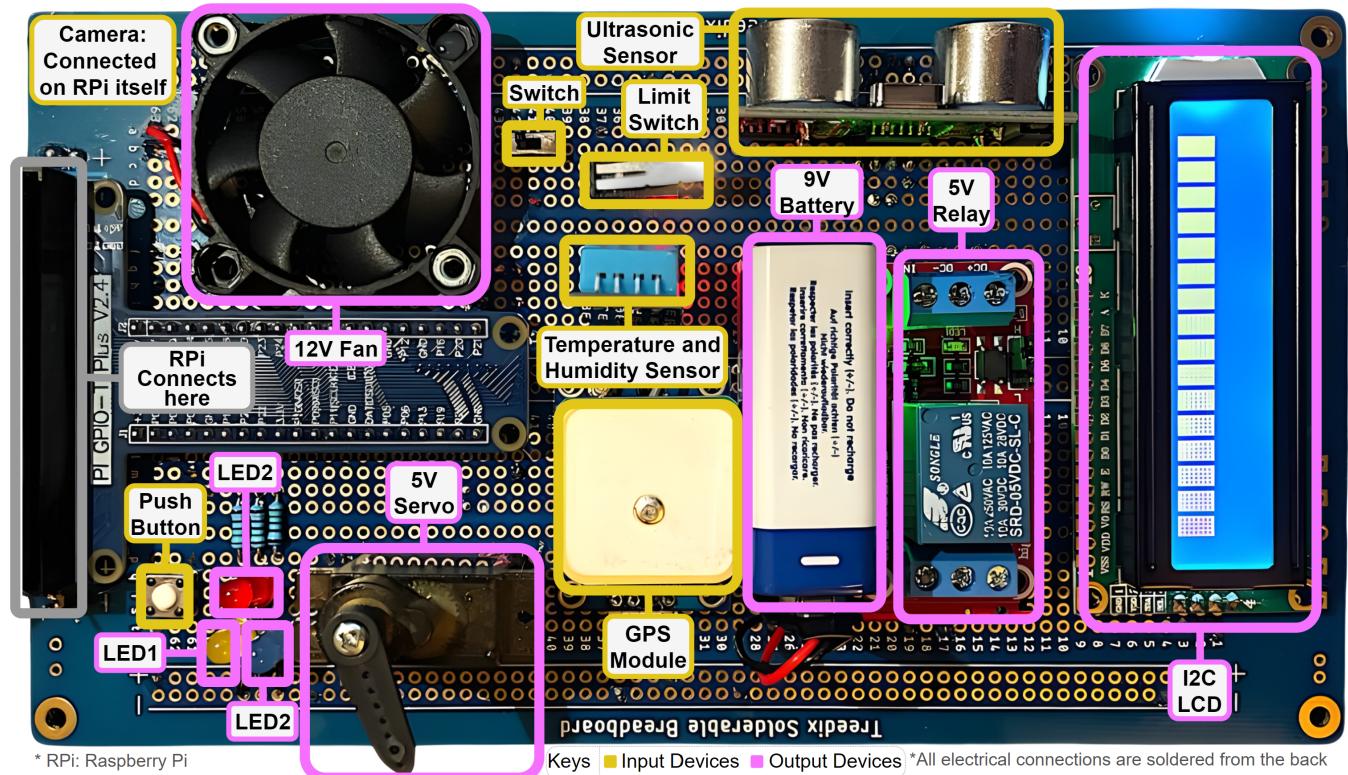


FIGURE 2. Soldered physical circuit connected to the RPi

TABLE 1. Physical devices defined on the Control Server, which are then supplied to the LLM

Symbol	Type	Description
ULTS	Input	Ultrasonic Distance Sensor in 'cm'
CAM	Input	Camera device for picture input
GPS	Input	GPS device for longitude and latitude coordinates
TMP	Input	Temperature sensor giving response in degree celcius
FAN	Output	12V fan controloed by a digital GPIO pin through a relay
LCD	Output	I2C LCD for displaying strings
SRV	Output	Servo motor rotates using PWM to a given angles
LED1	Output	Yellow LED light
LED2	Output	Red LED light
LED3	Output	Blue LED light

V. CONCLUSION

ACKNOWLEDGMENT

REFERENCES

- [21] G. O. Young, "Synthetic structure of industrial plastics," in *Plastics*, 2nd ed., vol. 3, J. Peters, Ed. New York, NY, USA: McGraw-Hill, 1964, pp.

15–64.

- [2] W.-K. Chen, *Linear Networks and Systems*. Belmont, CA, USA: Wadsworth, 1993, pp. 123–135.
- [3] J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," *IEEE Trans. Electron Devices*, vol. ED-11, no. 1, pp. 34–39, Jan. 1959, 10.1109/TED.2016.2628402.
- [4] E. P. Wigner, "Theory of traveling-wave optical laser," *Phys. Rev.*, vol. 134, pp. A635–A646, Dec. 1965.
- [5] E. H. Miller, "A note on reflector arrays," *IEEE Trans. Antennas Propagat.*, to be published.
- [6] E. E. Reber, R. L. Michell, and C. J. Carter, "Oxygen absorption in the earth's atmosphere," Aerospace Corp., Los Angeles, CA, USA, Tech. Rep. TR-0200 (4230-46)-3, Nov. 1988.
- [7] J. H. Davis and J. R. Cogdell, "Calibration program for the 16-foot antenna," Elect. Eng. Res. Lab., Univ. Texas, Austin, TX, USA, Tech. Memo. NGL-006-69-3, Nov. 15, 1987.
- [8] *Transmission Systems for Communications*, 3rd ed., Western Electric Co., Winston-Salem, NC, USA, 1985, pp. 44–60.
- [9] *Motorola Semiconductor Data Manual*, Motorola Semiconductor Products

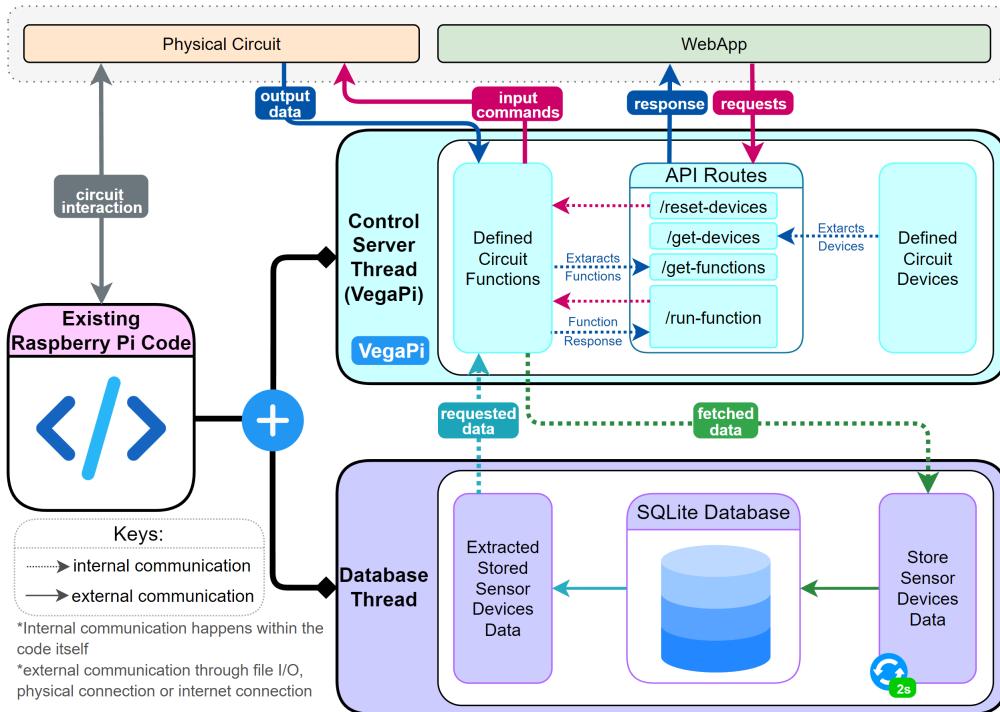


FIGURE 3. Architecture design of the RPi control server

TABLE 2. Defined functions on the Control Server, called by the LLM based on user input, executes on the RPi and processed on the webapp

Function	Description	Use Case
set_led	Toggles specific LED	"Turn on yellow LED"
set_fan	Toggles fan on or off	"Turn on the fan"
get_recorded_sensor_data	Gets interval sensor data from database	"Plot me the distance data in last 30 seconds"
get_raspberry_stats	Gets CPU, RAM, Disk of RPi	"What is the current disk usage"
capture_image	Captures an image and uploads it to Imgur	"Capture an image, does it contain a pen?"
get_connected_devices	Fetches the data of connected devices	"What is the current humidity and temperature"
get_location_	Gets the current location from GPS	"From the location are we currently in Leeds?"
set_servo_angles	Turn servo to certain angle	"Turn the servo to 10 then 180 degrees"

- Inc., Phoenix, AZ, USA, 1989.
- [10] G. O. Young, "Synthetic structure of industrial plastics," in Plastics, vol. 3, Polymers of Hexadromicon, J. Peters, Ed., 2nd ed. New York, NY, USA: McGraw-Hill, 1964, pp. 15-64. [Online]. Available: <http://www.bookref.com>.
- [11] *The Founders' Constitution*, Philip B. Kurland and Ralph Lerner, eds., Chicago, IL, USA: Univ. Chicago Press, 1987. [Online]. Available: <http://press-pubs.uchicago.edu/founders/>
- [12] The Terahertz Wave eBook. ZOmega Terahertz Corp., 2014. [Online]. Available: http://dl.z-thz.com/eBook/zomegabookpdf_1206_sr.pdf. Accessed on: May 19, 2014.
- [13] Philip B. Kurland and Ralph Lerner, eds., *The Founders' Constitution*. Chicago, IL, USA: Univ. of Chicago Press, 1987, Accessed on: Feb. 28, 2010, [Online] Available: <http://press-pubs.uchicago.edu/founders/>
- [14] J. S. Turner, "New directions in communications," *IEEE J. Sel. Areas Commun.*, vol. 13, no. 1, pp. 11-23, Jan. 1995.
- [15] W. P. Risk, G. S. Kino, and H. J. Shaw, "Fiber-optic frequency shifter using a surface acoustic wave incident at an oblique angle," *Opt. Lett.*, vol. 11, no. 2, pp. 115-117, Feb. 1986.
- [16] P. Kopyt *et al.*, "Electric properties of graphene-based conductive layers from DC up to terahertz range," *IEEE THz Sci. Technol.*, to be published. DOI: 10.1109/TTHZ.2016.2544142.
- [17] PROCESS Corporation, Boston, MA, USA. Intranets: Internet technologies deployed behind the firewall for corporate productivity. Presented at INET96 Annual Meeting. [Online]. Available: <http://home.process.com/Intranets/wp2.htm>
- [18] R. J. Hijmans and J. van Etten, "Raster: Geographic analysis and modeling with raster data," R Package Version 2.0-12, Jan. 12, 2012. [Online]. Available: <http://CRAN.R-project.org/package=raster>
- [19] Teralyzer. Lytera UG, Kirchhain, Germany [Online]. Available: http://www.lytera.de/Terahertz_THz_Spectroscopy.php?id=home, Accessed on: Jun. 5, 2014.
- [20] U.S. House, 102nd Congress, 1st Session. (1991, Jan. 11). *H. Con. Res. 1, Sense of the Congress on Approval of Military Action*. [Online]. Available: LEXIS Library: GENFED File: BILLS
- [21] Musical toothbrush with mirror, by L.M.R. Brooks. (1992, May 19). Patent D 326 189 [Online]. Available: NEXIS Library: LEXPAT File: DES
- [22] D. B. Payne and J. R. Stern, "Wavelength-switched passively coupled single-mode optical network," in *Proc. IOOC-ECOC*, Boston, MA, USA, 1985, pp. 585-590.
- [23] D. Ebehard and E. Voges, "Digital single sideband detection for interferometric sensors," presented at the 2nd Int. Conf. Optical Fiber Sensors, Stuttgart, Germany, Jan. 2-5, 1984.
- [24] G. Brandli and M. Dick, "Alternating current fed power supply," U.S. Patent 4 084 217, Nov. 4, 1978.
- [25] J. O. Williams, "Narrow-band analyzer," Ph.D. dissertation, Dept. Elect. Eng., Harvard Univ., Cambridge, MA, USA, 1993.
- [26] N. Kawasaki, "Parametric study of thermal and chemical nonequilibrium nozzle flow," M.S. thesis, Dept. Electron. Eng., Osaka Univ., Osaka, Japan, 1993.
- [27] A. Harrison, private communication, May 1995.
- [28] B. Smith, "An approach to graphs of linear forms," unpublished.
- [29] A. Brahms, "Representation error for real numbers in binary computer arithmetic," IEEE Computer Group Repository, Paper R-67-85.

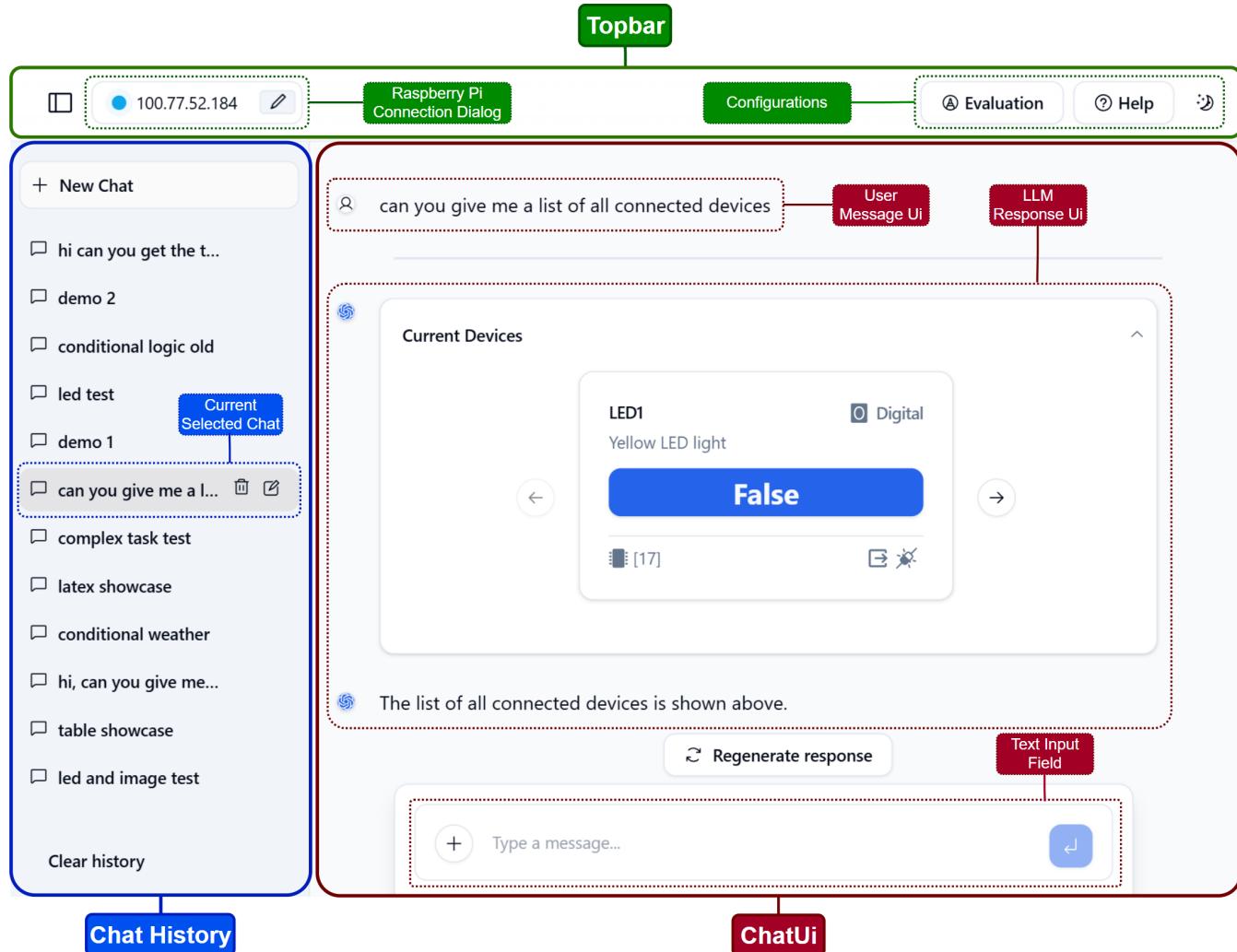
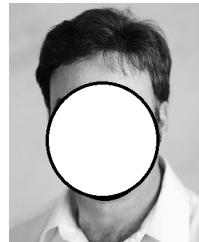


FIGURE 4. Webapp user interface implementation

- [30] IEEE Criteria for Class IE Electric Systems, IEEE Standard 308, 1969.
- [31] Letter Symbols for Quantities, ANSI Standard Y10.5-1968.
- [32] R. Fardel, M. Nagel, F. Nuesch, T. Lippert, and A. Wokaun, "Fabrication of organic light emitting diode pixels by laser-assisted forward transfer," *Appl. Phys. Lett.*, vol. 91, no. 6, Aug. 2007, Art. no. 061103.
- [33] J. Zhang and N. Tansu, "Optical gain and laser characteristics of InGaN quantum wells on ternary InGaN substrates," *IEEE Photon. J.*, vol. 5, no. 2, Apr. 2013, Art. no. 2600111.
- [34] S. Azodolmolky *et al.*, Experimental demonstration of an impairment aware network planning and operation tool for transparent/translucent optical networks," *J. Lightw. Technol.*, vol. 29, no. 4, pp. 439–448, Sep. 2011.



FIRST A. AUTHOR received the B.S. and M.S. degrees in aerospace engineering from the University of Virginia, Charlottesville, in 2001 and the Ph.D. degree in mechanical engineering from Drexel University, Philadelphia, PA, in 2008.

From 2001 to 2004, he was a Research Assistant with the Princeton Plasma Physics Laboratory. Since 2009, he has been an Assistant Professor with the Mechanical Engineering Department, Texas A&M University, College Station. He is the author of three books, more than 150 articles, and more than 70 inventions. His research interests include high-pressure and high-density nonthermal plasma discharge processes and applications, microscale plasma discharges, discharges in liquids, spectroscopic diagnostics, plasma propulsion, and innovation plasma applications. He is an Associate Editor of the journal *Earth, Moon, Planets*, and holds two patents.

Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

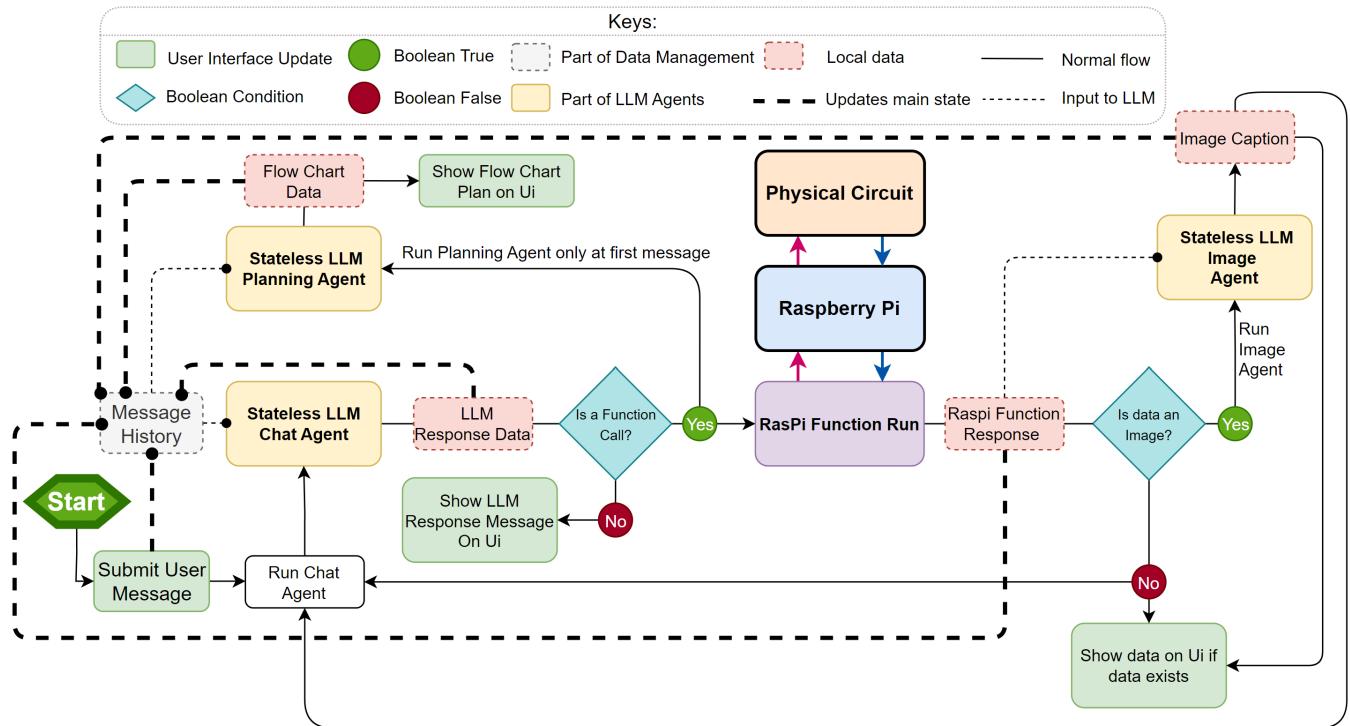


FIGURE 5. Webapp logic design



SECOND B. AUTHOR (M'76–SM'81–F'87) and all authors may include biographies. Biographies are often not included in conference-related papers. This author became a Member (M) of IEEE in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year the degree was earned. The author's major field of study should be lower-cased.

The second paragraph uses the pronoun of the person (he or she) and not the author's last name. It lists military and work experience, including summer and fellowship jobs. Job titles are capitalized. The current job must have a location; previous positions may be listed without one. Information concerning previous publications may be included. Try not to list more than three books or published articles. The format for listing publishers of a book within the biography is: title of book (publisher name, year) similar to a reference. Current and previous research interests end the paragraph.

The third paragraph begins with the author's title and last name (e.g., Dr. Smith, Prof. Jones, Mr. Kajor, Ms. Hunter). List any memberships in professional societies other than the IEEE. Finally, list any awards and work for IEEE committees and publications. If a photograph is provided, it should be of good quality, and professional-looking. Following are two examples of an author's biography.

THIRD C. AUTHOR, JR. (M'87) received the B.S. degree in mechanical engineering from National Chung Cheng University, Chiayi, Taiwan, in 2004 and the M.S. degree in mechanical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 2006. He is currently pursuing the Ph.D. degree in mechanical engineering at Texas A&M University, College Station, TX, USA.

From 2008 to 2009, he was a Research Assistant with the Institute of Physics, Academia Sinica, Taipei, Taiwan. His research interest includes the development of surface processing and biological/medical treatment techniques using nonthermal atmospheric pressure plasmas, fundamental study of plasma sources, and fabrication of micro- or nanostructured surfaces.

Mr. Author's awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).

WebApp - ChatUi - Case 1

- Get temperature. If more than 20°C, capture image. If image describes neon light, write 'hi everyone' on LCD. If both conditions fail, set red LED on.
- Gpt Flow Chart**

```

graph TD
    A[get_connected_devices{"deviceNames": "tmp"}] -- result > 20 --> B[capture_image]
    B --> C[description does not contain "neon light"]
    C --> D[set_led{"name": "LED_RED", "value": "on"}]
    C --> E[description contains "neon light"]
    E --> F[print_lcd{"text": "hi everyone"}]
  
```
- Current Devices**
- Raspberry Pi Image**

The image depicts a bright white neon lightning bolt mounted on a wall, with the dark surroundings, creating a modern, minimalist mood
- Button was clicked more than 3 times, Servo was set and data is displayed.

WebApp - ChatUi - Case 2

- If location is Leeds, check button click count. If more than 3, set servo to 45, 90 and get ULTS sensor data for last 30s. Else, turn on fan.
- Gpt Flow Chart**

```

graph TD
    A[get_connected_devices{"deviceNames": "BUTTON"}] --> B[location == leeds]
    B --> C[clicks > 3]
    C --> D[set_servo_angles{"angles": "45, 90"}]
    C --> E[get_recorded_sensor_data{"sensorNames": "ULTS", "interval": "30s"}]
    B --> F[set_fan{"value": "on"}]
    E --> G[after setting servo]
  
```
- Map**
- Plot of ULTS (Time (s) vs Values)**

Time (s)	Values
390	2.34
392	2.34
394	2.34
396	2.34
398	2.34
400	2.34
402	1.94
404	2.34
406	2.34
408	2.34
410	2.34
412	2.34
414	2.34
416	2.35
418	2.34
- Button was clicked more than 3 times, Servo was set and data is displayed.

Physical Circuit - LCD

Physical Circuit - LCD

FIGURE 6. System case studies

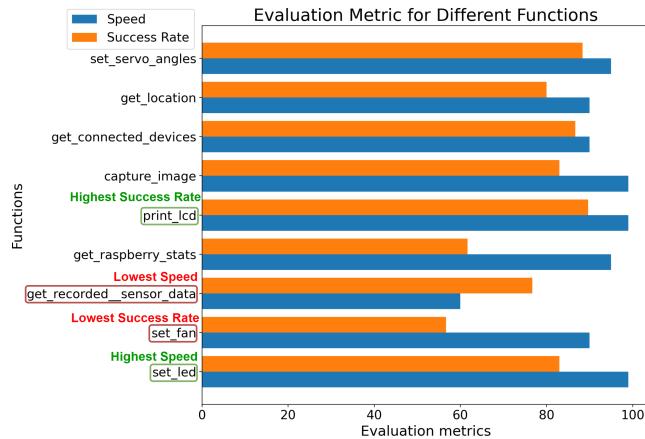


FIGURE 7. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

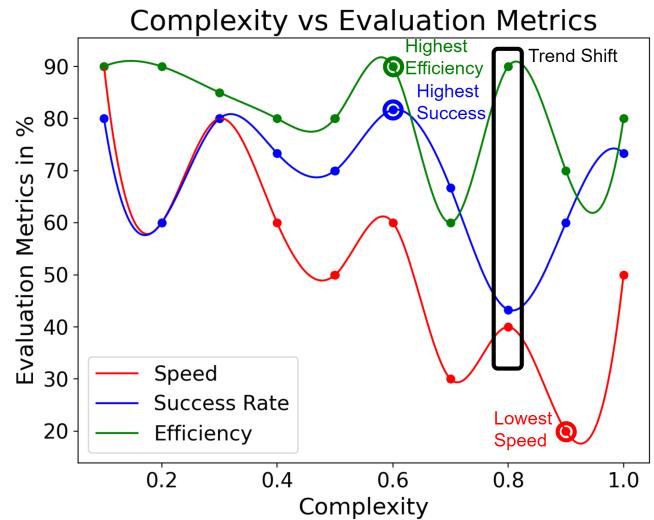


FIGURE 9. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

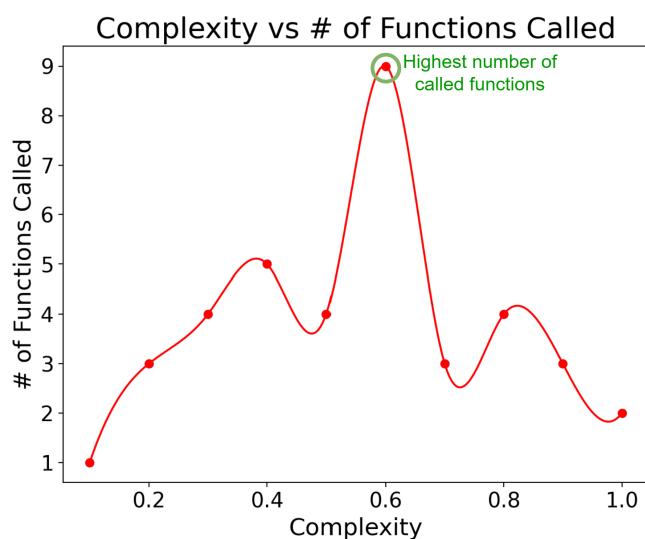


FIGURE 8. Magnetization as a function of applied field. It is good practice

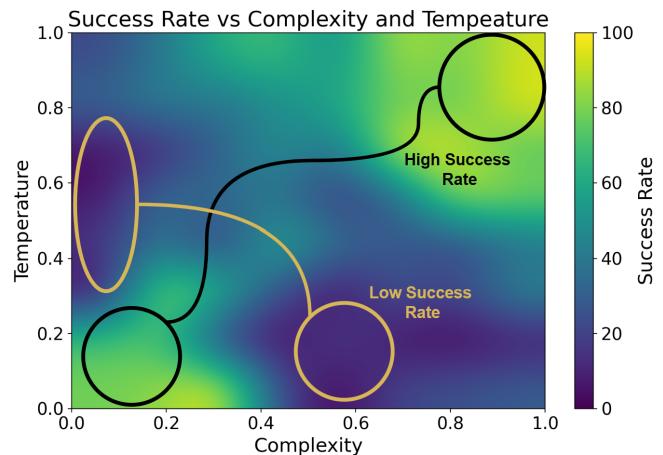


FIGURE 10. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

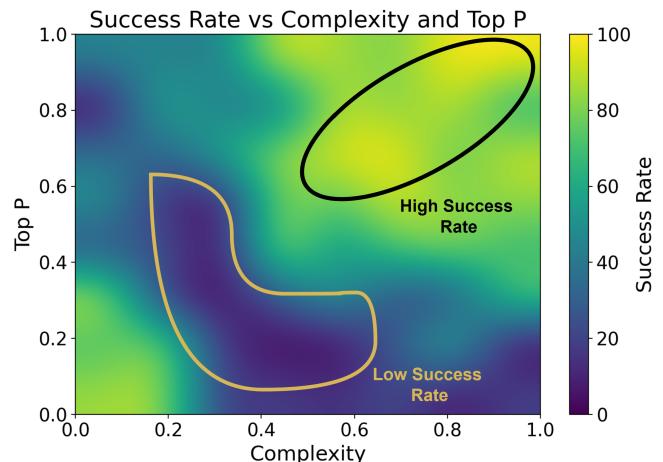


FIGURE 11. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

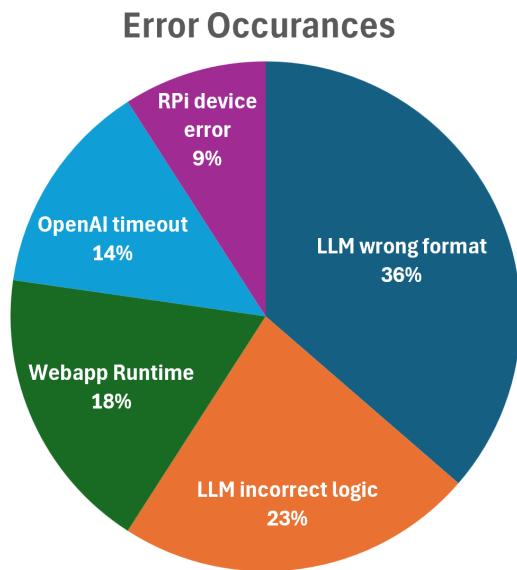


FIGURE 12. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.

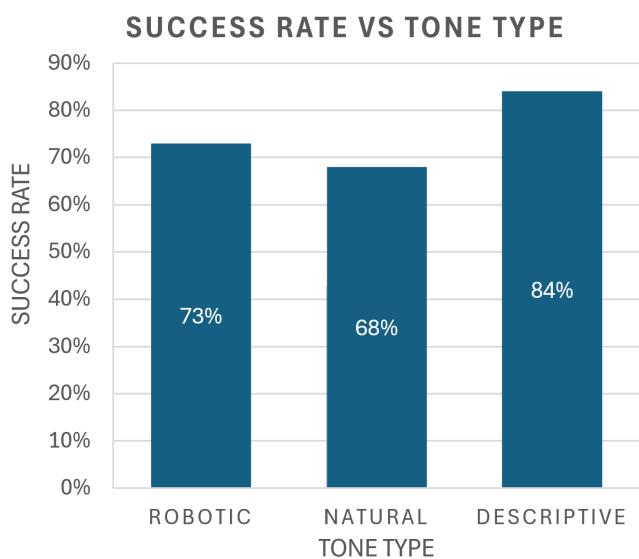


FIGURE 13. Magnetization as a function of applied field. It is good practice to explain the significance of the figure in the caption.