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Review article

A comprehensive review on applications of Raspberry Pi

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ABSTRACT

Raspberry Pi is an invaluable and popular prototyping tool in scientific research for experimenting with a wide variety of ideas, ranging from simple to complex projects. This review article explores how Raspberry Pi is used in various studies, discussing its pros and cons along with its applications in various domains such as home automation, agriculture, healthcare, industrial control, and advanced research. Our aim is to provide a useful resource for researchers, educators, students, product developers, and enthusiasts, helping them to grasp the current status and discover new research possibilities using Raspberry Pi.

1. Introduction

The Raspberry Pi is a small but versatile prototyping device that has revolutionized scientific research and education. Its low cost, small size, and ease of use make it an ideal platform for a wide range of scientific applications, including data acquisition, control systems, and modeling [1,2]. Raspberry Pi is also a powerful tool for scientific modeling and simulation. Its high-performance processor and abundant memory make it capable of running complex scientific software [3].

Fig. 1 show the basic components of a typical Raspberry Pi board. This includes the General Purpose Input/Output (GPIO) pins, which are crucial to interface with various scientific instruments and sensors. Other components are the processor, memory, power source, and various input/output interfaces. The specific layout and components may vary depending on the model of the Raspberry Pi.

Prototyping is an essential step in the design and development process, as it allows for the early identification of potential issues and promotes a "fail fast" philosophy. This enables the development team to make adjustments and improvements to their designs before investing significant resources into creating a final product. The Raspberry Pi, with its low cost and ease of use, is an excellent platform for prototyping. Its popularity among researchers and developers is due to its ability to be used for a wide range of projects, from simple solutions to dedicated custom-built devices. Applications of Raspberry Pi include but are not limited to behavioral recording, healthcare monitoring, surveillance, industrial automation, plant phenotyping, and wildlife and ecosystem monitoring.

By testing and validating partial implementations of ideas and designs, researchers can determine whether a fully functional prototype can be developed. On the basis of a review of the literature, most of the works referred to in this paper are focused on building prototypes for various purposes such as automation and monitoring. The Raspberry Pi's versatility and accessibility make it an ideal tool for researchers and developers to explore new ideas and push the boundaries of what is possible.

Raspberry Pi is being released in a variety of models to cater to different user needs. These models include Zero, ZeroW, ZeroWH, A/A +, 2, 3, 3B/3B +, 4, 4B, and 400. Each model has its own unique features and capabilities, making them suitable for a wide range of applications. Fig. 2 provides a visual representation of these models to help users better understand their differences and similarities. The reason for having multiple Raspberry Pi models is to cater to a broad spectrum of users with different needs, budgets, and project requirements. By offering a variety of models with varying capabilities and price points, the Raspberry Pi Foundation ensures that the platform remains accessible and versatile for hobbyists, educators, makers, and professionals in various fields. Table 1 provides a comparative description of the different Raspberry Pi models. It provides details of each model, including their advantages and limitations, potential applications, and typical users for whom each model is best suited.

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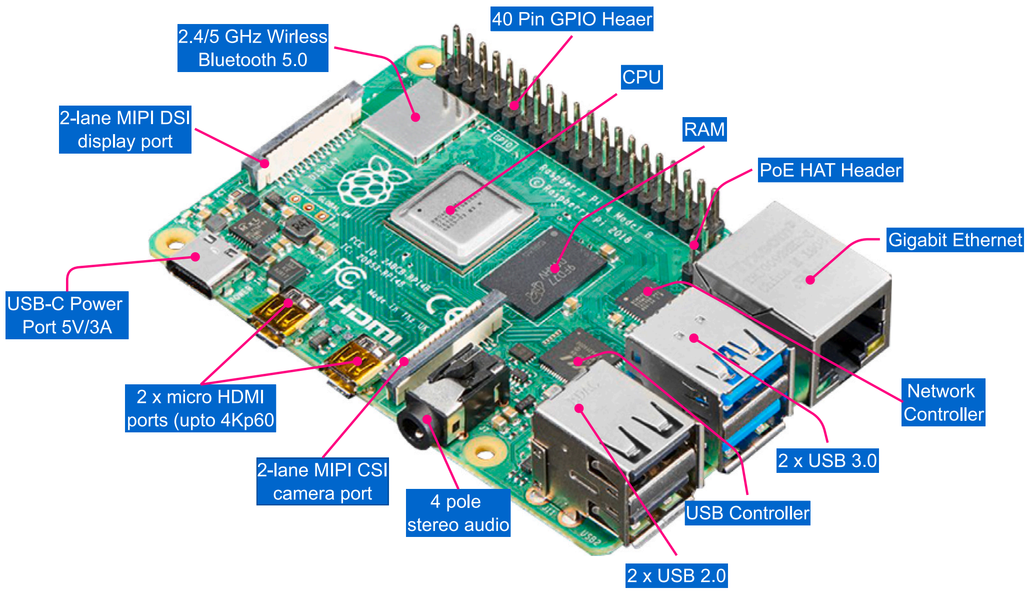

Fig. 1. Components of the Raspberry Pi.

Table 1
Comparison of various Raspberry Pi models.

Model	Advantages	Limitations	Applications	Users
Zero	Compact in size, light-weight board, low power consumption, long standby time	Mini-HDMI only, no HDMI, no ethernet connectivity, no USB port, no built-in GPIO header, no networking capabilities	Suitable for ultra low cost, space-constrained projects. Simple applications which do not require much computational power	Students, beginners
Zero W	Compact in size, light-weight board, low power consumption, long standby time	Mini-HDMI only, no HDMI, no ethernet connectivity, no USB port, no built-in GPIO header	Suitable for ultra-low cost, space-constrained projects. Simple applications which do not require much computational power but require Wifi capabilities	Students, Beginners
Zero WH	Compact in size, light-weight board, low power consumption, long standby time, built-in GPIO header,	Mini-HDMI only, no HDMI, no ethernet connectivity	Suitable for ultra low cost, space constrained projects. Simple applications which do not require much computational power but require Wifi capabilities	Students, Beginners
A/A+	Suitable for low-cost projects, decent IO support	Slow, less powerful than later models, No networking capabilities	Simple applications which do not require much computational power such as high-altitude ballooning, robotics, wall display	Students, Beginners
3B/3B+	Less heating issues, availability of more cases and accessories	Slower than the 4B model, more power hungry, lack of features like dual display, USB 3.0	good for simple and medium-level projects such as desktop PC, media center, web server, gaming emulator, computer vision	Beginners, Hobbyists, Students, Researchers
4B	More processing capacity, more ports, improved standards	Heating issues, no HDMI ports	Simple to advanced projects such as creating a web server, Desktop PC, multi-functionality robots, home Kubernetes cluster, home server and media center, gaming emulator, computer vision.	Beginners, Students, Experts
400	Newest and Fastest, Perfect for teaching and learning purposes	No HDMI ports, larger in size	Desktop PC, classrooms, gaming emulator, computer vision	Students Teachers Beginners

1.1. Advantages of using Raspberry Pi

The Raspberry Pi is a widely accepted and popular single-board computer, with a large and supportive community of developers and researchers [4]. It has a faster and more powerful processor when compared to other prototyping boards such as Arduino, and can also be used as a desktop PC. The Raspberry Pi offers a wide range of capabilities, including coding, photo editing, and audio/video processing. Some of the advantages and limitations of considering Raspberry Pi for prototyping are shown in Fig. 3.

The Raspberry Pi has 40 general-purpose input/output (GPIO) digital signal pins, allowing the use of multiple digital sensors in embedded projects. Furthermore, it supports a wide variety of programming languages, including C, C++, Java, Ruby, Python, and C#, unlike Arduino which supports C, and C++ only.

There are many Integrated Development Environments (IDEs) available for coding programs to work with the Raspberry Pi. Some of the most popular and widely used IDEs include Python Integrated Development and Learning Environment (IDLE) [5], BlueJ [6], Lazarus [7], Geany [8], Thonny [9], Code::Blocks [10] and Adafruit WebIDE [11]. A comparison of these IDEs is presented in Table 2.

1.2. Literature review on other works

Some researchers [4,12–26] attempted to review the literature on Raspberry Pi applications in Surveillance, Biotechnology, Agriculture,

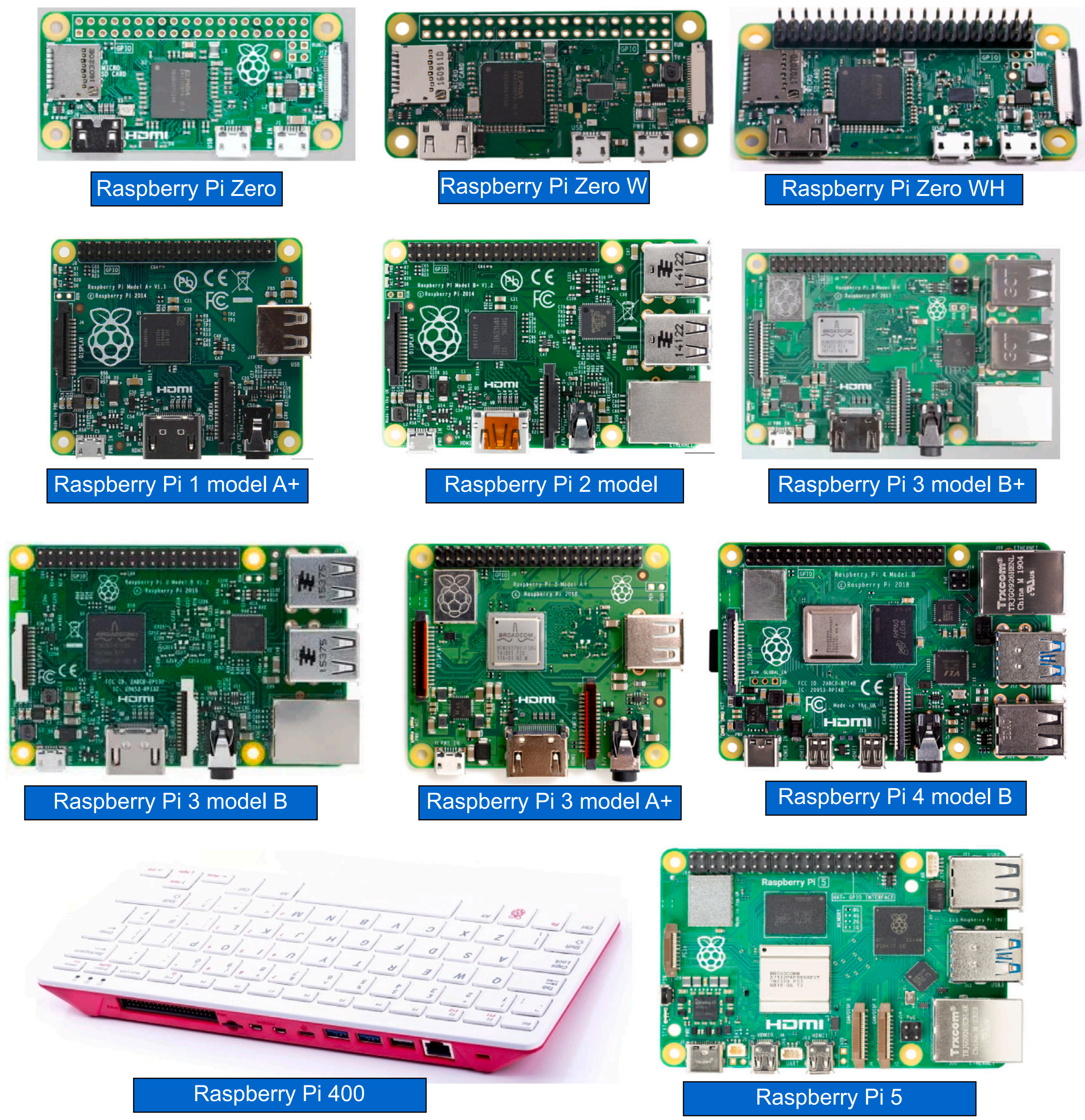

Fig. 2. Various models of Raspberry Pi boards.

Biological, and Smart applications. However, no one attempted to present a comprehensive review of a wide variety of applications of Raspberry Pi.

In [27], the authors presented a systematic review of the literature on Arduino prototyping applications. They discussed the advantages, limitations, and challenges associated with using Arduino for prototyping. They also presented a comparative overview of Arduino variants and other commonly used prototyping boards such as Raspberry Pi. However, this review did not present the applications of Raspberry Pi. Jolles et al. [12] reviewed the applications and uses of Raspberry Pi in the area of biological studies that were carried out in the field, laboratories, and classrooms. In [14], Saari et al. performed a systematic review of the literature on the benefits and limitations of using the Raspberry Pi in the development of prototypes. They also reviewed different methods used to test the functionalities of prototyping boards. In [15], the authors reviewed how various researchers used Raspberry Pi to develop autonomous robots for applications such as line following robots, fire fighting robots, terrain, indoor mapping robots, etc.

Farouk et al. [17] reviewed the prototypes of human surveillance systems developed using Raspberry Pi. They described commonly used hardware, software, feature extraction techniques, and classification models. In [18], the authors conducted a survey on research work that used Raspberry Pi and image processing to solve real-world problems. In another work [19], the authors reviewed some vehicle detection and tracking systems. They compared the features and potentials of multiple prototyping boards for measuring and estimating vehicle travel time.

Mathe et al. [20] performed a review of various Raspberry Pi applications in smart agriculture, and Vappangi et al. [21] performed a survey on applications in biotechnology. Marzuqi et al. [22] compared various work on software-defined network (SDN) architecture and discussed the chances of using Raspberry Pi to implement the SDN architecture. In [24], the authors reviewed various works related to the development of smart mirrors and discussed their applications. Bidyanath et al. [13] presented a review of multiple methods used to develop industrial process automation systems using Raspberry Pi. In [4], the authors conducted a bibliometric study on various medical

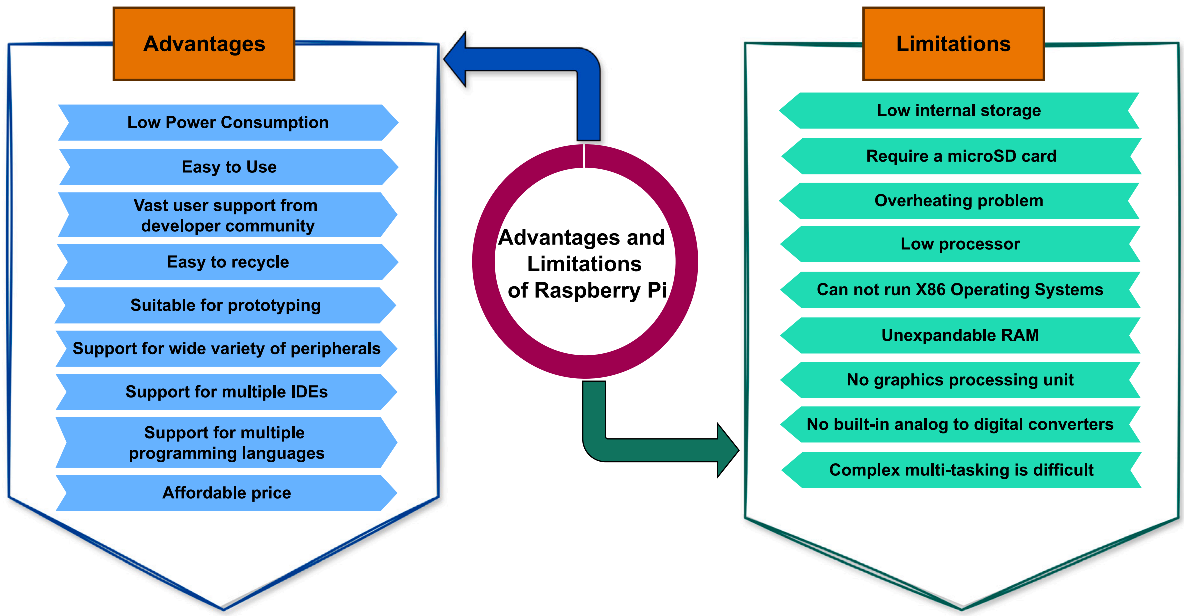

Fig. 3. Advantages and limitations of Raspberry Pi.

Table 2
Comparison of IDEs to work with Raspberry Pi.

Name of the IDE	Highlights	Supporting programming languages	IDE features
IDLE	Cross platform, Python shell window, Interactive interpreter, multiwindow text editor, search within any window	Python	Syntax highlighting, Auto completion, Smart indentation
BlueJ	Educational tool, Portable application, Simple interface, Interaction based design, GUI provides class structure	Java	Interactive object creation and method invocation, Simplified debugging and teamwork controls, Interactive line-based statement evaluation
Geany	Contains a text editor, Uses Scintilla and GIMP Toolkit (GTK+), Supports more than 50 Programming languages, Supports a lot of plug-ins	C, C++, C# Java, Python, HTML, PHP Ruby, Perl, Erlang	Code Folding, Code Navigation, Syntax Highlighting, Auto completion, Auto closing of HTML/XML tags, etc.
Thonny	Building Python 3.7, Simple and Clean interface, Equipped with a debugger, Easy interface to install packages	Python	Auto Completion, Bracket Matching, etc.
Code::Blocks	Suitable for beginners, Cross-platform IDE, Supports multiple compiler options Ex: GCC, Clang, and Visual C++ - Built-in debugger and compiler	C, C++ Fortran	Syntax Highlighting, Code Completion
Lazarus	Cross-platform and GUI based, Uses Free Pascal Compiler (FPC), Supports performance testing, Supports drag-and-drop components, Supports the principle of 'Write once and compile anywhere'	Object Pascal	Code completion, Syntax Highlighting, Code formatting
Adafruit WebIDE	Web-based interface, Supports interaction with GIT repository, Easy compilation and running, Consists of Debugger and Visualizer	Python Ruby JavaScript	Code tracking, Code navigation

applications of Raspberry Pi and presented the influence of publications on Raspberry Pi in the medical field. Marzuqi et al. [22] compared various works on software defined network (SDN) architecture and discussed the potential of using Raspberry Pi to realize the SDN architecture. Sahana et al. [24] reviewed various works related to the development of smart mirrors and discussed their applications. Bidyanath et al. [13] presented a review of multiple methods used to develop industrial process automation systems using Raspberry Pi. Kondaveeti et al. [4] conducted a bibliometric study on various medical applications of Raspberry Pi and presented the influence of publications on Raspberry Pi in the medical field.

Previous reviews have explored various applications of Raspberry Pi in different fields such as Surveillance, Biotechnology, Agriculture, Biological, and Smart applications; however, a comprehensive review is needed that covers a wide variety of applications of Raspberry Pi.

Karthikeyan et al. [26] provided an exploration of the Raspberry Pi, covering its features, versions, hardware components, and software programming, serving as a beginner guide for users and enthusiasts. However, this review lacks comprehensiveness, as it does not cover a wide range of applications, refers to an insufficient number of works, and fails to discuss existing research gaps. Our work aims to fill the above-mentioned gaps and provide a comprehensive overview of the current state of the art.

1.3. Need and motivation behind this review

To the best of our knowledge, a comprehensive review or survey of the literature on Raspberry Pi applications has been published yet. We were unable to find any review papers that cover one specific application domain. A comprehensive literature review is an important tool for researchers to understand the current state of research, to become familiar with the research field, and to identify research trends, gaps, and challenges. With this goal in mind, we aim to compile a wide range of Raspberry Pi applications in various research areas and present them to the research community in a way that allows easy access to a comprehensive overview of the literature.

1.4. Objectives of this review

Objectives of this review are (i) to gather and compile the existing literature on applications of Raspberry Pi; (ii) to examine the potential and significance of Raspberry Pi in prototyping; (iii) to identify and survey a wide range of applications developed in various research fields; (iv) to analyze the advantages and limitations of using Raspberry Pi for prototyping; (v) to address research issues and challenges associated with the development of prototyping solutions in different fields; (vi) to provide an overview of the commonly used sensors, hardware, and software that are utilized with Raspberry Pi during prototyping; (vii) to identify and discuss potential gaps and unexplored areas for future research and development in various domains.

1.5. Target users/End beneficiaries

This review is expected to be a valuable resource for interdisciplinary researchers developing innovative automation solutions using the latest advances and developments in technologies related to engineering and other disciplines. It will serve as a quick reference for researchers looking to familiarize themselves with the current state of the art in the field of Raspberry Pi applications and to identify areas where further research is needed.

This work extends its benefits beyond the realm of researchers, offering valuable insight to a broad spectrum of individuals and groups. It holds particular significance for educational institutions, encompassing schools, undergraduate, graduate, and postgraduate students, as well as research scholars, teachers, academicians, and professors. Moreover, it beckons researchers and research communities across diverse disciplines, fostering their interest in interdisciplinary research and igniting the spark of innovation. This review also serves as an invaluable resource for those involved in the pedagogy of interdisciplinary research, providing them with the means to provide students with up-to-date knowledge in the field. By consolidating a comprehensive overview of relevant literature within a single resource, it simplifies access for the research community, allowing swift identification of knowledge gaps, and facilitating their pursuit of new and groundbreaking research solutions.

1.6. The overall structure of this paper

The structure of this research paper is as follows. Section 1 provides an introduction and background information on Raspberry Pi. It also includes a review of the literature, the need and motivation for this work, the research objectives and the limitations of this study. Section 2 describes the databases used for the literature search and the process of selecting relevant documents. It also highlights any limitations of the data selection process. Section 3 presents the various applications of Raspberry Pi in different research domains. Section 4 discusses the technical and non-technical issues associated with the development of prototyping solutions using Raspberry Pi. Section 5 provides the final conclusions and recommendations for future research.

2. Document selection

2.1. Document sources and selection procedure

For this literature review, we sourced our documents from the widely-used databases Web of Science (WoS) and Scopus. Our process of document selection began with searching the WoS database using the keywords "Raspberry Pi" in the title, abstract, and author keywords. This initial search yielded 4793 documents covering a wide range of publication years, open access options, and document types such as proceeding papers, articles, book chapters, and more. To narrow down the search, we refined our criteria to include only publications from 2015 to 2024, limited to articles written in English. This resulted in a final count of 1322.

In the Scopus Database, when we search the database on March 2024, using the command TITLE-ABS-KEY ("Raspberry Pi") to fetch all the documents containing the keyword "Raspberry Pi" in Title, Abstract, or Keywords. We got 13125 documents as a search result, including all papers published between 2014 and 2024 with open access options such as Gold, Hybrid Gold, Bronze, Green, and document types: Conference article, article, book chapter, and review. However, we refined the search key as TITLE-ABS-KEY ("Raspberry Pi") AND PUBYEAR > 2014 AND PUBYEAR < 2025 AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar")) restricting publication years from 2015 to 2024, document type as "Article" and language as "English"). We got 3633 documents as a result of the above search key.

The search results from both databases encompassed publications from approximately 296 different publishers, including industry leaders such as IEEE, Springer, Elsevier, Wiley, Cambridge, and Oxford University Press. To be included in our review, 400+ documents were carefully selected from the results to ensure a diverse representation of applications such as detection, identification, recognition, control, and monitoring, as well as a variety of application domains including healthcare, agriculture, biotechnology, and industrial automation. Furthermore, a few review papers on Arduino and Raspberry Pi applications were also considered to provide a comprehensive understanding of the current state of the literature. Fig. 4 shows the precise criterion for document selection followed in this work.

2.2. Limitations of this review

The goal of this review is to present a comprehensive overview of the various potential applications of Raspberry Pi to the research community by compiling all relevant literature on the topic. However, since there are thousands of papers in the literature on this topic, we were unable to select a specific set of papers using fixed criteria. Additionally, this review is not a systematic review of the literature, which is why we did not establish specific inclusion and exclusion criteria for selecting documents. Instead, we carefully selected the documents in such a way that a wide variety of applications is covered. Despite taking great care in selecting the documents, there may be some papers that were useful for rare research works that were not included. Additionally, important developments and findings may have been missed as we did not consider conference/proceedings papers or book chapters in this review. Furthermore, articles published before 2015 were not included in this review, which may have caused important work to be missed.

3. Applications of Raspberry Pi

The potential applications of Raspberry Pi span a wide range of disciplines, including Engineering, Computer Science, Physics and Astronomy, Biochemistry, Genetics, and Molecular Biology, Materials Science, Chemistry, and Environmental Science.

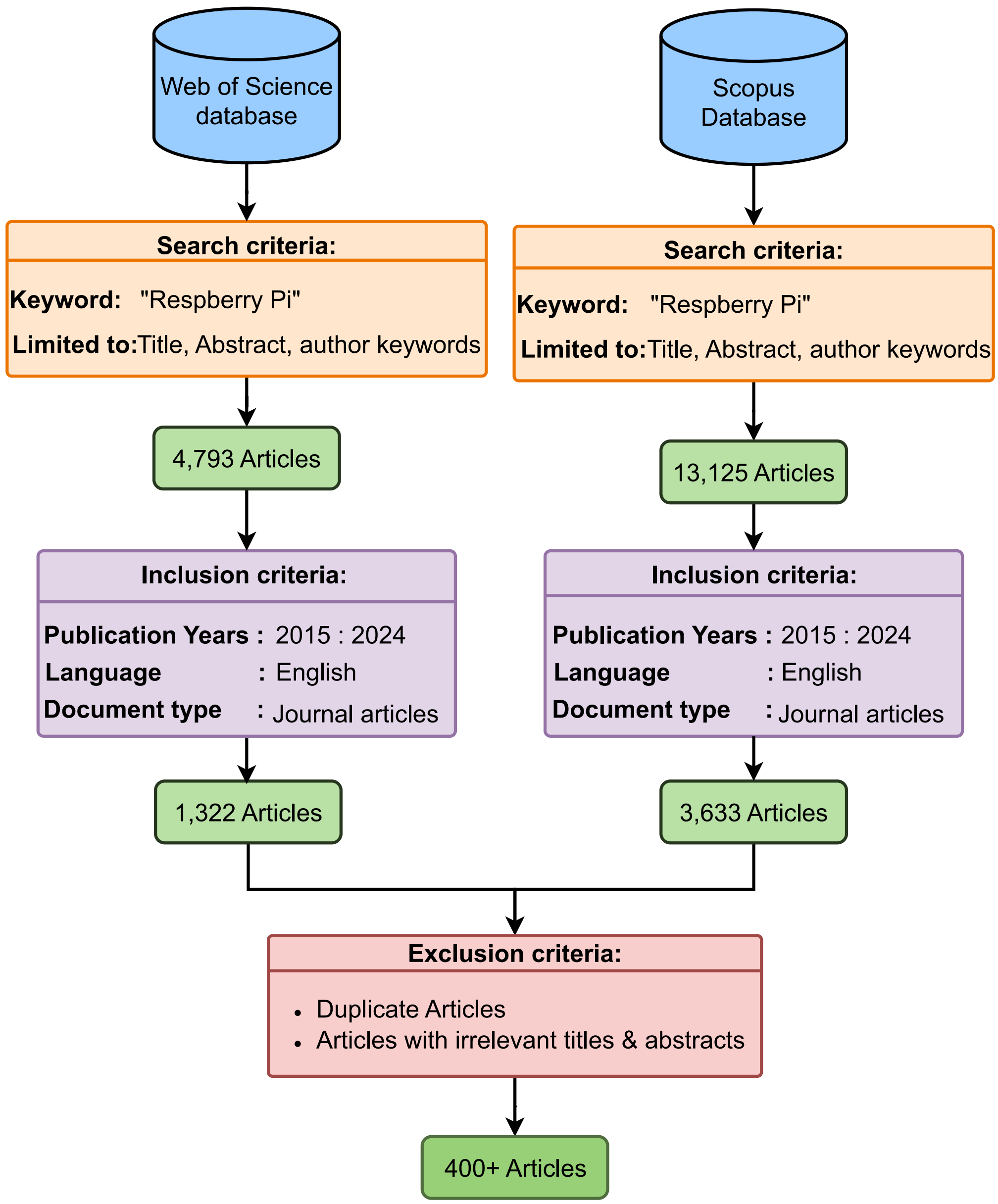

Fig. 4. Document selection criteria.

Potential applications of Raspberry Pi can be found in a variety of fields including Home Automation [28–32], Control of household appliances [33–35], Intelligent vehicle parking solutions [36], Surveillance systems [37–39], Nanotechnology [40–46], Chemical applications [47–52], Astronomy [53–57], Telecommunications [58–60], Environmental Science [61–64], Physics [65,66], Plant Science [67,67–69], Mechanical Engineering [70,71], and Intelligent Transport Systems [72,73]. Fig. 5 illustrates some of the research domains where Raspberry Pi is widely used for prototyping. In the following sub-sections, some of these applications published in the literature are discussed in more detail.

Sensors play a crucial role in the collection of environmental data, and interact with Raspberry Pi to process information and make informed decisions. Their applications span a wide spectrum of domains, each catering to specific needs. For instance, within the realm of home automation, temperature and humidity sensors diligently monitor and regulate environmental conditions within a room. In the domain of intelligent transportation systems, accelerometers are deployed to discern vehicle movement, while proximity sensors are vigilant to detect the presence of neighboring vehicles. In the field of chemistry, gas sensors are invaluable in identifying the presence of noxious gases in the surroundings, enhancing safety measures. In the realm of plant science, light sensors meticulously gauge light intensity, contributing to the optimization of plant growth. In the healthcare sector, temperature sensors prove instrumental in measuring body temperature, while infrared sensors exhibit their prowess in detecting fluctuations in blood flow. These diverse sensors are essential constituents in the development of prototypes and the seamless realization of an array of applications driven by the Raspberry Pi platform.

3.1. Home automation and surveillance

Raspberry Pi is widely adopted in home automation due to its affordability and wide availability. Acting as a central controller, it efficiently manages various systems such as lighting, Heating, Ventilation, and Air Conditioning (HVAC), and security locks, thus improving comfort, convenience, security, and energy efficiency. Raspberry Pi-based home automation systems enable control over lighting, fans,

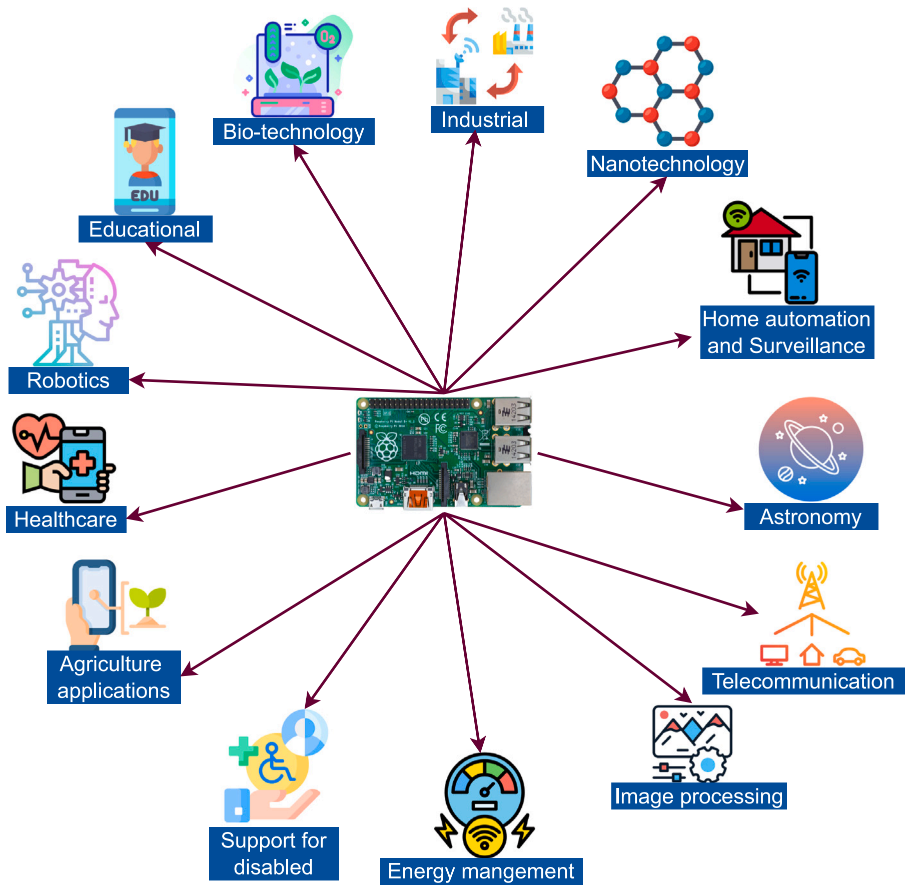

Fig. 5. Research domains where Raspberry Pi is widely used for prototyping applications.

air conditioning, house temperature, and CCTV monitoring through online platforms. In addition, these systems facilitate remote monitoring and control of home devices, improving both convenience and security. Raspberry Pi can be used to develop comprehensive systems for data organization, automation mode configuration, device management, and data analysis. Raspberry Pi offers a cost-effective solution for establishing stable home automation systems, eliminating the need for expensive infrastructure upgrades. In addition, its compatibility with pre-existing home environments further enhances its practicality and cost-effectiveness.

The studies reviewed exemplify the applications of Raspberry Pi in developing cost-effective and user-friendly home automation systems. Ashraf et al. [28] and Ghanghas et al. [29] both utilized Raspberry Pi as a central controller for home automation. Ghanghas et al. [29] incorporated deep learning techniques for enhanced functionality. Akour et al. [30] created a Raspberry Pi-based voice-controlled home appliance management system, particularly beneficial for elderly and disabled individuals.

Sowah et al. [31] emphasized security, implementing Raspberry Pi in a wireless home automation system while providing remote control through mobile and web applications. Majeed et al. [32] designed a comprehensive home automation system, featuring admin and user interfaces and integrating machine learning.

Mehmood et al. [33] developed an IoT framework that surpassed FIWARE in device registration. Akbar et al. [34] integrated ubiquitous technology with Raspberry Pi, Xbee, and UPnP protocols, showcasing Raspberry Pi's control capabilities over TCP/IP networks.

Xu et al. [35] enhanced smart control systems with embedded edge computing, rule-based functions, and optimization engines, achieving autonomous temperature control. These studies collectively underscore the adaptability and potential of Raspberry Pi for creating innovative, efficient and budget-friendly home automation solutions, catering to diverse user needs and technological advances. Table 3 presents the details of some of the home automation applications.

The integration of Raspberry Pi into home automation and surveillance systems presents technical challenges in performance, scalability, security, and energy efficiency. Although Raspberry Pi is capable of handling multiple sensors, it can often struggle with the demands of multiple sensors, affecting real-time responsiveness. Scalability issues often arise from the management of multiple devices within a smart home environment. Automated home automation systems raise concerns about data security and unauthorized access. Protecting user and sensory data and ensuring secure transmissions by implementing robust authentication mechanisms and using advanced encryption mechanisms are crucial. Energy efficiency is also a concern, with IoT-based systems aiming to optimize energy usage. Addressing these challenges is crucial to ensure the successful implementation of Raspberry Pi based home automation systems, focusing on optimal performance, scalability, security, and energy efficiency.

3.2. Support for disabled

Raspberry Pi is playing a key role in the development of assistive technologies for people with disabilities. Due to its wide availability, low cost, and open source nature, developers are using it to create low-cost aids that address a variety of disabilities, such as visual, hearing, speech, locomotor, and mental impairments. These systems utilize sensor-based and computer vision technologies to act as assistive devices, making daily tasks of the disabled more manageable. Unlike traditional solutions, Raspberry Pi based solutions offer cost-effective alternatives to improve the quality of life of people with disabilities, facilitating their participation in society.

Table 3
Home automation applications of Raspberry Pi.

Reference	Work done	Hardware	Software	Remarks	Reported issues
[28]	Implemented cost-effective, energy-efficient home automation with Raspberry Pi acting as a server.	Raspberry Pi	N/A	Enabled remote control of electrical appliances; maintained a database for each appliance.	Security and privacy concerns needed to be addressed, ensuring reliable and stable wireless connectivity was a challenge
[29]	Designed a home automation system employed deep learning	Raspberry Pi, Android mobile, relays, sensors	Deep learning algorithms	Cost-effective and user friendly system	Security measures for facial recognition are not considered
[30]	Developed a home automation system with voice control for the elderly and disabled.	Raspberry Pi, Android smartphone		Recognized and differentiated user commands for appliance control.	Offline control for critical appliances needs to be incorporated
[31]	Created a secure wireless home automation system using OpenHAB 2	Raspberry Pi	OpenHAB 2, mobile and web apps	ensured security and provided control of various home appliances.	Secured with encryption to keep hackers out, saves energy by letting the users control appliances remotely.
[32]	Designed a home automation system with admin and user sides	Raspberry Pi		Admin side for home design, user side for appliance control; decision mechanism.	Advanced machine learning and data privacy need to be considered for further enhancement.
[33]	Developed a secure and reliable IoT framework for device registration	Raspberry Pi	IoT framework	Efficient device registration and performance.	Security considerations for managing and sharing virtual objects could be a valuable addition.
[34]	Integrated the pervasive technology with Raspberry Pi, Xbee, and UPnP protocols for smart home control.	Raspberry Pi, Xbee		Combined pervasive technology with single board computers for smart home control.	Further exploration in security and broader appliance compatibility would enhance the system's practicality
[35]	Enhanced smart control systems with embedded edge computing and rule-based functions	Raspberry Pi	Embedded edge computing, fuzzy control	Optimized smart home temperature control without human intervention.	Cloud-based solutions for smart home management had latency issues and security concerns.

Hidayat et al. [74] developed an electronic examination device that aids disabled students by using the Raspberry Pi as a data processor, employing braille codes and navigation buttons. Park et al. [75] proposed a Raspberry Pi-based object recognition system that enhances the safety of blind individuals on the road by identifying pedestrian signals and obstacles. Khan et al. [76] introduced a cost-effective visual aid system, while ABirami et al. [77] utilized deep learning in a smart glass for object recognition by the blind.

Anandan et al. [78] presented an object detection and navigation system incorporating the Raspberry Pi, converting visual information into audio. Ou et al. [79] developed an obstacle recognition system that guides blind individuals through obstacles using the Raspberry Pi and Google object detection API. Vasanth et al. [80] employed Google speech API and Raspberry Pi to assist blind and deaf people.

Addressing wheelchair users, Lu et al. [81] designed an IoT system to monitor smart wheelchairs. Chatterjee et al. [82] developed a mixed control wheelchair (MCW) using Raspberry Pi with improved accessibility. Hidayat et al. [74] also contributed to the assistance of disabled students with an electronic examination device, facilitating exams for the visually impaired. Tables 4 and 5 provide an overview of studies that support people with disabilities.

Using the Raspberry Pi to develop assistive technologies for the disabled comes with various challenges. It takes a lot of time and effort to customize these systems to meet the diverse needs of people with different disabilities. Another problem is that these technologies may not be accessible or affordable for everyone who needs them, making widespread use difficult. Ethical considerations, such as ensuring user privacy and addressing design biases, require careful attention during the development and deployment of assistive technologies.

3.3. Educational applications

The affordability, versatility, and user-friendly features of Raspberry Pi have made it a significant tool in the education sector. Its widespread adoption in the educational sector is demonstrated by several studies that present its positive impact on student learning in a variety of subjects, ranging from computer science to mathematics. By facilitating hands-on experimentation, coding, and project-based learning, Raspberry Pi contributes to enhancing Science, Technology, Engineering, and Mathematics (STEM) education by fostering practical problem-solving skills and critical thinking. The following paragraphs provide an overview of how Raspberry Pi is used in the educational sector:

Table 4
Raspberry Pi applications to support the disabled.

Name of the application	Reference
Blind support systems	[74–76,78,79]
Deaf and dumb support systems	[80]
Smart wheel chairs	[81–85]
Disabled support systems	[86,87]

In recent times, it can be seen that the fast-expanding IoT market offers diverse opportunities for application development, which has a significant impact on various aspects of everyday life. Since this IoT technology is rapidly evolving, educational institutions face several challenges in providing students with essential IoT skills. The authors in [88], conducted a systematic review of the literature, identifying 60 articles and articles that discuss the integration of the IoT curriculum, instructional methods, and assessment techniques for college and university students. It is to be noted that the authors in this research work emphasized that in educational settings, IoT hardware comprises an array of sensors such as environmental sensors proximity and motion sensors, biomedical sensors, and radio frequency identification (RFID) tags and readers alongside tangible computing tools like Arduino boards, Raspberry Pi boards, MicroBit, and ESP modules.

Over the past few years, a significant amount of attention has been paid to design thinking in K-12 education. The research findings in [89] show that design thinking is being used in STEM subjects and various

Table 5
Support for Disabled applications of Raspberry Pi.

Reference	Work done	Hardware	Software	Remarks
[74]	Electronic examination device for disabled students using Raspberry Pi, braille codes, and navigation buttons.	Raspberry Pi	Braille codes, navigation buttons	Aids disabled students in taking exams.
[75]	Object recognition system for blind individuals using the Raspberry Pi, identifies pedestrian signals and obstacles.	Raspberry Pi	Object recognition system	Enhances safety for blind individuals on the road.
[76]	Cost-effective visual aid system for individuals with visual impairments.	Raspberry Pi	Visual aid system	Provides a cost-effective visual aid.
[77]	Smart glass with deep learning for object recognition by the blind.	Smart glass, Raspberry Pi	Deep learning model	Assists the blind in object recognition.
[78]	Object detection and navigation system using the Raspberry Pi, converts visual information into audio.	Raspberry Pi	Object detection, audio conversion	Helps users detect objects and navigate using audio cues.
[79]	Obstacle recognition system for guiding blind individuals using the Raspberry Pi and Google's object detection API.	Raspberry Pi	Google's object detection API	Guides blind individuals through obstacles.
[80]	Assistive system using Google speech API and Raspberry Pi for blind and deaf people.	Raspberry Pi	Google speech API	Aids individuals with hearing and visual impairments.
[81]	IoT system for monitoring smart wheelchairs.	Raspberry Pi, IoT devices	IoT software, monitoring system	Monitors smart wheelchairs for wheelchair users.
[82]	Mixed-control wheelchair (MCW) with Raspberry Pi for improved accessibility.	Raspberry Pi	Mixed-control system	Enhances wheelchair accessibility.
[74]	Electronic examination device for visually impaired students using Raspberry Pi.	Raspberry Pi	Examination software	Facilitates exams for visually impaired students.

evaluation methods are being employed, including the usage of tools like Raspberry Pi. The research study in [90] show how open source hardware, such as Arduino and Raspberry Pi, has grown due to its cost-effective nature and active community. The researchers of this study have looked at its educational advantages, such as promoting creativity and improving technical skills. The study provided insight into related literature, educational uses and future research directions. The authors in [91] highlight the importance of laboratories for students to put theory into practice. They discuss how remote labs, using IoT technology, offer flexibility and resource efficiency. Platforms such as Arduino and Raspberry Pi are cost-effective options for these projects, and user-friendly interfaces make them accessible to all learners.

The authors in [92], focused on creating a prototype solution mainly for using in Ugandan schools, considering technical and social factors. The goal is to show how such a tool can teach science, engineering, and computing in developing areas. Raspberry Pi was created to encourage programming among preuniversity learners by offering an inexpensive computer for programming, unlike many family PCs. Initially, it included Scratch and IDLE, and later on, it included Greenfoot and BlueJ, Java-based programming environments. These additions provide more graphical, interactive experiences, helping students better understand programming concepts such as object orientation. In [93], Greenfoot and BlueJ development, optimization, and integration were explored in the Raspberry Pi ecosystem, showing their potential to improve programming engagement. The summary of the applications of Raspberry Pi in the educational sector is tabulated in Table 6.

3.4. Nanotechnology

Raspberry Pi can be utilized in the field of Nanotechnology for collecting and analyzing the data related to Nanotechnology experiments. It not only helps to control and monitor nanoscale processes but also enhances efficiency and precision in nanotechnology studies. The compact size and adaptability of the Raspberry Pi make it suitable for various nanotech applications. Here is a list of earlier research findings indicating the applications of Raspberry Pi in the field of Nanotechnology:

It is necessary for certain medicines to be turned into very small particles called nanoparticles if they do not work well in the body. It is important to get the ingredients and how they are made just right to make sure that the nanoparticles work properly. Microfluidic platforms are helpful because they let us control the process very precisely, especially when things are tiny. Sometimes, it is hard to find good information about how to use these platforms with the right equipment. Taking these aspects into account, the authors in [40] proposed a simple and inexpensive model that uses a Raspberry Pi computer and some other parts to mix fluids well. In particular, their proposed model has four parts: one to control everything, one to add the ingredients, one to mix them together, and one to collect the finished product. The research findings in [41] introduced a novel approach to energy management for nanogrid appliances. Using cloud computing, Smart Energy Management as a Service (SEMaas) was used for efficient energy usage. An energy management strategy was proposed for IoT-enabled residential buildings to minimize electricity costs and improve efficiency. The system includes hardware components such as base station units, terminal units, and Raspberry Pi together with software such as Wi-Fi network programming and message queue telemetry transportation (MQTT) broker.

The authors in [42] developed an experimental setup to measure magnetic fields using Rb D2 line spectra and reflection spectroscopy in a thin optical cell. In addition, from this research work, it can be evidenced that the authors employed affordable electronic components such as an Arduino Due board and a Raspberry Pi computer for data processing. To detect iron ions in water and blood, the authors in [43] have developed a device called FENSOR which is based on the Pi camera. The authors in [46] introduced a nanoplasmonic sensing platform to detect uropathogenic Escherichia coli (UPEC), which is generally considered a common cause of urinary tract infections. It is stunning to note that the authors of this work employed a Raspberry Pi interface in conjugation with a metallic flow-through nanohole array-based sensor. Table 7 describes the applications of Raspberry Pi for nanotechnology.

3.5. Chemical applications

Raspberry Pi is becoming increasingly popular in chemistry as it can monitor and control chemical reactions, analyze data, and show results. Raspberry Pi works well with different sensors and tools, so

Table 6
Applications of Raspberry Pi in the field of Educational Sector.

Reference	Work done	Hardware	Software	Remarks
[88]	Review of IoT education strategies	Array of sensors, Arduino boards, Raspberry Pi	Python	IoT education with diverse devices.
[89]	Identification of design thinking usage	Raspberry Pi	Python	Design thinking applied in STEM subjects in K-12 schools.
[90]	Analysis of open-source hardware usage	Arduino, Raspberry Pi	Python	Examined educational benefits, analyzed 676 publications for insights.
[91]	Emphasized the significance of labs for practical learning	Arduino, Raspberry Pi	Python	Discussed the cost-effectiveness and accessibility of IoT projects.
[92]	Developed a prototype solution for educational use in Ugandan schools	Raspberry Pi	Python	Focused on demonstrating the educational potential in developing regions.
[93]	Explored the development, optimization, and integration of Greenfoot and BlueJ into Raspberry Pi ecosystem	Raspberry Pi	Greenfoot, BlueJ	Showed potential to enhance programming engagement.

Table 7
Applications of Raspberry Pi in the field of Nanotechnology.

Reference	Work done	Hardware	Software	Remarks
[40]	Development of a modular, low-budget prototype for microfluidic mixing	Raspberry Pi, commercially available syringe pumps, custom-built fraction collector	Customizable python scripts	Demonstrates the prototype's efficiency in nanoparticle assembly.
[41]	Development of energy management strategy for IoT-enabled residential buildings	Base station unit (BSU), terminal units (TUs), Raspberry Pi	MQTT broker	Presents a low-cost platform for monitoring and decision-making.
[42]	Measurement of magnetic field at various distances	Arduino Due board, Raspberry Pi	Not specified	Computational tasks handled by Arduino Due for laser control, spectrum acquisition, and Raspberry Pi for fitting.
[43]	Development of FeNSOR nano-sensor and FeNSOR Device	Digital Pi-camera with associated hardware	Python	FeNSOR nano-sensor and FeNSOR Device utilize fluorescence spectrophotometry for iron ion detection.
[46]	Creating a nanoplasmonic sensing platform to detect UPEC in real time below UTI diagnosis limits.	Red LED light source, lens assembly, CMOS detector, Raspberry Pi interface, metallic flow-through nanohole array-based sensor.	ImageJ software	Successfully detects UPEC in clinical and spiked urine samples

it is used to sense the environment, automate processes, and perform experiments in labs. It is also open source, which makes it great for scientists and others working in chemistry. The following paragraphs briefly describe the chemical applications in which Raspberry Pi is used. The authors in [47] proposed a portable microfluidic device for cortisol detection in saliva using a nickel-modified screen printed electrode and a 3D printed microfluidic platform. The device is made up of laboratory-made electrodes with optimized ink proportions and measurements were conducted with Raspberry Pi. The research work in [48] introduced an advanced open-source potentiostat/galvanostat instrument with expanded capabilities for a wide range of electrochemical measurements that can be controlled using any computer, including the Raspberry Pi. The study carried out by the authors in [49] affirms that students were engaged in a hands-on project to improve a Raspberry Pi spectrophotometer, learning practical skills in error management and data processing. The research study in [50] used a Raspberry Pi computer with 3D printed parts to analyze the antioxidant capacity of tea using diphenylpicryl-hydrazyl (DPPH) tests. The Raspberry Pi-based measurements showed a strong correlation with a research grade spectrophotometer, indicating its potential for research and education. In [51], open source technologies such as RAMPS, Python, PySerial, and OpenCV were utilized to automate a flow chemical synthesis system to produce benzamides. Raspberry Pi served as the interface between the control computer and the RAMPS motor driver boards. The authors in [52] show that an affordable 3-axis autosampler automated an acid-catalyzed flow chemical desilylation reaction. Open-source software, including Python and OpenCV, controlled computer vision guided liquid-liquid extraction for inline purification. A Raspberry Pi single-board computer was utilized to interface with the autosampler's motors and fluidic valves. Table 8 illustrates the applications of Raspberry Pi in chemical engineering

3.6. Astronomy

Astronomers utilize Raspberry Pi for various applications, including telescope control, image processing, data logging, and remote monitoring. With its low cost and compact size, the Raspberry Pi enables amateur astronomers to build observatories and automate tasks such as tracking celestial objects and capturing images. The following works highlight the utilization of Raspberry Pi for Astronomy applications:

The research work in [53] states that Raspberry Pi served as the onboard computer for testing gamma-ray detection in a near-space environment. Furthermore, the authors evaluated the performance of a new CeBr3 scintillator combined with a silicon photomultiplier (SiPM) readout. The results confirmed the feasibility of using Raspberry Pi, CeBr3 scintillator, SiPMs, and SIPHRA in future space missions. The authors of [54] utilized Raspberry Pi 3 B+ in the development of the SPE Lab Open Star Tracker (SOST), which offers a low-cost solution for CubeSat missions. The SOST achieves subarcminute precision in estimating the spacecraft attitude using open-source astronomy software. The work in [55] illustrates that Raspberry Pi was utilized as the data acquisition and logging system for a three-axis magnetic field sensor designed for educational purposes. This sensor system achieves high precision in collecting and analyzing data, contributing to the advancement of self-built electronic systems.

The research findings in [56] emphasize that Raspberry Pi 3 device was used as the control system for a low-cost web-controlled digital telescope designed for educational institutions. The telescope's remote orientation is achieved via Internet-connected motors, and a Message Queue Telemetry Transport (MQTT) based server enables wireless communication for control, visualization, and data acquisition. The study in [57] demonstrated that the MURAVES detector, equipped with low-power consumption electronics, incorporates a Raspberry Pi board to

Table 8
Usage of Raspberry Pi in Chemical Applications.

Reference	Work done	Hardware	Software	Remarks
[47]	Created new method with printed electrode and 3D platform.	Raspberry Pi, Portable and microfluidic electrochemical device, Texas Instruments LMP91000 chip	HTML5, Java and python scripts	Demonstrated successful analysis of salivary cortisol with good recovery values.
[48]	Developed instrument for accurate electrochemical measurements	Raspberry Pi	Python	Instrument offers wide measurement range suitable for research and teaching labs.
[49]	Developed lesson plan for improving a Raspberry Pi spectrophotometer	Raspberry Pi, basic spectrophotometer components	Python scripts for data processing and plotting	Students learned about instrumental error management.
[50]	Employed Raspberry Pi computer with 3D printed parts and inexpensive opto-electronic components for DPPH tests	Raspberry Pi, 3D printed parts, opto-electronic components	Python	Supports diagnostics in resource-poor countries.
[51]	Automated flow chemical synthesis system	Raspberry Pi, RAMPS motor driver boards	Python, PySerial, OpenCV	Raspberry Pi served as electronic interface between control computer and motor driver boards.
[52]	A 3-axis autosampler was utilized for automation in a range of flow chemical desilylation reactions.	Inexpensive 3-axis autosampler, Raspberry Pi	Python, OpenCV	Used for automation of acid-catalyzed flow chemical desilylation reaction.

Table 9
Raspberry Pi applications in Astronomy.

Reference	Work done	Hardware	Software	Remarks
[53]	Creation of compact high-performance gamma-ray detectors which can be deployed on small low-cost satellites.	CeBr3 scintillator, array of 16 J-Series SiPMs by ON Semiconductor, Raspberry Pi, temperature and pressure sensors, Global Navigation Satellite System receiver, satellite modem	SIPHRA	Operated continuously for 8 h, measured spectra from 100 keV to 8 MeV.
[54]	Created low-cost SOST for precise Lost-In-Space tracking.	Raspberry Pi 3 B+, camera	Open source astronomy software	Algorithm compares images with stellar catalog segments. Tested with satellite and ground images.
[55]	Built a three-axis magnetic field sensor using Raspberry Pi and fluxgate magnetic sensors for educational use.	Raspberry Pi, fluxgate magnetic sensors	python	Achieves root-mean-square precision better than 1 nanoTesla at a 5-second cadence.
[56]	Developed a low-cost web-controlled digital telescope for educational use.	Two webcams (one wide field of view, one narrow field of view with a 40 cm focal length lens), Raspberry Pi 3, two motors	In-house developed software running on Raspberry Pi 3	Utilizes image processing for camera alignment using Fourier domain cross-correlation.
[57]	Developed 4 m^2 muon tracker for volcanic areas	Raspberry Pi, multilayer electronic boards	Python	Emphasizes accurate channel adjustment, time-of-flight measurement via time expansion.

control multiple square meters of detectors. The focus was to accurately measure the muon time of flight, using a time-expansion technique facilitated by the Raspberry Pi. Table 9 summarizes the applications of Raspberry Pi in Astronomy.

3.7. Telecommunications

Due to its affordability and compact size, the Raspberry Pi can be used to create communication systems such as Voice over Internet Protocol (VoIP) servers, private branch exchange (PBX) systems, and session initiated protocol (SIP) gateways. It is also handy for tasks such as monitoring networks, analyzing packets, and managing firewalls. Its GPIO pins allow it to be interfaced with hardware to make custom communication devices, and it works well with different software for telecommunication protocols and services. It can be evidenced from [59] that the authors developed a Cognitive Radio (CR) system test bed to address wireless frequency shortage using the Software Defined Radio (SDR) platform, Universal Software Radio Peripheral (USRP) board, GNU Radio, and Raspberry Pi3. The research work in [60] talks about creating remote labs for some courses in electronics and telecommunications with mobile devices. The system used a Raspberry Pi 4 server and a Red Pitaya system, allowing students to perform experiments on their Android phones or tablets during the pandemic. In [94], it was shown that the RTL-2832U USB receiver connected to a Raspberry Pi decodes frequency modulation (FM) signals for transmission over a Local Area Network, supporting communication. The authors in [95] employed Raspberry Pi and introduced P4Pi, an affordable open source hardware platform for networking education that facilitates students with hands-on experience in switches and router structures. The research paper in [96] evaluated the performance of an Asterisk-based IP PBX on a Raspberry Pi 3 platform for the simultaneous handling of calls with various codecs. The research paper in [97] shows that Raspberry Pi was used as a server to facilitate voice and video call communications over a local area network (LAN), monitored with Wireshark for packet analysis. In [98], the authors proposed a lab-scale router testbed in passive optical networks (PON) by using Raspberry Pi to measure throughput, delay, and jitter for downstream and upstream transmissions. Table 10 summarizes the implementations of Raspberry Pi in the field of Telecommunications.

3.8. Environmental science

Raspberry Pi is extensively used in environmental science mainly for data collection, monitoring, and analysis. It enables low-cost solutions for weather monitoring, air and water quality assessment, wildlife tracking, and ecological research, contributing to studies on climate change, biodiversity, and pollution. Its ability to work with open source

Table 10
Roles of Raspberry Pi in Telecommunications.

Reference	Work done	Hardware	Software	Remarks
[59]	Authors built CR system testbed using SDR, USRP board, and Raspberry Pi3.	SDR platform, USRP board, Raspberry Pi3	SDR development toolkit, GNU Radio	Testbed performs spectrum sensing and determines channel occupancy.
[60]	Development of remote laboratory architectures for electronics telecommunications courses	Raspberry Pi 4, Red Pitaya	Embedded system	Intended to support remote experiments in telecom courses.
[94]	Reception and decoding of FM signals transmitted to another computer over LAN.	RTL-2832U USB receiver, Raspberry Pi	SDR-Sharp (on remote PC), GNU Radio	Signal reception and processing.
[95]	Development of a low-cost, open-source hardware platform for networking education.	Raspberry Pi	P4 programming language	Hands-on experience in network programming.
[96]	Evaluation of Asterisk-based IP PBX	Raspberry Pi 3 (model B)	Asterisk, SIP, RTP	Useful in warzones or disaster-affected areas.
[97]	Implementation of VoIP communication using Raspberry Pi as a server	Raspberry Pi	VoIP software, Wireshark	Manages voice and video call communications over LAN networks.
[98]	Implementation of a lab-scale router testbed in PON architecture	Raspberry Pi	PON networking software	Results confirm the suitability of Raspberry Pi in fiber networking.

software and its flexibility enables it to contribute towards environmental research. The following works illustrate the applications of Raspberry Pi in environmental science: The research work in [61] demonstrated that Raspberry Pi is used with neural networks to analyze scattered light to identify particle mixtures and solution salinity, serving as a low-cost environmental sensor. The authors in [62] integrated Raspberry Pi and Arduino in a mobile greenhouse monitoring system where the Raspberry Pi acts as a data server, improving the efficiency of data processing. The authors in [64] developed an IoT-based automatic sensor control system using Raspberry Pi to monitor indoor environmental parameters such as gas, temperature, and humidity. It processes data and triggers alarms for any deviation from set standards, with the aim of improving indoor air quality and safety. The authors in [99] aimed to popularize the usage of Raspberry Pi in biology research, making science more accessible and enhancing knowledge at different biological levels.

3.9. Agriculture applications

Raspberry Pi serves as a remote sensing and automation tool in agriculture. It is used to develop a wide range of applications, such as soil and weather monitoring, plant growth monitoring and tracking, automated watering, crop selection, yield prediction, disease, and pest detection. Its integration with IoT hardware enables real-time data collection and processing, providing farmers with timely information for informed decision making. Some of the applications are discussed in the following paragraphs. These applications improve productivity while conserving resources, especially in rural areas, promising to revolutionize farming with real-time data and task automation. Tables 11 and 12 present an overview of some agricultural applications.

Table 11
Raspberry Pi applications in Smart Agriculture.

Name of the application	Reference
Automatic fertilization system	[100]
Soil quality and micro-nutrient measurement	[101]
Disease Detection	[102–107]
Crop identification	[108]
Crop selection	[109]
Crop monitoring	[110–112]
Crop protection	[113]
Phenotyping	[67,101,112,114–116]
Yield evaluation	[117]
Smart irrigation	[118–120]
Precision farming	[108,119,121–124]
Water quality testing and monitoring	[125–129]
Fruit grading	[130]
Apiculture (Beekeeping)	[131,132]
Aquaculture and Aquaponics	[133,134]
Smart Poultry Farm	[135,136]
Hydroponic Systems	[137–139]
General applications	[140–143]

3.9.1. Smart agriculture and crop optimization

Several studies have explored precision agriculture systems to improve farming practices. These studies collectively showcase innovative applications of Raspberry Pi in precision agriculture, ranging from fertilization and root growth analysis to weed detection, bee colony monitoring, and honeybee behavior analysis.

Savani et al. [100] developed an autonomous fertilization system, using Raspberry Pi for the user interface and Arduino for control, enabling precise fertilizer delivery customized to crop needs in small-scale farms. Bontpart et al. [101] developed an affordable Rhizobox system to perform root growth studies in greenhouses to improve crop yields.

Ukaegbu et al. [121] studied weed-related yield challenges with a quadcopter-based UAV system. Their Raspberry Pi-powered system detected and treated weeds quickly, improving agricultural productivity. Kamath et al. [124] implemented a Raspberry Pi-based wireless sensor network for weed monitoring in paddy crops, facilitating timely interventions to boost crop production.

Morais et al. [122] developed a mySense precision agriculture system for the acquisition of viticulture data. Komasilovs et al. [123] designed and developed a solar powered wireless system using Raspberry Pi for bee colony monitoring, helping beekeepers identify the state of the colony. Gao et al. [131] developed a sound monitoring system using Raspberry Pi to detect queenless states in bee colonies, providing beekeepers with valuable information. Zhang et al. developed an automated video system to monitor the behavior of honeybees at the entrances of the hive, providing real-time data and accurate bee counts [132].

3.9.2. Plant disease detection and classification

Gonzalez-Huitron et al. [102] used Raspberry Pi for training and evaluating low-power optimized deep learning models to classify tomato leaf diseases cost-effectively. Aasha et al. [104] developed a disease detection system utilizing compressed sensing, achieving high-accuracy leaf disease identification on a Raspberry Pi 3 board.

3.9.3. Crop identification and precision agriculture

Tufail et al. [108] utilized machine learning to improve the identification of tobacco crops for precise agricultural spraying. Their study

Table 12
Agricultural applications of Raspberry Pi.

Reference	Hardware	Software	Parameters sensed	Remarks
[144]	pH, CO, Co2, Temperature, Moisture and light Sensors, Raspberry Pi, Arduino	Python, HighCharts, JustGuage, Flask, SQLite	pH, temperature, environmental, soil moisture, soil temperature and humidity	AI, Deep Learning, edge computing capabilities can be added
[145]	SixFab cellular shield, Quectel EC25 PCIe	GStreamer, Latency measurement libraries, Python	Latency values, Effect of video resolution, transmission distance and transmission type on transmission latency,	Further research is required to determine the appropriate resolution of videos to reduce the latency according to the capabilities of the networks
[117]	DHT11 sensor, BH1750FVI light intensity sensor	Android, Python IDE	Air temperature for greenhouse illumination	Can be extended to aquaponics
[146]	Raspberry Pi, Lithium-ion battery, Humidity and temperature sensor.	Contiki operating system, Python,C	Radio Wave Attenuation	Can be extended to determine attenuation curves at 868/915 and 2400 MHz bands.
[147]	WSN	Labview	Wind Speed and Direction, Communication latency	This system needs to be refined and more field tests are required to verify the performance.

showcased effective image processing techniques. Bhojwani et al. [109] implemented IoT-based precision agriculture, using sensor nodes for environmental monitoring and cloud analysis, enhancing crop management decisions.

3.9.4. Phenotyping for crop analysis

Susko et al. [112] developed an automated camera system with a Raspberry Pi and 360FLY 4K camera to quantify crop lodging and movement under field wind conditions, which allowed high-throughput data collection for complex plant trait measurements. Adami et al. [113] introduced an economical phenotyping system, employing a Raspberry Pi NoIR camera, to measure Arabidopsis thaliana rosette growth and phenotypic traits. Minervini et al. [116] developed a low-cost, user-friendly system called Phenotiki for the phenotyping of rosette-shaped plants. It facilitates plant research with efficient data processing capabilities.

3.9.5. Water management in agriculture

Tolentino et al. [117] created a self-sustainable smart aquaponics system for monitoring and corrections, maintaining optimal plant growth conditions by adjusting factors such as light, temperature, and pH in real time. Benyezza et al. [118] proposed a zoning irrigation system powered by IoT. Raspberry Pi processes data and makes decisions, reducing water and energy usage in agriculture.

Abioye et al. [119] addressed water scarcity with precision irrigation using Raspberry Pi. It reduces water waste while keeping costs low for embedded devices. Hamdi et al. [120] introduced a smart irrigation system in Pakistan using IoT and Raspberry Pi. This efficiently monitors and manages water distribution in agriculture, addressing water scarcity.

3.10. Image processing

Raspberry Pi can be used for image processing applications such as image segmentation, searching, correlation, and compression. Raspberry Pi can even be used to identify, recognize, and track different objects in videos. In addition, to these applications, the Raspberry Pi can be employed in many computer vision applications such as smart control systems, gait identification, animal tracking, and many more.

Raspberry Pi is also utilized for real-time object detection and recognition due to its efficiency and speed. Various techniques are commonly used to achieve this, including the Histogram of Oriented Gradients (HOG) and Support Vector Machine (SVM), which exhibit acceptable performance in real-time human detection. Deep learning algorithms such as Convolutional Neural Networks (CNN), Region-Based CNN (R-CNN), Fast R-CNN, Faster R-CNN, and You Only Look Once (YOLO) are used for real-time object recognition. Hardware implementation using Raspberry Pi enables real-time object detection performance without the need of external memory or image acquisition devices. Software libraries such as OpenCV play a crucial role in the implementation of real-time object detection systems. A list of all SOME significant works illustrating the image processing applications of Raspberry Pi is highlighted in Tables 13 and 14.

Table 13
Image processing applications of Raspberry Pi.

Name of the application	Reference
Object identification	[35,148–150]
Object recognition	[30,75,79,151–171]
Object tracking	[172]
Image segmentation	[173]
Image correlation	[174,175]
Image search	[176]
Image compression	[177,178]
Computer vision applications	[132,179–185]
General applications	[117,186–191]

In a study by Xu et al. [35], embedded edge computing and rule-based objective functions were used to enhance smart control systems, specifically optimizing home temperature based on user comfort. Their work showcased how Raspberry Pi devices can autonomously control home temperature without human intervention. Llamas et al. [148] contributed to open-source hardware by developing a versatile platform for gait identification, which facilitates data acquisition. This platform, utilizing Raspberry Pi and open source tools, enables efficient data collection from multiple sensors.

Bolanos et al. [149] devised a protocol to automate animal experimentation using RFID technology and the Raspberry Pi. This cost-effective approach improves consistency and reduces animal stress, with potential applications in tracking individual animal weights and brain imaging. Meniri et al. [150] presented an inexpensive RFID-triggered trap for small animals, offering ecological researchers a reusable framework to build similar devices. Their successful trapping experiments demonstrate its practicality.

Peng et al. [151] designed an autonomous tennis ball collection robot employing Raspberry Pi and image processing techniques. This real-world application showcases Raspberry Pi's capabilities in robotics and computer vision. Demir et al. [152] addressed energy-efficient marine monitoring through adaptive image recognition. They used the Raspberry Pi for efficient power management and a CNN-based recognition system, achieving substantial energy savings.

Sajjad et al. [154] proposed a cost-effective system to recognize facial expressions, primarily for law enforcement. Leveraging Raspberry Pi's capabilities in image capture and analysis, this system identifies emotions, aiding in preventing hostile situations. In a similar vein,

Table 14
Image processing applications using Raspberry Pi.

Reference	Work done	Hardware and Software	Remarks
[154]	Energy-efficient facial expression-based suspicious activity recognition using Raspberry Pi.	Hardware: Raspberry Pi, Programming language: Python.	Valuable for law enforcement and security.
[155]	Real-time emotion recognition on a Raspberry Pi-based robot.	Hardware: Raspberry Pi, Software: Custom software.	Useful in interactive real-time applications.
[156]	Hand gesture classification system leveraging Raspberry Pi's edge computing.	Hardware: Raspberry Pi, Programming language: Python.	Effective for gesture-based interfaces.
[151]	Designed an autonomous tennis ball collecting robot with Raspberry Pi.	Hardware: Raspberry Pi, Camera, Motors, Software: OpenCV.	Successful real-world implementation.
[152]	Developed an energy-efficient image recognition system for marine monitoring with Raspberry Pi.	Hardware: Raspberry Pi, Pi NoIR Camera, LEDs	Significant energy savings were achieved.
[167]	Demonstrated occupancy-predictive HVAC control in a mosque using Raspberry Pi.	Hardware: Raspberry Pi, Sensors, Software: Video processing, EnergyPlus simulator.	Improved energy efficiency in building automation.

Table 15
Identification applications of Raspberry Pi.

Name of the Application	Reference
Failure identification	[35,192]
Disease identification	[193]
Gait identification	[148]
Criminal identification	[194–196]
Frequency identification	[149,150,197]
Fault identification	[198–201]
Driver distraction identification	[202]
Electronic load identification	[203]
System identification	[204]
Weeds and Crops identification	[205–208]
Damage identification	[209]

Table 16
Raspberry Pi in detection applications.

Name of the application	Reference
Fire detection	[210,211]
Smoke detection	[212]
Object detection	[213–218]
Flood detection	[219–222]
Volatile compound detection	[223]
Vehicle detection	[224,225]
Stress detection	[226,227]
Pathogen detection	[228,229]
Fault detection	[199,230–235]
Violence detection	[236]
Motion detection	[237,238]
Emotion detection	[239–242]
Kidney detection	[243]
Driver fatigue/drowsiness detection	[244–249]
Anomaly detection	[250–252]
Face detection	[253,254]
Road pavement quality detection	[255]
Lane detection	[256]
Face Mask detection	[257]
Fluoride level detection	[258]
Intrusion detection	[259,260]
Fermentation detection	[261–263]
Parking space detection	[264]
Fall detection	[179,265]
Pest detection	[266,267]
Human/Pedestrian detection	[182]
Eye detection	[268]
Eye Strain detection	[269]
Compiler error detection	[270]
Malware detection	[271]
Social distance detection	[272]

Palaniswamy et al. [155] utilized the Raspberry Pi in real-time emotion recognition, with potential applications in various fields, including human–computer interaction and medical systems.

Breland et al. [156] developed an efficient hand gesture classification system based on Raspberry Pi, achieving a remarkable accuracy of 99.2%. This technology has broad implications for human–computer interaction and edge computing.

Raspberry Pi is used to develop various recognition, identification and detection applications, which are summarized in Tables 15, 16, 17, and 18, respectively.

Elderly populations face numerous challenges related to their physical and mental health, significantly affecting their well-being. Many prefer to stay in their own homes, which requires solutions that can autonomously detect health issues and reduce the burden on caregivers. In response, Chapron et al. developed a sensor platform, detailed in [162], that uses infrared proximity sensors to accurately identify basic bathroom activities such as toileting and showering. This system, with a notable F-Score of 96.94%, prioritizes simplicity, affordability, and reliability, offering a valuable tool to monitor the health of elderly individuals at home.

Another notable application involves face recognition technology, as demonstrated in [164]. This technology helps law enforcement by identifying suspects and locating missing persons through facial detection and cross-referencing with criminal databases. The proposed framework integrates a Raspberry Pi, cloud support, and a wireless camera for secure and efficient face recognition. The testing revealed superior capabilities compared to existing methods, positioning it as a valuable asset for law enforcement in smart cities.

Hsia et al. proposed a high-performance algorithm for embedded finger vein recognition systems in [165]. This system addresses challenges in user database expansion employing semantic segmentation, adaptive preprocessing, and feature extraction. It achieves high accuracy and efficiency, overcoming previous limitations in embedded finger-vein verification systems.

Rodriguez et al. introduced an innovative use of the Raspberry Pi in education in [166]. Their system facilitates student questionnaires on mobile devices, enabling teachers to monitor in real time. This approach improves classroom participation.

Aftab et al. explored intelligent building automation systems in [167]. They designed an occupancy-predictive HVAC control system using the Raspberry Pi 3, which achieved real-time occupancy recognition through video processing and machine learning. This system dynamically analyzed occupancy patterns and used predictive control of the model for HVAC operations, ultimately leading to significant energy savings in a large mosque.

Raspberry Pi based image and video processing applications face various challenges due to the limited processing power of the devices, memory limitations, and lack of hardware acceleration. The ARM architecture of the Raspberry Pi requires algorithmic optimization and adaptation for efficient execution. Real-time processing tasks face additional issues that require careful tuning to meet performance requirements. Storage limitations and power consumption concerns further complicate the development of image and video processing applications. Heat dissipation mechanisms are necessary to prevent thermal throttling and maintain optimal performance during intensive

Table 17
Raspberry Pi in detection applications (continued).

Name of the application	Reference
Unmanned Areal Vehicle (UAV) detection	[273]
Injury detection	[274]
Mask detection	[275]
Speed bump detection	[276]
Pathogen detection	[277]
Apple detection	[278]
Liveness detection	[279]
Obstacle detection	[218,280]
Salmonella detection	[281]
E. coli detection	[46,282]

Table 18
Recognition applications of Raspberry Pi.

Name of the application	Reference
Facial expression recognition	[153,154]
Emotion recognition	[155]
Sign language recognition	[156]
Speech recognition	[157–160]
Activity recognition	[161,162]
Face recognition	[163,164]
Object recognition	[75]
Vein recognition	[165]
Optical Character Recognition	[283–285]
Obstacle recognition	[79]
Number plate recognition	[286,287,287]
Voice recognition	[30,166]
Speaker recognition	[288,289]
Occupancy recognition	[167]
Banknote/paper currency recognition	[168]
Hand gesture recognition	[169,170]
Fish recognition	[171]
Traffic sign recognition	[290,291]
Sleep Posture Recognition	[193]

processing tasks. Overcoming these challenges involves a combination of hardware optimization and algorithmic optimizations tailored to specific needs.

3.11. Bio-technology

Raspberry Pi is used to develop automated bioprocessing systems such as bioreactors and biosensors. Raspberry Pi is also used to develop systems that track environmental factors such as temperature, humidity, and CO2 levels and to control various crucial parameters to optimize biological processes. Monitoring real-time data in greenhouses, growth chambers, or bioreactors helps trigger alarms or automate the response if conditions deviate. The capabilities of Raspberry Pi help to develop systems for collecting biological data on cell growth, enzyme activity, or biomolecule concentrations, and supporting experiments. Additionally, Pi can be used for data acquisition, basic analysis, or wireless transmission of data to central computers for further exploration. In bioprinting, Raspberry Pi serves a key role in the precise control of bioprinters, allowing for the creation of required structures. Some of such applications are presented here.

In [292], a low-cost automated bioreactor sampling system controlled by a Raspberry Pi is designed to take samples and maintain them at a predefined temperature. In [293], a low-cost bioreactor is developed to stimulate stress in tissues and collects information via a Raspberry Pi, achieving cell cultivation without contamination. In [294], a rapid biosensor is designed to detect Salmonella bacteria using a mobile application, with image processing for bacterial counting.

In [295], a smart measuring system using Plastic Optical Fibre (POF) based sensors is developed to detect selective substances in water, with a focus on monitoring pollutants. In [296], a device is developed for color change detection, which is particularly useful in biosensing applications. Some of the applications of Raspberry Pi in the field of biotechnology are described in Table 19.

Table 19
Applications of Raspberry Pi in Biotechnology.

Name of the application	Reference
Biosensor	[294,295]
Biochemical	[306]
Biological	[43,188,296]
Bioaerosol	[307]
Bioengineering	[308]
Biosensors	[46,294,295]
DNA extraction monitoring and analysis	[309,310]

Developing Raspberry Pi-based solutions for biotechnology poses several challenges, including ensuring data integrity and validation, accuracy and calibration of sensors to measure biological parameters, maintaining biological safety during experimentation, protecting sensitive data, complying with regulatory standards, integration with existing laboratory equipment, ensuring long-term stability and reliability. Collaboration between biotechnology experts, software developers, and regulatory professionals is required to ensure the effectiveness, reliability, and compliance of applications with required standards and regulations.

3.12. Robotics

Raspberry Pi plays a crucial role in the development of multipurpose robots and a wide range of robotic applications. It is widely used in the field of robotics due to its ability to process images for object recognition, control robot movements, integrate various sensors for environmental awareness, and interface with sensors, motors, and actuators, enabling the creation of autonomous systems. Its variety of connectivity options allow remote control and data transmission, and its open source nature facilitates software development and customization. From autonomous lawn mowers and quadcopters to surveillance and service robots, Raspberry Pi provides the necessary computational backbone for these systems to operate effectively, allowing developers to implement diverse functionalities and making it suitable for applications ranging from simple line-following robots to complex autonomous vehicles. Furthermore, its compatibility with popular software frameworks and libraries facilitates rapid prototyping and experimentation, driving innovation in the field of robotics.

Liao et al. developed a lawn mower equipped with image recognition capabilities [297]. This mower has the ability to identify and avoid obstacles, thus improving its efficiency and safety. Alonge et al. developed a quadcopter [298], which has implications for aerial surveillance and delivery systems. Al-Tameemi et al. [299] have developed a cost-effective surveillance robot that offers a practical solution to monitor large areas. Similarly, the retail industry can benefit from the development of efficient shopping robots [300], which can assist customers and manage inventory.

To combat extreme heat, researchers have designed a cooling robot [301] that can operate in high temperature environments. In the domestic sphere, smart home service robots [302] have been developed to assist in household tasks. Trash collection robots [303] and gardening robots [304] have been introduced to automate manual labor. Lastly, the field of quantum computing has been applied to warehouse operations [305], improving efficiency and accuracy. Detailed descriptions of these robots are presented in Tables 20 and 21.

3.13. General applications

Raspberry Pi has several general applications. Researchers in [318] created an affordable microscope for laboratories. It allows scientists to customize experiments without breaking the bank. In another

Table 20
Raspberry Pi applications in smart robots.

Name of the application	Reference
Automatic robotic lawn mower	[297]
Quadcopters	[298]
Surveillance Robot	[299]
Supermarket Service Robot	[300]
Air Conditioner Robot	[301]
Home Service Robot	[302]
Trash Collecting robot	[303]
Gardening Robot	[304]
Line following Robot	[311,312]
Smart Robots	[151,180,214,305,313–316]

work [319], the researchers developed Do-It-Yourself (DIY) lab equipment. They built a low-cost imaging system using Raspberry Pi and Arduino for microbiology tasks (see Table 22). The imaging system is flexible and can handle various tests, such as watching bacteria grow or testing microfluidic devices. Tables 23 and 24 present the details of some general applications of Raspberry Pi.

The work in [162] presents a smart authentication system that combines fingerprints, passcodes, and phone devices for secure access. Similarly, in [355], a system with similar authentication features is developed. On the other hand, [356] explores an IoT-based system that focuses on the extraction of wearable plantar bio-features for authentication, which improves user security.

Shifting the focus to real-time monitoring, [357] introduces an IoT drug monitoring system designed to detect drug concentrations in human serum, offering potential benefits in the medical field. Additionally, [358] presents a measurement system using Raspberry Pi for the recording of ECG and impedance cardiography, showcasing the versatility of this technology in healthcare applications.

In [359], a biosignal-based system is developed to detect aggressive driving behaviors and address road safety concerns. In another work [309] the authors proposed a low-cost, highly integrated real-time Digital Polymerase Chain Reaction (dPCR) device for DNA quantification, providing a cost-effective solution for DNA analysis.

The importance of accurate modeling and optimized control systems for greenhouse cultivation is emphasized in [320]. The researchers used MATLAB/Simulink for energy balance simulation and fuzzy logic control, integrated with IoT for real-time monitoring. In [321], a remote greenhouse monitoring system is developed using Raspberry Pi, tracking parameters such as temperature and humidity.

Smart mirrors for mental well-being are developed in [322,323], with sentiment analysis and gesture control. The implementation of an IoT-based E-waste monitoring system is performed in [324], while [325] focused on real-time visual recognition for smart city surveillance. An innovative IoT solution for the tracking of public transport buses without GPS is discussed in [360]. Security concerns in smart cities and IoT are addressed through the SafeCity architecture in [326]. Secure protocols for smart city wireless applications are proposed in [329]. Edge blockchain-based data access control for the smart grid is developed in [327].

The monitoring of trace moisture in gas-insulated SF6 switchgear is developed in [328], utilizing microcantilever sensors and IoT connectivity. The development of a robot operating system to assist independent walking in aging individuals is described in [331]. Fall and posture detection systems for the elderly are developed in [332, 361]. A smart wearable device for the safety of children is presented in [328]. Smart waste management using IoT and AI is explored in [333]. A web-controlled digital telescope is detailed in [56]. A MURAVES detector for volcanoes is developed in [57]. Microscopes using Raspberry Pi for customization, such as the MicroHikari3D microscope in [338] and the Twitter controlled 3D printed microscope in [337], are created. Small autonomous electric vehicles for farming tasks are designed in [334]. A robotic vehicle for students is proposed in [335]. A DIY vision for customizable IoT applications is introduced in [336]. A build-your-own visible-range spectrophotometer is presented in [49]. In [339] a mobile device-based learning support system is developed for stepper motors. An interface to control a compact spectrograph is described in [340]. An energy management system for portable/portable devices is designed in [343]. Temperature analysis using Raspberry Pi is performed in [344]. A model for diabetes patients predicting insulin patterns using Artificial Neural Networks (ANN) is proposed in [345]. Prediction-based lossless compression for CT images is discussed in [346].

3.14. Energy management

Raspberry Pi is utilized in the development of various energy management and monitoring applications. In energy consumption monitoring, the Raspberry Pi interfaces with sensors and smart meters to provide real-time information on energy usage and implements optimization strategies such as scheduling and automation, thus reducing unnecessary energy consumption. Raspberry Pi serves as a data logger for energy metering/logging, allowing a detailed analysis of consumption patterns over time. Integration into energy harvesting systems allows the Raspberry Pi to capture and store renewable energy efficiently. Acting as a central hub, it aggregates data from various sources in energy management systems, enabling informed decision-making and control. In addition, Raspberry Pi facilitates the development of energy-efficient applications such as smart lighting and heating, ventilation, and air conditioning (HVAC) systems. Finally, it supports energy trading by monitoring production and consumption, facilitating peer-to-peer trading within microgrids or communities.

The authors [376] developed a home energy monitoring server system that monitors, processes and displays the information using a Raspberry Pi. The proposed system monitors the power consumption of laptops, mobile phones, and TVs. Khanna et al. [377] developed a system that tracks the power usage of individual electronic home appliances.

In [378] a dynamic algorithm is proposed for the optimized usage of IOT electric appliances. The irrigation system is developed in [379] to monitor plant growth, water, and energy consumption using Raspberry pi and Fuzzy logic controllers. In [380], an optimized energy management system has been developed.

Al-Kaseem et al. [381] developed a system that simplifies and gives flexibility to machine-to-machine network management using a Software-Defined Network (SDN), Network Function Virtualization (NFV) and cloud computing. In [382] a low-cost and energy-efficient transcoder cluster is proposed, which is VideoCoreCluster, which is suitable for live video streaming. In [383] proposed a multi-agent system for real-time manufacturing monitoring in industries for strategic decision making. An algorithm has been proposed in [384] to reduce data during transimission and sensor node level in wireless video sensor networks (WVSN). This algorithm reduces the number of images sent from node to coordinator.

Li et al. [385] developed an Energy trading system based on FeneChain, a blockchain to maintain energy trading processes and quality energy systems for industries. Table 25 presents several energy management applications that have been developed using Raspberry Pi.

3.15. Healthcare

Healthcare domain is benefited significantly by using Raspberry Pi in the development of various systems such as remote patient monitoring, telemedicine, medical imaging, and data analysis. Raspberry Pi can be used to develop systems to improve patient care through remote diagnostics, real-time monitoring of vital signs, and improved access to medical services in underserved areas. Raspberry Pi also facilitates the development of portable medical devices and wearables that can

Table 21
Raspberry Pi Robotic Applications.

Reference	Work done	Hardware	Software	Remarks
[297]	Robotic lawn mower	DSP, Raspberry Pi	Control, Image Recognition	Innovative lawn maintenance robot.
[298]	Quadcopter control	Raspberry Pi	Control	Effective quadcopter control system.
[299]	Robotic surveillance	Raspberry Pi	Surveillance	Cost-effective surveillance robot.
[300]	Supermarket service	Raspberry Pi	ROS, DCNN (SSD)	Efficient supermarket robot.
[301]	Outdoor cooling	Raspberry Pi	Image Processing	Combines robotics and cooling technology.
[302]	Smart home service	Raspberry Pi, Arduino mega2560, USB camera, GSM Module, CC2530 ZigBee network	Speech Recognition API	Versatile home service robot.
[303]	An innovative mechanical design featuring the Rocker-Bogie mechanism for resilient Trash-Collecting Robots	Raspberry Pi, Arduino, Sensors	YOLOv4-tiny	Effective Trash-Collecting Robot.
[304]	Gardening robots	Raspberry Pi, ESP32	Android control	Effective solution for rural gardening.
[305]	AGV line follower	Raspberry Pi 3	Meta-heuristic algorithms	Real-time line tracking for AGV.
[312]	Quantum robotics	Raspberry Pi 4	Quantum algorithms	Warehouse optimization with quantum.

Table 22
Raspberry Pi applications in Smart device development.

Name of the application	Reference
3D printers	[317–319]
Smart greenhouse	[320,321]
Smart mirrors	[322,323]
Smart city	[324–326]
Smart grids	[327–330]
Smart devices	[331–333]
Telescopes	[56,57]
Do It Yourself applications	[334–338]
Smart education	[49,339–341]
Smart healthcare	[342]
General applications	[343–346]

track and manage health conditions efficiently. Raspberry Pi can aid in medical research for data collection and analysis, ultimately leading to advancements in personalized medicine and healthcare delivery.

General healthcare applications [4,391,392], patient care [393], support for disabled people [84,394,395], telemedicine [396,397]

In [391], the authors developed an automated monitoring system to monitor the health status of a patient considering health parameters such as heartbeat and temperature using related sensors, camera, Raspberry Pi and web and Andriod applications.

The authors proposed an algorithm that predicts the health status of the elderly collecting data from health centers [398]. The proposed method uses principal component analysis (PCA) and support vector machine (SVM) techniques. The techniques are implemented using Raspberry pi.

The authors [399] developed a system which uses wireless visual sensor network (WVSN) nodes. Nodes are used to sense the signals from the patient. WVSN relies on raspberry pi. Kinect and ID sensors are used for processing core and image capturing units.

The authors [86] developed a prototype for home automation for disabled people using the brain computer interface (BCI). It collects brain signals for specific operations. Graphical User Interface (GUI) acts as a control and monitoring system for home appliances. BCI is the input to the GUI. NeuroSky MindWave headset is used to detect the brain EEG signal. The prototype is developed using Raspberri pi 3.

The authors [87] proposed a multimodal body-machine interface (BoMI) that helps people with disabilities of the upper limb. In the proposed system, wearable and wireless body sensor network (WBSN) are used for upper-body gestures. Muscular activities and activities of the upper body parts are measured using inertial measurement units (IMUs) and surface electromyography (sEMG).

The authors [400] developed a model using Raspberry Pi that collects vital signs of patients such as body position, glucose level, air flow, electrocardiogram (ECG), oxygen saturation (SPO2), blood pressure, temperature, height, weight. The model is mainly built for people who reside in remote areas of the country.

When developing healthcare systems using Raspberry Pi, it is essential to provide data security by encrypting patient information and storing it securely. It is also important to ensure the reliability of the systems to prevent failures and comply with regulatory standards such as HIPAA. Designing user-friendly interfaces for both patients and healthcare professionals and maintaining interoperability with existing healthcare systems are also crucial. Incorporating features for remote monitoring is one of the key aspects to consider. Scalability to accommodate growth is also crucial. In addition, addressing power requirements is essential, especially in environments with limited power sources. By focusing on these aspects, researchers can create effective healthcare solutions.

3.16. Monitoring applications

Raspberry Pi is widely used to develop automated monitoring applications in various domains due to its affordability, flexibility, and connectivity capabilities. In environmental monitoring, the Raspberry Pi interfaces with sensors to measure parameters such as air and water quality, and weather conditions. Health monitoring systems use Raspberry Pi to track fitness metrics, monitor patient health parameters, and detect physiological abnormalities. Structural monitoring applications use Raspberry Pi to monitor vibrations, strain, and temperature in buildings and infrastructure, ensuring safety and early defect detection. For transportation monitoring, the Raspberry Pi integrates with cameras and GPS modules to monitor driver behavior, track vehicle speed, and analyze traffic flow. Behavioral monitoring applications employ Raspberry Pi for surveillance, wildlife tracking, and crowd monitoring by analyzing video footage and sensor data. With its real-time data processing capabilities, the Raspberry Pi enables efficient monitoring, analysis, and decision-making in automated monitoring applications, making it a cost-effective solution for a wide range of monitoring needs.

Buildings/Structural health monitoring is useful to monitor, estimate, and fix the damages and deterioration in the strength/health of structures at early stages. Abdelgawad et al. [401] developed a structural health monitoring system to estimate the life span of a building/structure using piezoelectric sensors, Wifi module, and a Raspberry Pi. In [402], Morgenta et al. designed a software framework for wifi-based wireless sensor networks to use in the development of cost-effective structural health monitoring systems. This framework was validated on Raspberry Pi. In a later work [403], the authors developed a system to monitor the structural health of the concrete beam members.

Table 23
General Applications-1.

Reference	Objective of the work	Hardware	Software	Remarks
[347]	To design and develop an IoT-based architecture that integrates artificial neural networks into low-cost kits with different hardware architectures	Raspberry Pi Camera V2.1.	Python	Developed a Low-Cost Astronomy Software
[348]	To propose a facial biometric system based on a client–server paradigm using the Raspberry Pi 3 model B	Raspberry-pi 3 Model B, Raspberry-pi Camera, Power Adaptor, Touch Screen Display, Micro SD Card	Python, C++, Open CV	Extended LGHP algorithm-based facial biometric system
[349]	To develop and deploy a Stereo Imaging based LSPIV system capable of reconstructing three-dimensional topography and water surface distribution	Light source module, camera, projector, ultrasonic distance sensor, Raspberry Pi	NA	Handheld fluorescence imaging device
[333]	To develop a smart waste management system using the LoRa communication protocol and TensorFlow-based deep learning models	IR sensor, Moisture sensor, DHT22 temperature sensor, MQ-135 gas sensor, IR sensor, passive infrared, PIR sensor	Python	Lora WAN based Dry and Wet Waste Management System
[350]	To develop an open-source behavioral recording system using Raspberry Pi	Raspberry Pi Zero W, 3B	Bash Unix shell, Python	Behavioral analysis system
[169]	To develop a low-power, low-latency wearable deep learning system using FPGA acceleration and Cortex-M0 IP core	AHB-Lite BUS, APB BUS	Cortex-M0 Kernel	A Wearable device, hand gesture recognition system using FPGA accelerator
[351]	To develop a centralized flood monitoring and coordination system using IoT and open-source technologies	HC-SR04	OPENCV	Remote monitoring, Autonomous Floodgate, Water Management and Control
[352]	To design and implement an IoT-based platform for developing cities that uses 3G cellular connections	Raspberry Pi 3, Camera, Arduino, 3G Modem, ADC Board	OpenCV	An adaptive IoT platform
[353]	To propose a lightweight attribute-based security scheme based on elliptic curve cryptography for fog-enabled cyber–physical systems	Raspberry Pi	Python	A Lightweight Security Scheme, Cyber Physical Systems
[251]	To develop prediction techniques using the Deep Neural Network, Support Vector Regression, and k-Nearest Neighbors to forecast anomalies in electricity usage in smart grid systems	NVIDIA GTX, Raspberry Pi	Python, Tensorflow, Keras	Anomaly Detection in Edge Computing for Smart Meters
[354]	To propose an integrated IoT platform using blockchain technology to guarantee sensing data integrity	Raspberry Pi 3B	Python	IoT Blockchain Platform for Sensing Data Integrity

Table 26 presents various automated monitoring applications developed using Raspberry Pi such as air and water quality monitoring, weather and environmental monitoring, health and behavioral monitoring, etc.

3.17. Industrial applications

Automating industrial processes such as detection, tracking, monitoring, controlling, and managing using electronic sensors, embedded systems, and wireless technologies is termed industrial automation. Automation improves reliability, safety, product quality, and productivity in industrial processes with minimum labor costs and efficient use of materials [455]. Automation systems designed using Raspberry Pi, web technologies, and networking standards can be used to sense process variables such as liquid/chemical levels, flow, pressure, temperature, and distance to continuously monitor and control industrial processes remotely with less engineering costs and less human intervention.

Some of the industrial applications of Raspberry Pi can be found in Automation [455,456], fault detection [200], load control, maintenance [457], monitoring and control, security [458].

In [455], the authors used low-cost hardware and open-source software to develop a strategy to control liquid levels in tanks. They evaluated the performance of this system and examined whether low-cost automation technologies can be considered as enabling factors of the Industrial Internet of Things (IIoT).

Ahmed et al. [456] proposed a new network architecture using Raspberry Pi as a software-defined controller to improve the efficiency and scalability of the automation process in a food processing plant. They used the Mininet emulator to analyze the modified topology.

In [200], the authors proposed a new framework called cognitive fog of things to improve the detection and rectification of faults in the equipment manufacturing industry.

Tian et al. [457] developed a system for dynamic target detection and tracking on the production line. They used the HAAR cascade and Continuously adaptive mean shift (CAMShift) for target detection and tracking, respectively.

In [458], Praveena et al. developed a fire, gas leak detection system. This system is capable of sending an email to the personnel concerned if an intruder is detected.

Developing industrial-grade applications using Raspberry Pi poses several challenges such as reliability, durability, and longitivity. Reliability concerns arise due to its general-purpose design, and potential durability issues arise due to harsh industrial environments. Industrial applications often require sustained performance. This demand may exceed the processing power capabilities of Raspberry Pi boards. In addition, industrial applications need specific input/output interfaces and connectivity options, which may not be fully supported by the Raspberry Pi. Providing ongoing software support, updates, and compatibility with industrial standards is crucial. Proper planning, appropriate hardware selection, and environmental considerations are all important aspects to consider. Additionally, rigorous testing of products is vital. All these steps help develop reliable and efficient industrial applications using the Raspberry Pi.

Table 24
General Applications-2.

Reference	Objective of the work	Hardware	Software/Model	Results	Remarks
[362]	Investigate secure and privacy-preserving consensus for multi-agent systems under cyberattacks	Raspberry Pi	Privacy-preserving adaptive resilient consensus algorithm (PPARCA)	Effectively protects privacy and achieves resilient consensus under cyberattacks	Theoretical analysis and simulations
[363]	Introduce a unified and flexible framework for learner-centered learning scenarios	Raspberry Pi	Mathematics to Practice Laboratory (M2PLab)	Successful implementation of M2PLab for experimental courses	Student feedback verifies effectiveness
[364]	Design a blended laboratory using Raspberry Pi Pico for Digital Circuits and Systems course	Raspberry Pi Pico, Wokwi simulator	–	Intended learning outcomes achieved, effectiveness verified	Considers impact of COVID-19
[365]	Propose a lightweight network architecture called all-MLP for human activity recognition	Raspberry Pi	All-MLP	Comparable classification score with fewer FLOPs and parameters	Evaluated on Raspberry Pi for real-world simulation
[366]	Construct an edge computing platform for people counting using a fisheye lens	Raspberry Pi 4, fisheye lens	Modified YOLO model, TensorFlow Lite	Mean average error of 0.249, detection speed of 2 FPS	Solves privacy and bandwidth issues
[367]	Estimate velocity of a mass involved in non-smooth impacts	Raspberry Pi	Hybrid observers	Semiglobal exponential convergence to zero	Experimental evaluation on Raspberry Pi
[368]	Investigate performance of a container-based architecture to integrate LoRaWAN and IP-based networks	Raspberry Pi	CoAP	Enables seamless interaction between LoRaWAN and CoAP-based nodes	Virtualization approaches evaluated.
[369]	Combine ultrawide band and magnetic ranging systems for position estimation	Raspberry Pi 4 Model B	Adaptive tightly coupled extended Kalman filter (ATCEKF)	6.9 cm error in outdoor environment, improved accuracy and robustness	Mobile node implementation on Raspberry Pi 4
[370]	Retrieve information from pipeline interiors using an air-coupled ultrasonic array	Raspberry Pi 4, crawler robot	Custom array controller	Ability to image joints, surface roughness and pipe wall shape	Potential for detecting faulty joints and corrosion
[371]	Propose ETradeChain, a platform for energy trading based on blockchain technology	Raspberry Pi 4 Model B	Modified double auction scheme, blockchain	Minimized consensus delay, high throughput, low overhead	Testbed experiments using Raspberry Pi devices.
[372]	Present PIX instrument for measuring ionizing particles on stratospheric balloons	Raspberry Pi, MiniPIX device	neural network for particle identification	Proton, electron and photon fluxes presented	Experimental evaluation and comparison with MAIRE model
[373]	Compare collaborative learning strategies for air quality prediction on edge devices	Raspberry Pi, Jetson Nano	Federated learning, clustered model exchange, spatiotemporal data exchange	Spatiotemporal data exchange achieves highest accuracy	Implementation and comparison on real hardware
[374]	Explore fat-intrabody communication (Fat-IBC) for high-speed data communication within the body	Raspberry Pi	IEEE 802.11n wireless communication	Link speeds of 92 Mb/s achieved	Among the fastest measured with intrabody communication
[375]	Propose an efficient re-encryption scheme for secure communication in vehicles	Raspberry Pi	Proxy re-encryption, MIRACL cryptography library	Secure scheme for forwarding and processing encrypted messages	Simulations and security analysis
[330]	Propose a blockchain-based decentralized frequency control for an islanded microgrid	Raspberry Pi, OPAL-RT	Federated learning fractional order recurrent neural network (FL-FORNN), smart contract participation matrix (SCPM)	Robust frequency control, comparative analysis with other techniques	Implementation on OPAL-RT and Raspberry Pi devices

Table 25
Raspberry Pi in Energy metering and conservation.

Name of the application	Reference
Energy generation/Consumption monitoring	[376]
Energy Metering/Logging	[377]
Energy Harvesting	[378]
Energy consumption optimization	[253,386]
Energy saving	[379]
Energy management systems	[380,387]
Energy-efficient applications	[152,381–384,388–390]
Energy trading	[385]

4. Discussions

Developers may face a number of technical and nontechnical issues when prototyping IoT applications using Raspberry Pi. Technical issues include hardware compatibility issues, OS/software compatibility issues, connectivity issues, code debugging issues, security and data privacy issues, improper design and printing of components, heating/burning of components, general limitations of hardware such as storage, processing capacities, network connections, and bandwidth limitations, network bandwidth requirements, power consumption, radiation, performance issues over time due to extreme weather conditions, device/system reliability issues, sensor precision issues, and synchronization issues between multiple devices.

Nontechnical issues include inadequate budget planning and management, difficulty in sourcing and procuring required components, lack of expertise or knowledge in specific areas, difficulty in assembling and testing the prototype, difficulty in finding or recruiting the right personnel, difficulty in coordinating and communicating effectively with the different stakeholders involved, difficulty in identifying and addressing the needs of the target users and customers, and difficulty in determining the feasibility, scalability, and sustainability of the prototype.

Security and privacy concerns are a common issue in IoT development, as connected devices can potentially be vulnerable to hacking or

Table 26
Automated monitoring applications.

Application	Reference
Air quality monitoring	[404–407]
Water quality monitoring	[408–410]
Weather monitoring	[411]
Body fitness monitoring	[412]
Wildlife monitoring	[413]
Plant growth and disease monitoring	[69,414,415]
Waste/Sewage/Dustbin monitoring	[324]
Driver monitoring	[245,246,359,416]
Traffic monitoring	[417–419]
Patient health monitoring	[420–425]
Building and structural health monitoring	[401–403,426]
Volcano monitoring	[427–430]
Behavioral monitoring	[132,431–437]
Glucose level monitoring	[438–440]
Settlement monitoring	[441]
Environment monitoring	[62–64,442]
Vehicle Speed monitoring	[443]
Video monitoring	[444]
Heartbeat Abnormality monitoring	[445]
Noise monitoring	[446,447]
Condition monitoring	[448–450]
Vehicle monitoring	[451]
Water level monitoring	[452]
Photovoltaic system monitoring	[453]
Physiological signal monitoring	[454]

unauthorized access. Energy consumption is also a concern, as many IoT devices are battery-powered and must be designed to be energy-efficient. The handling of large amounts of data is also a challenge, as IoT devices often collect and transmit large amounts of data. Furthermore, the lack of standard platforms, protocols, and programming languages can make it difficult to develop and implement IoT prThe availability of theaspberry Pi is a powerful and versatile platform for IoT development, but it does have its own set of limitations and challenges that must be considered. [459].

The availability of the required hardware, accessories, and compatible components and sensors is a significant challenge for IoT developers. The inaccessibility of these components in local markets or e-commerce websites can cause delays in development and testing processes, as developers may need to wait for components to be imported. Importing components from other countries can also involve additional taxes and customs duties, which can make researchers deal with budgetary issues and unexpected expenses. Additionally, components that are received in a damaged condition can further delay the development process, as developers need to wait for the seller to replace the damaged components with working ones. Ahsan et al. in their research [460] also discussed some of the issues included, including long lead times, high costs, and lack of standardization.

Table 27 provides a wider view of platforms, including Arduino, Raspberry Pi, smartphones, and laptop/desktop computers, highlighting their unique features, strengths, and weaknesses for different purposes, such as education, prototyping, development, and general computing tasks. Arduino excels in sensor integration and real-time applications. Raspberry Pi offers affordable, customizable computing with community support. Smartphones provide portability and high performance, but limited customization. Laptops and desktops offer extensive customization and versatility, suitable for a wide range of tasks, including industrial applications. Each device caters to distinct needs such as Arduino for electronics prototyping, Raspberry Pi for education and DIY projects, smartphones for on-the-go computing, and laptops/desktops for demanding tasks and industrial applications.

Some of the technical and nontechnical issues associated with prototyping applications are discussed in the following sub-sections.

4.1. Technical issues

- Hardware compatibility issues can arise when using different components and sensors that may not be compatible with the Raspberry Pi platform.
- OS/Software compatibility issues can occur when trying to run software or operating systems that are not compatible with the Raspberry Pi.
- Connectivity issues, such as WiFi, Bluetooth, or LAN connectivity, can also be a challenge.
- Debugging code for naive programmers can also be difficult, especially for those who are not familiar with the programming languages used in IoT development.
- Security and data privacy issues are also a concern, as connected devices can be vulnerable to hacking or unauthorized access.
- Improper design and printing of components can also cause problems, and sudden voltage fluctuations and improper circuit connections can cause heating or burning of components.
- The general limitations of hardware such as storage, processing capacities, network connections, and bandwidth limitations, as well as network bandwidth requirements, power consumption, and radiation, can also affect the performance of the prototypes.
- Additionally, prototypes may experience performance issues over time due to extreme weather conditions, device/system reliability issues, sensor precision issues, and synchronization issues between multiple devices.
- Compatibility issues in IoT development can arise from the use of nonunified cloud services, the unavailability of standardized communication protocols, and diversities in firmware and operating systems among IoT devices.
- Security breaches can occur due to various reasons such as using weak passwords for device and account protection, having a weak software update mechanism, not updating the software with new security patches on a regular basis, insecure interfaces, using improper data protection methods, poor IoT device management, and lack of proper IoT skills.
- Researchers from nonengineering domains or without coding experience may face challenges while writing code for IoT applications.
- Improper exception or error handling mechanisms, using old and deprecated functions, can cause debugging errors.
- Changes in the names of functions in newer versions of programming languages, lack of knowledge of improved and efficient libraries and functions, and lack of efficient code writing skills can also deteriorate the performance of the systems.

4.2. Non-technical issues

Improper estimation of budget, improper selection of required components, and lack of expertise can cause delays in the development process and can also affect the quality of the prototype. Some nontechnical issues that may arise are:

- Inadequate budget planning and management, which can lead to delays or even the cancellation of the project
- Difficulty in sourcing and procuring required components, which can lead to delays and additional costs
- Lack of expertise or knowledge in specific areas such as IoT, embedded systems, or programming can lead to difficulties in the development process and can affect the quality of the prototype
- Difficulty in assembling and testing the prototype due to lack of proper tools and equipment
- Difficulty in finding or recruiting the right personnel with the necessary skills and expertise
- Difficulty in coordinating and communicating effectively with the different stakeholders involved in the project

Table 27
Comparative study of features of Raspberry Pi with similar devices.

Aspect	Arduino	Raspberry Pi	Smartphones	Laptop/desktop computers
Prototyping	Excellent for prototyping electronics projects	Ideal for hardware and IoT prototyping projects	Limited hardware prototyping capabilities	Suitable for prototyping and developing various projects.
Development	Limited software development capabilities	Excellent for developing applications and software	Offers robust development environment and tools	Suitable for developing a wide range of applications.
Sensor Integration	Designed for sensor integration, extensive compatibility with sensors	Supports various sensors through GPIO and expansion boards	Limited support, primarily relies on built-in sensors	Supports sensor integration through various interfaces and expansion cards.
Affordability	Inexpensive microcontroller boards	Relatively inexpensive hardware	More expensive, especially high-end models	Wide range of prices, from budget to high-end.
Customization	Limited hardware customization, extensive software options	Highly customizable hardware and software	Limited hardware customization, software options	Extensive hardware and software customization.
Performance	Limited processing power, optimized for specific tasks	Moderate performance, suitable for basic tasks	High-performance processors, advanced capabilities	High-performance processors, capable of demanding tasks.
Portability	Portable, compact form factor	Less portable, requires additional peripherals	Highly portable, fits in a pocket or bag	Less portable, typically stationary.
Connectivity	Limited built-in connectivity, expansion modules available	Requires external adapters for wireless	built-in support for various wireless technologies	Built-in support for various connectivity options.
User Interface	No user interface, typically programmed via IDE	Less user-friendly, lacks touch screen	Intuitive touch screen interface	User-friendly interface, often with keyboard and mouse.
Multifunctionality	Limited to specific tasks, but highly customizable	Primarily focused on computing tasks	Serves as a multipurpose device (camera, GPS, etc.)	Versatile, capable of various tasks and applications.
Battery Dependency	Not Battery-dependent, Operates on external power	Not Battery-dependent, Needs constant power source	Relies on built-in batteries, requires charging	Not battery-dependent, operates on external power.
Community Support	Large and active community providing support	Large and active community providing support	Limited community support beyond manufacturer	Extensive support network, including manufacturers and developers.
Security	Generally more secure due to limited connectivity	Generally more secure due to open source nature	Susceptible to security risks and privacy concerns	Vulnerable to security risks and privacy concerns.
Education	Widely used for teaching electronics and embedded systems	Widely used for teaching programming, electronics	Not typically used for educational purposes	Commonly used for educational purposes.
Real-time Deployment	Suitable for real-time applications with appropriate programming	Can be used for real-time applications with proper configuration	Limited real-time capabilities, depends on hardware and OS	Capable of real-time operations with proper software and hardware configurations.
Industrial Usage	Widely used in industrial automation and control due to reliability and durability	Used in industrial applications for monitoring, automation, and control	Limited industrial usage due to durability and specialized requirements	Commonly used in industrial settings for automation, monitoring, and control applications.

- Difficulty in identifying and addressing the needs of the target users and customers
- Difficulty in determining the feasibility, scalability, and sustainability of the prototype.

4.3. Issues related to the development of industrial grade applications

Industrial-grade applications with Raspberry Pi refer to the use of the Raspberry Pi platform in industrial settings such as manufacturing, transportation, energy, and utilities. These applications typically require robustness, reliability, and compatibility with industrial protocols and standards. Examples of industrial-grade applications include industrial control systems, predictive maintenance, building automation, Smart grid, robotics, industrial IoT gateways, vision systems, and industrial monitoring and reporting. The flexibility and adaptability of the Raspberry Pi make it a cost-effective and efficient solution for industrial automation in various domains. However, the development of industrial grade applications with Raspberry Pi can present certain challenges, some of which are as follows:

- Industrial applications typically have a longer lifespan and require a higher level of reliability compared to consumer applications. The Raspberry Pi platform may not be able to withstand harsh industrial environments and may not have the same level of longevity and reliability as specialized industrial control systems.
- Industrial applications often require the integration of multiple systems and devices, and the Raspberry Pi platform may not be compatible with all industrial protocols and standards.
- Industrial applications must comply with various safety and regulatory standards. The Raspberry Pi platform may not be fully compliant with all relevant industrial standards, and additional measures may need to be taken to ensure safety and compliance.
- Industrial applications may require the ability to handle large amounts of data and a large number of devices, and the Raspberry Pi platform may not have the necessary processing power and storage capacity to handle such requirements.
- Industrial applications often handle sensitive data and require a high level of security. The Raspberry Pi platform may not have the same level of security features as specialized industrial control systems, and additional measures may need to be taken to ensure data security.
- Industrial applications are often powered by an industrial power supply, and the Raspberry Pi may not be able to operate on a wide range of input voltage and frequency.
- Industrial applications may be subjected to a wide range of temperatures, and the Raspberry Pi may not be able to operate at extreme temperatures.
- Industrial applications may be subjected to high levels of electromagnetic interference (EMI) and electromagnetic compatibility (EMC), and the Raspberry Pi may not be able to operate in such an environment.

Raspberry Pi with additional hardware support can be considered for developing reliable industrial grade applications. Raspbian [461] is a stable operating system that has been developed especially for the Raspberry Pi family of boards. However, this operating system is developed for the desktop user experience and not for industrial applications. Some security, behavior, and stability patches have been suggested in [462] to make the Raspbian operating system suitable for industrial use cases. Other operating systems such as Yocto-based images, Clean Debian [463] and Ubuntu [464] are easy to install and can be considered as another go for developing industrial applications.

There are various products available such as IOT-GATE-RPi [465], Revolution Pi [466], and Strato Pi [467] that can be used to build more reliable industrial grade applications with Raspberry Pi. These products come with industrial cases, which provide protection and durability for the Raspberry Pi. Additionally, UpSwift.io [468] is a remote management system that provides tools to remotely monitor, control, update and secure Raspberry Pi and other Linux-based IoT devices. These tools and products can be used to improve the reliability, security, and overall performance of the industrial grade applications.

Some companies such as Sferalabs [469] and Revolution Pi [470] are providing custom extension modules to support the development of industrial-grade products using Raspberry Pi boards. This customization includes designing different mounting or enclosure solutions, adding, removing, and combining features of standard hardware configurations, rebranding, software and firmware development. This allows developers to tailor their Raspberry Pi systems to their specific needs and use cases, making them more suitable for industrial applications. It also enables the developers to have a better control over the system and its performance and make the system more robust and reliable.

Coral USB Accelerator [471] can be added to the Raspberry Pi to enable high-speed machine learning and deep learning inference. The Coral USB accelerator is an Edge Tensor Processing Unit (TPU) coprocessor that can be connected to the Raspberry Pi via the USB port. This allows for faster and more efficient processing of machine learning and deep learning algorithms, which is particularly useful for industrial applications that require high-speed data processing, such as image and video analysis, predictive maintenance, and autonomous systems. By adding the Coral USB Accelerator to the Raspberry Pi, developers can create more powerful and efficient industrial grade applications that can handle larger amounts of data and perform more complex tasks.

There are some holistic systems available for rapid IoT application development using Raspberry Pi, such as TinyLink [472]. SmartThings [473] allows users to connect, monitor, and control multiple devices in a quicker and easier way. open Home Automation Bus (openHAB) [474] is an open source home automation software developed to connect devices and services from different vendors. openHAB can be integrated with Google Assistant, Amazon Alexa, and Apple HomeKit. However, openHAB has the problem of limited connectivity. This limited device compatibility issue can be solved using IoTOne [475]. IoTOne supports heterogeneous IoT devices and avoids security vulnerabilities. These holistic systems provide a framework for the easy and fast development of IoT applications and make it more convenient to connect and control devices on a single platform.

Other similar systems for the rapid development of IoT applications using a Raspberry Pi include Node-RED [476], Thingsboard [477], MQTT [478], Home Assistant [479], and Open Remote [480] can be used with a Raspberry Pi, which is a small and affordable computer that is often used as hardware for IoT projects. Table 28 presents the details of some IoT platforms.

These tools and technologies can be installed and run on a Raspberry Pi to create various IoT applications, such as home automation, data collection and visualization, and device management. They provide a framework for easy and fast development of IoT applications and make it more convenient to connect and control devices in a single platform. They have different features, functionalities, and compatibilities, and developers can choose the best one that suits their needs.

4.4. Alternatives of Raspberry Pi

Compared to Raspberry Pi, each of these alternatives has its own set of potentials and features that may make it more suitable for certain projects and use cases.

Arduino: Arduino is often considered more suitable for projects that require simple control of sensors and actuators, and is often used in projects such as robotics and physical computing projects.

BeagleBone [481]: BeagleBone is more powerful than the Raspberry Pi and has more hardware resources, making it suitable for more demanding projects such as data acquisition and real-time control projects.

Adafruit Feather [482]: Adafruit Feather is lightweight and portable, making it suitable for projects that require mobility and portability, such as wireless sensor networks and wearable devices.

ESP8266 and ESP32 [483]: ESP8266 and ESP32 are specifically designed for IoT projects, making them suitable for projects that require wireless connectivity and low power consumption, such as home automation and sensor networks.

Intel NUC [484]: Intel NUC has more powerful hardware than the Raspberry Pi and can handle more demanding projects such as media centers, gaming, and machine learning.

Jetson Nano [485]: Jetson Nano is specifically designed for machine learning and AI projects, making it suitable for projects that require high-performance computing such as computer vision and robotics.

UDOO X86 [486]: UDOO X86, due to its x86 architecture, is more powerful and versatile than the Raspberry Pi and can run a wide range of operating systems such as Windows and Linux, making it suitable for projects that require more computing power and flexibility.

Each of these alternatives has its own set of potentials and features that make them more suitable for certain projects and use cases. Raspberry Pi is a versatile platform that can be used for a wide range of projects, but these alternatives can be more suitable for projects that require specific resources and capabilities.

The Table 29 provides a detailed comparison of various Raspberry Pi alternatives, highlighting their special features, technical specifications, processing power, memory capacity, and connectivity options. This comparison can be extremely useful in choosing the right platform according to the specific needs of the project. Fig. 6 visually presents some of the alternative boards. This figure provides readers with a better understanding of the physical characteristics of these boards, such as the size, layout, and arrangement of various components. It is important to note that while these alternatives may offer certain advantages over the Raspberry Pi, the choice of platform ultimately depends on the specific requirements of the project.

5. Conclusion

The Raspberry Pi is a small and affordable computer that has become increasingly popular in the field of Internet of Things (IoT) and other domains. This article presents a comprehensive overview of the various ways in which the Raspberry Pi can be used in different domains, such as industrial, agriculture, biotechnology, energy management, mining, and healthcare. Despite the breadth of its applications, the use of Raspberry Pi in the scientific community is still relatively limited.

One of the main applications of the Raspberry Pi is in the field of industrial control and automation. This computer can be used to control and monitor industrial processes and machines, such as conveyor belts, robotic arms, and 3D printers. The Raspberry Pi can be connected to sensors and actuators, and can be programmed to perform specific tasks, such as controlling the speed of a motor or monitoring the temperature of a machine. This allows for greater flexibility, efficiency, and cost-effectiveness in industrial processes.

Another important application of the Raspberry Pi is agriculture and biotechnology. The small size and low power consumption of the

Table 28
Details of IoT platforms support prototyping.

	Node-RED	Thingsboard	Home assistant	Open remote
Description	Flow-based programming tool for IoT	Open-source IoT platform	Open-source home automation	Open-source platform for building IoT apps
Language	JavaScript (Node.js)	Java	Python	Java, Groovy, JavaScript, Ruby, PHP
UI	Browser-based visual editor	Web UI	Web UI, Mobile apps	Web UI, Mobile apps
Data Visualization	Limited	Built-in dashboards	Limited	Built-in dashboards
Protocol Support	HTTP, WebSocket, MQTT, CoAP, etc.	MQTT, CoAP, HTTP, OPC-UA	MQTT, HTTP, Z-Wave, Zigbee, etc.	MQTT, CoAP, HTTP, WebSockets
Device Management	Limited	Included	Limited	Included
Rules/Automation	Flow-based	Rule Engine, Node-RED	Automation Editor	Rule Engine
Data Storage	Limited (file-based)	Time-series DB	File-based, databases	Time-series DB, relational DB
Scalability	Limited	Horizontally scalable	Limited	Horizontally scalable
Community	Active	Active	Very active	Active
License	Apache 2.0	Apache 2.0	Apache 2.0	AGPL 3.0

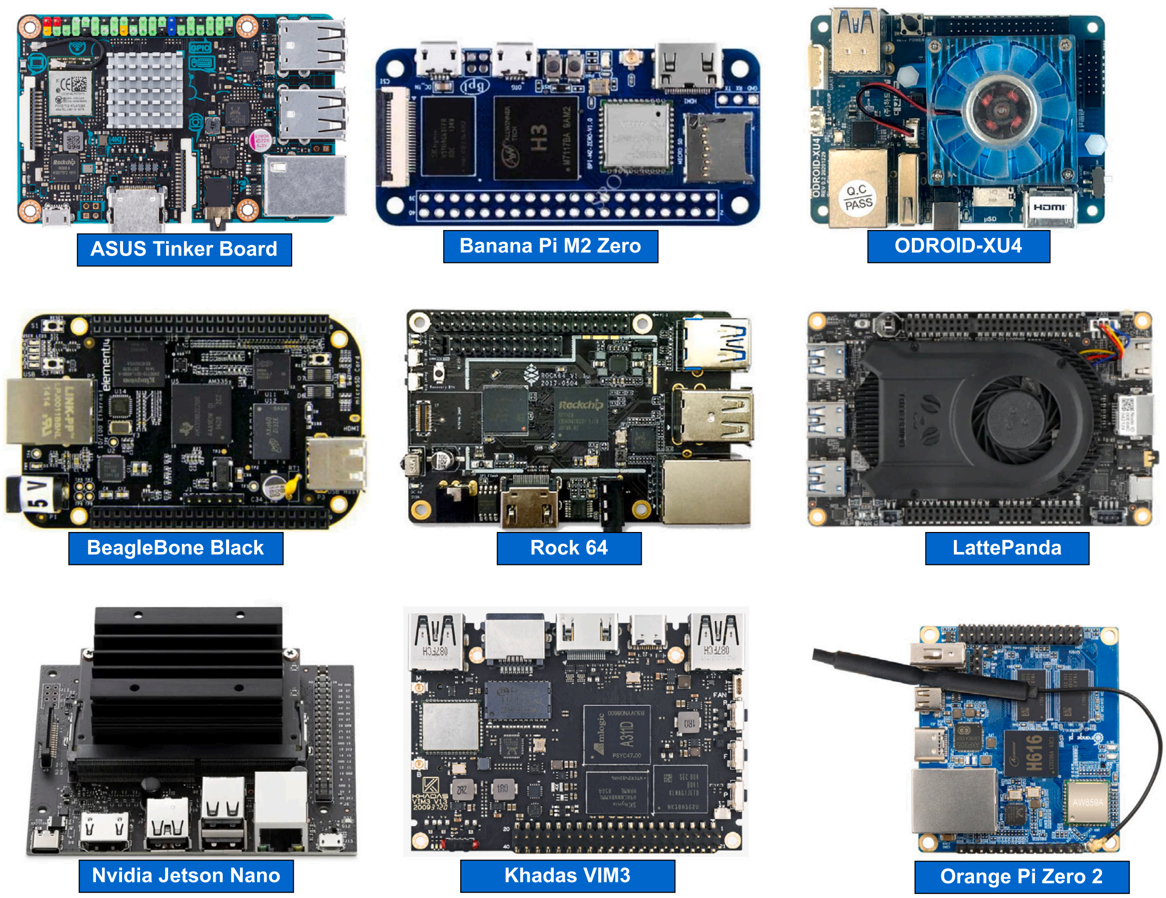

Fig. 6. Raspberry Pi alternatives.

Raspberry Pi make it ideal for use in remote and harsh environments, such as on a farm or in a greenhouse. The Raspberry Pi can be used to monitor soil moisture, temperature and humidity and can be programmed to control irrigation systems and other farm equipment. Additionally, the Raspberry Pi can be used for data collection and analysis in biotechnology, such as to monitor the growth of plants or microorganisms.

The Raspberry Pi also has applications in energy management and conservation. The computer can be used to monitor energy consumption in buildings and homes and can be programmed to control lighting, heating, and cooling systems. Additionally, the Raspberry Pi can be used to monitor and control renewable energy systems, such as solar panels and wind turbines.

The Raspberry Pi can also be used in the field of mining and healthcare. In mining, the Raspberry Pi can be used to monitor and control drilling and excavation equipment, while in healthcare, the Raspberry Pi can be used to monitor vital signs, such as heart rate, blood pressure, and temperature.

The purpose of this article is to raise awareness of Raspberry Pi among researchers, developers, and academic communities to promote the spread of science and technology. In addition, this paper serves as a quick reference guide for the various applications of the Raspberry Pi and the opportunities and challenges related to using it for prototyping.

The Raspberry Pi can be used for a wide range of applications, and in different domains, we hope that by highlighting the potential of Raspberry Pi it will be more widely used by the scientific community

Table 29
Comparative analysis of Raspberry Pi alternatives.

Board	Processor	RAM	OS support	IO pins	Connectivity	USB	External memory	Variants	Special features
ASUS Tinker Board [487]	Quad-Core ARM Cortex-A17	2 GB	Linux, Android	40-pin GPIO	WiFi, Bluetooth, Gigabit Ethernet	4 ×USB 2.0	microSD	Tinker Board, Tinker Board S	4K video support.
Banana Pi M2 Zero [488]	Allwinner A33 Quad-Core	512 MB	Linux, Android	28-pin GPIO	WiFi, Gigabit Ethernet	2 ×USB 2.0	microSD	Banana Pi M2 Zero, Banana Pi M2+	Low-cost, compact size.
ODROID-XU4 [489]	Samsung Exynos5422 Octa-Core	2 GB	Linux, Android	30-pin GPIO	WiFi, Bluetooth, Gigabit Ethernet	2 ×USB 3.0, 1 ×USB 2.0	microSD	ODROID-XU4, ODROID-XU4Q	Advanced Mali GPU.
BeagleBone Black [490]	AM335x 1 GHz ARM Cortex-A8	512 MB	Linux	92-pin GPIO	USB Client for power/data, Ethernet	1 ×USB 2.0 (Host), 1 ×USB 2.0 (Client)	microSD	BeagleBone Black, BeagleBone Black Wireless	Large GPIO pin count
ROCK64 [491]	Quad-Core ARM Cortex-A53	Up to 4 GB	Linux, Android	40-pin GPIO	WiFi, Bluetooth, Gigabit Ethernet	2 ×USB 2.0, 1 ×USB 3.0	microSD	ROCK64, ROCK Pi 4	Good performance-to-price ratio
LattePanda [492]	Intel Atom x5-Z8350 Quad-Core	2 GB/4 GB	Windows 10, Linux	40-pin GPIO	WiFi, Bluetooth, Gigabit Ethernet	4 ×USB 2.0	microSD, M.2 SSD	LattePanda Alpha, LattePanda Delta	Windows 10 support, M.2 SSD slot
Nvidia Jetson Nano [485]	Quad-Core ARM Cortex-A57	4 GB	Linux	40-pin GPIO	WiFi, Bluetooth, Gigabit Ethernet	4 ×USB 3.0	microSD	Jetson Nano, Jetson Nano 2 GB	Designed for AI and deep learning applications
Khadas VIM3 [493]	Amlogic A311D Hexa-Core	Up to 4 GB	Linux, Android	40-pin GPIO	WiFi, Bluetooth, Gigabit Ethernet	3 ×USB 3.0, 1 ×USB-C	microSD, M.2 SSD	Khadas VIM3, Khadas VIM3L	M.2 SSD slot, USB-C support
Orange Pi Zero 2 [494]	Allwinner H616 Quad-Core	512 MB	Linux, Android	28-pin GPIO	WiFi, Gigabit Ethernet	1 ×USB 2.0, 1 ×USB-C	microSD	Orange Pi Zero 2, Orange Pi Zero 2 Plus	Low-cost, USB-C support

and researchers. The Raspberry Pi is a cost-effective, easy to use, and powerful tool that can be used for a variety of different tasks and projects. We also hope that this work will serve as a reference for researchers and developers to quickly access information about the different applications of the Raspberry Pi and the opportunities and challenges related to using it for prototyping.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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