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PAPER

Development of a Digital Twin Prototype for Industrial Manufacturing Monitoring System Using IoT and Augmented Reality

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ABSTRACT

The world is currently abuzz with the rapid development of technology in the era of Industrial Revolution 4.0. Various technological advancements are facilitating progress and accelerating the development of industrial technology. This evolution has led to automation in production processes, transitioning toward digitalization. With the implementation of sensors that provide real-time data, production processes can now be monitored remotely. However, direct monitoring is still necessary at times to periodically check the condition of each operating machine. Therefore, there is a need for technology that can monitor production processes and reduce high maintenance costs. Currently, numerous new technologies are emerging to enhance the performance and efficiency of production processes in various industries. One such technology is the digital twin. A digital twin is a visual representation that offers insights into the continuous operations of a system. This research focuses on an industrial manufacturing monitoring system that integrates the Internet of Things (IoT) and augmented reality (AR) technologies. The system is composed of an application and a prototype machine in the form of a conveyor, which can simulate a digital twin of the prototype machine. It also transmits sensor data and error notifications to the application in real time. The designed system can serve as a prototype for implementing digital twin technology, combining IoT and AR. This makes it possible to apply the technology to machinery and production tools in various industrial sectors.

KEYWORDS

industrial revolution 4.0, industrial manufacturing, digital twin, Internet of things, augmented reality (AR)

1 INTRODUCTION

The development of communication technology, the Internet of Things (IoT), sensor technology, big data, and simulation technology has significantly contributed to

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the technological advancements in the current industrial era, 4.0. Business models undergo significant changes, not only in the production process but also throughout the entire industrial value chain [1] [2]. Smart manufacturing has become a top priority for all manufacturing industries at present. The rapid development of simulation, data acquisition, data communication, and other advanced technologies has led to increased interaction between physical and virtual spaces [3]. Manufacturing systems and machines can be connected and integrated into the digital world using current technologies. Companies can gain a clearer insight into the performance and operational conditions of manufacturing machines in the real world through real-time data connectivity. This enables them to make optimal operational decisions based on the data [4]. By obtaining accurate information from manufacturing machines, companies can enhance their situational awareness, reduce operational costs, and improve operational flexibility, especially in the regular maintenance of systems and machines.

The concept of the digital twin, which has evolved from various technological iterations, has gained considerable traction due to its applicability. It serves as a virtual representation of the real world, providing a simulation platform for predicting and optimizing physical manufacturing systems and processes. A digital twin involves an integrated simulation within machines or systems, which includes a physical model and integrates real-time sensor data along with historical data. This effectively generates a digital replica of the machine or system [5]. "The fusion of IOT technology and simulation technology, such as AR, plays a pivotal role in implementing digital twin."

In the future, the IoT will play an increasingly pivotal role in operations across various industrial sectors [2]. The use and analysis of data will be crucial factors in decision-making. IoT sensors, capable of retrieving real-time data and integrating with physical devices, will transcend technological barriers. The technological significance of the IoT in industries will extend beyond being mere support tools, and instead become a primary industry driver [6]. AR, on the other hand, allows users to see virtual objects in a real-world environment [7] [8]. Leveraging cameras and sensors, digital data and collaborative information are collected, processed interactively, and transmitted. Mobile phone cameras have the capability to capture and analyze surroundings, collect data, recognize physical objects, and generate three-dimensional images [9].

Through the use of digital twin technology, the operational status of machines or systems can be assessed to ensure they align with desired functions under specific operational conditions and time intervals. This real-time monitoring occurs through a digital interface [5]. With the system's direct monitoring capability, potential malfunctions can be promptly identified, allowing for swift corrective actions and reducing the risk of system failure. Furthermore, by gaining real-time insights into system conditions, one can accurately assess maintenance needs and identify specific components requiring attention. This targeted approach optimizes maintenance efforts, reducing costs by focusing on critical areas. Consequently, this approach contributes to cost-effective maintenance practices.

Currently, the adoption of technologies such as the IoT and digital twin in industries is still relatively limited. It is important to recognize, however, that similar monitoring and control systems have been used in industries for a considerable duration, such as SCADA (supervisory control and data acquisition), which manages processes from the initial procedure to the conclusion. However, companies do not fully utilize the features provided by SCADA systems. Sensors that were supposed to be installed and monitored through SCADA have not been installed, leading to numerous unknown variables within the system [10].

Technologies such as the digital twin can be considered a progression from SCADA systems. The digital twin has the capability to visually represent operating systems in a three-dimensional replica and can be further developed to conduct visual simulations of these systems. This enables companies to predict suitable actions to address real-world issues. Beyond its digital simulation capabilities, the digital twin can also serve as a predictive tool based on accumulated data during the production process, thereby improving production efficiency and effectiveness for companies [11].

This study aims to develop an industrial manufacturing monitoring system by integrating IoT and AR technologies. The goal is to create an integrated digital twin prototype using Firebase as the server or cloud to connect the application and the designed conveyor machine. The application is developed using Unity, which allows for the integration of AR to showcase 3D models and simulate the digital twin of the machine. The prototype machine is equipped with microcontrollers connected to the internet and sensors that collect real-time data. The development of this prototype is expected to serve as a template for further advancement and application across various industrial sectors.

1.1 Digital twin and IoT

The digital twin technology has shifted its focus to manufacturing activities and has become closely linked with the Internet of Things, artificial intelligence, and big data. When a complex system is interconnected, it can generate data records and valuable information for data scientists and other IT professionals [12]. Additionally, it has the capability to optimize various "what-if" scenarios to achieve efficiency.

A digital twin is a digital representation of a physical object or an operational system. The technology behind the digital twin has advanced to include applications in buildings, factories, and even city-scale scenarios, expanding its applicability.

In 2011, the first journal article was published, outlining the instrumental role of digital twins in predicting aircraft structural behavior. In 2012, NASA expanded the definition of the digital twin to include an integrated simulation within machinery or systems. This simulation incorporates physical models, updated sensor data, and historical data records to emulate a digital replica of the flying vehicle [5].

In conclusion, a digital twin is a computer program that uses real-world data about a physical object or operating system as input to generate predictive or simulation outputs about how that physical object or system will be influenced by those inputs.

The explosive growth of IoT sensors has enabled the implementation of digital twins. Each IoT device can be fine-tuned for various digital twin scenarios, allowing even the smallest integral components of machines to be simulated. This provides substantial advantages to businesses [12].

1.2 Augmented reality with digital twin

Augmented reality (AR) is a technological concept that integrates digital information with real-world objects. This technology enables information to be overlaid onto a user's perception, providing a more immersive and contextual experience in the real world by displaying simple digital data. Examples of this technology can now be found in navigation systems that project information directly onto the environment, as well as in assembly machinery devices that allow for zooming in and immediate highlighting of required component placements.

In 1990, Caudell introduced the term AR while working at Boeing's computer services. He developed a technology to visualize and understand the structure of electrical cables in aircraft using a head-mounted display [13]. An AR environment has the following characteristics: 1) It combines real and virtual worlds; 2) It is interactive in real-time; and 3) Virtual objects are spatially registered in 3D spaces [14] [20] [21] [22].

The use of AR in fields such as education, gaming, social media, medicine, and broadcasting has elevated AR to a significant technology in the current era of technological advancement. Furthermore, the rapid advancement of AR technology in the manufacturing industry is heavily influenced by the progress in big data and other technologies. These can be synergistically integrated, further establishing AR as a crucial technology in Industry 4.0.

1.3 Augmented reality with digital twin

Small computer chips, commonly referred to as microcontrollers, are frequently used in the IoT to control and monitor various systems and devices. These chips are connected to sensors, actuators, and other electronic components, allowing them to gather sensor data, process it, and transmit it. Microcontrollers (MCUs) are commonly used in IoT systems because of their small size, cost-effectiveness, and low power consumption. The MCU can be programmed for various tasks, making it suitable for IoT implementations. Moreover, MCUs are frequently used in battery-powered devices because of their low power consumption.

Sensors are devices designed to detect and respond to changes in various forms of energy, including electrical, physical, chemical, biological, and mechanical [15]. In the present day, sensors have been developed in extremely small sizes, even down to the nanometer scale. This extremely compact size facilitates use and conserves energy. Sensors are essential components of larger systems, often accompanied by signal conditioning circuits and various types of analog or digital signal processing. In the IoT, sensors play a crucial role in capturing data from the environment, connected systems, or devices [16] [17] [18] [19].

2 RESEARCH METHOD

The waterfall model is a traditional and linear software development methodology. This model consists of several sequential stages, akin to the flow of water from one stage to the next. It is a well-structured model that is frequently utilized in the development of intricate digital twin applications. Here is an explanation of how the waterfall model can be applied in the development of digital twin applications:

1. **Planning stage:** The planning stage provides plans for the digital twin application project. Identify the fundamental requirements, objectives, necessary resources, and timeline. In the context of digital twins, this involves a comprehensive understanding of the physical object or system to be replicated in digital form, as well as the technology to be utilized.
2. **Analysis stage:** The analysis stage details the software requirements to be developed. In digital twin development, this involves a comprehensive understanding of the sensors to be used, the data collection process, and the structuring of the 3D model. Analysis also involves a clear understanding of the objectives to be achieved with the digital twin.
3. **Design stage:** The design stage includes creating the 3D model structure, developing the user interface, and planning the collection and integration of data from physical objects into the digital twin. This design should consider both the visualization and functionality aspects of the digital twin.

4. **Implementation stage:** This is where the actual software development, based on the approved design, takes place. In the context of digital twins, the development of a prototype 3D model begins. During this stage technologies such as the IoT and AR are utilized.
5. **Testing stage:** After being implemented, the digital twin undergoes comprehensive testing. This includes testing the 3D model, testing connectivity with physical devices, and functionality testing. When errors or issues are found, they are addressed for improvement either during the implementation or design stages.

The waterfall model is well-suited for developing digital twin applications because it enables thorough planning and in-depth analysis before progressing to the more expensive implementation stage. However, it is important to note that significant changes in requirements or design in later stages can lead to delays and additional costs. Therefore, a strong understanding of requirements is crucial for digital twin development using this model.

2.1 System analysis

System analysis involves breaking down a complete system into its components to identify and assess the system's issues, opportunities, obstacles, and anticipated requirements in order to propose improvements.

System functionality analysis. System functionality refers to the features that are built into the system. Table 1 presents a list of functions used for monitoring and controlling the application process.

Table 1. System functionality analysis

No	Functional	Description
1	Application is able to read markers	Application utilizes resources from the Vuforia SDK to activate the camera and read AR markers
2	Application is able of show a 3D model of the prototype machine	Application have features from the Vuforia SDK to display 3D models through detect AR markers
3	Application is able connect to internet and displaying the connectivity status with the prototype machine	Application have connection to internet and displaying real-time connectivity status with the device, where the connectivity refers to connection application and prototype machine
4	Application is able show indications of operational failures	Application is able to display real-time status of the device, including internet connectivity and sensor reading failures
5	Application is able of providing other relevant information related to the prototype machine	Application can display real-time information related to sensor reading and operation
6	Application is able to simulating the working process of the prototype machine in real-time	Application can simulate prototype machine, along with its operations in real-time through a 3D model on the AR marker

Device requirement analysis. Device requirement analysis is a crucial segment that supports the development of systems, applications, and prototype machines. Table 2 will outline the minimum development and testing requirements.

Table 2. Device requirement analysis

No	Requirements	Description
1	Hardware	**Development:** PC with specification minimum processor Intel Core i5 (~2.3 Ghz with Graphic Card, RAM 4 GB and 128 GB SSD). **Testing:** Android with camera, accelerometer and gyroscope sensor. Prototype machine have microcontroller, sensors and actuators, also have connection to internet
2	Software	**Development:** Unity Game Engine, Vuforia SDK, Android SDK, Google Firebase, Arduino IDE and CAD Software **Testing:** Android 6.0 Marshmallow (API level 23)
3	Brainware	**Development:** Developers with an understanding of Augmented Reality, 3D modeling, and IoT device development **Testing:** No specific requirements

Usage procedure analysis. The analysis of usage procedures is a section that users need to consider when using the application and operating the prototype machine. The recommended procedures for system usage are outlined in Table 3.

Table 3. Usage procedure analysis

No	Procedures	Analysis
1	AR marker can be clearly captured by the camera	Camera is able to capture the marker image clearly and without blurriness. Markers that appear blurry to the camera cannot be detected by the application.
2	The captured AR marker is in the form of a computer-generated printout image	Marker is a printout result and not a hand-drawn image. Images created by hand sometimes do not have the same shape as those used in the application.
3	Design of AR marker is not overly complex	An overly complex design will make it difficult for application to detect marker. A simple marker design can facilitate the application in detecting the marker.
4	Camera position can capture the entire area of the AR marker	User adjusts the camera position to capture the marker, allowing the application to detect the marker and display the 3D model.
5	Prototype machine can move and operate when powered on	After the prototype machine is powered on, the prototype can operate and function again, as well as connect to the Internet.

2.2 Document content

In general, system design is undertaken with the goal of providing an overview of the intended system. During the system design phase, the primary focus is on modeling user needs.

Modeling is carried out using the unified modeling language (UML). Because some diagrams are straightforward to model with UML, application design is only represented in a few UML diagrams.

Use case diagram. Use case diagrams represent the dynamic aspects of the system. Specifically, use case diagrams are used to capture system requirements, including both internal and external influences (Figure 1).

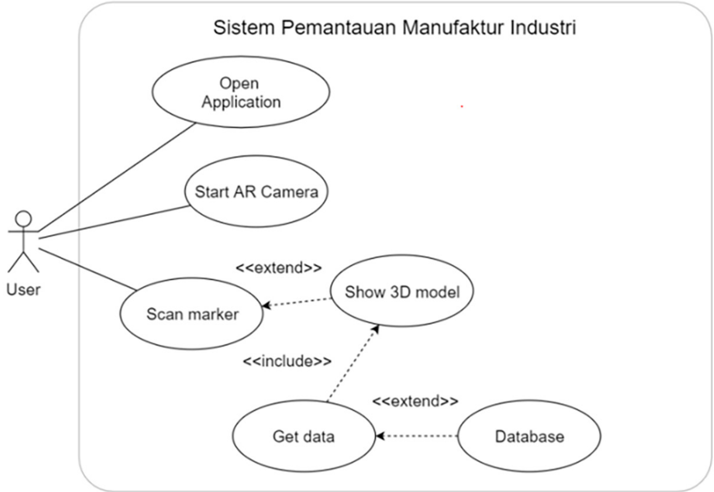


Fig. 1. Designed use case diagram

Activity diagram. An activity diagram is essentially a flowchart that represents the flow from one activity to another. An activity can be described as an operational system or a process that involves user interaction with the user interface (Figure 2).

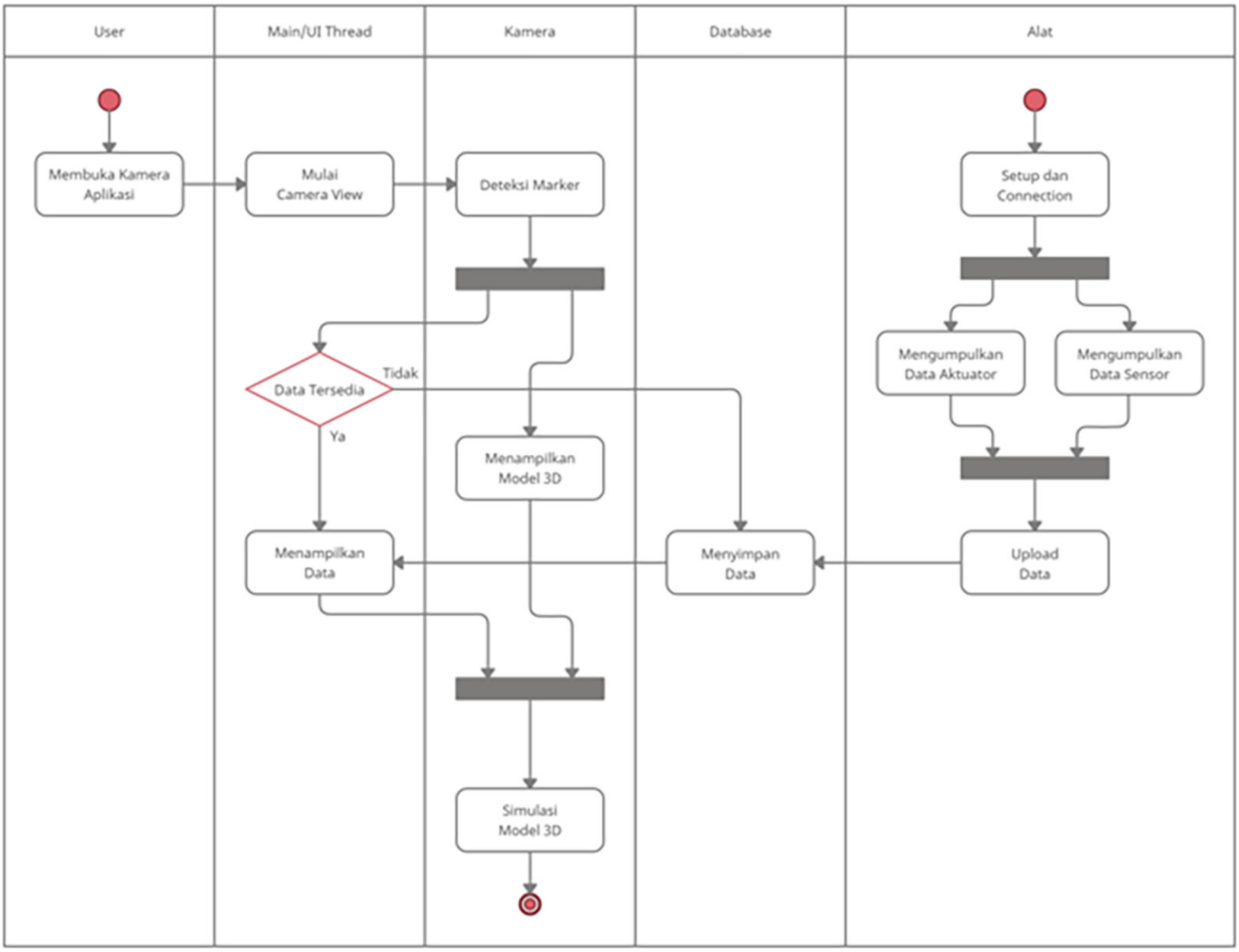


Fig. 2. Designed activity diagram

Sequence diagram. A sequence diagram is a diagram that illustrates the interaction between objects over a period of time. Its purpose is to display a sequence of messages exchanged between objects and interactions that occur at a specific point during system execution. Figure 3 presents the sequence diagram of the application.

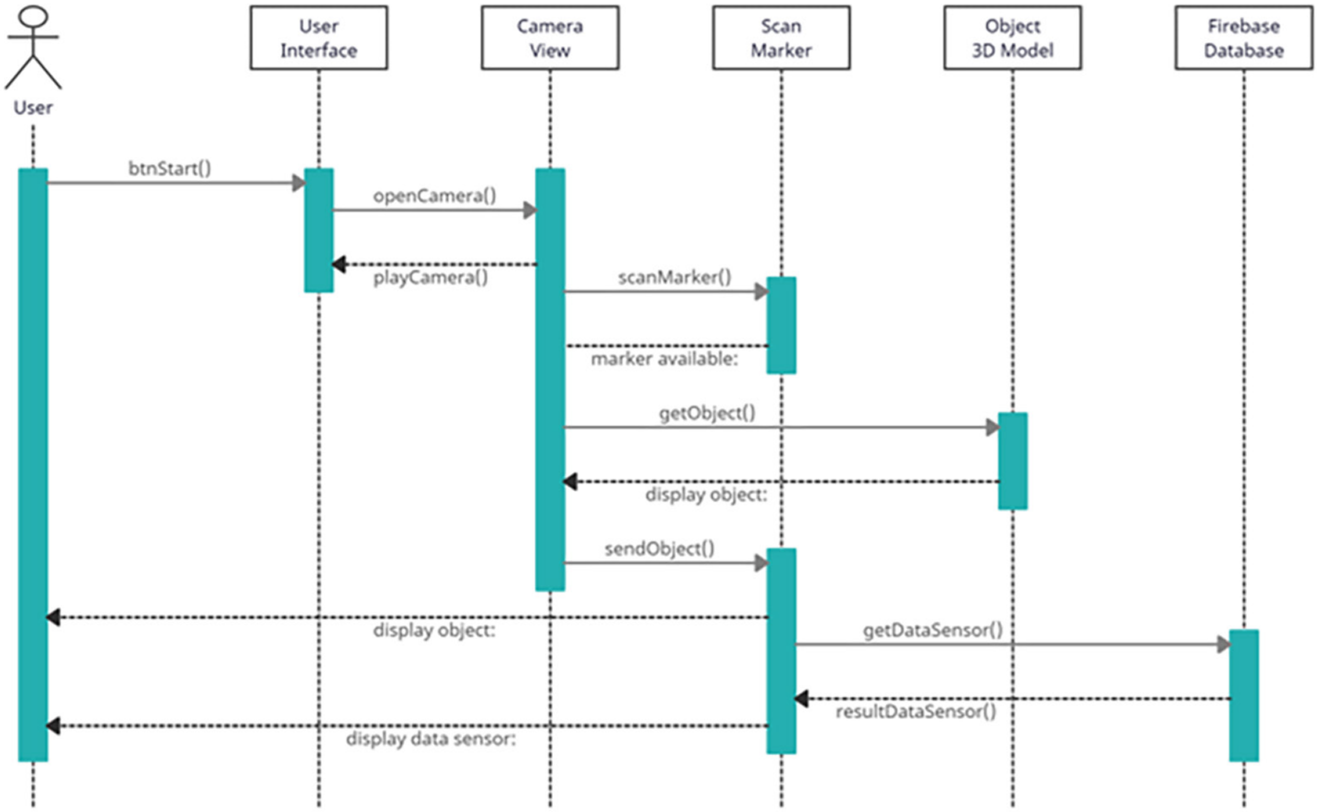


Fig. 3. Designed sequence diagram

2.3 Prototype machine design

The design prototype aims to create a digital twin prototype capable of representing the implementation of the digital twin concept, with a focus on its potential application in the industrial sector. Figure 4 depicts the communication design between the prototype and the application. The prototype is designed to simulate machinery commonly found in the manufacturing sector. This prototype is equipped with sensors to collect valuable data and information. Additionally, an accompanying application is provided to display data, information, and indications of machinery faults or failures.

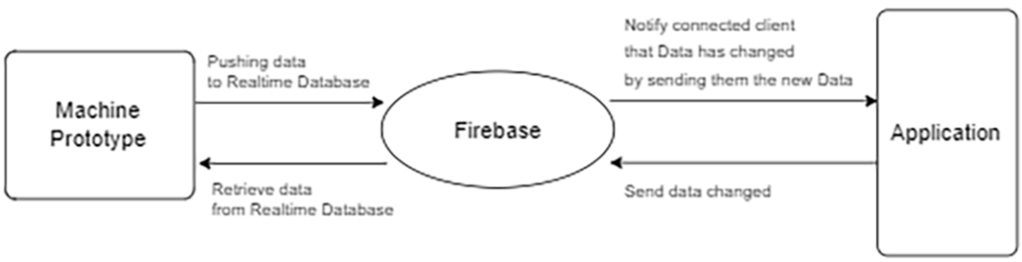


Fig. 4. Communication prototype

3D model design. The implementation of models is significant in AR applications, where 3D objects are projected based on markers. Figure 5 presents the visualization of the 3D model, which was designed using CAD software.

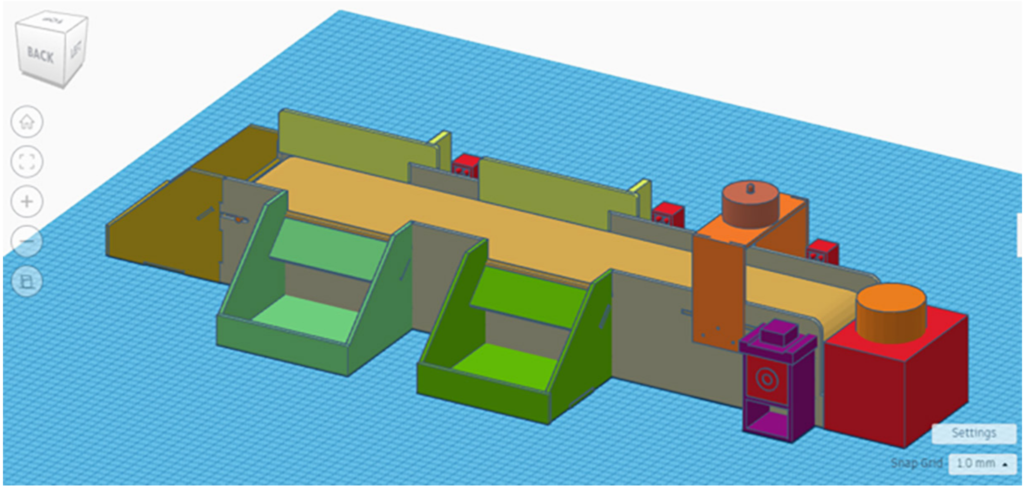


Fig. 5. 3D model prototype machine

Block diagram. The design of a prototype for a production machine involves creating a block diagram that illustrates the interconnected control relationships of each component. Figure 6 shows the block diagram design.

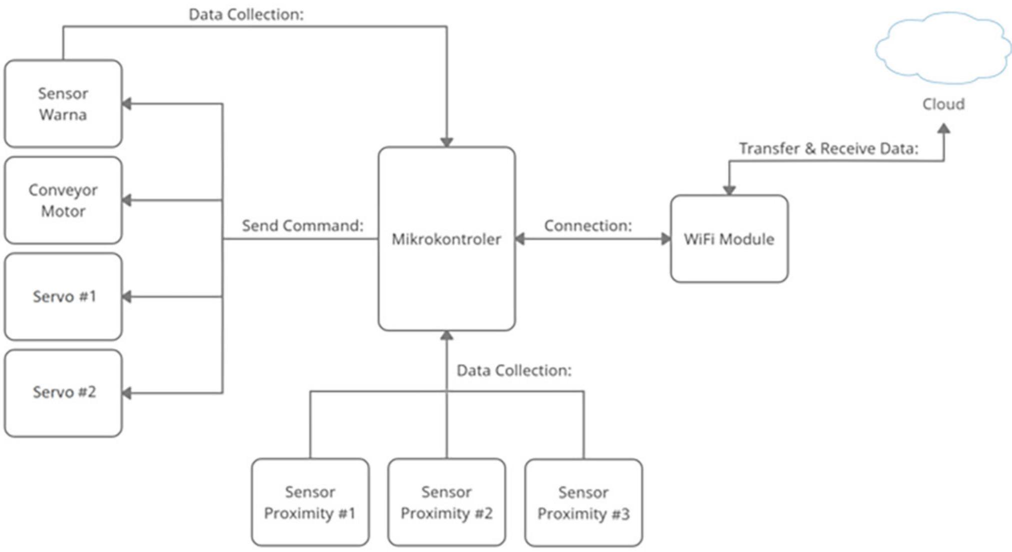
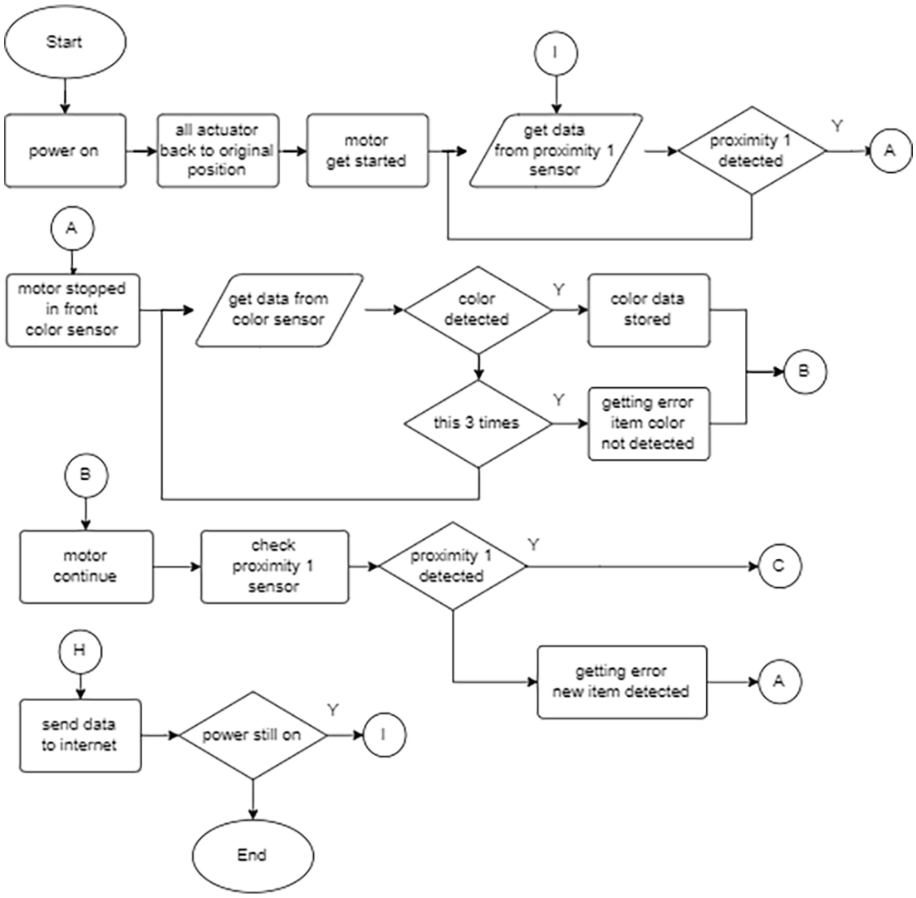
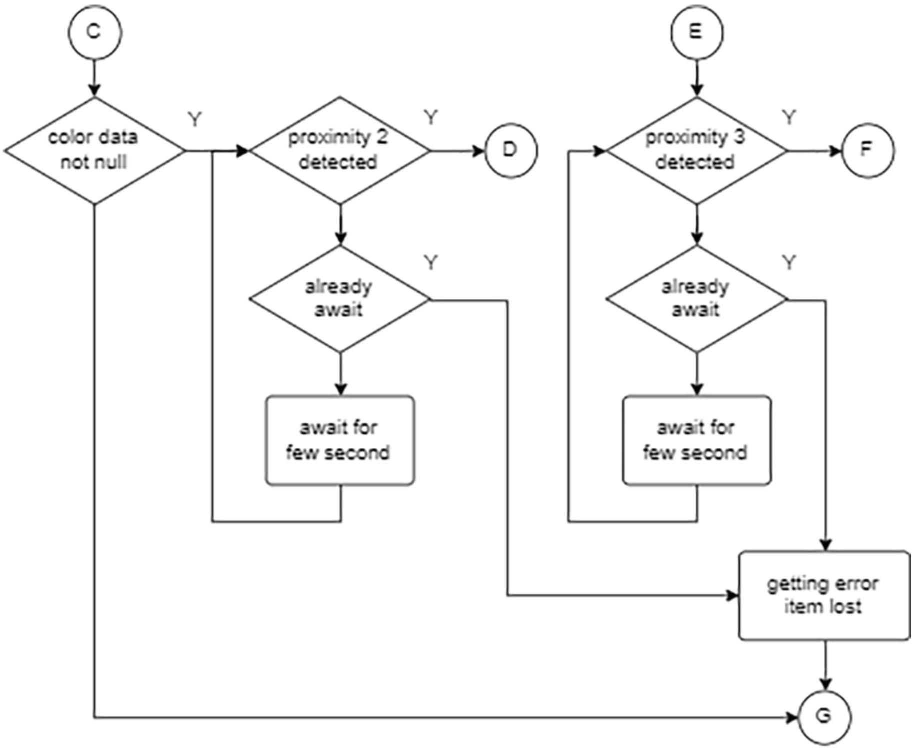


Fig. 6. Block diagram

Algorithm prototype machine. The machine concept is designed as a conveyor used to transport and categorize items based on their detected types using integrated sensors. The conveyor is an essential component of industrial machinery in the manufacturing industry, primarily used for sorting items. Figure 7 depicts a flowchart illustrating the operation of the designed prototype.

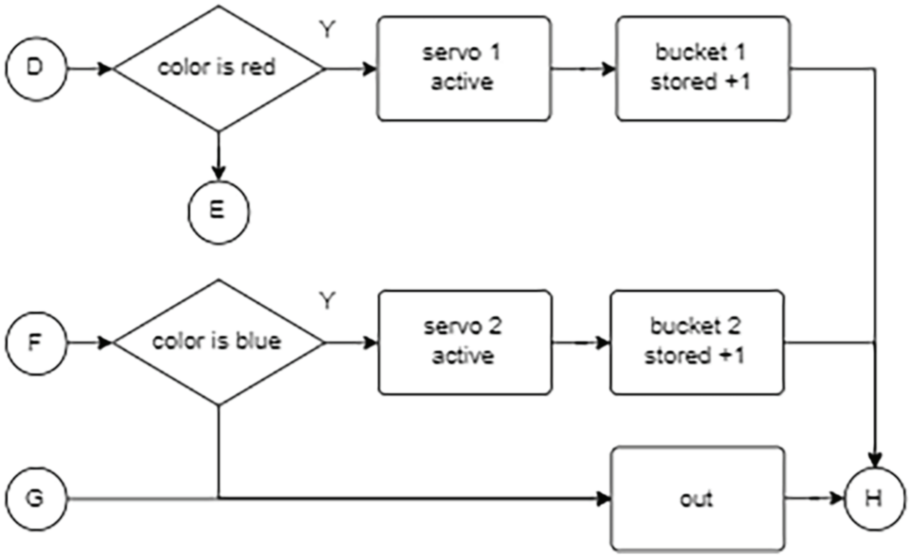


a)



b)

Fig. 7. *(Continued)*



c)

Fig. 7. Flowchart machine

3 RESULT AND DISCUSSION

3.1 System implementation

The system implementation will explain the processes that occur within the interface and the real-time interactions between the application and the database. This will ensure that the simulation displayed on the application aligns with the occurrences in the prototype.

Main scene interface. The main scene, or main menu page, functions as a launcher to initialize Firebase for use within the application. This page contains two button components that are used to guide users to other pages (Figure 8).

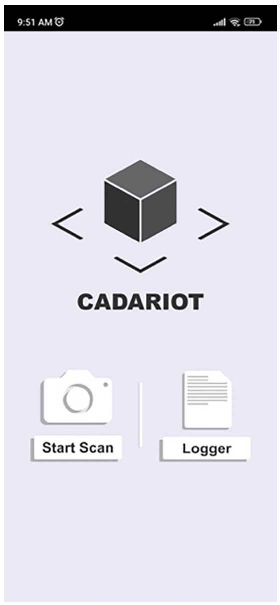


Fig. 8. Main menu

ScanArScene interface. Upon launching the application, the main scene's user interface is presented as the primary entry point. On this page, there is a "start scan" button. Clicking this button will direct the user to the AR scan page. When the ScanArScene is loaded, Vuforia will be initialized, allowing the application to access the smartphone camera and detect markers. Furthermore, the Firebase save manager code initializes the Firebase database, enabling real-time communication between the application and the Firebase Realtime Database (RTDB).

In the FirebaseSaveManager, a database reference is created using the Firebase Database instance. An observer for the value changed function (for Firebase database changes) is also declared, and the observer will invoke the HandleValueChanged function. Within the HandleValueChanged function, the JSON data is parsed into a model that serves as a data structure. Moreover, a UnityEvent is triggered to pass model data to a script that subscribes (listener) this event. With each alteration of data values in RTDB, the FirebaseSaveManager triggers an event. This event has multiple listeners, including:

- The FirebaseSyncToSave script is used to save data into the DeviceData script for display on the 3D model.
- The GraphData script is used to display real-time data graphs.
- The ErrorHandler script is used to store error data in the local database.

ScanArScene algorithm. The application is designed to be an AR application that displays a 3D model of the prototype when the app detects a marker. The application retrieves sensor data and periodically updates 3D model information from the Internet. The app periodically checks for connectivity and data, which are then processed by the application. Figure 9 is a flowchart outlining the procedural application [12] [13] [14].

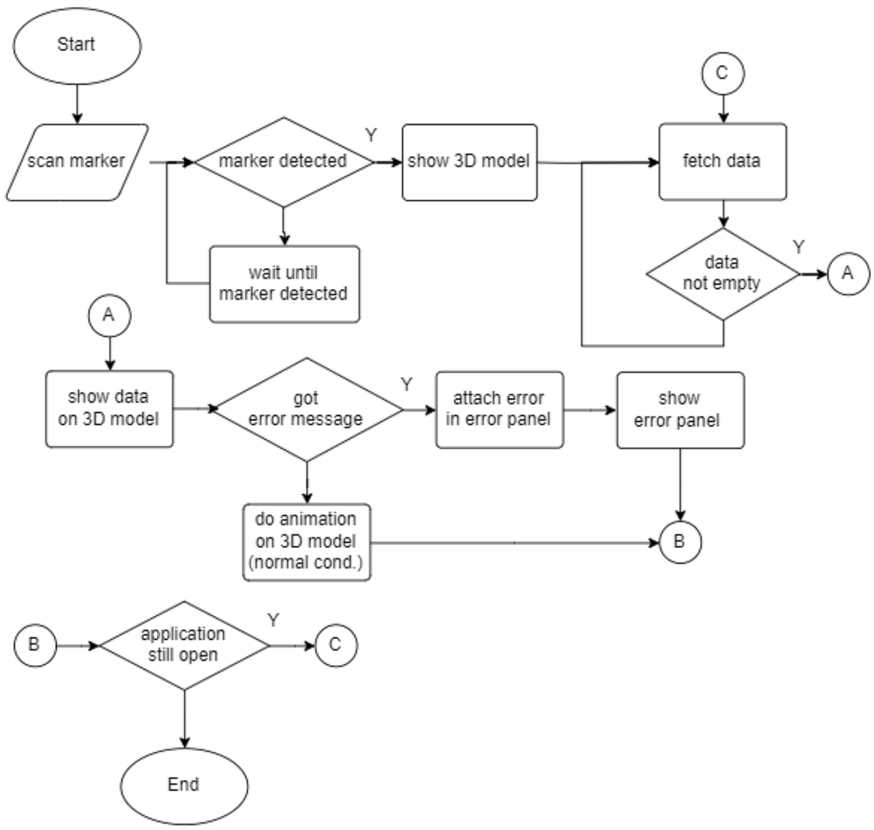


Fig. 9. Scan marker algorithm

Scan marker. Upon detecting the marker with the camera, a 3D model is rendered to simulate the digital twin of the interconnected prototype machine. Figure 10 illustrates how the app displays the rendered 3D model and all the associated information.

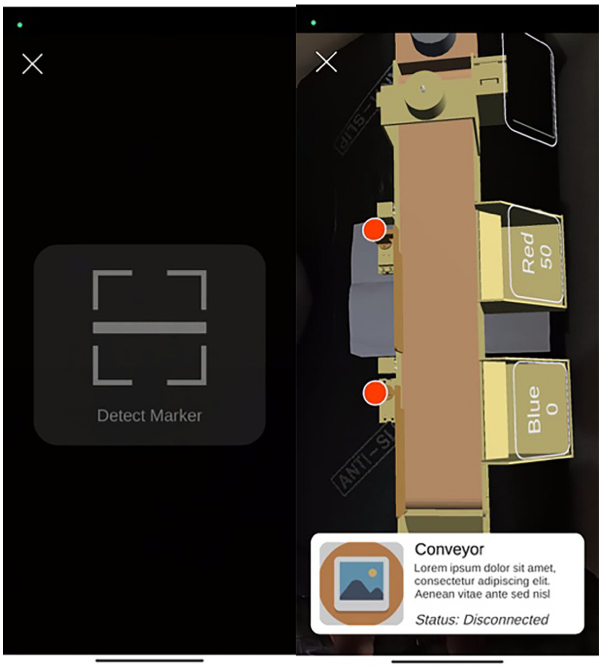


Fig. 10. Camera detects marker

Errors indication. If there are discrepancies with the actual machine condition, the application detects errors and communicates them to the user. These errors are handled by the ErrorHandler script. Within the CheckError function, incoming error codes are filtered, and the DataService script is called to store newly received errors in the SQLite database. Additionally, the CheckError function triggers a UnityEvent to allow other subscribing scripts (listeners) to receive the event and specific error details. Within this context, the event in the ErrorHandler script is used to display error pop-up notifications, as shown in Figure 11.

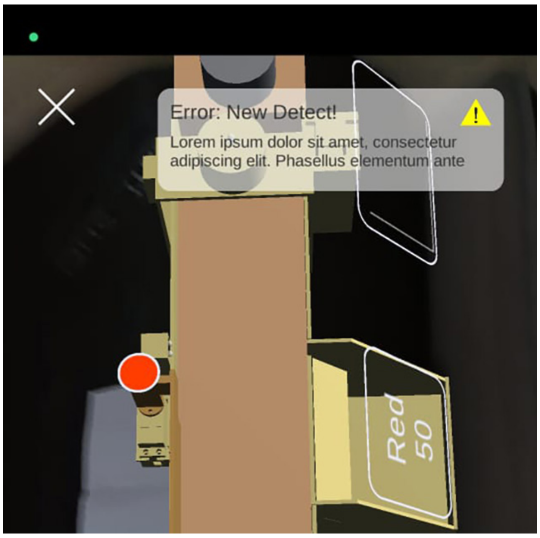


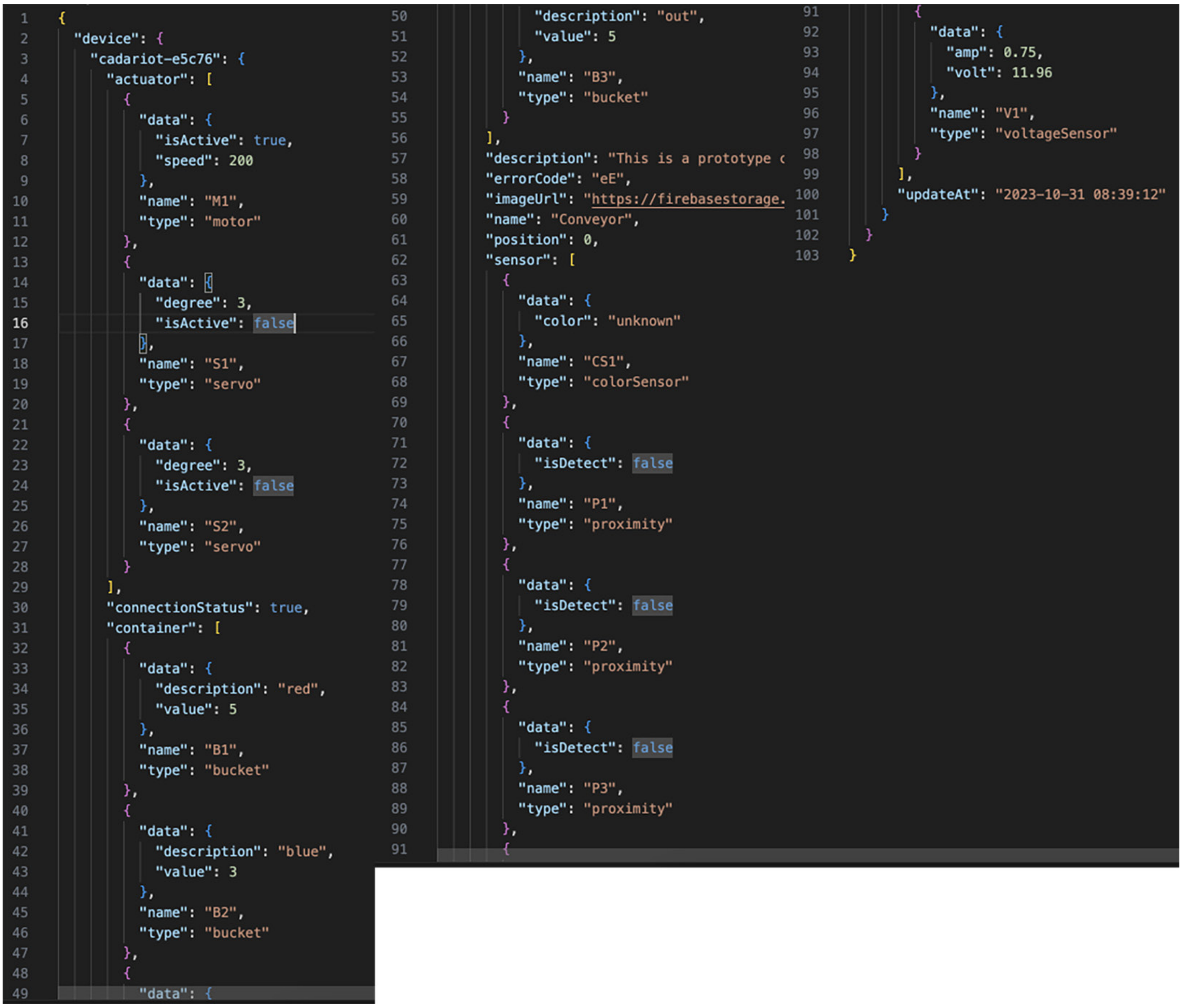
Fig. 11. Pop-up error view

LogScene interface. The LogScene serves as a dedicated interface for reviewing error histories. It can be accessed through the main page by clicking the "logger" button. This feature enables users to review error logs captured when the application detects errors. On this page, the application reloads and displays recorded errors in a list format, along with comprehensive details and timestamps for each error event (Figure 12).

Fig. 12. Logger page

Firebase RTDB. Google, as part of the Firebase platform, provides RTDB, a cloud database service. This database is designed to store and synchronize data in real time between connected users or devices. The primary data storage format in

Firebase RTDB is JSON (JavaScript Object Notation). When data on a device changes, the synchronization application will automatically update it with the latest information, ensuring that the displayed data is always current. Figure 13 presents the JSON format used for data storage.



```
{
  "device": {
    "cadariot-e5c76": {
      "actuator": [
        {
          "data": {
            "isActive": true,
            "speed": 200
          },
          "name": "M1",
          "type": "motor"
        },
        {
          "data": {
            "degree": 3,
            "isActive": false
          },
          "name": "S1",
          "type": "servo"
        },
        {
          "data": {
            "degree": 3,
            "isActive": false
          },
          "name": "S2",
          "type": "servo"
        }
      ],
      "connectionStatus": true,
      "container": [
        {
          "data": {
            "description": "red",
            "value": 5
          },
          "name": "B1",
          "type": "bucket"
        },
        {
          "data": {
            "description": "blue",
            "value": 3
          },
          "name": "B2",
          "type": "bucket"
        },
        {
          "data": {
            "description": "out",
            "value": 5
          },
          "name": "B3",
          "type": "bucket"
        }
      ],
      "description": "This is a prototype c
      "errorCode": "eE",
      "imageUrl": "https://firebasestorage.
      "name": "Conveyor",
      "position": 0,
      "sensor": [
        {
          "data": {
            "color": "unknown"
          },
          "name": "CS1",
          "type": "colorSensor"
        },
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            "isDetect": false
          },
          "name": "P1",
          "type": "proximity"
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        },
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          "name": "P3",
          "type": "proximity"
        },
        {
          "data": {
            "amp": 0.75,
            "volt": 11.96
          },
          "name": "V1",
          "type": "voltageSensor"
        }
      ],
      "updateAt": "2023-10-31 08:39:12"
    }
  }
}
```


Fig. 13. JSON format data

Prototype machine. During the testing phase, it is crucial to develop a prototype machine capable of replicating the functionality of a real production machine in the manufacturing industry. The prototype machine is designed as a conveyor equipped to filter red and blue colors, and it includes sensors to monitor the real-time conditions of the machine. Figure 13 shows the prototype machine. This prototype is designed to transmit real-time data through an internet connection to a designated server or cloud platform, utilizing Firebase RTDB in this context. It also has the capability to detect and relay notifications regarding any errors to the application simulating the digital twin of the operational prototype machine (Figure 14).

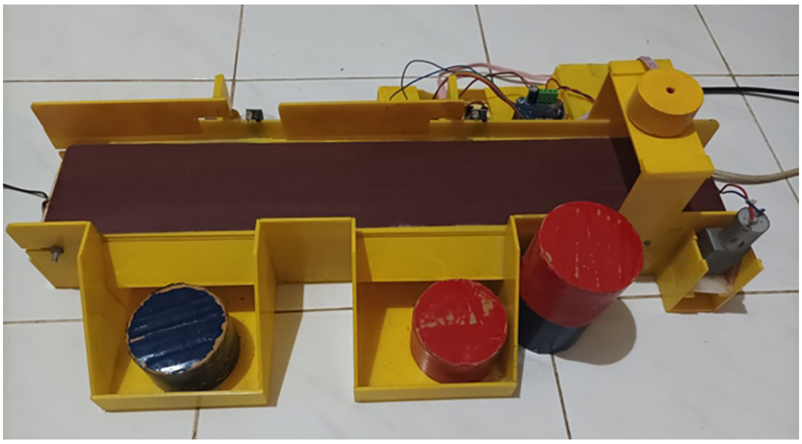

Fig. 14. Prototype machine

3.2 Test results

The implemented system underwent testing directly on Android operating system devices. The testing process aimed to validate the integration between the application and the prototype machine while also ensuring the system's consistency across various trials. Additionally, the testing was conducted to assess the consistency of input and output with the expected scenarios. The designed system is tested using black box testing. Black box testing is conducted to observe the execution outcomes using test data and to examine the functionality of the application. The testing scenarios and results are presented in Table 4.

Table 4. Test result application

No	Features	Testing Method	Expected Results	Test Result
1	Main menu page	Open the application	Application load main menu page	Succeed
2	AR Scan page	Press the **Start Scan** button	Load and show camera capture	Succeed
3	Logger page	Press the **Logger** button	Displays the logger page and loads the list items if any	Succeed
4	Info for detecting markers	Application has not detected the marker	Show pop-ups	Succeed
5	Marker detection	Shows marker to AR camera	Load and showing 3D objects	Succeed
6	Displays other information and connectivity status with the prototype machine	Marker detected	Displays UI detail info and status of the machine	Succeed
7	Displays specific information related to the prototype machine	Marker detected	Displays information related to sensor reading data, machine operation on 3D models in real time	Succeed
8	Simulate the operation of the machine in real time	The prototype machine is operating normally to separate red, blue and other colored cylinder objects	There is a simulation on the 3D model according to the actual condition of the prototype machine when sorting colors of the sorted object	Succeed
9	Simulating when operational failures occur on the 3D model	An error occurred in the machine prototype according to the specified scenario	There is a simulation on the 3D model based on the actual prototype machine condition when an error occurs by stopping the ongoing sorting simulation	Succeed

(Continued)

Table 4. Test result application *(Continued)*

No	Features	Testing Method	Expected Results	Test Result
10	Detecting an error when a new cylinder object is detected while the previous cylinder has not been sorted	Entering the second cylinder object before the first one has finished sorting	There is a notification about incoming errors in the application	Succeed
11	Detecting an error when the sorted cylinder object is lost/not moving	Eliminates or stops the movement of the cylinder object	There is a notification about incoming errors in the application	Succeed
12	Detecting an error when the device fails to read the color of the cylinder object	Failure of sensor readings on the prototype machine	There is a notification about incoming errors in the application	Succeed
13	The recorded errors are stored in the local database of the application	An error occurred in the machine prototype according to the specified scenario	Data stored in the local database can be viewed on the logger page	Succeed

3.3 Test results analysis

Based on the test results, it is essential to conduct a comprehensive analysis of the application. This analysis involves identifying weaknesses through systematic examination and recognizing the strengths that contribute to the application's resilience and effectiveness.

System weakness analysis

Table 5. System weakness analysis

No	Features Analysis	Expected Results
1	Main menu page	–
2	AR Scan page	–
3	Logger page	When load the error list data from the local database there is a delay of 2–5 seconds before the data appears and there is no loading indicator
4	Info for detecting markers	–
5	Marker detection	Marker detection is only limited to one marker
6	Displays other information and connectivity status with the prototype machine	The displayed information is in real-time, but it takes 0.5–3 seconds to show new data
7	Displays specific information related to the prototype machine	The displayed information is real-time, but showing new data takes 0.5–3 seconds, and the system only presents the latest data. Therefore, data from a few seconds ago may not be displayed
8	Simulate the operation of the machine in real time	The simulation conducted requires 2–8 seconds to update the animation conditions based on the actual machine conditions
9	Simulating when operational failures occur on the 3D model	The simulation carried out is limited to three scenarios, so when an error condition outside the specified scenarios occurs, it may not trigger an error
10	Detecting an error when a new cylinder object is detected while the previous cylinder has not been sorted	The error scenario goes undetected when combined with the scenario of failure to read the color of the cylinder object
11	Detecting an error when the sorted cylinder object is lost/not moving	The error scenario goes undetected when combined with the scenario of failure to read the color of the cylinder object
12	Detecting an error when the device fails to read the color of the cylinder object	The error scenario can interfere with other error scenarios
13	The recorded errors are stored in the local database of the application	Data storage requires 0.5–3 seconds to save errors into local database

In addition to the points listed in Table 5, a limitation of the system lies in the fact that the application is designed to detect only one marker for one machine. In actual implementation, the designed application should be capable of simulating various types of machines for more efficient use.

System strengths analysis. In this analysis, the objective is to identify and comprehend the positive aspects or strengths of the designed system. At this stage, the focus is placed on system elements that positively contribute to the overall performance, reliability, and effectiveness of the system (Table 6).

Table 6. System strengths analysis

No	Advantage
1	Application can show data in real time
2	Application is capable to displaying error notifications
3	Application can store error data locally, allowing it to be viewed again in offline connection
4	Application can simulate the operation of the prototype machine on a 3D model
5	Application implements an Augmented Reality, allowing it to be deployed with more than one marker

4 CONCLUSION

After completing the planning, development, and testing phases for the digital twin application in the industrial manufacturing monitoring system, the following conclusions can be drawn:

1. The designed application successfully demonstrates the functionality of the digital twin in real-world scenarios. By utilizing the Vuforia library, the application effectively integrates AR to facilitate the creation of a 3D model that accurately represents the prototype machine.
2. The prototype machine incorporates IoT technology principles, allowing it to establish real-time communication with the server (Firebase). This enables seamless connectivity between the application and the prototype machine.
3. The establishment of this industrial manufacturing monitoring system serves as an example of how digital twin technology can provide a solution for remotely monitoring actual production machines.
4. The test results of both the application and the prototype machine align with the overall system analysis, effectively reflecting the successful implementation of the design phase.

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