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Proposal and Development of Simulation Models concerning the Supervision and Control of Patients at the hospital based on Digital Twin technology

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Proposed and Directed by :

— **RAHIM Messaoud**

Prepared and Presented by :

— **HACEINI Amani**

— **BENALIA Imane**

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Dedication

“

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”

- Amani

Dedication

“

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- Imane

Abstract

This work aims to develop a digital twin-based system for patient control and supervision. The control and the supervision of patients is conducted by collecting vital signs from sensors implanted on hospital beds and patients. The proposed system offers also a real-time monitoring of patients enhanced with prediction and analytic services based on artificial intelligence API, which we design relying on the historical health data of patients. These services are provided, for medical staff, through a convivial user interface.

The implementation relies on using the Eclipse Ditto tool for the creation and management of the digital twin and Node-RED tool for simulation purposes. So, simulation models are proposed for representing patients vital signs.

Keywords :system , Digital twin ,Patients , Connected hospital Beds, Vital Signs, Artificial Intelligence API, Prediction , Eclipse Ditto, Node-RED, IOT

Résumé

Ce travail vise à développer un système basé sur un jumeau numérique pour le contrôle et la supervision des patients. Le contrôle et la supervision des patients sont effectués en collectant les signes vitaux à partir des capteurs implantés sur les lits d'hôpitaux et les patients. Le système proposé offre également une surveillance en temps réel des patients améliorée par des services de prédiction et d'analyse basés sur une API d'intelligence artificielle, que nous concevons à partir les données historiques de santé des patients. Ces services sont fournis au personnel médical a partir d'une interface utilisateur conviviale. L'implémentation repose sur l'utilisation de l'outil Eclipse Ditto pour la création et la gestion du jumeau numérique et de l'outil Node-RED à des fins de simulation. Ainsi, des modèles de simulation sont proposés pour représenter les signes vitaux des patients.

Mots clés : système, Jumeaux Numériques, Lits d'hôpitaux Connectés, Signes Vitaux ,API d'intelligence artificielle, prédiction , Eclipse Ditto, Node-RED, IOT

ملخص

يهدف هذا العمل إلى تطوير نظام قائم على المحاكاة والتوأم الرقمي لـ مراقبة المريض والإشراف عليه. يتم التحكم والإشراف على المرضى من خلال جمع العلامات الحيوية من أجهزة الاستشعار المزروعة على أسرة المستشفيات والمرضى. يوفر النظام المقترح أيضًا مراقبة في الوقت الفعلي للمرضى معززة بخدمات التنبؤ والتحليل بناءً على واجهة برمجة تطبيقات الذكاء الاصطناعي ، والتي نصممها بالاعتماد على البيانات الصحية التاريخية للمرضى. يتم توفير هذه الخدمات ، للموظفين الطبيين ، من خلال واجهة مستخدم مبهجة.

يعتمد التنفيذ على استخدام أداة (Eclipse Ditto) لإنشاء وإدارة التوأم الرقمي وأداة (Node-RED) لأغراض المحاكاة. لذلك ، تم اقتراح نماذج محاكاة لتمثيل العلامات الحيوية للمرضى.

كلمات مفتاحية :نظام, التوأم الرقمي، مرضى، التنبؤ، أسرة المستشفى المتصلة، العلامات الحيوية، واجهة برمجة التطبيقات الذكاء الاصطناعي ، Eclipse Ditto ، Node-RED ، IOT.

List of Acronyms

AI	*Artificial Intelligence*
AMQP	*Advanced Message Queuing Protocol*
API	*Application Programming Interface*
APP	*Application*
CEI	*Commission Électronique Internationale*
CSS	*Cascading Style Sheets*
CURL	*Client URL*
DT	*Digital Twin*
HTML	*Hyper Text Markup Language*
HTTP	*Hyper Text Transfer Protocol*
IoT	*Internet of Things*
ISO	*Organisation Internationale de Normalisation*
JSON	*JavaScript Object Notation*
MQTT	*Message Queuing Telemetry Transport*
PHP	*Hypertext Preprocessor*
REST	*Representational State Transfer*
RFID	*Radio Frequency Identification*
SysM	*Systems Modeling Language*

TCP *Transmission Control Protocol*

UI *User Interface*

URI *Uniform Resource Identifier*

URL *Uniform Resource Locator*

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General Introduction

A digital twin is a virtual representation or mirror image of a physical object or system. The concept of a digital twin has gained significant attention in recent years. Revolutionizing various industries, including healthcare. In the context of a smart hospital,a digital twin offers tremendous potential to enhance patient care, optimize comfort, and improve health outcomes.
Through a digital twin, healthcare professionals can remotely monitor and manage the smart bed, gaining insights into patient comfort, sleep quality, and vital signs. It facilitates real-time data collection from various sensors embedded in the bed, such as pressure sensors, heart rate monitors, respiratory sensors, and temperature sensors. These sensors provide valuable information about the patient's condition and the bed's performance.
Due to these benefits of the digital twin, this study treats the problematic issue of how designing a digital twin based solution that allows the control and supervision of patients. This problematic can be subdivided into the following questions:

- How to design a digital twin model that can replicate the hospital beds and the patient's health state?
- How can supervision and control functionalities be provided for the medical staff in a secure and convivial manner?
- How can the physical system (hospital beds and patients) be connected to the digital twin?
- How can we provide analytic services concerning the health state of patients?
- In addition, in the absence of a physical bed and real patients, we have to deal with vital signs simulation to emulate the physical system.

The remainder of the document is structured as follow:

- The first chapter provides an overview of digital twin technology and its impact on healthcare. It discusses the concepts, capabilities, components, types, and applications of digital twins. It also explores the connection between digital twins and the Internet of Things (IoT), along with communication protocols and platforms used for their development.
- The second chapter discusses vital signs in the healthcare domain and presents the main sensors that can be used to collect such signs. The chapter also discusses the concept and benefits of simulation in the context of healthcare and presents how one can simulate some of the patient's vital signs.
- The third chapter will provide a detailed description of the proposed solution and how this latter is designed to allow controlling and supervising patients. It will cover the design of the digital twin model for the connected hospital beds and show the architectural aspects of the proposed platform, emphasizing the interactions between the various stakeholders, the physical system, and the digital twin.
- Finally, the fourth chapter will present the implementation of the proposed solution. This will include providing a detailed description of the various tools used,

emphasizing the implementation of the key components of the proposed solution, and illustrating the functionalities of the developed platform.

Chapter 1

Digital twins

1.1 Introduction

The digital twin is an exciting concept and undoubtedly one of the hottest tech trends right now. Its power comes from connecting real-world assets (physical systems) with real-world data. Digital twins integrated with IoT provide valuable insights, optimize operations, and support decision-making across various domains.

The purpose of this chapter is to provide an overview of the "digital twins" technology. By discussing the concept used by this technology and exploring its capabilities, components, types, applications, and the transformative impact it has on health care. While exploring the power of digital twin technology, this chapter elucidates the concept of the Internet of Things (IoT) along with other communication protocols and dedicated the platforms designed for their development.

1.2 Connected objects

A connected object(often referred to as an Internet of Things (IoT) device) is a physical device or object capable of communicating various information to another object or to the internet [31].
It can capture, transmit, and sometimes process data to help with decision-making or initiate action.
This object is designed to communicate. It operates using connectivity that can be existing from the start or added later and integrates into the IoT network infrastructure[31].

1.2.1 Characteristics and functions of connected objects

A connected object is distinguished by essential characteristics:

- Its ability to collect data through sensors according the application, various data can be collected such as location, distance, temperature, vibration.
- Its ability to transmit, process information and initiate action if necessary[31].

  For example, a wearable device measures vital signs such as blood pressure, heart rate, and oxygen saturation and continuously collects and transmits vital health information from a patient to healthcare providers or monitoring systems.

Additionally, connected objects can be integrated with an IoT infrastructure, and this is how connected objects can benefit from integration within an IoT infrastructure:

- **Interconnectivity:** by integrating with an IoT infrastructure, the connected object can communicate and exchange data with other devices, sensors, and systems.
- **Data Sharing and Aggregation:** the connected object can share its collected data with other devices or systems within the IoT infrastructure.

- **Enhanced Analytics and Insights:** integration with an IoT infrastructure allows the connected object to leverage advanced analytics and machine learning algorithms.
- **Scalability and Flexibility:** integration within an IoT infrastructure provides scalability, allowing the connected object to handle larger volumes of data and interact with a growing number of devices and systems.
- **Centralized Control and Management:** integration with an IoT infrastructure provides a centralized control and management platform. This allows for remote monitoring, configuration, and control of the connected object, as well as the ability to manage software updates, security protocols, and device settings from a centralized location.
- **Ecosystem Synergies and Innovation:** integration within an IoT infrastructure opens up opportunities for ecosystem synergies and innovation. The connected object can leverage the capabilities and services provided by other devices, platforms, or cloud-based applications within the IoT ecosystem.

The connected object sends the collected data to dedicated infrastructure. The data is stored, analyzed using calculation algorithms, and then returned to the user in the form of usable information[31].

1.3 Internet of things

The Internet of Things, or IoT, refers to a system of interconnected physical devices that communicate via the internet, all collecting and sharing data with other devices. Connecting up all these different devices by adding sensors, actuators, and processors and enabling them to communicate real-time data without involving a human[39].

1.3.1 IoT technologies

IoT technologies are the array of tools that underpin and power Internet of Things devices and networks. These are some IoT technologies:

- **Sensors:** devices capable of transposing a physical measurement (temperature, movement, etc.) into digital data. The purpose of the sensors is to collect information from a physical system.
- **Actuators:** sort of the opposite of the sensor. The actuator is the device that transforms digital data into a physical phenomenon through an action. Actuators are alarms, motors, switches or dimmers to control a bulb for example, etc.
- **Connectivity:** the main and differentiating element of a connected object. It makes it possible to connect the object to an infrastructure or to another connected object via a communication channel. The connected object integrates one or more

IoT network. There are several communication technologies which can be used such as LTE, 5G, Zigbee, Z-Wave, LoRa (long range), NB-IoT, and Wi-Fi – which enable devices to receive and transmit data. Machine-to-machine (M2M) communication protocols are especially relevant in the context of IoT.

- **Gateway technologies:** allow inter-device and device-to-cloud communication, as well as data preprocessing and device management, in some cases Software and cloud technologies for the storage and analysis of data generated by IoT devices. Examples of IoT databases include InfluxDB, MongoDB, and SQLite for data storage, as well as an array of signal processing, machine learning, and artificial intelligence tools for data analysis and business intelligence.
- **Security technologies:** such as endpoint encryption, context-aware authentication, and network segmentation, to protect IoT devices as well as the data they transmit and receive[17].

1.3.2 IoT architecture

The IoT architecture refers to the system design and structure of interconnected devices. Sensors, networks, and cloud services that enable the exchange of data and communication in the IoT ecosystem,the architecture typically consists of multiple layers, each serving specific functions and contributing to the overall functionality of the IoT solution.

IoT architecture can vary depending on the specific use case, requirements, and scalability needs. Different IoT platforms or frameworks may offer variations or additional layers to support specific functionalities.
But no matter the use case or number of layers, the key building blocks of any IoT structure are always the same, namely:

- Smart things
- Networks and gateways enabling low-power devices (which is often the case in IoT) to enter the big Internet[9].
- The middleware or IoT platforms providing data storage spaces and advanced computing engines along with analytical capabilities[9].
- Applications, allowing end users to benefit from IoT and manipulate the physical world[9].

Below is the illustration 1.1 which shows the key building blocks of IoT architecture:

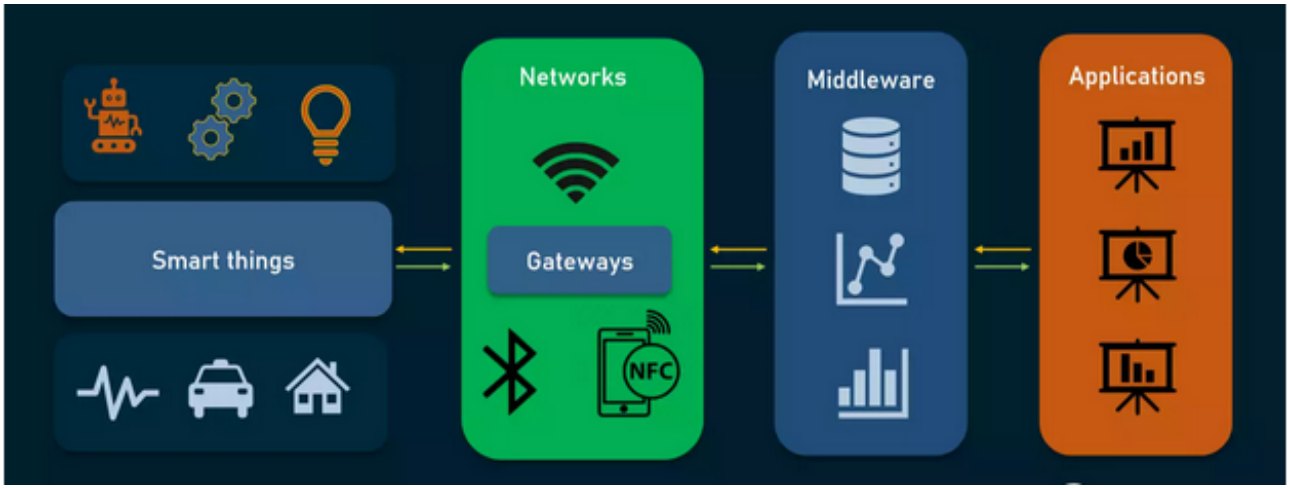


Figure 1.1: IoT Key building blocks
[9]

These components provide the foundation of any IoT system, upon which an effective, multi-layered architecture can be built. Typically, these layers are:

- **Perception layer :**is the physical layer, which has sensors for sensing and gathering information about the environment. It senses some physical parameters or identifies other smart objects in the environment[2].
- **Transport layer :** transfers the sensor data from the perception layer to the processing layer and vice versa through networks such as wireless, 3G, LAN, Bluetooth, RFID, and NFC[2].
- **Processing layer:** is also known as the middleware layer. It stores, analyzes, and processes huge amounts of data that comes from the transport layer. It can manage and provide a diverse set of services to the lower layers. It employs many technologies such as databases, cloud computing, and big data processing modules.[2]
- **Application layer:** includes all the software necessary to offer a specific service. In this level, the data from the previous levels are stored, aggregated, filtered, and processed, and databases, analysis software, etc., are used. As a result of this processing process, the data is made available to real IoT applications(smart wearable, smart car, etc.)[3].

In addition to the most important components, we discuss three additional layers:

- **Edge Layer :** As IoT networks grow in scale, latency becomes one of the main performance challenges, as numerous devices connecting to a hub end up congesting the network. By enabling data processing and analysis as close to the source as possible, edge computing addresses these problems – which is handled through the edge layer of an IoT system architecture[30].

- **Business Layer:** Patterns decoded at the application level can be used to further distill business insights, project future trends, and drive operational decisions that improve the efficiency, safety, cost-effectiveness, customer experience, and other important aspects of business functionality. Indeed, all of this can be accomplished at the business layer of an IoT system architecture[30].
- **Security Layer:** Security is one of the most important requirements for an IoT system architecture. Ironically, it also happens to be one of the key challenges facing IoT architecture, and IoT devices themselves. Broadly, the IoT security layer comprises three main aspects:Equipment security, cloud security and connection security[30].

1.3.3 Benefits of the Internet of Things

The Internet of Things (IoT) provides several advantages across various industries and domains.Here are some important benefits of IoT:

- **Industrial Automation** Enterprises are using the Internet of Things as a way to increase the reliability of anything they may be doing that is automated.
- **Data Collection** The amount of data in the world has never been larger than it is today. And looking forward, the speed of generation is increasing constantly, pointing to an even more data-rich future[27]. But what good is all that data if we don't have the ability to access, aggregate, analyze, and also improve the way that data is used? The fundamental appeal of IoT is that the devices will generate unprecedented volumes of data. The wealth of information offers the potential for individuals and businesses to make better, more informed decisions. However, the data has to be retrievable.
- **Customer Experience** IoT allows for more personalization than ever before. Because all these devices are connected, customers expect a certain level of customer support that is ingrained within the device itself. Services can be adjusted on the fly, and refined based on what a customer is asking for at that particular moment, whatever it might be[27]. Devices are also able to improve over time as they gain more data and can make more accurate decisions tailored to each customers' needs.
- **Increased Revenue** Internet of Things can drastically reduce overhead and lower a business' expenses. At the same time, IoT will increase efficiency by allowing an enterprise to take advantage of a new business function. For instance, organizations can benefit from knowing exactly how much they need and when in terms of inventory[27].

1.4 Digital twin

A digital twin is a virtual model designed to accurately reflect a physical object. The object being studied is outfitted with various sensors related to vital areas of functionality.

These sensors produce data about different aspects of the physical object's performance. This data is then relayed to a processing system and applied to the digital copy. Once informed with such data, the virtual model can be used to run simulations, study performance issues and generate possible improvements, all with the goal of generating valuable insights which can then be applied back to the original physical object[28].

1.4.1 Digital twin types

Digital twins are capable of modeling everything from individual components to entire systems. While every type of digital twin fundamentally does the same thing (virtually modeling a real-world object or system) their purposes and scope greatly vary between one another. The four primary types of digital twin are:

- **Component twins :** are digital representations of an individual part of a system or product, such as a gear or screw. Rather than simply modeling all the individual parts of a product, though, component twins are typically used to model integral parts, such as those under particular stress or heat. By digitally modeling these parts and subjecting them to dynamic simulations, designers and engineers can see how the parts can be improved to ensure their integrity in likely scenarios.
- **Asset twins :** also called product twins, are virtual representations of a physical product rather than its individual parts. While asset twins can technically be composed of numerous component twins, their purpose is to understand how their various parts operate together within a single real-world product. For example, a wind turbine might have an associated asset twin used to monitor its performance and identify possible parts failure due to common wear-and-tear.
- **System twins :** also called unit twins, are virtual representations of systems of products working together. While asset twins model real-world products comprised of many parts, system twins model these individual products as components of a larger system. Understanding how assets interact with one another offers the opportunity to improve how they relate to one another, increasing productivity and efficiency as a result.
- **Process twins :** are digital representations of systems working together. For example, while a system twin might model a manufacturing line, a process twin could model the entire factory all the way down to the employees operating the machines on the factory floor[15].

The figure 1.2 represents Digital Twin types:

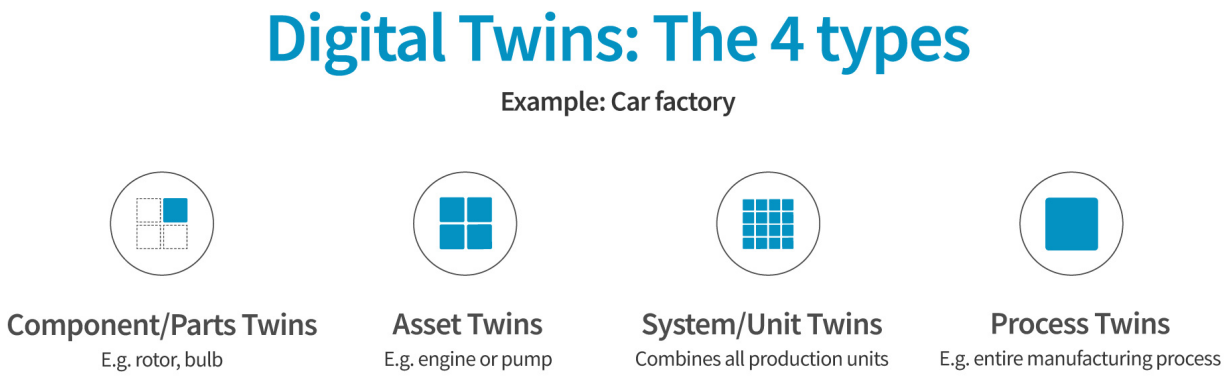


Figure 1.2: Digital Twin types
[19]

1.4.2 The Digital Twin Architecture

There is a general framework for the DT architecture which is composed of three main elements: the physical world, the virtual world and the connectivity between the two.

- The physical world: is composed of the physical object or process, sensors, actuators and processing capabilities.
- The digital world: is composed of the digital twin itself, machine learning and data processing capabilities and databases.
- Both are connected: in the communication element where several protocols and interfaces are available such as Wi-Fi, Bluetooth and wired connections.

For the user, this architecture allows constant monitoring and visualization[4].

The figure1.3 represents Digital Twin architecture:

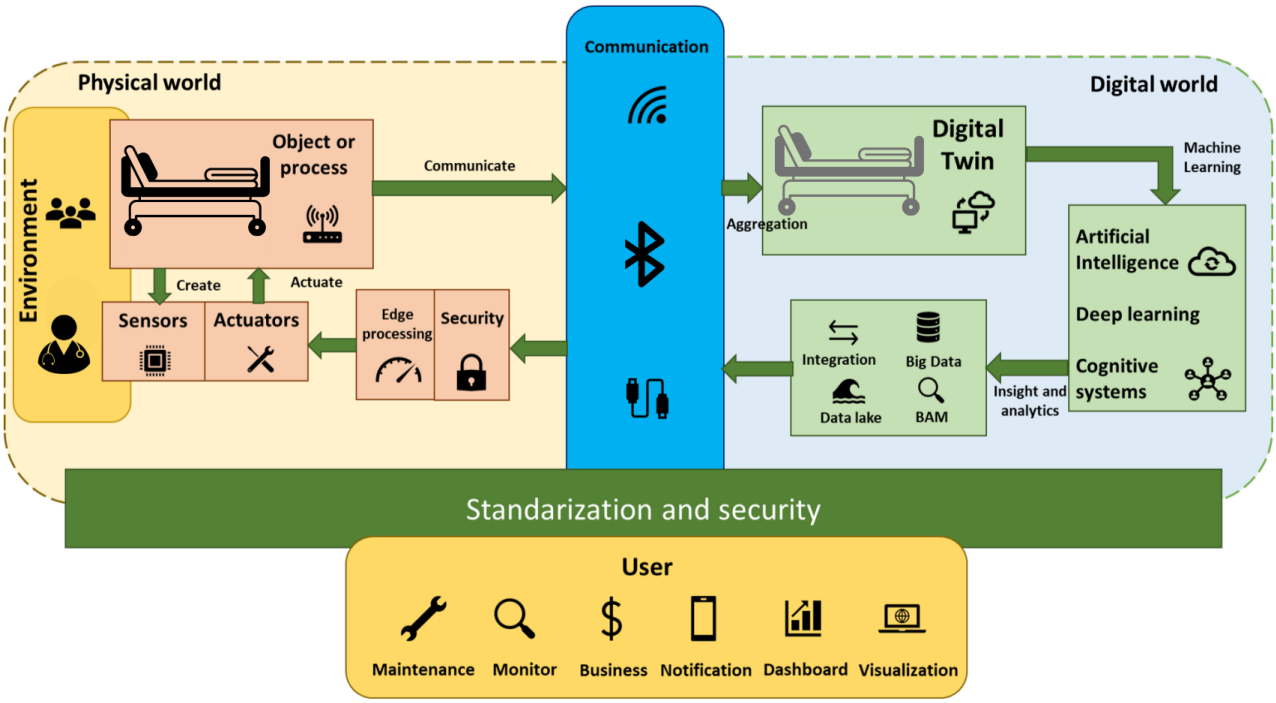


Figure 1.3: Digital Twin architecture

1.4.3 Digital twin technologies

Digital Twin uses four technologies to collect and store real-time data, obtain information to provide valuable insights, and create a digital representation of a physical object.

- Internet of Things (IoT): IoT uses sensors to collect data from real-world objects. The data transmitted by IoT is used to create a digital duplication of a physical object. The digital version then can then be analyzed, manipulated, and optimized. IoT constantly updates data and helps Digital Twin applications create a real-time virtual representation of a physical object. Therefore, every Digital Twin application uses IoT as a primary technology.

- Cloud Computing: Cloud computing provides Digital Twins with data computing technology and cloud data storage technology. Cloud computing allows Digital Twin, with large volumes of data, to store data in the virtual Cloud and easily access the required information from any location. Cloud computing enables Digital Twins to effectively reduce the computation time of complex systems and overcome the difficulties of storing large amounts of data .

- Artificial Intelligence (AI): AI can assist Digital Twins by providing an advanced analytical tool capable of automatically analyzing obtained data and providing valuable insights, making predictions about outcomes, and giving suggestions as to how to avoid potential problems.

- Extended Reality (XR) XR creates digital representations of objects where digital and real-world objects co-exist and interact in realtime. Digital Twins utilize XR capabilities to digitally model physical objects, allowing users to interact with digital content[6].
  The figure 1.4 represents Digital Twin technologies:

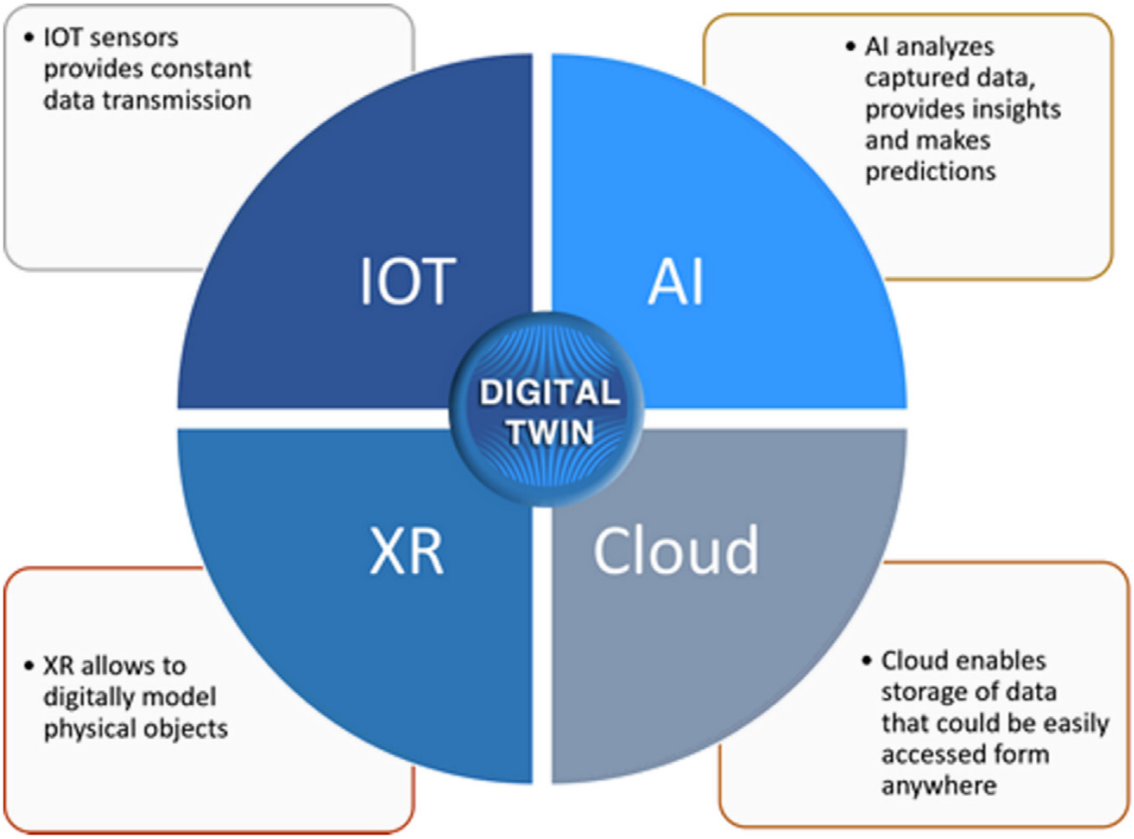


Figure 1.4: Digital Twin technologies.
[6]

1.4.4 Digital twin benefits

There are as many benefits to using digital twins as there are applications for them. However, some of the most common benefits of using them include:

- Lower overall costs by designing, testing, and refining products or systems in virtual environments before mass production or roll-out.
- Improve operational efficiency by modeling systems with up-to-date information, testing alterations in dynamic simulations, and ultimately implementing real-world changes.
- Provide swift maintenance to physical assets and existing systems, such as buildings or jet engines, by continually monitoring their performance and identifying issues when they first arise.

- Improve the customer experience when purchasing a product or entering a retail outlet by virtually modeling their customer journey[14].

1.5 Digital twin in healthcare

Digital twin is being applied in industry as a precision simulation technology from concept to practice. simulation plays a very important role in the healthcare field, especially in research on medical pathway planning, medical resource allocation, medical activity prediction..
By combining digital twin and healthcare, there will be a new and efficient way to provide more accurate and fast services

1.5.1 Clinical application of the DT

Assisted by improvements in engineering technology, the medical industry has gradually transitioned from traditional medicine to digital medicine and then to information medicine, resulting in today's concept of smart medicine, which satisfies the individual's preventive and personalised medical needs to a greater extent.

- **Cardiovascular disease**

  The application of the DT to the cardiovascular system includes the establishment of DT heart models and the precise treatment of cardiovascular disease. Models can be used to accurately determine the most valuable diagnostic basis and reliably infer biomarkers through non-invasive procedures.
  A DT can simulate dosage effects or the device response before a specific treatment and thus indicate whether the medical device or treatment is appropriate for patients and improve the treatment of patients with different causes of disease[8].

- **Surgery**

  The idea of using the DT in the surgical field is to create a patient model for multi-disciplinary teams to plan a surgery and verify the anatomy and thus avoid inadvertent damage to structures.
  A number of surgical specialties evaluated patient-specific simulation, including neurosurgery, vascular surgery and interventional radiology[8].

- **Pharmacy**

  The medicine used in treatment should be personalized as human bodies and physiology are different. DT models created using genetic code can reveal changes in the performance of the body and provide researchers a more cost-effective opportunity to evaluate new compounds with a more accurate result. In the phase of operation, DT can constantly provide real-time process control and optimisation information in order to support the product development and risk analysis[8].

- **Orthopaedics**

  With the development of numerical simulationand worn devices, the use of a DT for the real-time monitoring and analysis of the lumbar spine has become a highly promising cutting-edge technology in the biomechanical field. In applying the DT in the field of orthopaedics, it is important to develop physics-based experimental models and data-driven numerical models, which have the advantages of low cost and high integrity[8].

- **COVID-19**

  The COVID-19 pandemic has generated enormous interest in the modelling and simulation of infectious diseases. A coronavirus spreads through person-to-person contact via respiratory droplets, especially when an infected patient coughs or sneezes. A respiratory emission model and a combined DT phase were developed and a machine learning framework from which to improve ventilation systems During the pandemic, it has been necessary to find a way to vaccinate more people in a shorter time period, especially when healthcare workers are scarce. A DT system has been developed for the vaccination process and tested it in a clinic. The system allows a real-time simulation of patients and creates a dynamic vaccination centre. The virtual model can be run to find problems and address them in the real system, thus improving the efficiency of vaccination[8].

1.6 Technologies and tools used for digital twins

1.6.1 Eclipse Ditto

Eclipse DITTO™ is a technology in the IOT implementing a software "digital twins". The technology mirrors potentially millions and billions of digital twins residing in the digital world with physical "Things"[21]. This simplifies developing IoT solutions for software developers as they do not need to know how or where exactly the physical "Things" are connected. With Ditto a thing can just be used as any other web service via its digital twin.

Eclipse Ditto architecture

The components have the following tasks:

- **Policies:** persistence + enforcement(authorization) of Policies
- **Things:** persistence + enforcement (authorization) of Things and Features
- **Things-Search:** tracking changes to Things, Features, Policies and updating an optimized search index + executes queries on this search index
- **Gateway:** provides HTTP and WebSocket API

- **Connectivity:** persistence of Connections sends Ditto Protocol messages to external message brokers and receives messages from them[11].

All services run in the same Akka cluster and can reach each other via TCP without the need for an additional message broker in between[11]. All messages which are sent between Ditto microservices must in a way be serializable and deserializable. All Ditto signals can be serialized from Java objects to JSON representation and deserialized back from JSON to Java objects[11].
The figure 1.5 represents Ditto services :

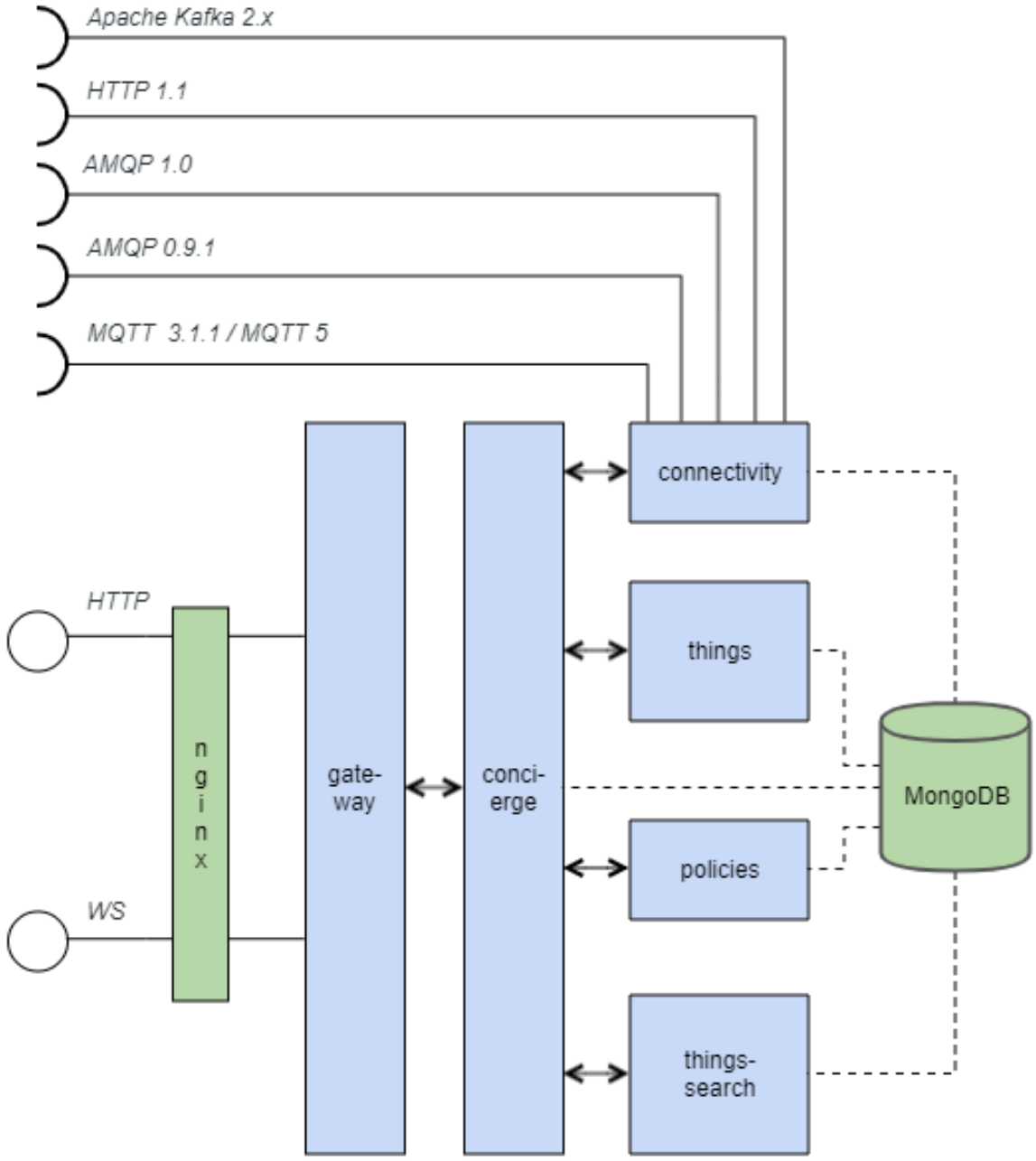


Figure 1.5: Ditto Architecture
[11]

Eclipse DiTTo protocols

Ditto communication protocols are modes of communication that protect and ensure optimum security to the data being exchanged between connected devices.
The figure 1.6 represents Ditto protocols:

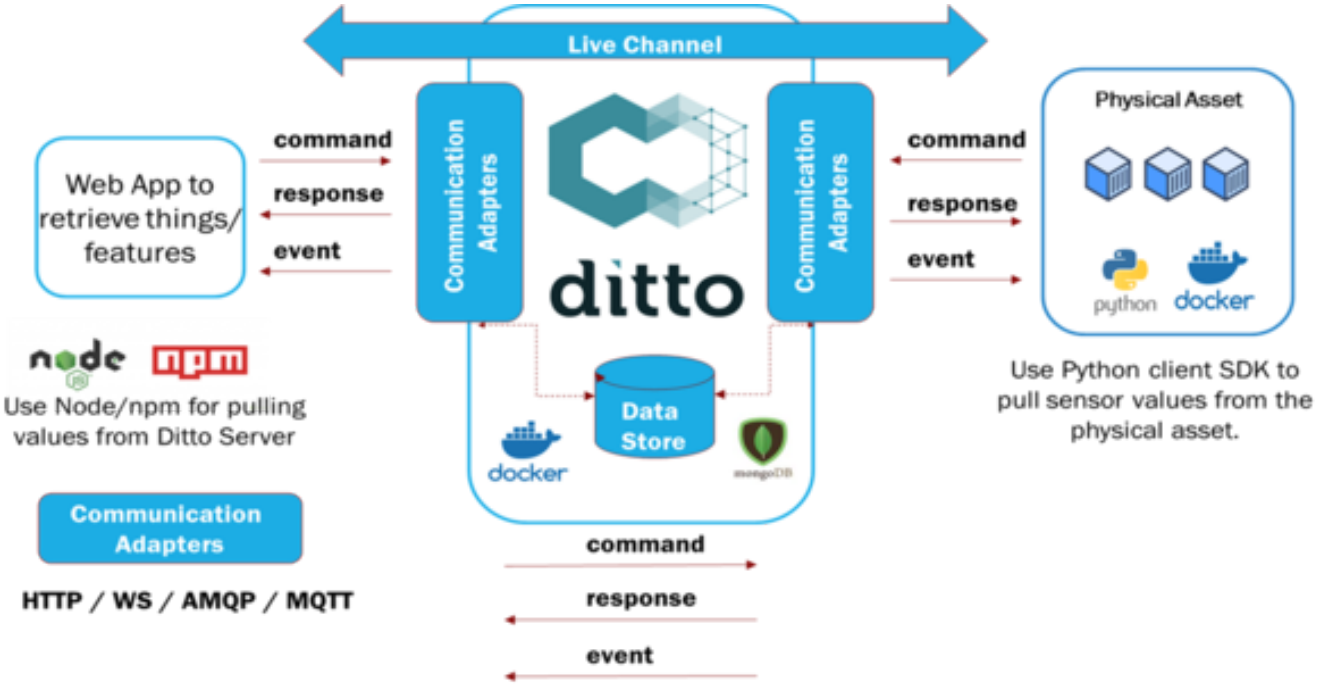


Figure 1.6: Ditto protocols
[25]

- **HTTP:** the Hypertext Transfer Protocol (HTTP) is the standard protocol used to transmit data [40], within the global distributed information system "World Wide Web" (Web). The transfer of resources happens using TCP (Transmission Control Protocol).TCP manages the channels between the browser and the server and many types of internet connections. HTTP is the command language that the devices on both sides of the connection must follow in order to communicate. IoT data protocols are used to connect low power IoT devices. These protocols provide point-to-point communication with the hardware at the user side without any Internet connection. Connectivity in IoT data protocols is through a wired or a cellular network.

The figure 1.7 represents HTTP Protocol:

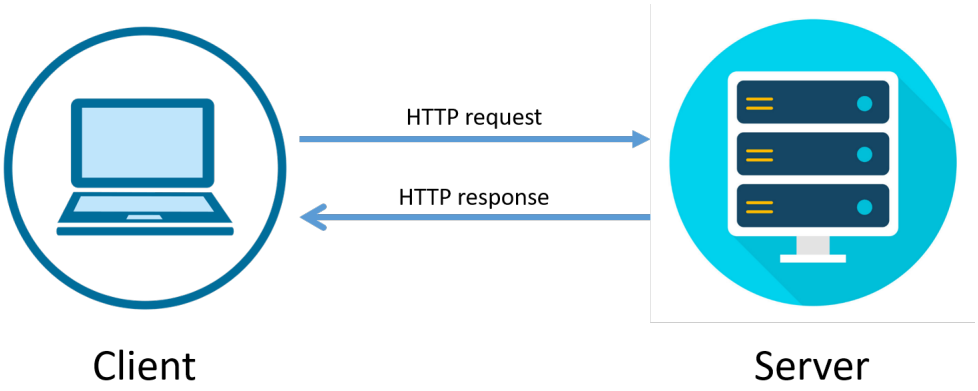


Figure 1.7: HTTP Protocol.
[24]

- **MQTT** Message Queuing Telemetry Transport Developed as an open OASIS standard and an ISO recommended protocol, the MQTT was aimed to operate on data transmissions with a small bandwidth and minimum resources IoT devices. It usually uses the TCP/IP protocol suite, which runs by first establishing connections, then allows multiple exchanges of data until one party finally disconnects itself.it is an ideal protocol for machine-to-machine (M2M) communication[34]. The MQTT technology runs using the MQTT Publish/Subscribe architecture and establishes the network from 2 different component categories: Clients (Publisher and Subscriber) and Brokers. The Publish/Subscribe architecture first divides the network's client devices into 2 categories, publishers and subscribers. These publishers are devices or nodes that input data to the system. On the other hand, the subscribers are the end devices or nodes that receive the data[34]. The data sent are in the form of different topics, in which the broker sorts the topic sent from the publisher, and sends it out to the appropriate client which has previously subscribed to the said topic[34].
  The figure 1.8 represents MQTT Protocol:

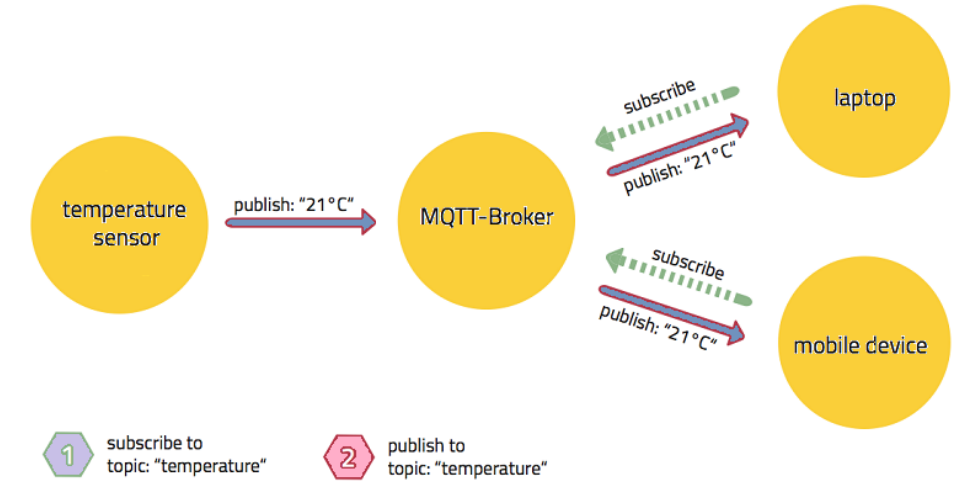


Figure 1.8: MQTT Protocol.
[35]

- **WebSocket protocol:** is an extension to the HTTP 1.1 protocol to enable two-way communication between a client and a server. It is an independent TCP-based protocol. Because it is very reliable and efficient, it is used by almost all clients. TCP establishes communication between two endpoints, which are referred to as sockets. This allows data to be transferred in both directions[48]. Two-way connections like WebSocket (sometimes written as Web Socket) allow data to be exchanged in both directions simultaneously. The advantage of this is that data can be called up more quickly. WebSocket in particular enables direct communication between a web application and a WebSocket server. In concrete terms, this means you can call up a web page and have it displayed in "real time."WebSocket enables Access Gateway to accept an HTTP upgrade request from a client.By default, the WebSocket protocol uses port 80 for regular WebSocket connections and port 443 for WebSocket connections tunneled over Transport Layer Security (TLS)[48].

The figure 1.9 represents Web socket communication:

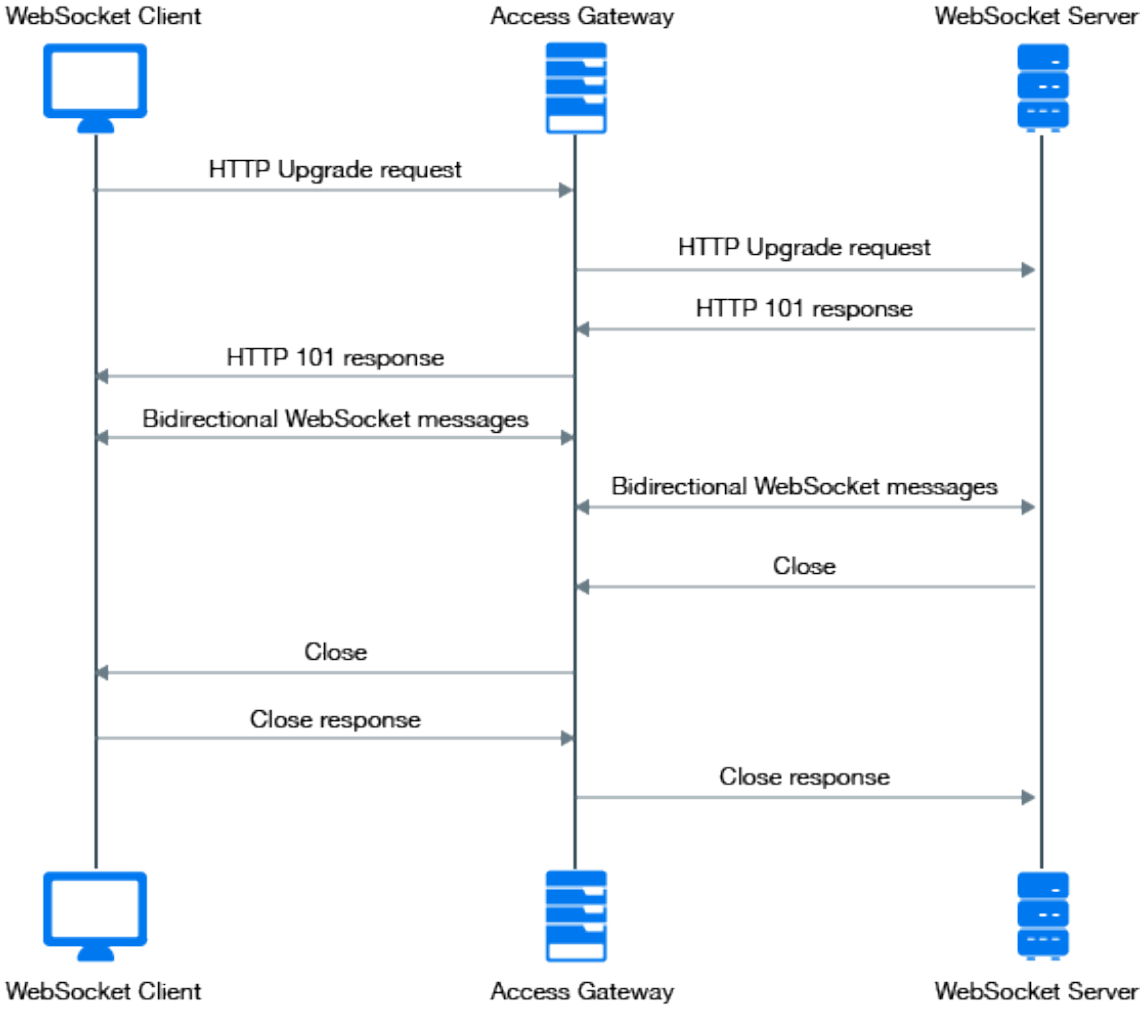


Figure 1.9: Web socket communication.
[44]

- **AMQP (Advanced Message Queuing Protocol) :**is an open standard for passing business messages between applications or organizations. It connects systems, feeds business processes with the information they need and reliably transmits onward the instructions that achieve their goals[10]. AMQP is an open standard, binary application layer protocol designed for message-oriented middleware i.e., AMQP protocol standardizes messaging using Producers, Brokers and Consumers and messaging increases loose coupling and scalability[46]. The AMQP was contrived to enable a wide range of applications and systems to work together, regardless of their internal designs, standardizing enterprise messaging on an industrial scale. AMQP protocol has been selected the OASIS industry standards group1, with the intention of moving to becoming an ISO/IEC standard. AMQP protocol is almost a complete superset, lacking only explicit protocol support for Last-Value-Queues and will messages. However, its deliberate design for extensibility, using an IANA-like approach with a discursive approach, ensures that such features can be added in a forward-compatible, widely agreed upon way[46].

1.7 Node red

Node-RED is an open source flow-based development tool for the integration of IoT hardware devices, APIs (Application Programming Interfaces) and online services developed by IBM Emerging Technology . Node-RED is a free JavaScript-based tool, built on Node.js platform, which provides a visual browser-based flow editor. The system contains nodes that are represented by appropriate icons. It can operate in two ways: drag, drop and wire up nodes, or import JavaScript code that can be wired together into a sequence and create flows.

NODE-RED Editor Components

- **Palette:** List of all nodes you can use to create flows. These are separated into categories to keep them organized[20].
- **Workspace:** This is where you create your workflows[20].
- **Header:** Deploy button is what you click to take your current flow configuration and send it to the node-RED run-time[20].
- **Menu:** Many useful features
- **Side-Bar:**
  - Number of Tabs with different tools.
  - Info Tab, Debug Tab (show messages passed to debug node), and Config Tab [20].

The figure 1.10 represents Node-RED Editor Components:

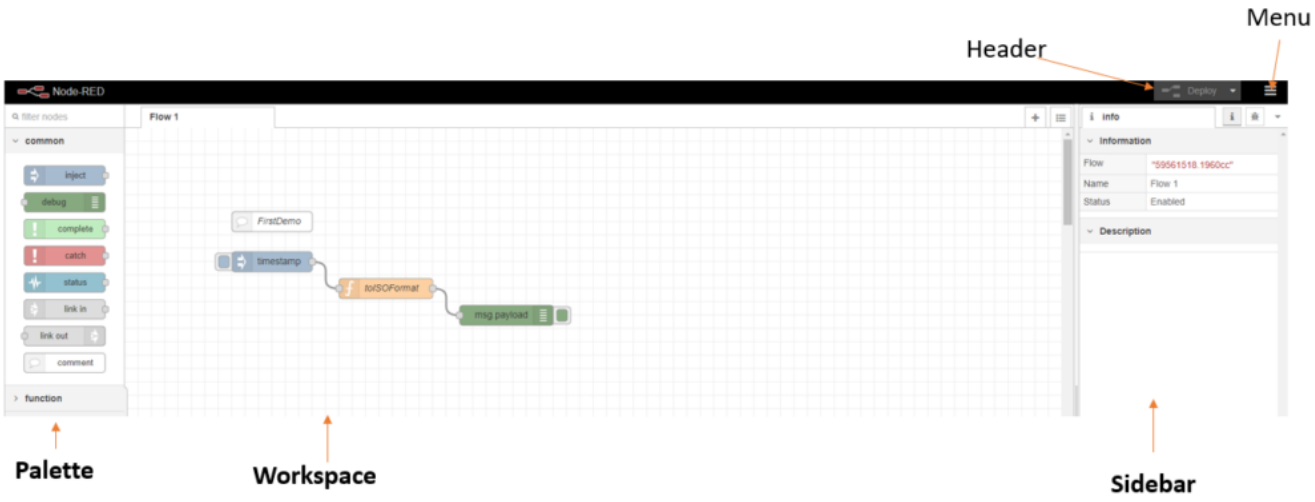


Figure 1.10: Node-RED Editor Components.
[20]

NODE-RED Benefit

- Programming with Node-RED simple. As the name no-code/low-code indicates, coding is eliminated and programming is intuitively completed with a minimal number of operations needing to be used

- The FBP typified by Node-RED can be completed with almost only GUI operations. Node-RED flow editor takes care of building the application execution environment, library synchronization, the integrated development environment (IDE), and editor preparation so that you can concentrate on development.

- In Node-RED, each common component exist as an easy-to-understand node (just a box). If you don't have a node as a common component you want to use, anyone can create one immediately and publish it to the world.

- Each node provided as a component is a complete module that has been unit tested. As a result, app authors can focus on checking the operation at the join level without worrying about the contents of node. This is a big factor that eliminates human error at the single level and ensures high quality.

- Node-RED is an open source piece of software. Therefore, it can be used flexibly under the Apache2 license.

- The library indexes all Node-RED modules published to the public npm repository, assuming they follow the proper packaging guidelines[38].

1.8 Conclusion

In this chapter, we discussed the concept of "digital twins" and explained the principles of operation, its components and types, as well as its use in health-care as our field of application is around health. The chapter presents also IoT technologies and gives a detailed description of Node-RED a tool used for wiring connected objects and IoT based services.

Chapter 2

Vital Signs in Healthcare

2.1 Introduction

Vital signs are an important aspect of healthcare, as they provide valuable information about a patient's overall health status and can help healthcare professionals diagnose and monitor medical conditions.
The purpose of this chapter is discuss various vital signs that can be effectively simulated as well as explore the concept of simulation in the healthcare field and the Internet of Things (IoT).

2.2 Healthcare

According to the World Health Organization, health is "a state of complete physical, mental and social well-being and not simply the absence of disease and infirmity".it can be promoted by encouraging healthful activities, such as regular physical exercise and adequate sleep, and by reducing or avoiding unhealthful activities or situations, such as smoking or excessive stress.
Health care or healthcare is the improvement of health via the prevention, diagnosis, treatment, amelioration or cure of disease, illness, injury, and other physical and mental impairments in people. [16] Healthcare is typically provided by a variety of professionals and organizations, including doctors, nurses, pharmacists, hospitals, clinics, and other healthcare facilities . Health care is delivered by health professionals who routinely measure vital signs as part of their initial assessment of a patient.

2.3 Vital signs

Vital signs are the physiological indicators that give the most data about a patient's health status[29].
There are five traditional vital signs, including:

- **Heart rate**: heart rate is the number of times that heart beats in a minute, which is normally between 70 and 90 times per minute for adults. the body automatically controls your heartbeat to match whatever it's doing or what's happening around it. heart rate is an important indicator of the overall health too. When the heart rate is too fast or too slow, that can be a sign of heart or other health problems.

  Measuring heart rate helps monitor the health and know if exercising at the right level to get the most benefits to your health.

  Electrocardiogram (ECG): electrodes are placed on the patient's body that are responsible for recording and amplifying the electrical impulses of the heart.[33]

These figures 2.1 2.2 represents ECG:

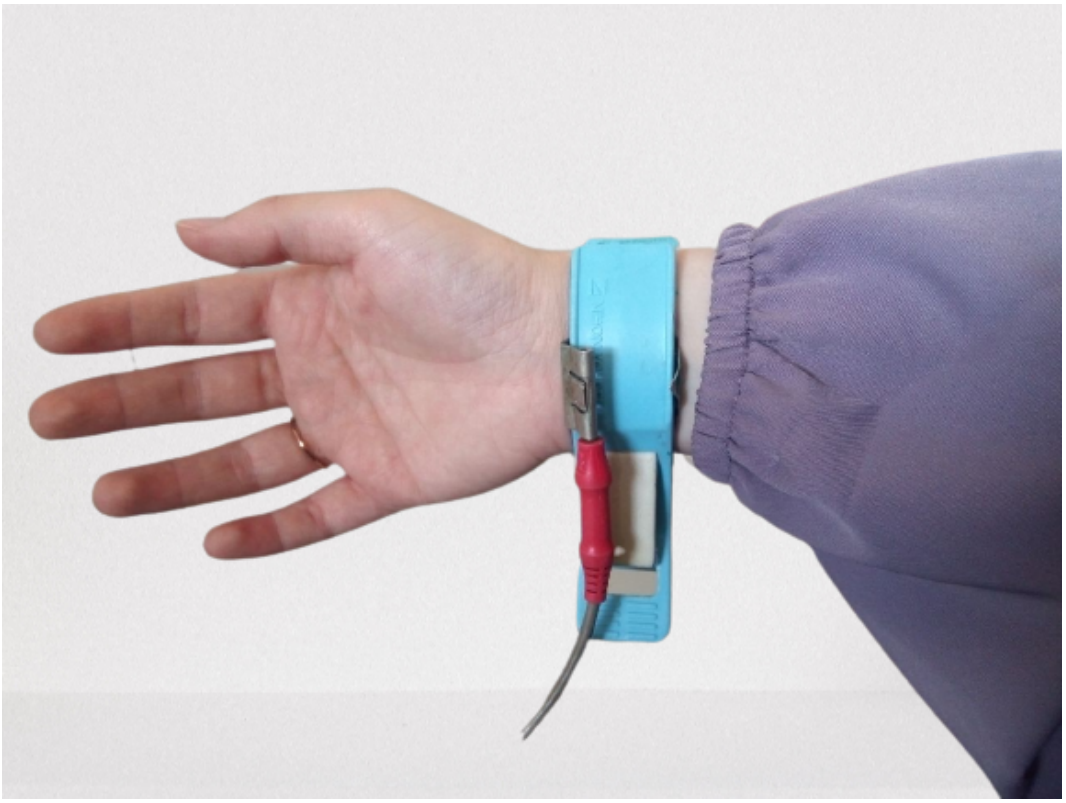


Figure 2.1: ECG

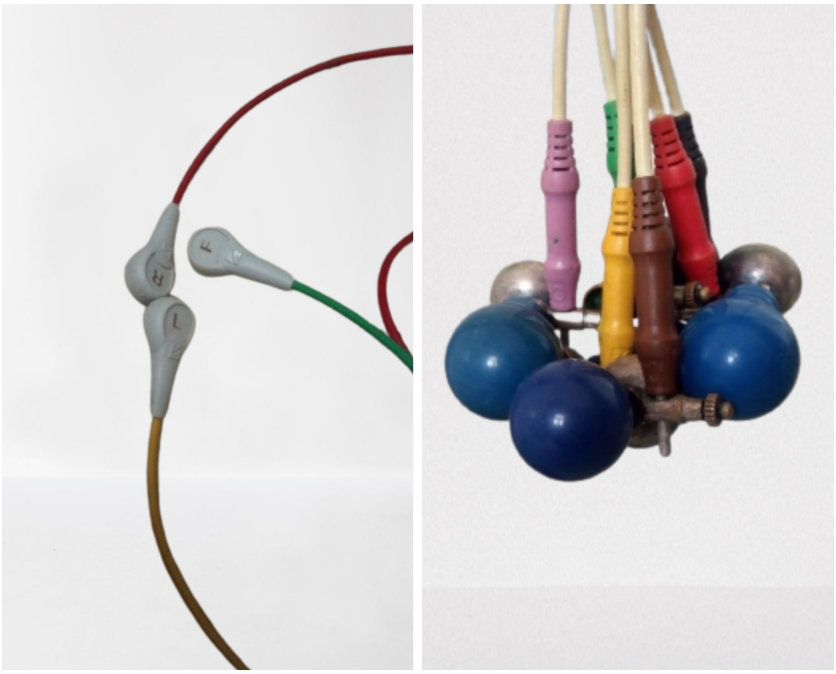


Figure 2.2: ECG electrodes

- **Respiratory rate**:A person's respiratory rate is the number of breaths you take per minute. The normal respiration rate for an adult at rest is 12 to 20 breaths per

minute[12]. A respiration rate under 12 or over 25 breaths per minute while resting is considered abnormal. Among the conditions that can change a normal respiratory rate are asthma, anxiety, pneumonia, congestive heart failure, lung disease[12], use of narcotics or drug overdose. controls the respiratory rate by measuring the thoracic impedance thanks to two of the electrodes used in the ECG

- **Oxygen saturation**:Oxygen saturation levels measure oxygen concentration in a patient's blood on a scale up to 100 (percent saturation).This is expressed in the percentage of red blood cells in the bloodstream that carries oxygen molecules. The target range should be between 95 and 100. For oxygenated blood to reach your patient's tissues, they must be breathing properly, with no airway problems. Their heart must be functioning with an effective rate and rhythm to keep the blood circulating.
  Oxygen saturation must be measured with a specialized device called a pulse oximeter.A pulse oximeter is placed on the patient's finger that emits light with two different wave densities to determine their blood oxygen level. In critical care, oxygen saturation is monitored continuously.
  That way, you'll be able to catch changes in status.
  The figure 2.3 represents Pulse Oximeter:



Figure 2.3: Pulse Oximeter

This sensor mesure heart rate and Oxygen saturation and display it on the monitoring device.

The figure 2.4 represents heart rate and Oxygen saturation sensor:

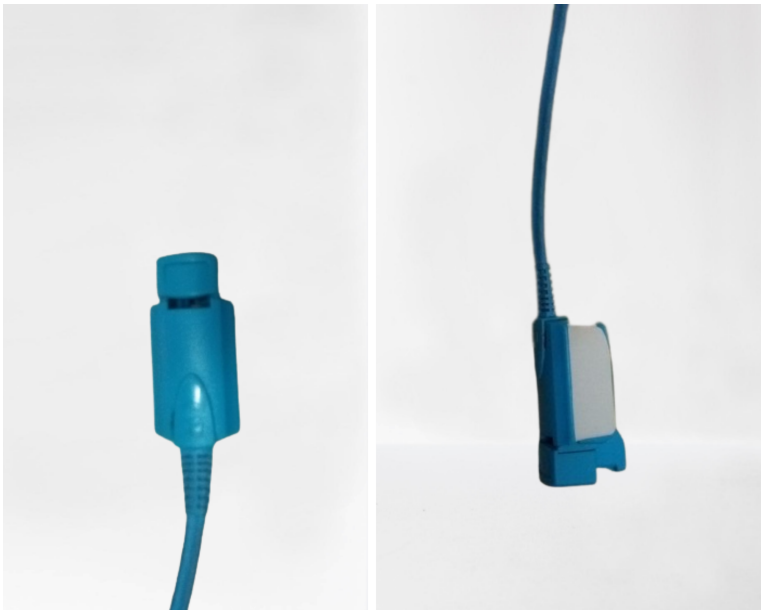


Figure 2.4: heart rate and Oxygen saturation sensor

- **Blood pressure**: when the heart beats, pressure is applied to the walls of the large vessels as blood travels through the body.Blood pressure is the amount of force that the patient's blood exerts on the walls of their arteries. When measuring a patient's blood pressure [43], it consider two different numbers: systolic and diastolic.
  - **Systolic:**indicates the patient's blood pressure at the peak of the heartbeat cycle(The top number) it is measured when the heart contracts and pumps blood through the body[43].
  - **Diastolic:**indicates the lowest level of blood pressure in the heartbeat cycle(he bottom number).it is measured when the heart relaxes, and the ventricles can refill with blood.

  Blood pressure is obtained using an electronic sphygmomanometer, whose bracelet is placed on the patient's arm.
  The average systolic pressure of an adult should measure between 100 and 130, and diastolic pressure should measure between 60 and 80.

The figure 2.5 represents blood pressure monitor:



Figure 2.5: Blood Pressure Monitor

- **Body temperature**: normal body temperature is 37 °C. On a vital signs monitor ,the patient's temperature will display under the section labeled TEMP. For example, if a patient's body temperature reads more than 38° C in the TEMP box, they have a fever. Body temperature below 36° C indicates hypothermia.

  Body temperature is measured by:

  - **Thermometer:** A thermometer is a device that measures temperature or a temperature gradient (the degree of hotness or coldness of an object). A thermometer has two important elements:
    - **Temperature sensor** (e.g. the bulb of a mercury-in-glass thermometer or the pyrometric sensor in an infrared thermometer) in which some change occurs with a change in temperature.
    - **Some means of converting** this change into a numerical value (e.g. the visible scale that is marked on a mercury-in-glass thermometer or the digital readout on an infrared model). Thermometers are widely used in technology and industry to monitor processes, in meteorology, in medicine, and in scientific research.

The figure 2.6 represents Thermometre:



Figure 2.6: Thermometre

– **Infrared (IR) temperature sensors :** enable accurate non-contact temperature measurement in medical applications. The most common applications for this type of temperature sensor is measuring ear temperature, forehead temperature, or skin temperature. The sensing element is composed of multiple thermocouples on a silicon chip to measure an object's infrared energy[13].

The figure 2.7 represents Infrared Thermometre:



Figure 2.7: Infrared Thermometer

These five indicators reflect the body's most important systems: the cardiac and respiratory systems. In other words, they give a quick snapshot of your patient's overall health. They are also extremely sensitive to physical changes. This means that if a patient starts to deteriorate, you'll see their vital signs change. If you are monitoring your patient's vital signs carefully, you'll be able to notice status changes before they affect your patient.

This is the monitoring device that display heart rate , Oxygen saturation,Blood pressure, electrical impulses of the heart,Body temperature.
The figure 2.8 represents Monitoring Device:



Figure 2.8: Monitoring Device

- **EMG:** Electromyography is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons). EMG results can reveal nerve dysfunction, muscle dysfunction or problems with nerve-to-muscle signal transmission[22].
  Motor neurons transmit electrical signals that cause muscles to contract. An EMG uses tiny devices called electrodes to translate these signals into graphs, sounds or numerical values that are then interpreted by a specialist.
  During a needle EMG, a needle electrode inserted directly into a muscle records the electrical activity in that muscle. A nerve conduction study, another part of an EMG, uses electrode stickers applied to the skin (surface electrodes) to measure the speed and strength of signals traveling between two or more points[22].

The figure 2.9 represents EMG:



Figure 2.9: EMG

- **EEG :** An electroencephalogram is a recording of brain activity.

  During this painless test, small sensors are attached to the scalp to pick up the electrical signals produced by the brain.

  These signals are recorded by a machine and are looked at by a doctor.

  An EEG can be used to help diagnose and monitor a number of conditions affecting the brain[36].
  The figure 2.10 represents EEG:

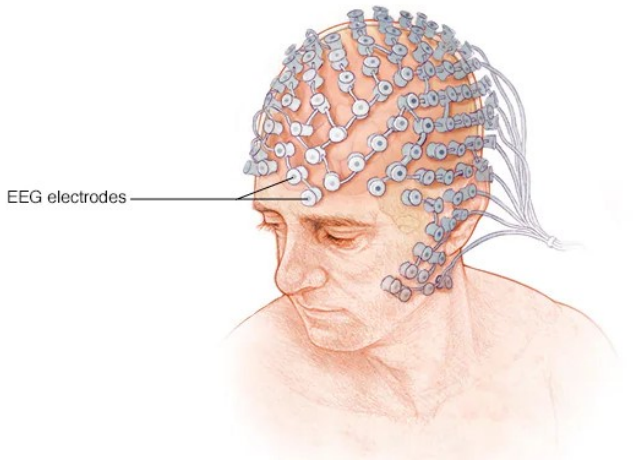


Figure 2.10: EEG

- **Weight:** Weight determines how heavy an object or quantity of a substance is.

  Rapid weight gain or swelling in particular areas of the body can be due to fluid retention and may be a sign of heart failure.

  If blood is flowing slowly to and from the heart, it affects the function of other major organs in the body. As a result, fluid collects in the tissues, which causes weight gain and swelling.

A scale or balance is a device used to measure weight or mass. The SI unit of mass (or weight) is the kilogram (kg).

- **Blood sugar :** Blood sugar, or glucose, is the primary type of sugar in the body expressed as milligrams per deciliter (mg/dl).it is one of the most important blood parameters to measure, as abnormal levels can cause severe complications.
  A blood sugar level outside the target range can have profound health implications.
    * **Low blood sugar(hypoglycemia):** can cause confusion, anxiety, weakness, sweating and vision problems. Extremely low levels of blood sugar can result in seizures and fainting.
    * **High blood sugar(hyperglycemia):** Normally, your pancreas releases insulin when your blood sugar, or blood glucose, gets high – after a meal.But if you have diabetes, your body doesn't make insulin (type 1 diabetes) or doesn't respond to it normally (type 2 diabetes). That can leave your blood sugar too high for too long. Over time, this can damage nerves and blood vessels and lead to heart disease and other problem

Blood sugar is often tested with a glucometer, which measures the amount of glucose in a sample of blood. A small drop of blood from the fingertip or arm is placed on a test strip and inserted into the glucometer. The results display on the glucometer's LCD screen within a few seconds.

Another way to test blood sugar is via continuous glucose monitoring (CGM), which typically involves placing a disposable, water-resistant sensor on the back of the arm or stomach. These sensors can be scanned with a reader, and can be used for three to 14 days, depending on the brand. Many CGM sensors are used along with a smartphone, allowing the individual and others (such as caregivers) the ability to see glucose trends over the last eight hours.
The figure 2.11 represents Glucometer:



Figure 2.11: Glucometer

2.4 Simulation of vital signs

2.4.1 Simulation

Simulation is the imitation of the operation of a real-world process or system over time [1], providing evidence for decision-making by being able to test different scenarios or process changes. This can be coupled with virtual reality technologies for a more immersive experience. it can be used to tune up performance, optimise a process, improve safety, testing theories, training staff and even for entertainment in video games! Scientifically modelling systems allows a user to gain an insight into the effects of different conditions and courses of action.

Key to any simulation is the information that is used to build the simulation model and protocols for the verification and validation of models are still being researched and refined, particularly with regard to computer simulation[47].

2.4.2 The Fundamentals of Simulation

Simulation works through the use of intuitive simulation software to create a visual mock-up of a process. This visual simulation should include details of timings, rules, resources and constraints, to accurately reflect the real-world process[47].

2.4.3 Simulation in healthcare field

Simulation as an imitation of a situation or process has a long history within fields such as aviation and construction. Since the turn of the century, simulation has been adopted in healthcare as 'a technique that creates a situation or environment to allow persons to experience a representation of a real event for the purpose of practice, learning, evaluation, testing, or to gain understanding of systems or human actions[7].

2.4.4 Benefits of Simulation Training in Medical Education

The use of simulation training in medical education is on the rise. Simulation training recreates real-world clinical environments for medical trainees across healthcare professions.

- **Simulation Training Prioritizes Patient Safety :**

  Simulation training in medical education is about patient safety. It is intended to reduce consequential medical errors when trainees eventually become practicing physicians. By replicating real-world clinical environments, simulation training offers the chance to build familiarity with the clinical setting while having the space to safely make mistakes, learn from those mistakes and try again. Additionally, this training happens under the supervision of a healthcare professional and may even be recorded. This allows the opportunity for thorough evaluation and feedback to be provided to medical trainees.

Simulation training is especially useful for novice medical trainees with limited clinical exposure. However, it is also beneficial for experienced medical professionals. As any medical situation can be replicated, more experienced trainees benefit from recreating complex, rare, and dangerous situations. No matter a trainee's level of experience, simulation training helps build clinical "muscle memory" that makes live patient interactions safer[37].

- **It Provides Customizable Learning Scenarios :**

  Because simulation learning utilizes mannequins and standardized patient training, it presents trainees with a broad spectrum of situations in which to learn. In real-world clinical settings, training is reliant on the cases patients bring to the clinic any given day. Through simulation training, program instructors can create any clinical and/or medical situation for the trainee.

  Some simulation centers may even work with trainees to determine which cases or situations they want to learn from and work with the trainee to schedule them throughout the simulation training. Also, because of simulation training's mistake-friendly nature, these scenarios can be recreated and rescheduled at will, which allows for more exposure to even the rarest of clinical situations[37].

- **It Instills Confidence :**

  Outwardly, familiarity with the clinical setting and the development of a clinical muscle memory translates to patient safety. As a trainee, this translates to confidence. Between a mistake-friendly environment and the ability to recreate any learning situation at will, repetition helps trainees develop their clinical decision-making skills. Confidence will make trainees more autonomous during their residency years. Short-term, confidence helps patients feel more secure and trusting of the clinic.

  The confidence gained from simulation training is not limited to determining a diagnosis. It can also include gaining confidence with patient interactions or approaching high-stress situations[37].

- **It Helps Apply Academic Knowledge :**

  Before stepping foot in a clinic, students will spend multiple years in classroom environments building a basic science foundation. Shadowing (for pre-med students) and clinical observerships can be a good means of seeing classroom knowledge in action. However, simulation training's more involved nature helps students apply that classroom knowledge sooner and more often.

  Again, the ability to make mistakes becomes an asset of simulation training. With the freedom to mess up, trainees are able to apply their knowledge sooner. Rather than diving into the high-stakes situation of a real-world patient interaction where they may mimic the behavior of the attending physician, simulation training allows trainees to apply their academic knowledge and theory to these situations. This affords trainees the ability to make mistakes and learn the concepts from their education that effectively translate to certain scenarios[37].

2.5 Conclusion

Vital signs are the main indicators for supervising and controlling patients health. Health care manufacturers have developed several type of vital signs sensors and monitors to provide more accurate physiological measures concerning patients. This chapter has explored the most used vital signs monitors and sensors in health care domain, specifically in the context of IoT, and their use to collect health data. In addition, the chapter have presented vital sign simulation in healthcare and how can such simulations provides healthcare professionals with a full and immersive learning experience, helping them to build the skills and knowledge required for patient care in a variety of clinical scenarios.

Chapter 3

Conception

3.1 Introduction

In recent years, digital twin technology is becoming popular, and the healthcare sector is one of the most domain where was applied. Digital twin technology create a virtual representation of the physical patient that helps healthcare professionals to monitor and understand patient's vital signs from different perspectives.
This Chapter introduce the architecture of the Proposal Simulation Model concerning the Supervision and Control of Patient's vital signs.
Furthermore , it introduce and explore the application of digital twin technology and the Artificial Intelligence services in healthcare.

3.2 Overall Architecture

The system architecture consists of several key components as physical system, the digital twin model, the AI services and the user interface. In this section, we briefly describe our proposed architecture and its main layers and components.

- The Physical System refers specifically to the hospital smart bed used for patient care,it is a specialized bed designed for use in healthcare,it is equipped with sensors, such as pressure sensors, heart rate monitors, respiratory sensors, and temperature sensors, that capture real-time data related to the patient's vital signs,These sensors continuously collect data from the patient.

- The junction layer it ensures seamless communication and data exchange between the physical system and the digital twin. The junction layer collects data from the sensors embedded in the physical system and facilitates its transmission to the digital twin for analysis.

- Digital twin serves as a virtual version of the physical system,it captures and mirrors the characteristics of the physical system. The digital twin receives the real-time data from the physical sensors, processes and analyzes it using advanced algorithms and AI techniques, and generates meaningful insights about the patient's vital signs.

- AI plays a pivotal role in the system architecture, it encompasses various AI techniques, including machine learning algorithms, which are applied to the collected data to predict patient outcomes, provide decision support, and offer personalized recommendations for patient care.

- User Interface provides an interactive platform for healthcare professionals to interact with the system, it presents the collected data, analysis results, and AI-driven insights, it allows medical staff to monitor vital signs, and obtain essential patient information. It ensures a convivial and intuitive user experience to control and supervision of patient vital signs.

The figure 3.1 depicts the proposed architecture and the interactions between its main components and actors.

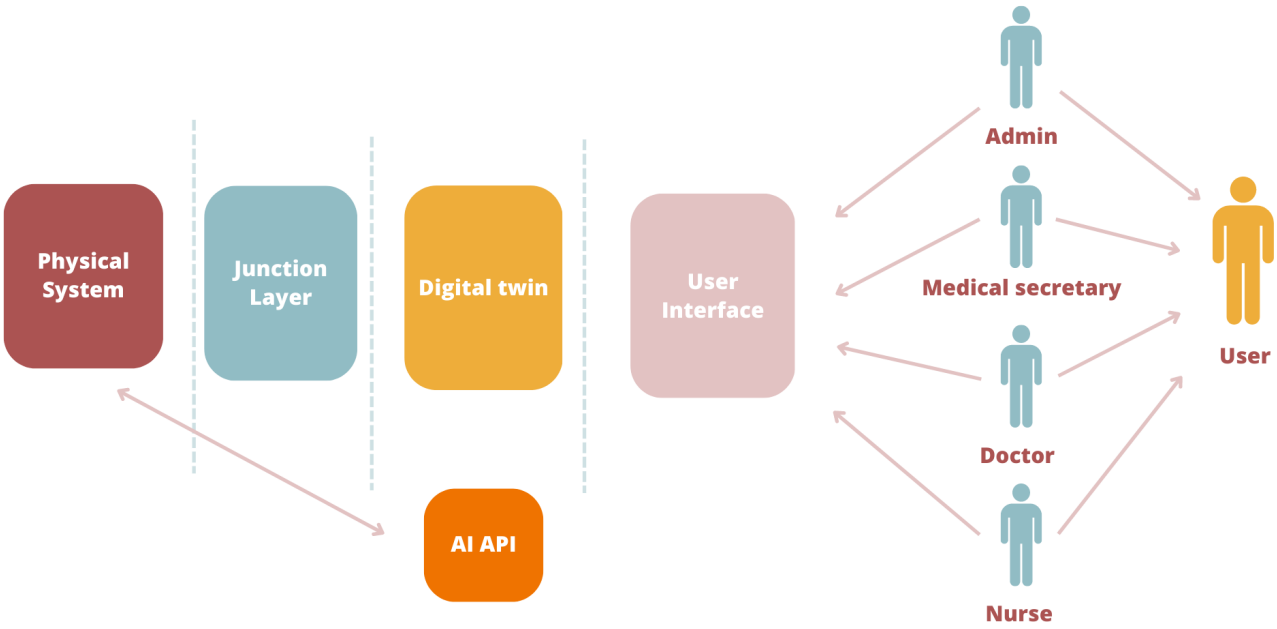


Figure 3.1: Overall Architecture

To illustrate the interactions between the system and its users and the external entities, we create a visual representation that capture multiple actors who play different roles in the system for visualizing the operation of the supervision, control, and simulation of patient's vital signs.
Here are the main actors in the system and their responsibilities:

- Administrator: The administrator is responsible for managing the digital twin beds, including their creation and update.
- Medical Secretary: The medical secretary handles patient management tasks, including the creation, assignment, and release of patients.
- Doctor: The doctor performs diagnostic activities, supervises patient conditions, and provides medical control.
- Nurse: The nurse is responsible for monitoring the patient's health progress and overseeing the physical aspects of the beds.

In the figure 3.2 a use case diagram representing the different actors and their functionalities and interaction with the proposed solution in order to allow patient control and supervision.

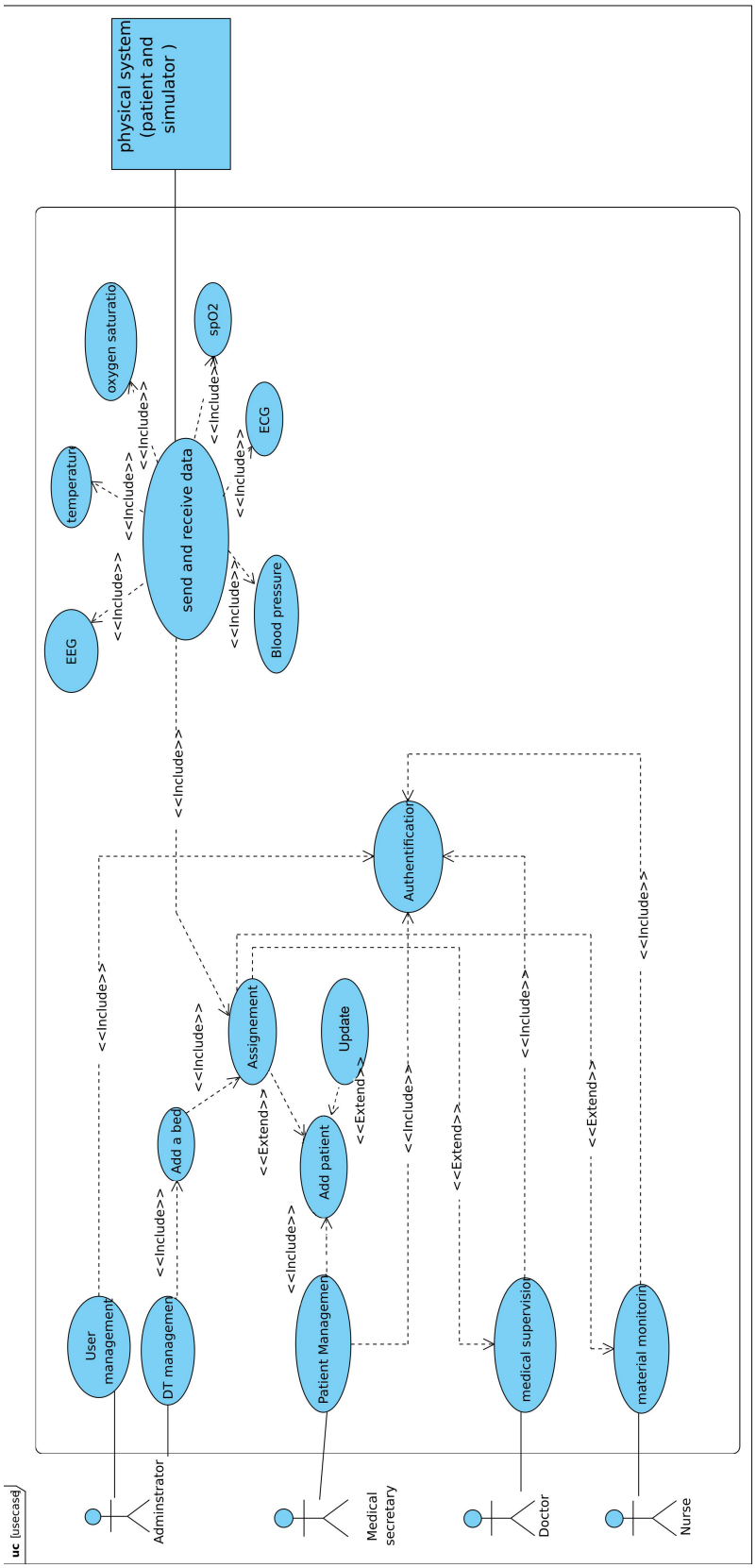


Figure 3.2: Use case diagram

- **DT Managment :** The administrator accesses the Twins Platform digital system and gains control over the inventory of beds and ensures their availability and proper

allocation. They can create new beds to expand the capacity or delete existing beds that are no longer needed. This use case is essential for maintaining an organized and efficient system for bed management within the hospital.

- **Patient Managment :** In this use case, the Medical Secretary takes on the responsibility of patient management and the assignment to specific smart beds, considering factors such as patient condition, bed availability, and specific requirements.
  The Medical Secretary ensures efficient coordination and proper allocation of patients to suitable beds,contributing to effective patient management.

- **Medical Supervision :** It is important for the hospital bed to be functional and equipped with sensors positioned correctly on the patient to ensure accurate data collection.
  IN this use case the doctor is responsible for ensuring that the bed is set up properly, the sensors are functioning correctly, and the collected data is transmitted to the digital twin system for further analysis and monitoring.
  By closely monitoring patient data collected from the sensors, doctors can gain valuable insights into the patient's condition, track their progress, and make informed medical decisions.

- **Material Monitoring :** In this use case the nurse address any hardware or software issues related to the bed.if there is a physical component failure, or if there are software discrepancies like incorrect values. The nurse's actions directly impact the state of the patient occupying the bed, as any technical problems with the bed can affect the quality of care and patient comfort.

3.3 Physical system

The physical system in the context of this study refers to the hospital beds and the patients themselves. The hospital beds serve as the primary interface between the patients and the digital twin model. These beds are equipped with various sensors, including pressure sensors, heart rate monitors, respiratory sensors, and temperature sensors.
These sensors are responsible for collecting vital signs and other relevant data from the patients. The data collected includes information about the overall health condition. This real-time data is crucial for monitoring the patient's well-being and providing appropriate care.
The physical system, comprising the beds and the patients, is interconnected with the digital twin model through the junction layer. This layer ensures seamless connectivity and data exchange between the physical system and the digital twin. It gathers data from the sensors embedded in the beds and sends it to the digital twin model for analysis and monitoring.

Additionally, in the absence of physical beds and real patients, the framework incorporates the simulation of vital signs to emulate the physical system. By simulating vital signs, such as heart rate, blood pressure, respiratory rate, and temperature, the

digital twin model can provide realistic and dynamic data for analysis and monitoring. This simulation aspect enhances the accuracy and functionality of the platform, enabling healthcare professionals to assess patient health states and make informed decisions based on the simulated data.

3.4 Digital Twin

Designing the digital twin of a smart hospital bed involves creating a virtual representation of the bed and its associated components, sensors, actuators, and interfaces.
This virtual representation is created using technologies , it provides the framework to the model and manage the digital twin.
The central entity for representing the digital twin is called a **"Thing"**.
Things are very generic entities and are mostly used as a "handle" for multiple features belonging to this Thing. [42]
Features are used to manage all data and functionality of a Thing that can be clustered in an outlined technical context.
For different contexts or aspects of a Thing different Features can be used which are all belonging to the same Thing [23].

The figure 3.3 represents a class diagram that shows the structure of a Thing :

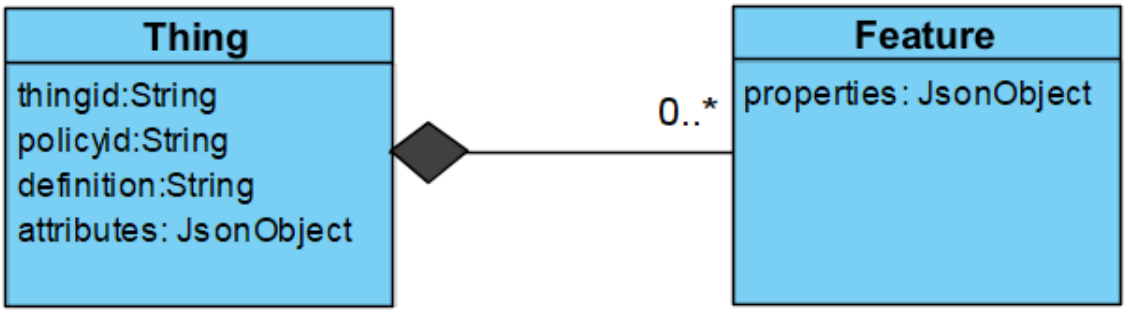


Figure 3.3: Class diagram of Ditto

Things are identified by :

- **ThingId :** Unique identifier representing the thing [42].
- **PolicyId :** Links to the ID of an existing Policy which contains the authorization information applied for this thing[42].
- **Definition :** a Thing may contain a definition. The definition can also be used to find Things. The definition is used to link a thing to a corresponding model defining the capabilities/features of it[42].
- **Attributes :** describe the Thing in more detail and can be of any type. Attributes can also be used to find Things. Attributes are typically used to model rather static properties at the Thing level. Static means that the values do not change as frequently as property values of Features[42].

Features are defined by :

- **Feature ID :** Within a Thing each Feature is identified by a unique string - the so-called Feature ID. A Feature ID often needs to be set in the path of an HTTP request. Due to this fact we strongly recommend using a restricted set of characters [23]. The Feature ID may not be the wildcard operator * because it has a special meaning and can lead to unexpected results when retrieving or searching for things/features[23].
- **Feature properties :** The data related to Features is managed in form of a list of properties. These properties can be categorized [23].
  Feature properties are represented as one JSON object. Each property itself can be either a simple/scalar value or a complex object [23] .

This diagram visually represents the relationships and interactions between these components, providing an overview of the key elements involved in the functionality of a smart bed.
The figure 3.4 represents the block model of the smart bed:

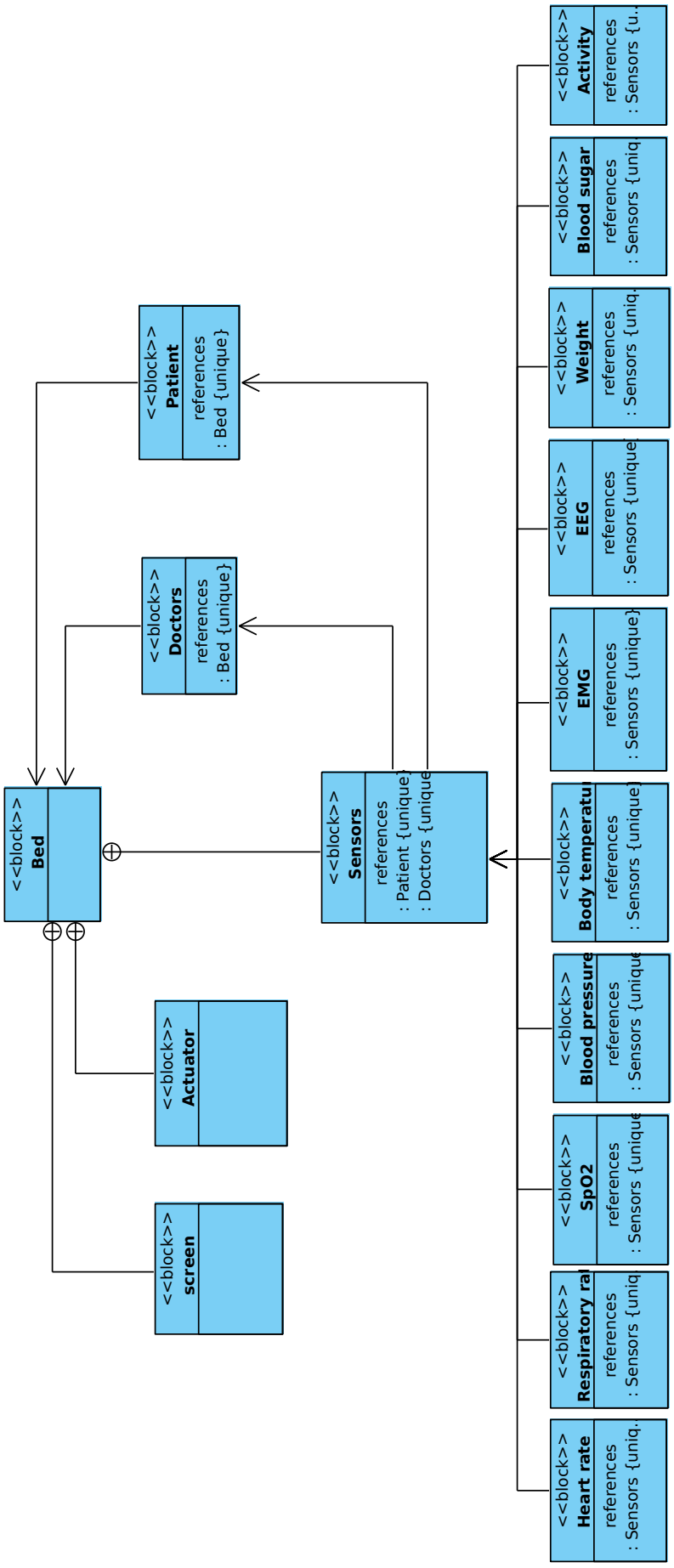


Figure 3.4: Block diagram

The main block is ”bed”, each block in the diagram represents an element of the smart bed.
It consists of:

- Sensors: this block includes various sensors embedded within the bed to capture relevant data. Examples of sensors commonly found in smart beds include pressure sensors, heart rate sensors, temperature sensors, and motion sensors to detect movement. It can be assigned to a patient,it can be needed a doctor.
- Actuators: this block represents the actuators responsible for physical adjustments and actions in the bed. It may include motorized systems to control bed positioning, adjustable firmness or height, or other features that enhance comfort and usability.
- Screen: his block represents the interface through which users interact with the smart bed. It could include touchscreens, buttons, or mobile applications that allow users to control and customize bed settings, access vital signs data, or receive alerts and notifications.

3.5 Artificial Intelligence API

Artificial intelligence (AI) is a wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence [12].
AI planning and forecasting is a field of artificial intelligence used to make scientific predictions about the future without requiring oversight. AI planning tools use time series data to estimate future developments for many industries, such as healthcare With the advent of AI application programming interfaces (APIs) that allow other software applications to interact with and utilize the capabilities of the machine learning model.[45]

The AI can be used for providing several services in healthcare domain. These services can be delivered as API services and exploited in our proposed solution to offer prediction and analytic and therefore helping medical staff in making decisions.
The figure 3.5 depicts a sequence diagram that describes the interaction between an AI API service and the other components of the proposed solution.

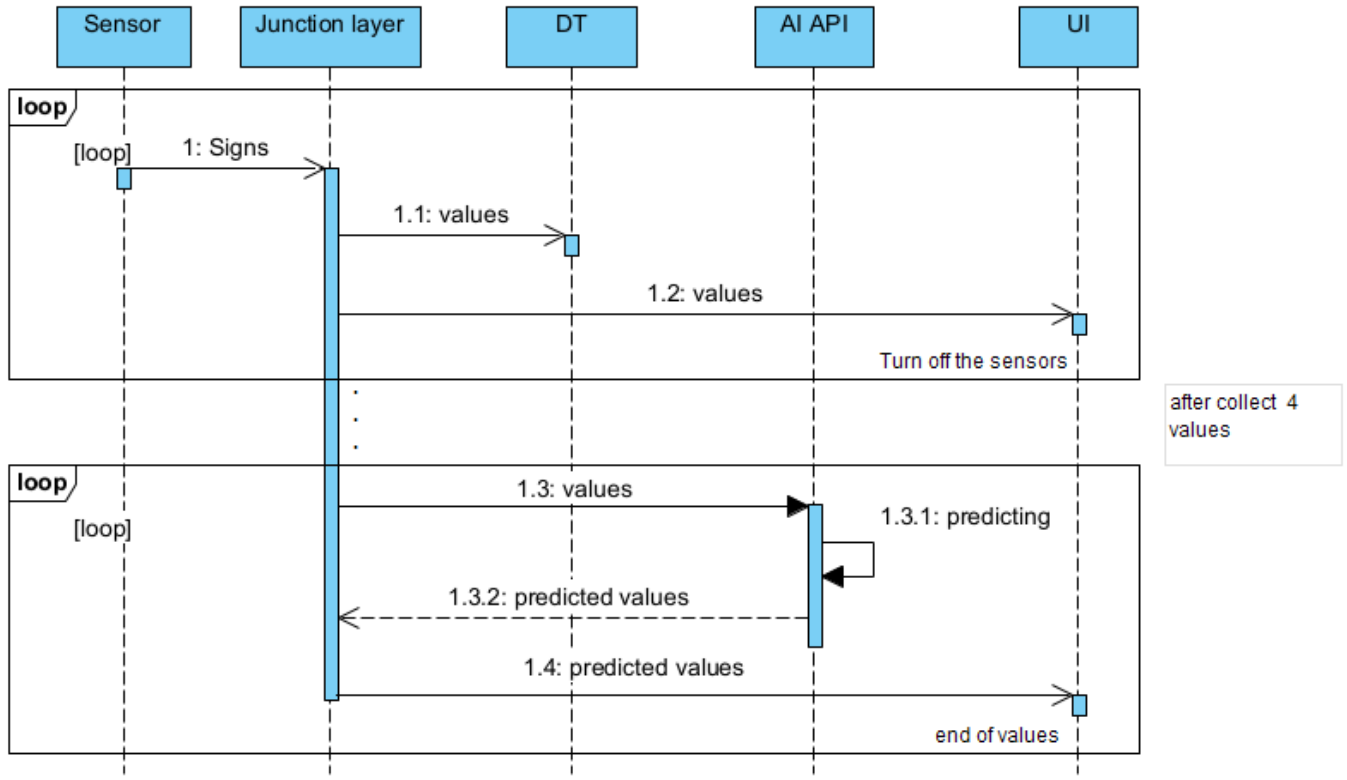


Figure 3.5: Sequence Diagram HR prediction

As prof of concept, we design an AI API for heart rate prediction. Predicting heart rate using artificial intelligence (AI) techniques is a powerful approach in healthcare and remote monitoring. By training AI models on time-dependent data (time series), they can learn the temporal patterns and relationships to make accurate predictions of heart rate.
Recently, deep learning models have become a promising tool for time series forecasting because of their strength in the automatic learning of temporal dependence and the automatic handling of temporal structures such as trends and seasonality as well as their ability to automatically learn arbitrary complex mappings from inputs to outputs and to support multiple inputs and outputs[5].

3.5.1 DATASET:

Traditionally most machine learning (ML) models use as input features some observations (samples/examples), but there is no time dimension in the data.
A time series dataset is a collection of observations or data points collected over time, where each data point is associated with a specific timestamp or time interval .
To train our model we used the "Heart Rate Time Series - MIT-BIH Database" [32] for training our model, this data is a publicly available dataset on Kaggle that provides a series of electrocardiogram (ECG) recordings from the MIT-BIH Arrhythmia Database.
Each series contains 1800 evenly-spaced measurements of instantaneous heart rate from a single subject. The two subjects were engaged in comparable activities for the duration of each series. The measurements (in units of beats per minute) occur at 0.5 second intervals, so that the length of each series is exactly 15 minutes. As can be easily confirmed, the means and standard deviations of the heart rate measurements are nearly identical in the two subjects ,it comes in a convenient CSV format, allowing easy access and analysis.
This dataset has been instrumental in advancing cardiovascular research and signal processing techniques. By delving into the dataset, researchers can gain valuable insights into heart rate dynamics, arrhythmia detection, and predictive modeling for cardiac events.

3.5.2 Research Applications:

The "Heart Rate Time Series - MIT-BIH Database" has found applications in numerous research studies and machine learning projects. Researchers have utilized this data-set to develop algorithms for arrhythmia detection, heart rate variability analysis, and predictive modeling for cardiac events. The availability of rich and diverse data has facilitated the development of innovative approaches to monitoring and diagnosing cardiovascular conditions.
This data-set serves as a foundation for advancing cardiovascular health monitoring, diagnosis, and treatment, ultimately leading to improved patient care and outcomes in the field of cardiology.

3.5.3 Model:

LSTM (Long Short-Term Memory) models are widely used in various fields and commonly used for time series forecasting tasks.
LSTM is a type of recurrent neural network (RNN) that is well-suited for capturing long-term dependencies and patterns in sequential data, making it suitable for forecasting tasks where the order of the data is important.
During training, the LSTM model learns to update its parameters by minimizing a defined loss function.
The backpropagation through time algorithm is used to compute gradients and adjust the weights of the network. This allows the LSTM to learn the patterns and relationships present in the training data.
In this study, we chose to utilize LSTM (Long Short-Term Memory) models for predicting the next heart rate due to their distinct advantages in handling sequential data.
LSTM models are specifically designed to capture long-term dependencies, making them suitable for modeling time series data like heart rate. Their ability to retain and selectively remember information over extended periods allows them to effectively capture the complex temporal dynamics inherent in heart rate patterns.
By leveraging LSTM models, we aim to accurately forecast the next heart rate, thereby contributing to improved healthcare monitoring and personalized interventions.

To train the LSTM model, we first divide the historical time series data into input sequences and their corresponding target values. The input sequences consist of a series of past heart rate measurements, while the target values represent the heart rate values that we aim to predict.
This division allows the model to learn the underlying patterns and relationships present in the data. During the training process, the LSTM model optimizes a suitable loss function, such as mean squared error (MSE). The loss function measures the discrepancy between the predicted values and the actual target values. By minimizing this loss, the model learns to make accurate predictions and captures the nuances of the heart rate patterns.
To optimize the model's performance and update its parameters, we utilize the Adam optimizer.
The Adam optimizer combines the advantages of both the AdaGrad and RMSProp optimization algorithms, adapting the learning rate for each parameter individually. This adaptive learning rate helps the model converge faster and achieve better results during training.

The figure 3.6 represent the summary of our LSTM neural network:

```
Model: "sequential_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 lstm_15 (LSTM)              (None, 4, 4)              96

 dropout_6 (Dropout)         (None, 4, 4)              0

 bidirectional_12 (Bidirecti  (None, 4, 8)             288
 onal)

 bidirectional_13 (Bidirecti  (None, 4, 8)             416
 onal)

 bidirectional_14 (Bidirecti  (None, 4, 8)             416
 onal)

 dropout_7 (Dropout)         (None, 4, 8)              0

 bidirectional_15 (Bidirecti  (None, 8)                416
 onal)

 dense_3 (Dense)             (None, 1)                 9

 activation_3 (Activation)   (None, 1)                 0

=================================================================
Total params: 1,641
Trainable params: 1,641
Non-trainable params: 0
```

Figure 3.6: LSTM Model summary

In addition to the loss function and optimizer, we use the R-squared metric to evaluate the performance of the LSTM model. R-squared measures the proportion of variance in the dependent variable (heart rate) that can be explained by the independent variables (historical heart rate data). A higher R-squared value indicates that the model can effectively explain a larger percentage of the heart rate variability.

The figure 3.7 represent the R-squared of our LSTM neural network:

```
6/6 [==============================] - 3s 7ms/step
R-squared: 0.9351443850566779
```

Figure 3.7: LSTM Model R-squared

The figure 3.8 represent the result of the heart rate prediction with LSTM model:



Figure 3.8: Heart Rate Prediction

After saving our feature engineering methods and our model parameters, then we build a simple API with following elements.
The key is to load the model and parameters at the API launch. Once launched and stored in memory, the API call triggers the feature engineering calculation and the "predict" method of the LSTM Model.

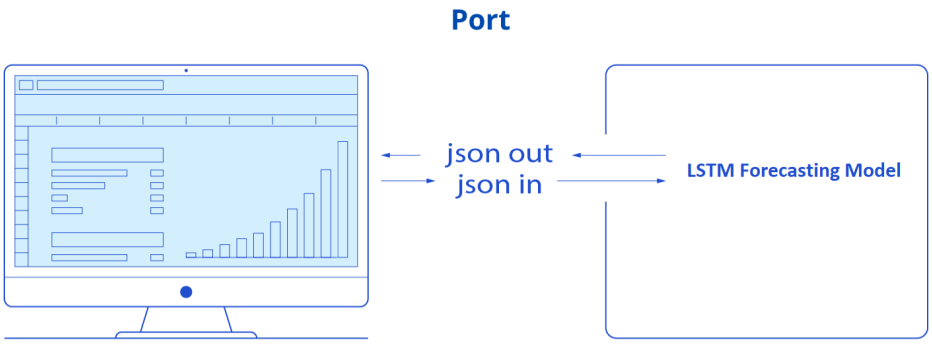


Figure 3.9: AI API

3.6 User Interface

The user interface plays a vital role in facilitating interactions between healthcare professionals and the digital twin model. It serves as the primary interface through which users, such as doctors, nurses, and system administrators, can access real-time patient data, receive alerts, and make informed decisions. The user interface in the proposed digital twin-based solution provides by create and control the objects (things) of the digital twin. The creation is done at the level of an open source platform (Eclipse ditto) implementing digital twins. The communication, sending and receiving of data from the physical system is done with the Node-RED tool.

To demonstrate the system's functions, we typically describe its expected behavior: what will occur and when.

There are four actors with different roles and responsibilities:

- The administrator, responsible for managing the digital twin beds, including their creation, deletion, and treatments.
- The doctor, responsible for diagnosing, supervising, and providing medical care.
- The nurse, responsible for monitoring patients' health status and the material supervision of beds, ensuring both material and software supervision.
- The medical secretary, responsible for managing patients, including their creation, assignment, and release, as well as updating bed status.

3.6.1 Authentication

User visit login page to log in and enters username and password into the login form then clicks on the ”Login” button.
Login Authentication System checks if the entered username and password match the stored in the database. If the entered credentials are incorrect, the username and password fields will be cleared.
If the entered credentials are correct, Login Authentication System grants access to the user,it is redirected to the main menu of the application.
User can now manage all operations related to username authorization and access other pages and functionalities within the application after successful login.
The figure 3.10 represents authentication sequence diagram:

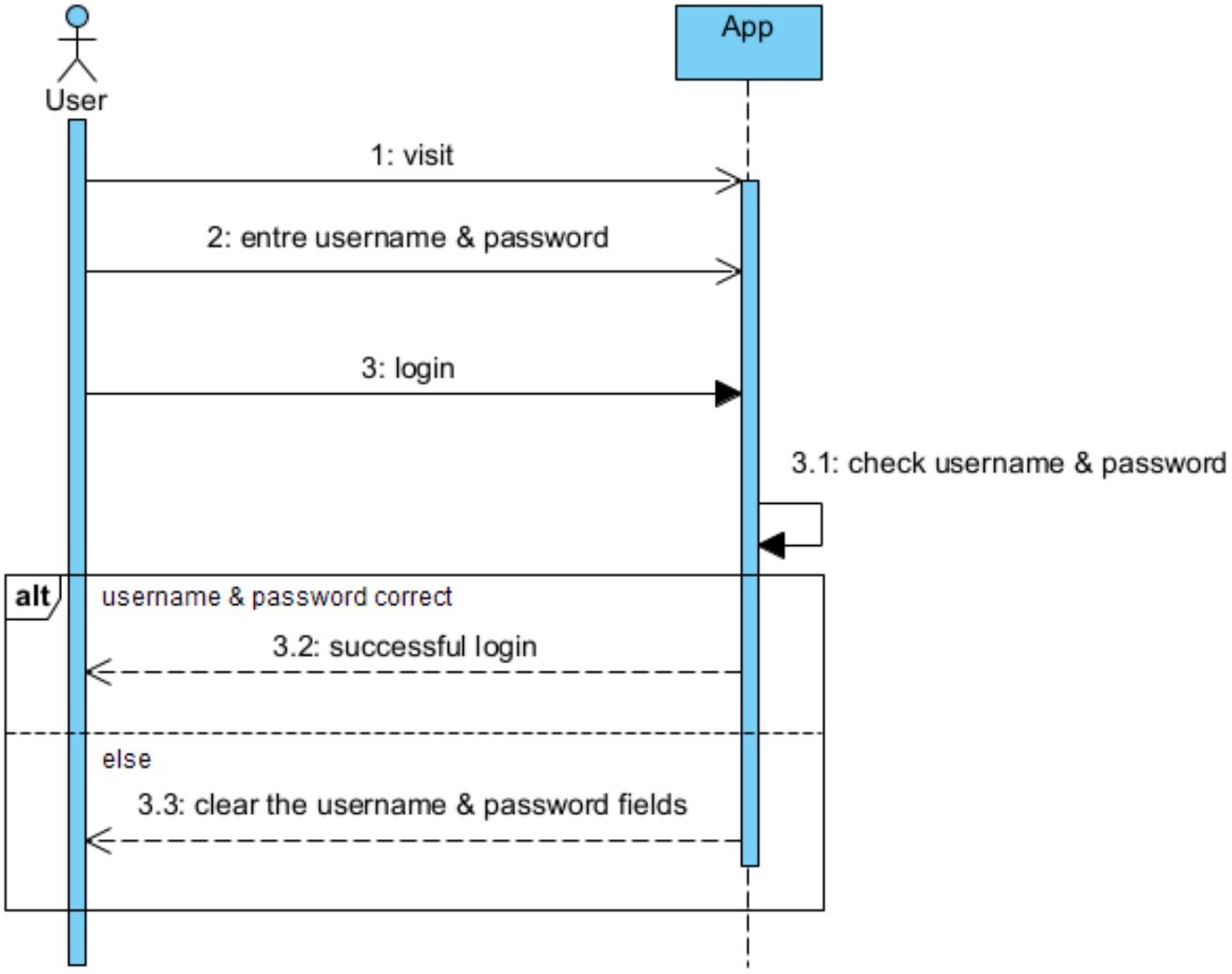


Figure 3.10: authentication sequence diagram

3.6.2 Bed creation

This sequence diagram describes the phases of the creation of beds on the digital twin platform.
First, the admin visits the app and sends a request to create the bed. This request is sent to the DT platform,and then the admin fills out the form and sends it to the DT platform. The app displays the beds information like free beds number to the admin or an error message if the bed isn't created.
The figure 3.11 represents bed creation sequence diagram:

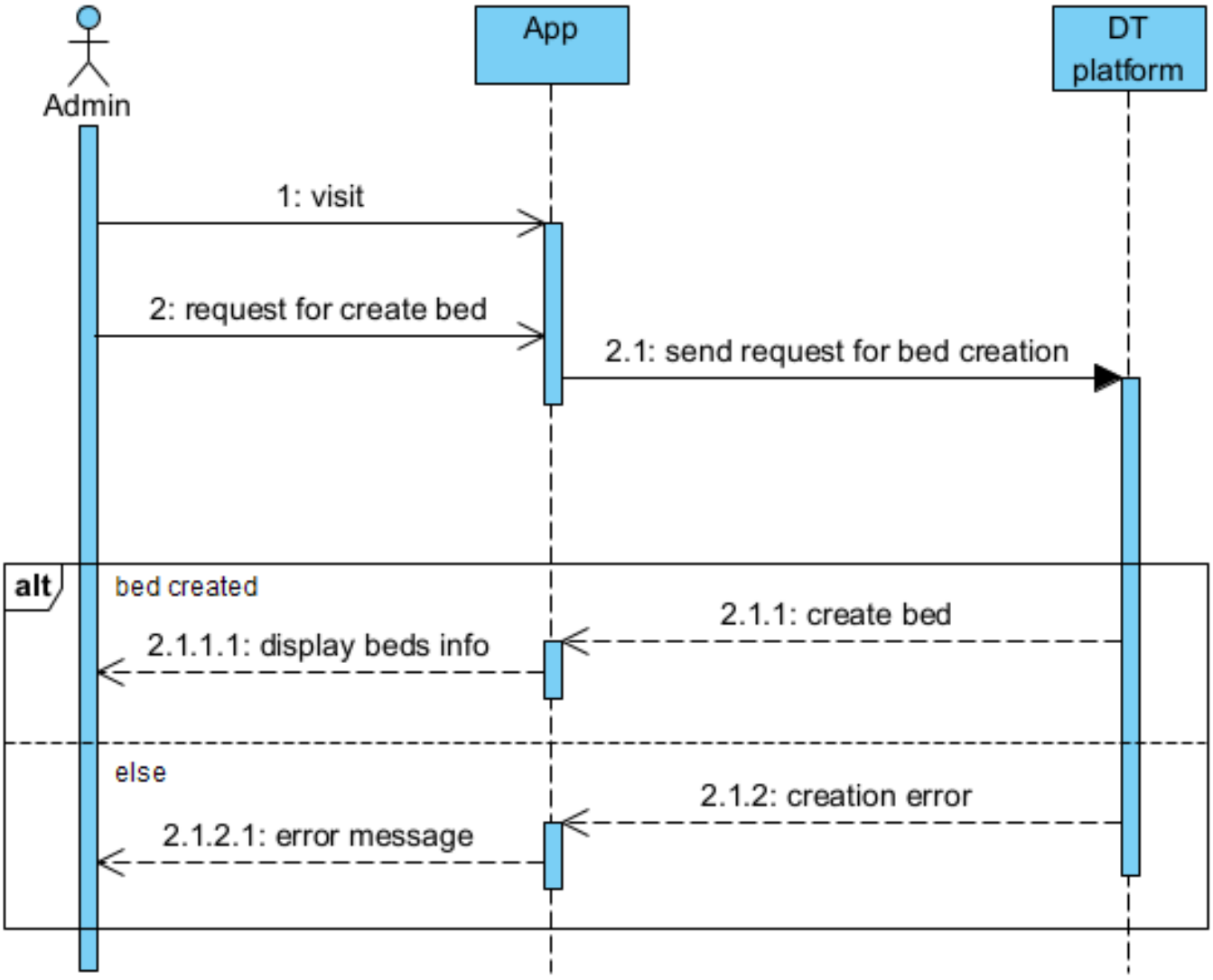


Figure 3.11: bed creation sequence diagram

3.6.3 Bed supervision

In this sequence diagram, the admin chooses a bed, and the app gets the bed information from the DT platform and displays it on the supervision page.
The figure3.12 represents bed supervision sequence diagram:

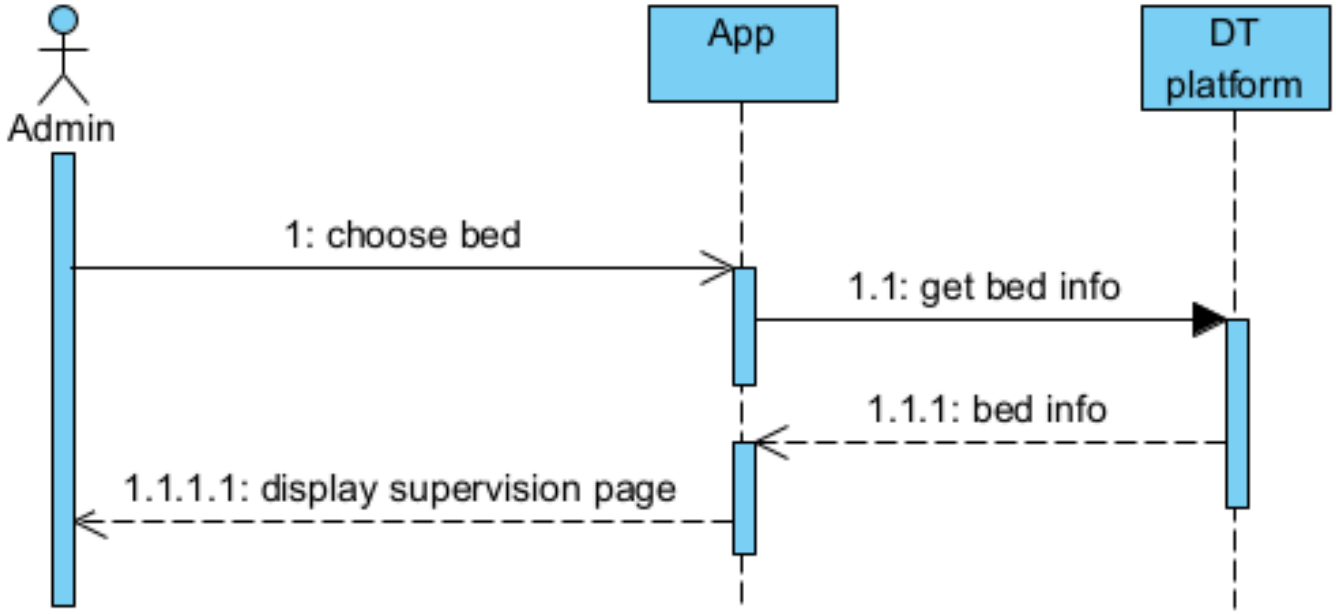


Figure 3.12: bed supervision sequence diagram

3.6.4 Patient supervision

In this sequence diagram the doctor choose a patient to see his healthcare information, the app get the patient healthcare information from the DT platform and display it in the supervision page.

The figure3.13 represents Patient supervision sequence diagram:

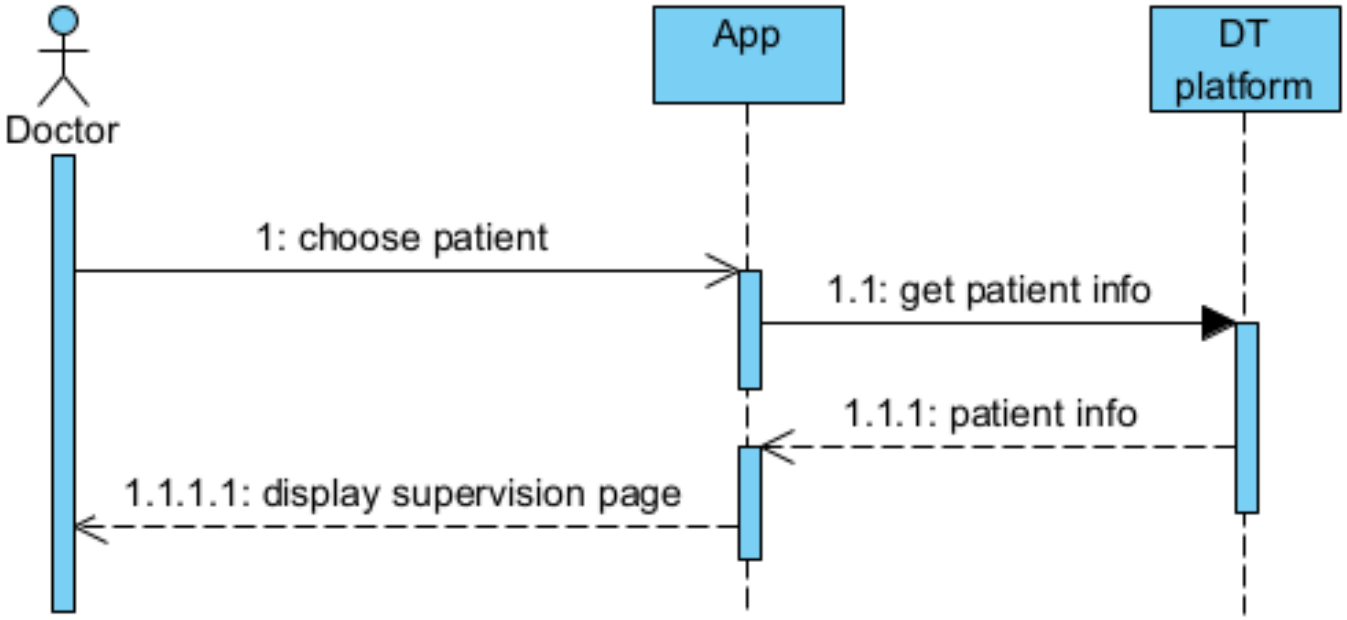


Figure 3.13: Patient supervision sequence diagram

3.7 Conclusion

This chapter describes our proposal for supervising and controlling patients and details the solution which we have proposed to achieve our objectives. By moving from the description of the overall architecture of the proposed solution to the specification of its functionalities and components, the chapter presents all the design aspects, the processes and the architectural components of the proposed solution. During the design process, we concentrated on transforming our conceptual concepts into real representations that influence the overall architecture by determining the actors, proposing the digital twin model, simulating the physical system, fascinating the junction layer, developing AI services for heath for predicting heart rate which can be generalised for other vital signs, and finally the designing of the user interface application. All this allow to offer for the medical staff mechanisms for controlling and supervising, in real time, their patients remotely and in a simpler manner, therefore improving the offered care services. In the next chapter, we will focus on creating our designed application by translating the abstract representations into functional software. This phase entails writing code, integrating various modules and components, and testing the program to ensure that it functions properly.

Chapter 4

Implementation

4.1 Introduction

The objective of this chapter is to put into action the methodology outlined in the preceding chapter.
To accomplish this, we have created a web application that facilitates the execution of all the steps involved in our design process.
Our web application serves as a comprehensive tool for the supervision and control of intelligent beds via their digital twins, as well as the capability to simulate the vital signs of patients.
Additionally, within this chapter, we provide an in-depth account of the technological resources utilized during the construction of our platform.

4.2 Implementation

In the implementation section, we provided a detailed explanation of the various components comprising our implementation environment. We also discussed the tools and technologies employed for creating digital twins and establishing communication with the smart hospital beds.

4.2.1 Digital Twin Platform

We used the Eclipse Ditto platform[21] in our project, which is a technology in the IoT implementing a software pattern called “digital twins”.[21]
This platform serves as a comprehensive toolset for creating software and facilitating the production of various applications.By leveraging Eclipse Ditto, we were able to harness its capabilities in constructing and deploying our software solution.

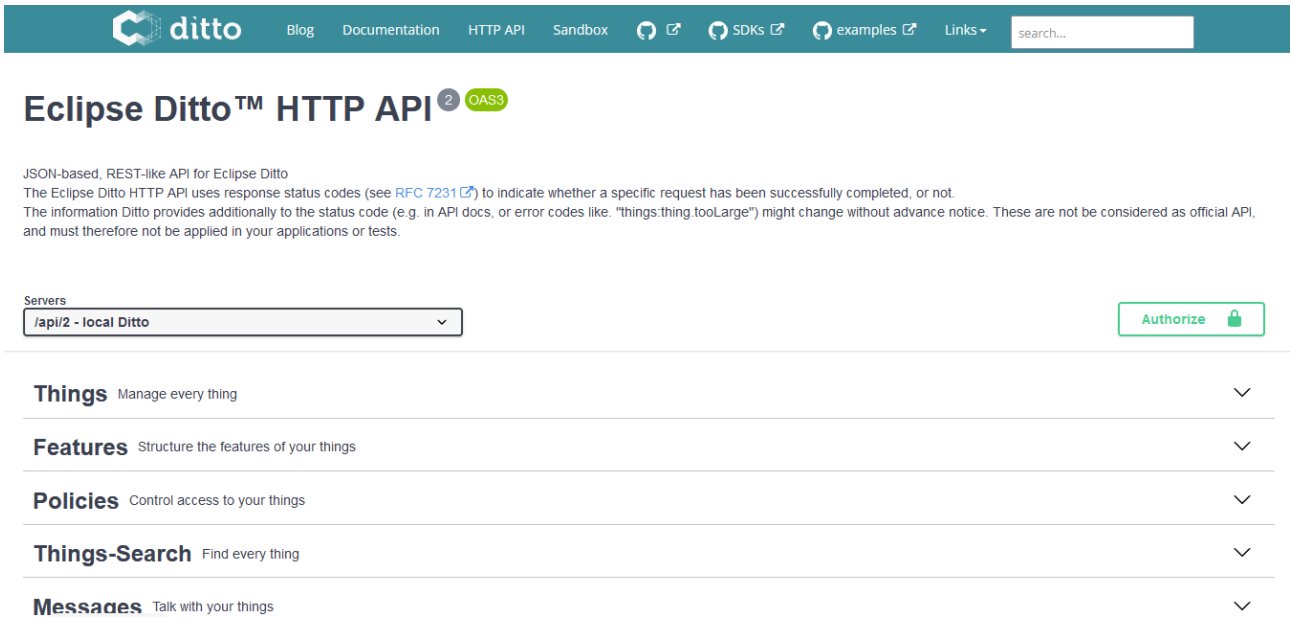


Figure 4.1: Eclipse Ditto API
[26]

4.2.2 Node Red

Node-RED is a programming tool for wiring together hardware devices, APIs and online services. Primarily, it is a visual tool designed for the Internet of Things, but it can also be used for other applications to very quickly assemble flows of various services.[41] To establish connectivity between the sensors, actuators, and the physical system, we employed the Node-RED tool. This powerful tool enabled us to seamlessly integrate and link the different components of the system, enabling the retrieval of captured data from sensors and transferring it to the digital twin for further analysis and communication.
Node-RED played a crucial role in facilitating the seamless flow of information between the physical system and its digital representation.
The figure 4.2 represent vital signs simulation and the connection with the bed digital twin :

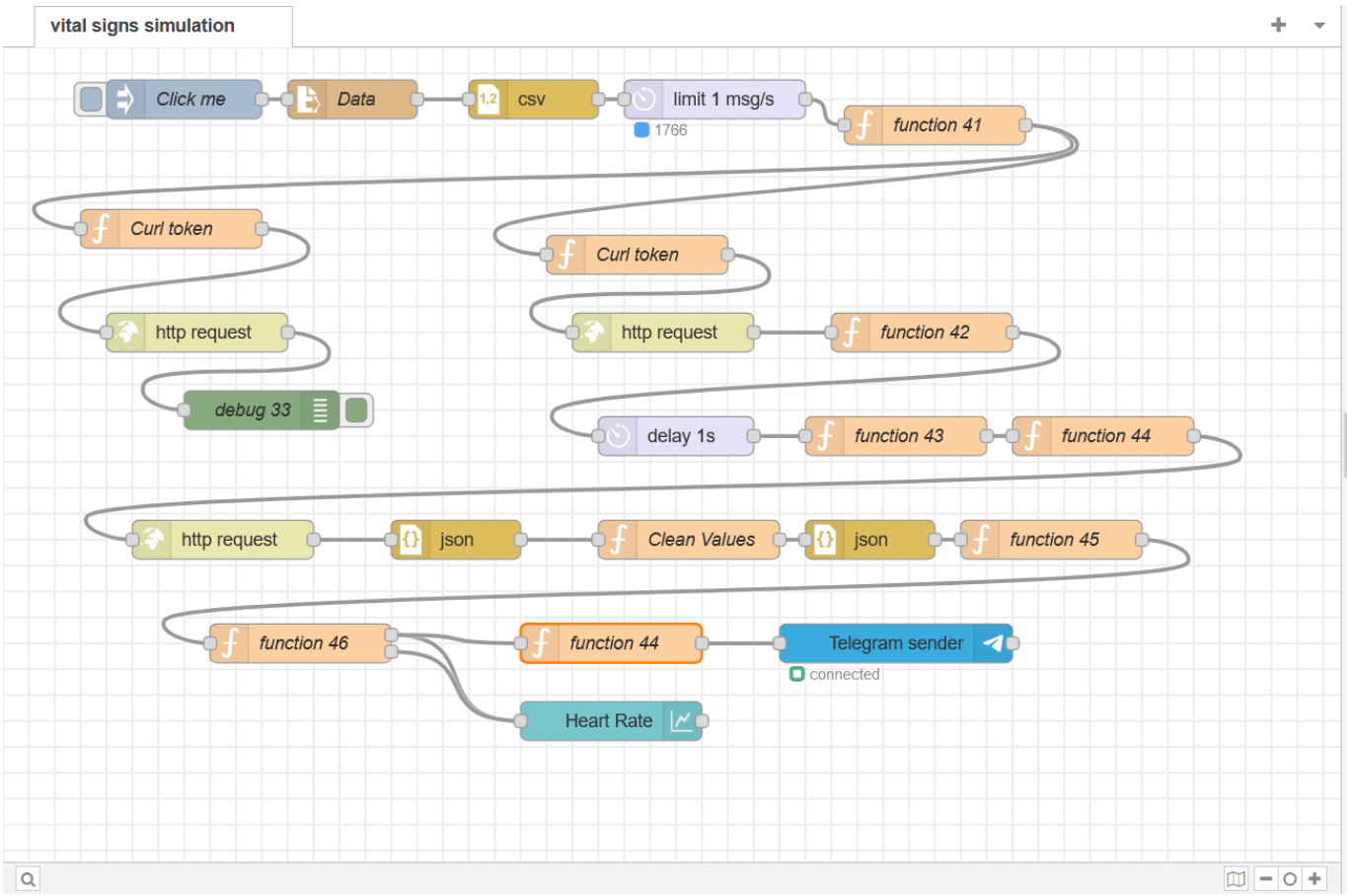


Figure 4.2: Vital Signs Simulation

4.3 Flask API

flask is a widely used micro web framework for creating APIs in Python. It is a simple yet powerful web framework that is designed to get started quickly and easily, with the ability to scale up to complex applications.[18] Deployment of an API refers to the process of making your API accessible and available for use by clients. It involves setting up the necessary infrastructure, configuring the server environment, and ensuring that the API can handle incoming requests efficiently and securely.
Thoroughly we test our Flask API using Node-red tools to Verify that the API endpoints are functioning correctly, and the model is providing accurate and expected results.
The figure 4.3 represent the CURL and the API Deployment to test of Flask API :

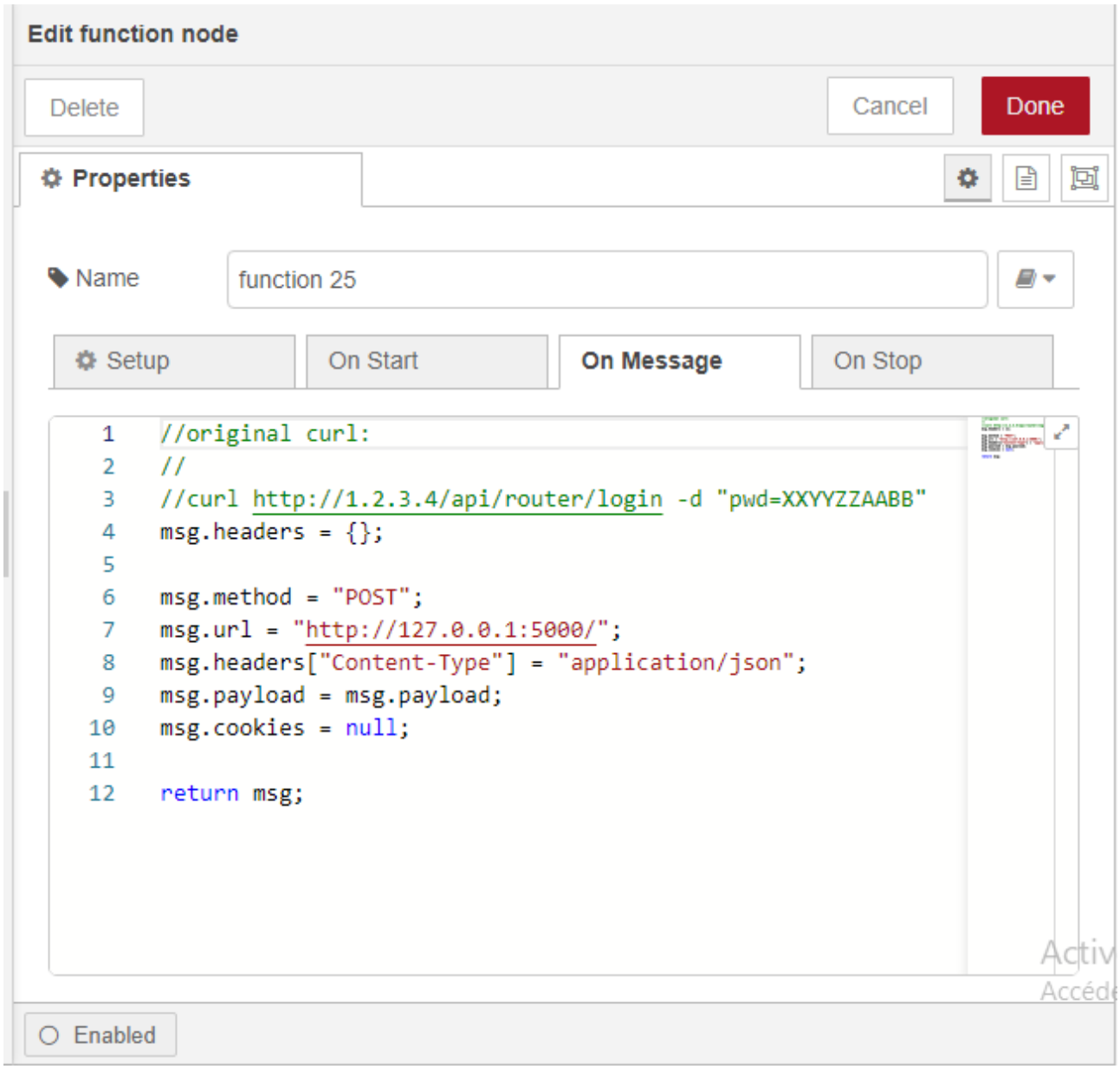


Figure 4.3: Test CURL

The figure 4.4 represent heart-rate simulation and the prediction heart-rate simulation:

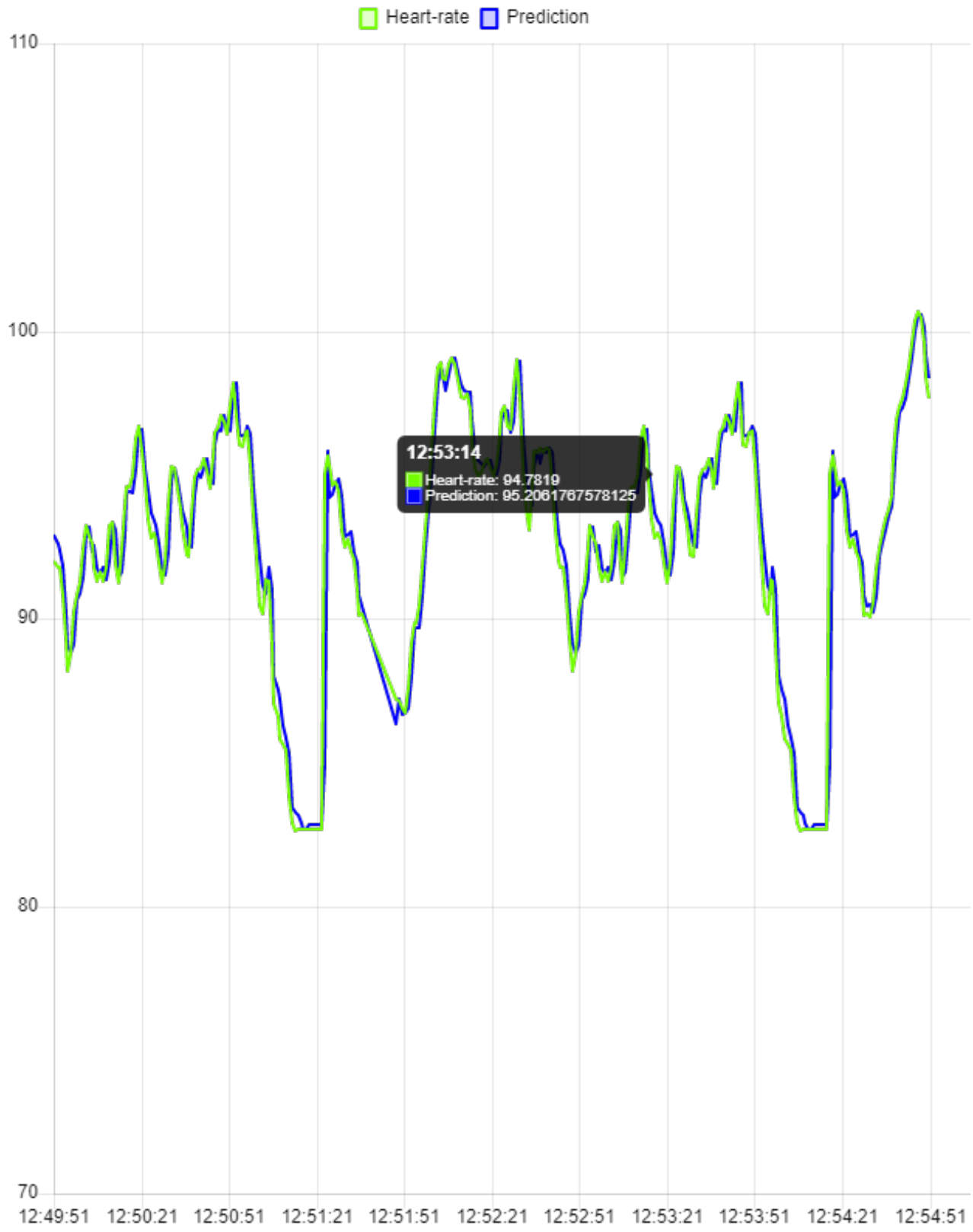


Figure 4.4: Heart-rate prediction

When the system detect a heart rate value not within the normal range ; it alerts the doctor by sending a msg within the telegram application .

4.4 Web Application

To create our application, we used several languages and development tools such as the following: HTML to represent web pages, CSS for styling and JavaScript and PHP to produce dynamic pages and send/receive HTTP requests in JSON format.

4.4.1 First Interface

This first interface is the primary entry point for users to access and interact with the system its allows users either (Admin, Doctor, Nurse, Medical Secretary) to go to the login page.
The figure 4.5 the represents First Interface:

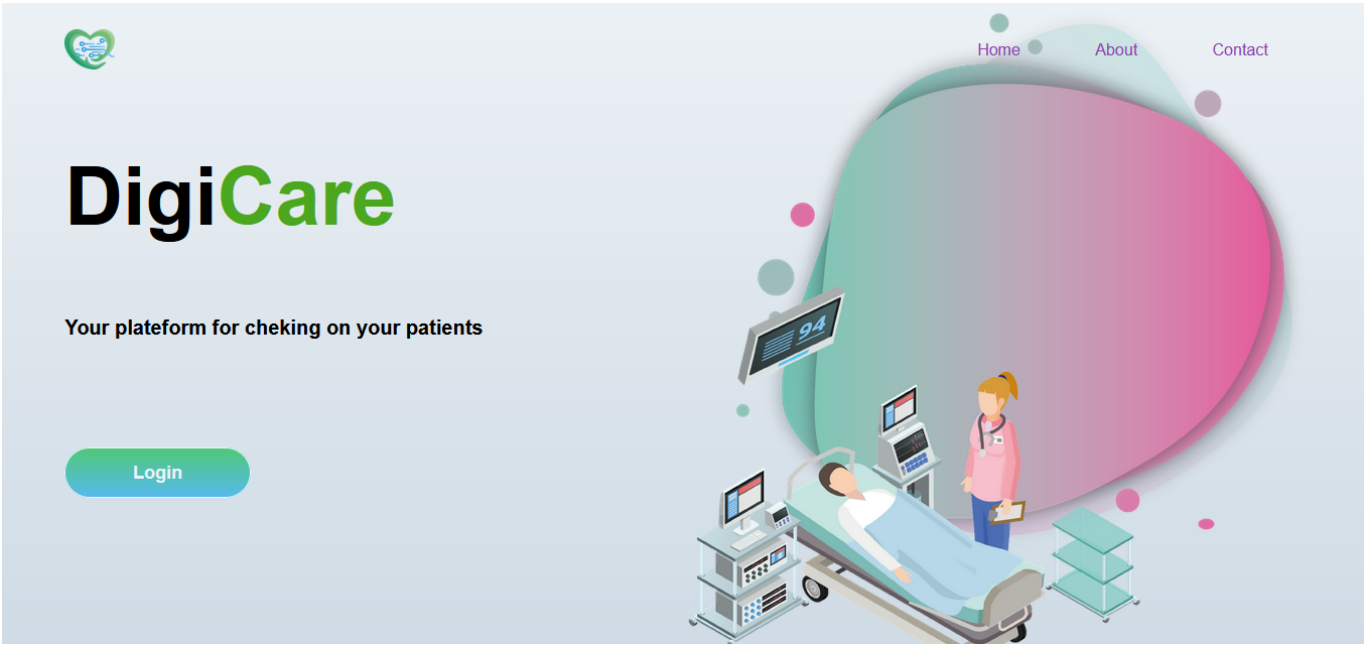


Figure 4.5: First Interface

4.4.2 Authentication Interface

The authentication interface of our web application serves as the initial point of interaction for users to access the system by username and password.
The figure 4.6 represents Authentication Interface:

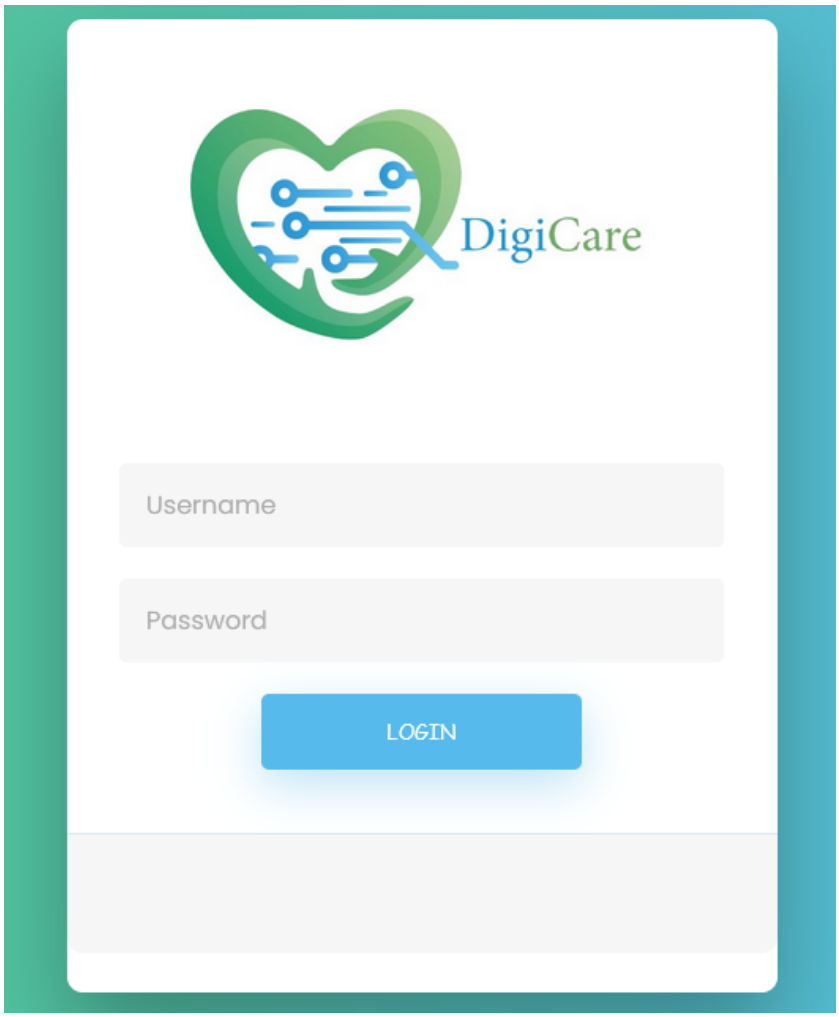


Figure 4.6: Authentication Interface

4.4.3 The Administrator Dashboard

The admin dashboard is a key component of our web application providing administrators with a comprehensive overview and control over the system's administrative functions and settings. The admin dashboard provides access to administrative tasks such as user management,where admin can create user accounts for healthcare professionals (Doctor, Nurse, Medical Secretary) In addition to user management, the admin dashboard may offer functionality for managing beds (create beds) Admin may also have the ability to manage medical equipment,add sensors. The Admin dash provides statistics on number of beds (free and occupied) and the number of patients.
The figure 4.7 represents Administrator Dashboard:

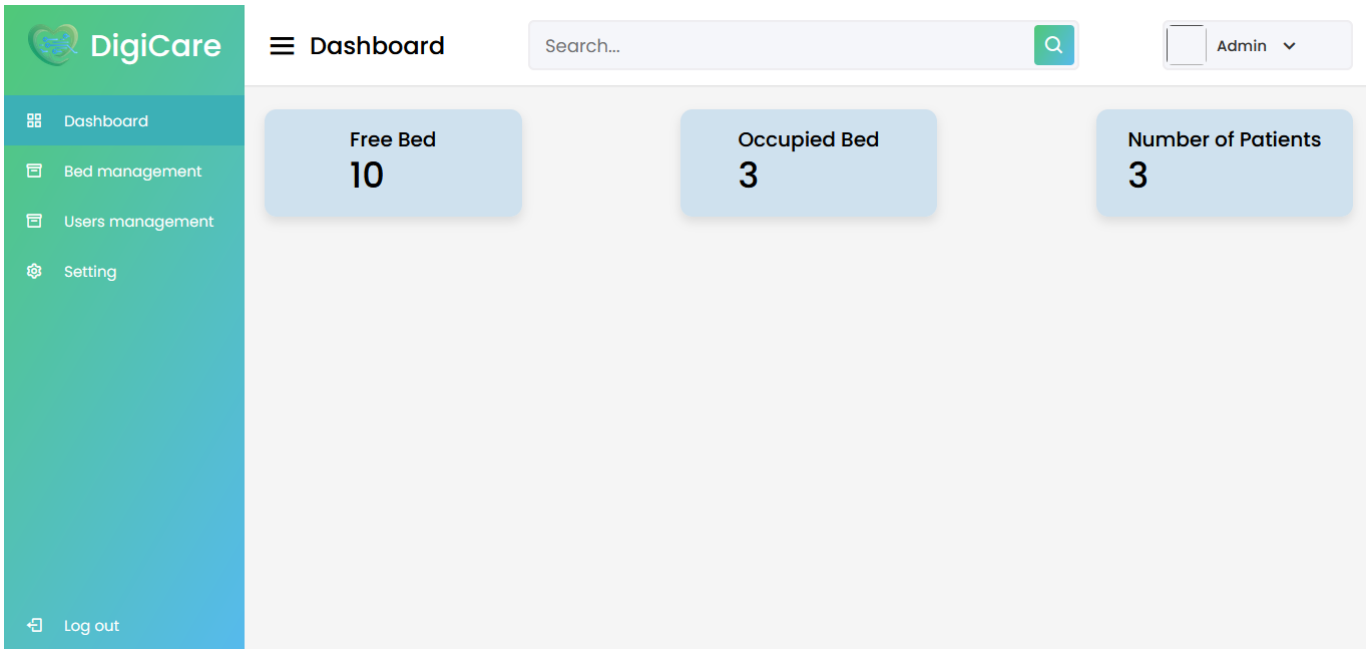


Figure 4.7: The Administrator Dashboard

4.4.4 Create Bed Interface

To create a smart hospital bed in the Ditto digital twin platform, the admin needs to enter the relevant bed information and initiate the creation process by clicking on the ”Create” button. This action triggers the generation of a digital twin representation of the bed within the Ditto platform.
The figure 4.8 represents Create Bed Interface:

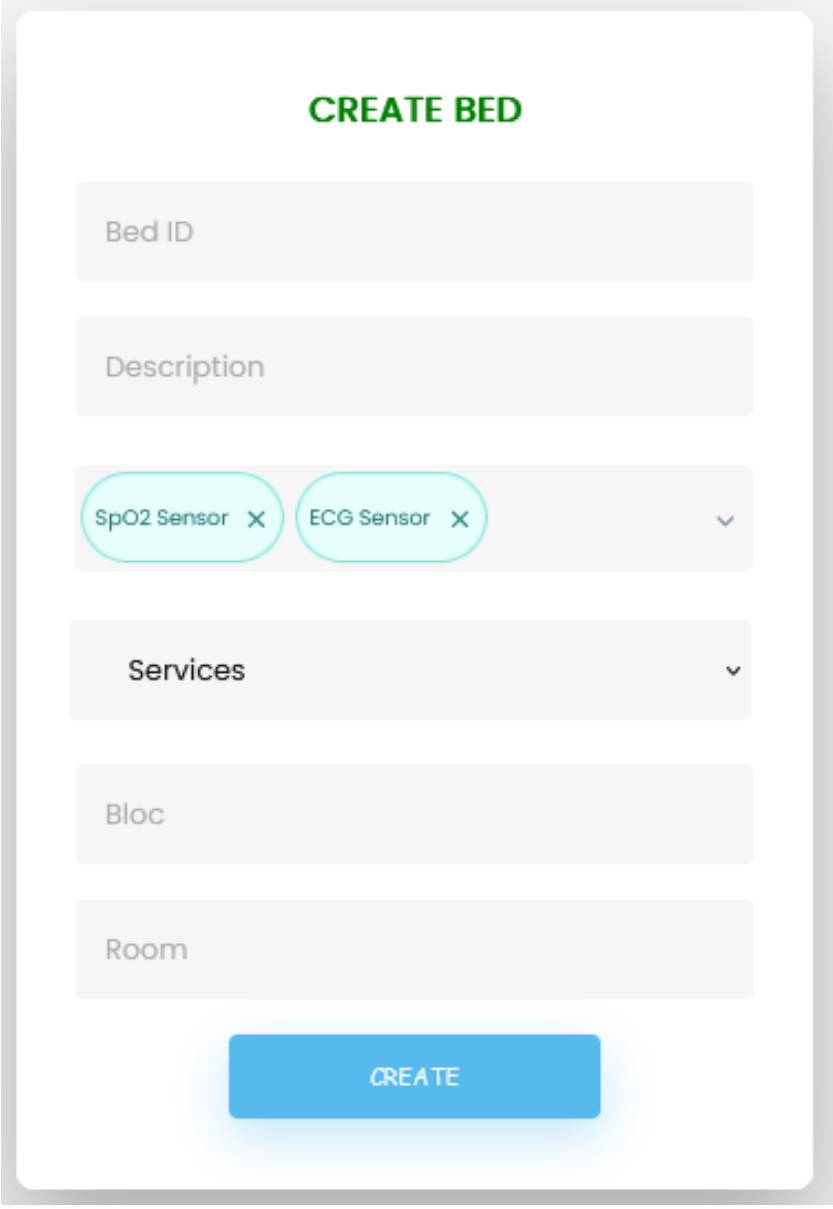


Figure 4.8: Create Bed Interface

4.4.5 Patient Management Interfaces

In these interfaces, the medical secretary can create and assign the patient to a free smart bed according to the patient case.

Add Patient interface

The figure 4.9 represents Add Patient interface:

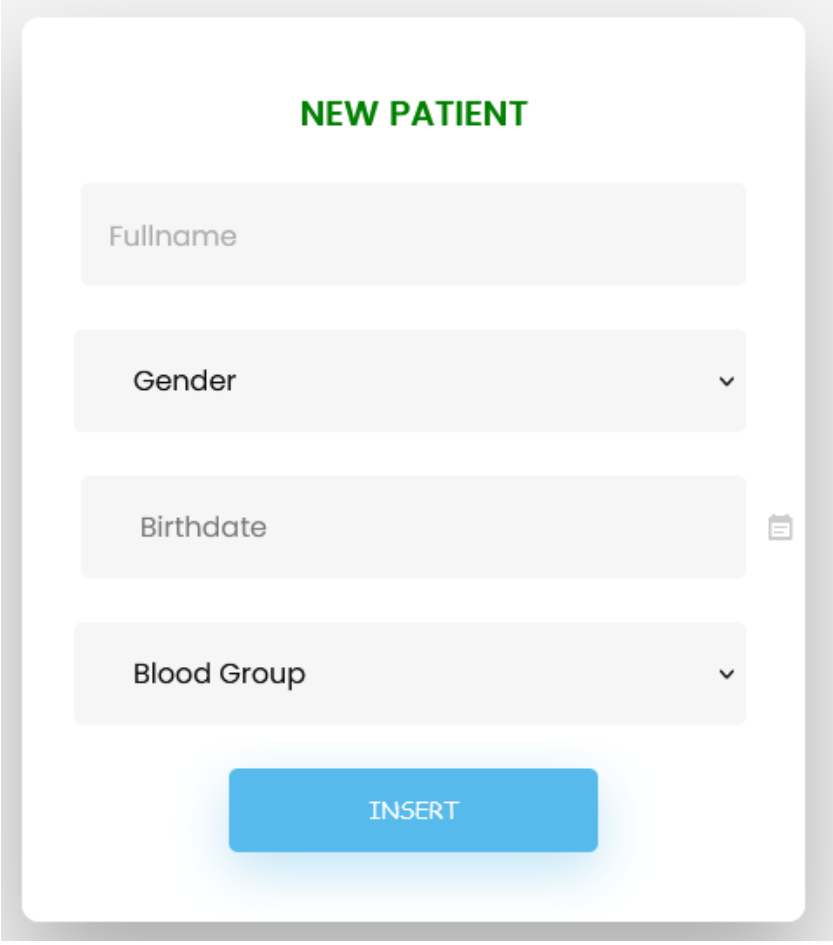


Figure 4.9: Add Patient interface

Interface for assigning patients to beds

The figure 4.10 represents Assignment Patient interface:

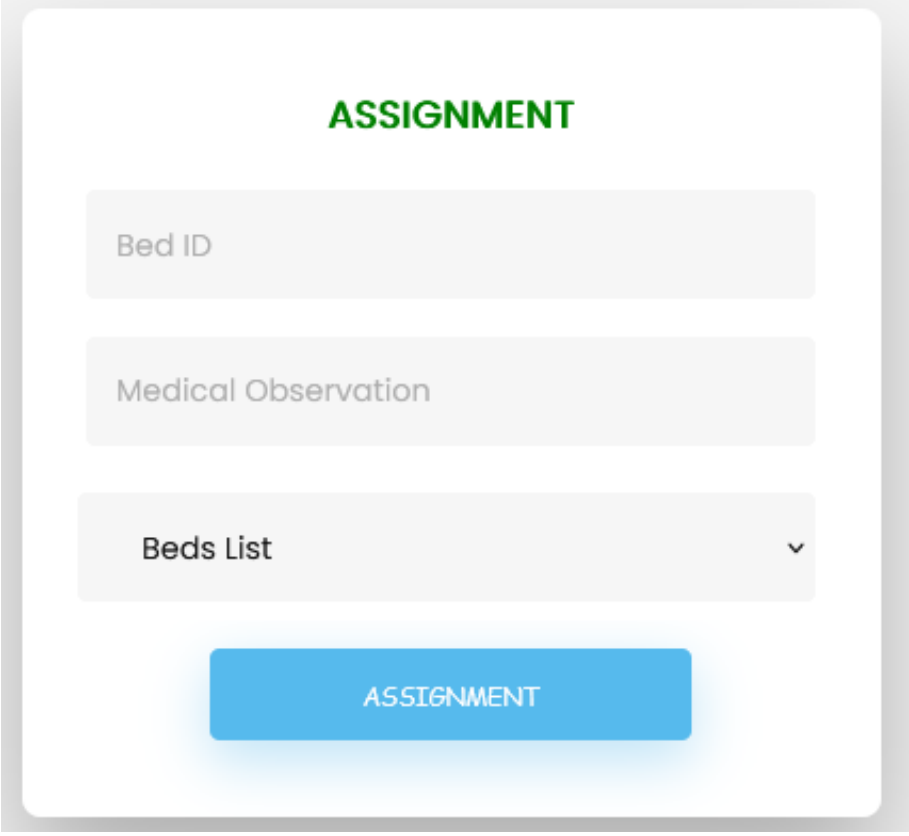


Figure 4.10: Assignment Patient interface

4.4.6 Patient Supervision and Control Interface

Supervision interface is designed to provide healthcare professionals (doctor, nurse) with a centralized platform to monitor and control various vital signs of a patient. This include a list individual patients, along with relevant information such as patient identifiers,and current status. To facilitate the process of finding a specific patient, doctors can conveniently search for patients by their name. This feature aims to streamline the patient search functionality and enable healthcare professionals to quickly locate the records of patients they are responsible for.
The figure 4.11 represents Doctor Dashboard:

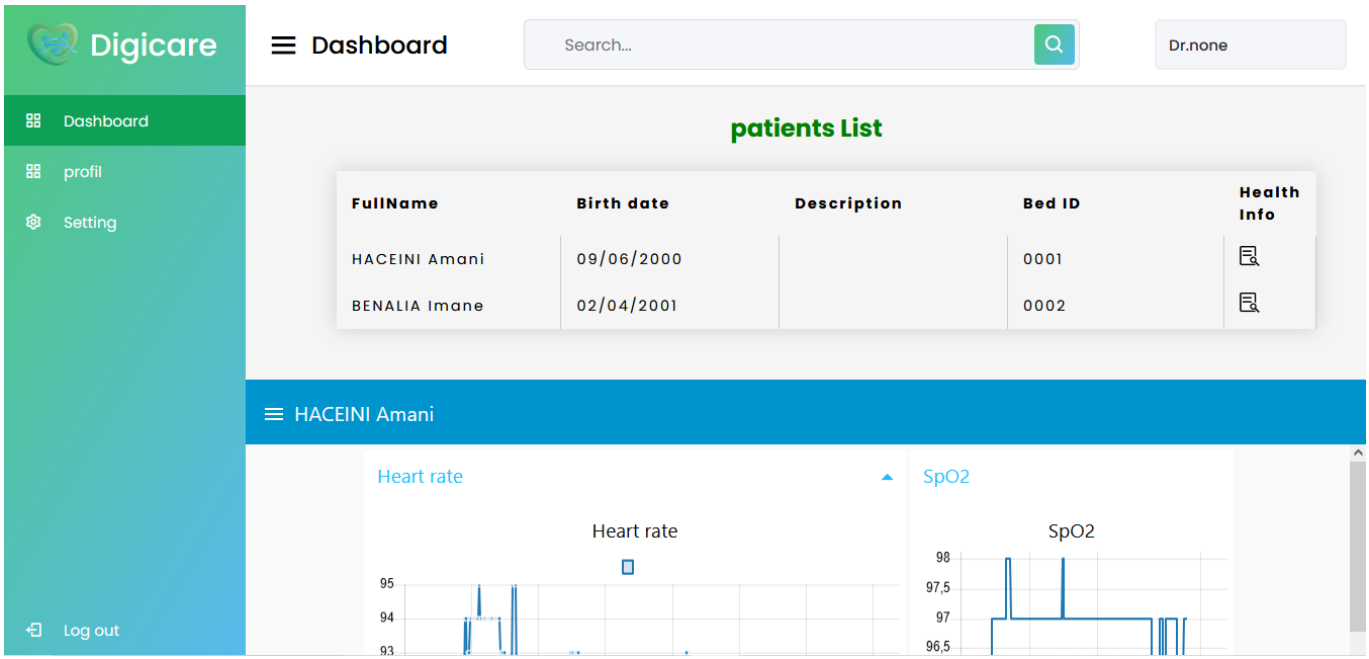


Figure 4.11: Doctor Dashboard

When the doctor click on the the icon in health information column it will be appear another dashboard that display the health information of a patient.
The figure 4.12 represents Health information of a patient:



Figure 4.12: Health information of a patient

4.5 Conclusion

In this chapter, we provided a comprehensive description of the implementation, focusing on the creation and connection of intelligent hospital beds with their digital twins. We offered detailed insights into the realization phase, outlining the steps taken to bring our solution to life.

The creation and connection of smart beds with their digital twins involved a thorough explanation of the technical aspects and functionalities.

In addition to the creation and connection of smart beds with their digital twins, a crucial aspect of our implementation is the ability to track vital signs of patients. This functionality plays a significant role in ensuring comprehensive patient care and timely interventions.

Additionally, we integrated AI services with our smart bed system to improve project implementation. These AI services provide machine learning algorithms can predict patient health conditions, allowing healthcare providers to intervene.

Finally, to provide a clear understanding of the project, we illustrated the practical application of our web application through the presentation of several interfaces. These interfaces showcased the different functions and features of the web application, allowing readers to visualize how the project comes together and how it can be effectively utilized in a real-world setting.

Conclusion

The purpose of the project was to address the issues of developing a digital twin-based system for patient control and supervision. It focused on creating a digital twin model that replicates hospital beds and patient health states, providing secure and user-friendly supervision and control functions for medical staff, connecting the physical system and the digital twin, and providing analytic services for analyzing patient health states.

To achieve these goals, a complete architecture was proposed. It includes a simulation layer to replicate the physical system, a digital twin model for capturing bed properties and patient data, a junction layer to facilitate connectivity, artificial intelligence services for analysis and prediction, and a web application as an end user interface for control and supervision.

The platform was developed based on a digital twin model that we specifically designed for hospital beds. This model allows for the storage of data collected from the different sensors implanted into the bed, on the patient body and on medical devices. These data points are then associated with the corresponding patient to capture their health status. The implementation of the digital twins was done using the Eclipse Ditto platform, which facilitated the creation and management of the digital twin instances.

By leveraging Node-RED within the junction layer, the platform achieves effective connectivity and data exchange, enhancing the overall functionality and performance of the digital twin-based solution for patient control and supervision.

The integration of AI services also enables system to predict patient outcomes based on historical data and current health status ,providing predictive analysis and raise alerts or notifications in case of any abnormal readings or critical situations.

Finally, this experience has been highly beneficial and valuable for us, as it has provided us with several important outcomes. Firstly, it has allowed us to explore and understand new concepts related to digital twin technology, patient control, and supervision systems. Through extensive research and practical implementation, we have expanded our knowledge and deepened our understanding of these innovative concepts.

As a perspective on what has been achieved, it is important to really evaluate the solution developed at a hospital level and enrich it with other advanced features using artificial intelligence techniques to predict more vital signs, detect early signs of patient deterioration, and alert healthcare providers, also we want to collect the data from real patients to work on it.

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Stratup

4.6 Problématique Abordée

- Supervision et contrôle des patients: Manque de mécanismes de supervision (consultation présentielle) Pas de notifications en cas de problème Intervention lente.
- Il y a environ 143 hôpitaux publics en Algérie. Cela comprend des hôpitaux universitaires, des hôpitaux spécialisés et des hôpitaux généraux.
- Il y aurait environ 600 cliniques privées
- Il y avait environ 99 000 lits dans les hôpitaux publics en Algérie.
- Il y a plus de 2 millions personnes âgées en Algérie.
- Et tout ces particuliers besoin de bon supervision et contrôle des patients.

4.7 Solution Proposée

- Système intelligent de supervision et de contrôle des patients.
- Contrôle à distance de patients Notification de médecins et des infermiers en cas d'anomalie.
- Applicable au niveau :
  - Hôpitaux
  - Cliniques privées
  - Maison de retraite
  - Particulier (à la maison)
- Stockage de données historiques concernant la santé des patients (Dossier médical électronique) Formation par simulation sur des données même en cas d'absence de patients.

Cette image ??présente le BMC de notre projet:

Principaux partenariats	Activités principale	Valeur fournie	Relation client	Segment de clientèle
Fabricants des lits d'hôpital Ministère de la santé Hôpitaux publiques Clinique privées	Developpement de solution et leur adaptation au besoin de chaque clients **Ressources clés** Les développeurs (dans un premier temps nous seulement) L'équipement médical (lits d'hôpitaux)	La qualité des soins Supervision à distance Surveillance continue des signes vitaux des patients Détection des chutes et alertes instantanées intégration au dossier médical électronique	Service client pour répondre aux questions et résoudre les problèmes Les réseaux sociaux Des ateliers **Les canaux** Les réseaux sociaux Ventes directes aux hôpitaux Distribution par des revendeurs spécialisés Visioconférences	Hôpitaux et établissements de santé Cliniques privées Patient (personne âgées besoin de soin à la maison) École de formation en médecine

Structure des coûts	Sources de revenus
Les salaires de l'équipe hébergement de serveur Publicité Les capteurs IoT	Hôpitaux Cliniques privées Contrats de maintenance et de support Écoles privés

Figure 4.13: BMC