อุปกรณ์ตรวจจับการรั่วไหลของสารละลายทางหลอดเลือดดำโดยใช้อุณหภูมิผิวหนังพร้อมระบบเฝ้าระวัง

INTRAVENOUS SOLUTION LEAK DETECTION DEVICE USING SKIN TEMPERATURE AND MONITORING SYSTEM

นิธิ เภตรานนท์

NITI PETRANON

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรบัณฑิต

สาขาวิชาวิศวกรรมชีวการแพทย์

คณะวิศวกรรมศาสตร์

สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

ปีการศึกษา 2567

KMITL-2024-EN-M-317-279

INTRAVENOUS SOLUTION LEAK DETECTION DEVICE USING SKIN TEMPERATURE AND MONITORING SYSTEM

นิธิ เภตรานนท์

NITI PETRANON

ผศ. ดร. ชูชาติ ปิณฑวุรุจน์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิศวกรรมศาสตรบัณฑิต

สาขาวิชาวิศวกรรมชีวการแพทย์

คณะวิศวกรรมศาสตร์

สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

ปีการศึกษา 2567

KMITL-2024-EN-M-317-279

วิทยานิพนธ์ อุปกรณ์ตรวจจับการรั่วไหลของสารละลายทางหลอดเลือดดำโดยใช้อุณหภูมิผิวหนังพร้อมระบบเฝ้าระวัง

นักศึกษา นายนิธิ เภตรานนท์

รหัสประจำตัว 64601082

ปริญญา วิศวกรรมศาสตร์มหาบัณฑิต

สาขาวิชา วิศวกรรมชีวการแพทย์

ปีการศึกษา 2565

อาจารย์ที่ปรึกษาวิทยานิพนธ์ ศ. ดร. ชูชาติ ปิณฑวิรุจน์

บทคัดย่อ

การให้สารอาหารและวิตามินทางหลอดเลือดดำ (IV Therapy) เป็นวิธีการรักษาทางการแพทย์ที่สำคัญ แต่การรั่วไหลของสารละลายออกจากหลอดเลือดดำระหว่างการรักษาอาจเกิดขึ้น ส่งผลต่อผู้ป่วยตั้งแต่การระคายเคืองเล็กน้อยไปจนถึงการทำให้เนื้อเยื่อเสียหาย วิธีการตรวจจับการรั่วไหลแบบดั้งเดิมอาศัยการสังเกตด้วยสายตา ซึ่งอาจมีความท้าทาย

งานวิจัยนี้เสนอแนวทางใหม่สำหรับการตรวจหาการรั่วไหลของสารที่ฉีดเข้าเส้นเลือดดำในระยะเริ่มต้นโดยไม่รุกราน โดยใช้ระบบติดตามตามอุณหภูมิที่เปลี่ยนแปลงไปเมื่อสารละลายรั่วไหล

วิทยานิพนธ์ฉบับนี้ได้ออกแบบและพัฒนาอุปกรณ์พร้อมวิธีการตรวจจับการรั่วไหลของสารละลายทางหลอดเลือดดำโดยใช้การเปลี่ยนแปลงอุณหภูมิบริเวณพื้นผิวที่ทำการให้สารละลาย อุปกรณ์ประกอบไปด้วยระบบบันทึกข้อมูล และแจ้งเตือน แสดงผลผ่านระบบ IoT และใช้อัลกอริทึมการคัดแยกแบบง่ายอาการ

จากการทดลองพบว่า เมื่ออัตราการเปลี่ยนแปลงอุณหภูมิมากกว่า 0.5% สามารถคัดแยกการรั่วไหลของสารละลายได้ด้วยความแม่นยำ 86.27% และมีความแม่นยำสูงสุดเมื่ออัตราการเปลี่ยนแปลงอุณหภูมิอยู่ที่ 0.7% ซึ่งมีความแม่นยำ 90.20% นอกจากนี้ ยังมีการใช้การเรียนรู้ของเครื่องอย่างง่าย เช่น logistic regression พบว่ามีความแม่นยำ 86.27% ซึ่งใกล้เคียงกับการคัดแยกด้วยอัตราการเปลี่ยนแปลงอุณหภูมิ 0.5%

Thesis	Intravenous Solution Leak Detection Device Using Skin Temperature and Monitoring System
Student	Niti Petranon
Student ID	64601082
Degree	Master of Engineering
Program	Biomedical Engineering
Year	2023
Thesis Advisor	Prof.Dr. Chuchart Pitavirooj

ABSTRACT

Intravenous (IV) therapy is a crucial medical treatment for correcting fluid and electrolyte imbalances in patients. However, leakage of the administered solution from the vein during treatment can occur, leading to complications ranging from mild irritation to tissue damage. Current leakage detection methods rely on visual observation, which can be challenging. This study presents a novel approach for early detection of intravenous leakage in a non-invasive manner using a temperature monitoring system that detects temperature changes during solution leakage.

This thesis proposes a device and method for detecting intravenous fluid leakage using temperature changes on the surface where the intravenous solution is administered. The device incorporates data logging, IoT-based visualization, an alerting system, and a simple classification algorithm. Experimental results demonstrate that when the temperature change rate exceeds 0.5%, the leakage of the solution can be detected with an accuracy of 86.27%. The highest accuracy is achieved at a temperature change rate of 0.7%, reaching 90.20%. Additionally, the application of a simple machine learning approach, logistic regression, yielded an accuracy of 86.27%, which is close to the classification performance at a temperature change rate of 0.5%.

ACKNOWLEDGEMENT

Thank you to my advisor, Asst. Prof. Dr. chuchart pintavirooj , who provides me with many suggestions and experiences in Biomedical Engineering and medical instrumentation

Thak you to midical staff at Phayathai3 Hospital, who provides me with many suggestions and experiences in Intravenous theraphy

Thank you to School of Engineering of King Mongkut's Institute of Technology Ladkrabang and Payathai 3 Hospital for providing me with the financial to complete this research.

Thank you my family who support me all times.

Niti Petranon

TABLE OF CONTENTS

Page

ABSTRACT IN THAI.....I

ABSTRACT IN ENGLISH.....II

ACKNOWLEDGEMENT.....III

TABLE OF CONTENTS.....

ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก

LIST OF TABLES.....

ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก

LIST OF FIGURES..... IX

CHAPTER 1 INTRODUCTION..... 1

1.1 Statement and Significance of the problems 1

1.2 Objectives 2

1.2.1 Prototype Extravasation Detector 2

1.2.2 Reusable Extravasation Detection Device. 2

1.2.3 Monitoring System Design for Medical Staff 2

1.3 Research Hypothesis 2

1.3.1 This device can design a solution leak detection device at an early stage. 2

1.3.2 This device can detect significant temperature changes in the solution area. 2

1.4 Scope of the research 3

1.5 Expected Result 3

1.5.1 Technicians can use this sensor to detect intravenous solution leaks. 3

1.5.2 This device can quickly detect and identify symptoms. 3

1.5.3 The equipment is cost-effective, easy to diagnose and reusable. 3

1.6 Research Plan 3

1.7 Research proposal 5

1.8 Definitions 5

CHAPTER 2 LITERATURE REVIEW 7

2.1 Definition of Infusion Therapy 7

2.1.1 Types of Intravenous (IV) Fluids 7

2.2 Definition of Extravasation 10

2.2.1 Risk factors that cause extravasation. 11

2.2.2 Infiltration Scale 17

2.2.3 Extravasation Scale 18

2.3 Human Body Temperature 20

2.4 Heat Transfer 21

2.5 Tonicity 22

2.6 Microcontroller 24

2.7 ESP32 Microcontroller 25

2.7.1 Tensilica LX6 internal architectural structure 26

2.7.2 Highly durable non-volatile memory 26

2.7.3 Characteristics of the internal working parts (Peripheral Features) 26

2.7.4 Working Voltage (Operating Voltage) 27

2.7.5 Working temperature range (Temperature Range) 27

2.7.6 Clock signal operating speed 27

2.7.7 Energy consumption 27

2.8 Internet of Things: IoT 28

2.8.1 Components of the Internet of Things system 28

2.8.2 IoT Platform is an important part in the back-end server system 29

2.8.3 Components and features of the IoT Platform 29

2.8.4 IoT Platform classification view 32

2.8.5 Classification of IoT Platforms 33

2.9 Blynk IoT Platform 35

2.10 Machine Learning 37

2.10.1 Logistic Regression 37

2.10.2 Decision Tree 39

2.11 Related Work 42

CHAPTER 3 RESEARCH METHODOLOGY 44

3.1 Design Concept 45

3.2 Hardware Design 45

3.2.1 Body Temperature Sensor (MAX30205) 45

3.2.2 Microcontroller 46

3.2.3 Button Pin 47

3.3 Appearance design 47

3.4 Software and Algorithm Design 47

3.4.1 Pre-processing 47

3.4.2 Processing 50

3.4.3 Flowchart 51

3.5 Blynk IoT Platform Design 53

3.6 Simulation Platform 55

3.7 Evaluate and test the performance of the classification model 56

3.7.1 Confusion Matrix 56

3.7.2 Accuracy 57

3.7.3 Precision 57

3.7.4 Recall/Sensitivity 57

3.7.5 Specificity 58

3.7.6 F1-Score 58

3.7.7 True Positive Rate 58

3.7.8 False Positive Rate 58

3.7.9 AUC-ROC Curve 59

CHAPTER 4 RESULTS 61

4.1 Device Design 62

4.2 Hyper-parameter Setup 64

4.3 Experimental results 64

4.3.1 Data form simulation platform 64

4.3.2 Data form patient 65

4.3.3 Data compairision between simulation and patient 67

4.4 Classification Methods 68

4.4.1 Threshold Methods 69

4.4.2 Logistic Regression 70

4.4.3 Decision Tree 71

4.5 Conclusion Result 72

4.6 Cause of Error 73

4.5.1 Cause of Type I Error 73

4.5.2 Causae of Type II Error 73

CHAPTER 5 DISCUSSION, CONCLUSION AND SUGGESTIONS 74

5.1 Discussion 74

5.2 Couclusion 74

5.3 Suggestion 75

BIBLIOGRAPHY.....

ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก

AUTHOR BIOGRAPHY.....78

LIST OF TABLES

Number of Tables

Table 1.1 Reserch schedule 3

Table 2.1 Infiltration Scale 17

Table 2.2 Extravasation Scale 18

Table 4.1 Hyper-parameter Setup 64

Table 4.2 The comparative performance of various classification methods in distinguishing between normal and leakage symptoms. 72

LIST OF FIGURES

Figure **Page**

Figure 2.1 Body Temperature areas 21
Figure 2.2 Micrographs of osmotic pressure on red blood cells 23
Figure 2.3 Microcontroller Architecture 25
Figure 2.4 Microcontroller Architecture of ESP32 27
Figure 2.5 Classification of IoT platforms with examples in each group 34
Figure 2.6 Blynk Application 35
Figure 2.7 Blynk Console 36
Figure 2.8 The standard logistic function (Sigmoid Function) 39
Figure 2.9 Decision Tree Diagram 41
Figure 2.10 The schematic and thermographic patterns under the infrared camera and of the thermosensitive liquid crystal film, where the extravasation event occurred 42
Figure 3.1 Block diagram of intravenous solution leak detection device 45
Figure 3.2 Circuit diagram of intravenous solution leak detection device. **ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก**
Figure 3.3 Raw signal from temperature sensor 48
Figure 3.4 Average signal from temperature sensor 48
Figure 3.5 Calculate the rate of temperature change 49
Figure 3.6 the rate of temperature change 49
Figure 3.7 Flowchart of extravasation Detector 52
Figure 3.8 Blynk Application Design 54
Figure 3.9 Blynk Console Design 54
Figure 3.10 Simulation Platform 55
Figure 3.11 Simulation Platform with pork 55
Figure 3.12 Confusion Matrix 56
Figure 3.13 AUC-ROC Curve 60
Figure 4.1 Extravasation Detector 62

Figure 4.2 Extravasation Detector Components..... 63
Figure 4.3 Installing equipment with the infusion pump..... 63
Figure 4.4 Raw temperature form Simulatioin..... 64
Figure 4.4 temperature change rate (%) form Simulatioin..... 65
Figure 4.6 Raw temperature form Patient..... 66
Figure 4.7 Average temperature form Patient..... 66
Figure 4.8 temperature change rate (%) form Patient..... 67
Figure 4.9 Copair temperature between Simulation and Patient..... 67
Figure 4.10 Copair temperature change rate (%) between Simulation and Patient..... 68
Figure 4.10 ROC Curve of Cutoff Temperature Change Rate 0.3% **ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก**
Figure 4.12 ROC Curve of Cutoff Temperature Change Rate 0.5% **ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก**
Figure 4.13 ROC Curve of Cutoff Temperature Change Rate 0.7% **ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก**
Figure 4.14 ROC Curve of Logistic Regression..... **ผิดพลาด! ไม่ได้กำหนดบุ๊กมาร์ก**
Figure 4.15 Visulization of Decision Tree..... 71
Figure 4.16 ROC Curve of Decision Tree..... 72

Chapter 1

Introduction

1.1 Statement and Significance of the problems

Hospitals serve as crucial healthcare facilities for diagnosing and treating patients. Intravenous (IV) fluid therapy plays a vital role in correcting or preventing fluid and electrolyte imbalances. This treatment method becomes necessary when patients are unable to consume fluids or food orally, or when rapid correction is essential.

The physician establishes the IV fluid therapy plan, outlining the specific fluids and medications needed. Registered nurses (RNs) are responsible for executing this plan, which encompasses administering the prescribed fluids according to the physician's orders. These fluids may include electrolytes, nutrients, whole blood, or specific blood components. To ensure safe and effective administration, RNs require in-depth knowledge and skills in IV therapy. This includes understanding the purpose of the therapy, the type of fluid being administered, the rate of infusion, and the appropriate needle insertion site. Additionally, RNs must meticulously monitor patients during therapy and employ strict aseptic technique to prevent complications.

A potential complication associated with IV fluid therapy is leakage of the solution from the vein. This leakage can occur at any point during treatment and can have varying degrees of severity. The leaked solution can cause irritation and damage to surrounding tissues, potentially harming the patient. Unfortunately, visually detecting leakage can be challenging.

This research presents the design of a prototype device for non-invasive early detection of intravenous infusion leakage. The device functions by detecting temperature changes at the infusion site. Furthermore, a basic monitoring system is designed to facilitate easy diagnosis of solution leaks by medical staff.

1.2 Objectives

1.2.1 Prototype Extravasation Detector

This section will detail the development and construction of a prototype device for the non-invasive detection of extravasation during intravenous (IV) fluid therapy. The focus will be on the specific design choices, materials used, and assembly process for the prototype.

1.2.2 Reusable Extravasation Detection Device.

Following the development of the initial prototype, this section will explore the design considerations for creating a reusable extravasation detection device. This will involve addressing factors like material selection, cleaning and sterilization procedures, and ensuring long-term functionality.

1.2.3 Monitoring System Design for Medical Staff

A crucial aspect of this research is the design of a user-friendly monitoring system for medical staff. This section will detail the functionalities and interface of the monitoring system, emphasizing its ease of use for healthcare professionals. The goal is to ensure the system effectively communicates alerts and data related to potential extravasation events, facilitating timely intervention by medical staff.

1.3 Research Hypothesis

1.3.1 This device can design a solution leak detection device at an early stage.

1.3.2 This device can detect significant temperature changes in the solution area.

1.4 Scope of the research

This research investigated the potential for harm caused by intravenous solution leakage in treated patients. The study focused on the development of a novel method for early detection. By employing body temperature sensors strategically placed at the infusion site, the research team aimed to exploit the temperature changes that occur when leakage takes place. This approach offers a non-invasive solution for monitoring leakage. Furthermore, the research designed a dedicated monitoring system to present the sensor data to medical staff in a clear and concise manner. This system can potentially improve the efficiency and accuracy of extravasation diagnosis, leading to earlier intervention and improved patient outcomes.

1.5 Expected Result

1.5.1 Technicians can use this sensor to detect intravenous solution leaks.

1.5.2 This device can quickly detect and identify symptoms.

1.5.3 The equipment is cost-effective, easy to diagnose and reusable.

1.6 Research Plan

This research period starts from August 2021 - May 2024

Table 1.1 Reserch schedule

Semester Month / Plan	1/2021	2/2021	1/2022	2/2022	1/2023	2/2023
Getting the information about the principle of method of infusion therapy						
Getting the information about the principle of method of Extravasation						

Design a device for collecting data on intravenous solution administration.						
Create a model for intravenous solution administration.						
Collect the results of experiments on patients and plot them against the model.						
Calculation of limit of detection, limit of quantitation, Sensitivity and any related value in the research for improving the result is better						
Discussion and conclusion, also write report and prepare publication and final presentation						

1.7 Research proposal

This research report, Temperature-based Skin Surface Monitoring Device for Intravenous Fluid Leakage Detection, contains all of information to explain the process including 5 parts.

Chapter 1 Introduction: This chapter contains statement of the problems, objective, scope of study, expectation results and research plan

Chapter 2 Literature Review: This chapter contains information about IV theraphy, Extravasation, Body temperature, Cell Swelling, Microcontroller, Iot Platform

Chapter 3 Research Methodology: This chapter contains about all of experiment process to make the device to detect and analyze of extravasation

Chapter 4 Result: This chapter contains all of result in each experiment

Chapter 5 Conclusion, discussion and suggestion: This chapter contains the summarize of result and problems of this research, also give the suggestion for future work.

1.8 Definitions

The words definition that used through the report are given below,

IV Therapy	Medical procedure where fluids, medications, and nutrients are delivered directly into a vein. This method is used for rehydration, providing nutrients to those unable to eat or drink, administering medications, and correcting electrolyte imbalances.
Extravasation	The leakage of fluid from a blood vessel or tube into the surrounding tissues. This fluid can be blood, lymph fluid, or even medication being delivered intravenously (IV). Extravasation can cause irritation, inflammation, and even tissue death depending on the severity and the type of fluid leaked.
Body temperature sensor	Medical device designed to measure the internal temperature of a living organism, most commonly a human. These sensors employ various technologies to

	detect and quantify thermal variations, converting them into a measurable electrical signal.
IoT Platform	software application or service that provides the foundation for connecting various devices and sensors within the Internet of Things (IoT) ecosystem. It acts as a central hub, facilitating communication, data management, and application development for these connected devices.

Chapter 2

Literature Review

2.1 Definition of Infusion Therapy

Infusion therapy is a method of administering medication or fluids directly into the bloodstream through a needle or catheter, often intravenously (IV). This form of treatment is used when oral medication is not possible or when the medication needs to be delivered at a controlled pace. Infusion therapy is particularly effective for drugs that lose their effectiveness when exposed to the digestive system, and it allows for precise dosing, which is crucial for treatments like chemotherapy that require slow, controlled delivery into the bloodstream. It can also be used to deliver medications quickly in emergency situations. Infusion therapy is administered by healthcare providers, such as nurses, in clinical settings and is used to treat a wide range of conditions, including cancer, autoimmune disorders, congestive heart failure, dehydration, immune deficiencies, infections, pain, and more. The therapy can be performed in a hospital or outpatient settings, with the latter often being more comfortable and less expensive for patients requiring multiple treatments over time.

2.1.1 Types of Intravenous (IV) Fluids

Intravenous (IV) fluids can be categorized based on their tonicity, which refers to the concentration of solutes (dissolved particles) relative to the concentration in blood plasma. This distinction is crucial as it dictates the fluid's movement between the bloodstream and the intracellular space.

2.1.1.1 Isotonic Fluids

Isotonic fluids possess a solute concentration akin to blood plasma. Consequently, they exert an equal osmotic pressure, preventing net fluid movement across cell membranes. These fluids are the mainstay for replenishing lost fluids and electrolytes in various clinical scenarios, including

1. Dehydration

Isotonic solutions effectively restore volume depletion caused by inadequate fluid intake or excessive losses.

2. Blood Loss

Following hemorrhagic events, isotonic fluids are essential for volume resuscitation.

3. Electrolyte Imbalances

Isotonic solutions containing specific electrolytes can correct imbalances caused by various conditions.

Common examples of isotonic IV fluids include:

1. Normal Saline (0.9% Sodium Chloride)

This is the most widely used isotonic fluid, containing water, sodium, and chloride.

2. Lactated Ringer's Solution

Similar to normal saline, this solution incorporates lactate, potassium, calcium, and chloride. Lactate is metabolized to bicarbonate in the body, aiding in the correction of acidosis.

3. Plasmalyte

This solution mirrors blood plasma composition more closely than normal saline or lactated Ringer's solution, containing sodium, potassium, chloride, magnesium, and lactate.

2.1.1.2 Hypotonic Fluids

Hypotonic fluids have a lower solute concentration compared to blood plasma. This disparity in osmotic pressure drives fluid movement from the bloodstream into the cells. Hypotonic solutions have several therapeutic applications:

Hypotonic IV fluids are primarily used to:

1. Provision of Free Water for Waste Excretion: By increasing urine output, these fluids facilitate the elimination of waste products by the kidneys.
2. Treatment of Cellular Dehydration: In cases where cells are shrunken due to dehydration, hypotonic fluids replenish their fluid content, promoting cellular rehydration.
3. Replacement of Cellular Fluid: Conditions like diabetic ketoacidosis lead to rapid fluid and electrolyte loss. Hypotonic fluids can help restore these deficits

Common examples of hypotonic IV fluids include:

1. 0.45% Sodium Chloride (Half Normal Saline): This is the most commonly used hypotonic solution, containing less sodium and chloride than normal saline.
2. D5W (5% Dextrose in Water): This solution solely contains water and dextrose (sugar). It is crucial to note that due to the absence of electrolytes, D5W can inadvertently worsen sodium levels if not administered judiciously.

2.1.1.3 Hypertonic Fluids

Hypertonic fluids possess a higher solute concentration compared to both blood plasma and interstitial fluid. This concentration gradient creates an osmotic pull, drawing fluid out of cells and into the bloodstream, thereby increasing blood volume. Hypertonic solutions are employed in specific circumstances:

1. Treatment of Hyponatremia: These fluids are used to correct low blood sodium levels (hyponatremia).
2. Reduction of Intracranial Pressure (ICP): Hypertonic solutions can help decrease pressure around the brain in cases of increased ICP.
3. Management of Diabetic Ketoacidosis: These fluids play a role in treating this complication of diabetes.

Common examples of hypertonic IV fluids include:

4. Hypertonic Saline (3% or 5% Sodium Chloride Solution): This is the most frequently used hypertonic fluid.
5. Mannitol Solution: Another osmotic diuretic employed to reduce intracranial pressure.

2.2 Definition of Extravasation

Extravasation signifies the unintended extravasation of a substance, typically a vesicant medication, from the intravascular space into the perivascular tissues. This iatrogenic event can transpire during intravenous medication administration, particularly prevalent during chemotherapeutic regimens. Vesicant medications are widely recognized for their propensity to induce tissue injury, manifesting as blistering and ulceration. Extravasation, if not promptly addressed, can culminate in substantial tissue damage, encompassing ulceration and even necrosis (cellular death). The clinical presentation of extravasation encompasses a constellation of signs and symptoms, including localized pain, a stinging or burning sensation, induration (tissue hardening), and cutaneous discoloration. Given its potential for severe sequelae, extravasation necessitates immediate medical intervention to mitigate the condition and curtail further tissue destruction.

It is imperative to distinguish between two interrelated concepts: infiltration and extravasation. Infiltration signifies the leakage of a non-vesicant substance or medication into the perivascular tissues. These substances lack the inherent capability to directly dissolve tissue. Conversely, extravasation involves the leakage of vesicant agents, which possess the capacity to lyse (break down) tissue. Extravasation is regarded as a redoubtable complication of intravenous medication administration, as it can cause significant tissue destruction at the injection site, potentially impacting adjacent nerves, blood vessels, and other tissues. The severity of the resultant damage is contingent upon the type, properties, and volume of the extravasated drug or substance. The clinical manifestations of extravasation can range from mild cutaneous blanching and discoloration to erythema (redness), induration, pain, blister formation, vascular occlusion, inflammation, phlebitis (inflammation of a vein), compartment

syndrome (increased pressure within a confined space), and in severe cases, necrosis, gangrene, and cutaneous ulceration with soft tissue loss.

Prophylaxis remains the cornerstone of managing extravasation. Rigorous training and education of healthcare professionals in meticulous venipuncture techniques and unwavering adherence to established preventive strategies are paramount in minimizing the occurrence of this complication.

2.2.1 Risk factors that cause extravasation.

Risk factors that cause the condition extravasation Can be classified into 3 types: risk factors caused by the patient Risk factors caused by personnel and risk factors arising from the properties of the drug properties as follows:

2.2.1.1 Risk factors caused by patients.

1. Age: It was found that young children and the elderly are at risk of developing extravasation This is because children have poor skin and blood vessel health. For the elderly who have changes in their skin Little or reduced tightness of the skin and veins from the deterioration of age The elasticity and stability of the blood vessels is less because the elastic fibers of the blood vessels in the tunica intima layer are reduced. causing a risk of developing more extravasation
2. Skin conditions and characteristics of blood vessels in patients with congenital diseases which abnormalities of the skin condition and the appearance of the veins Found in people with various diseases such as
    1) Superior vena cava syndrome
    2) Diabetes (diabetes)
    3) High blood pressure (hypertension)
    4) Hardening of the arteries (atherosclerosis)
    5) Deep vein thrombosis (vein thrombosis & stenosis)
    6) Vein spasm or venous abnormalities (peripheral vascular disease)

which has abnormalities of blood circulation and skin system As a result, when the needle is inserted into the blood vessel, it can easily cause irritation to the blood vessel and skin at the point where the needle is inserted. Including cancer patients who have received chemotherapy. (chemotherapy) and cancer that has previously been irradiated Chemotherapy causes venous abnormalities, causing inflammation. Causes abnormally high blood pressure. Resulting in the risk of leaking medicine or fluid out of the blood vessel. Radiation causes the skin and tissues in the area exposed to radiation to become toxic (recall phenomenon), causing injury and loss of skin function. May cause leakage of medicine from the skin at the area where the needle is inserted.

3. level of consciousness By people who have a reduced level of consciousness or are unable to tell about pain. or discomfort This may be caused by taking sleeping pills. muscle relaxants or have brain pathology or decreased sensation of the peripheral organs, such as diabetes (diabetes), diseases related to abnormalities of the peripheral nervous system (peripheral neuropathy), if there is leakage of drugs or fluids out of the blood vessels As a result, the patient cannot tell the change and pain sensation in the area where the medicine or fluid leaked, causing extravasation. There has been an increase in violence.
4. Inserting a needle into a vein is difficult, such as in people who are obese, dark-skinned, or have a history of inserting the needle many times. This will result in injury to the vein from inserting the needle and the possibility of drug or fluid leakage out of the blood vessel.
5. Having low blood pressure (hypotension) due to low blood pressure It will cause the medicine or fluid to stay in the blood vessels for a long time. Therefore it is in contact with blood vessels for a long time. Causes more irritation of blood vessels. Until it results in the leakage of medicine or fluid out of the blood vessels.

6. Have a history of previous extravasation, making it more likely to occur again (repeat intravenous infusion or injection)

2.2.1.2 Risk factors caused by personnel.

1. Personnel lack knowledge about drugs, which drugs are tissue destroyers (vesicants) or tissue irritants (irritants) or those that both destroy tissue and cause tissue irritation (vesicants). and irritant) including having knowledge about intravenous drug administration Factors affecting the severity of birth Extravasation includes the type of medicine and the amount received. Dosage rate Duration of receiving the medicine Dosage position Level of drug leakage and knowledge in evaluating the characteristics of extravasation Makes it possible to prevent and monitor to prevent the condition from occurring. extravasation possible
2. Skills for managing inappropriate medication or fluid administration are as follows:
   1) Choosing an inappropriate location, such as around joints or near various joints. This must be moved all the time, causing the risk of causing the needle to rub against the blood vessel causing injury. Until there is a leak of fluid outside the vein.
   2) Selecting an inappropriate intravenous needle, such as using a needle that is too long and too large This causes injury to the blood vessel or the length of the needle is not suitable for the depth of the blood vessel. causing the needle to penetrate the blood vessel Until there is a leak of medicine or fluid out of the blood vessel. Choosing a needle that is too small and not suitable for the blood vessel will cause high pressure while giving the medicine. This will cause a risk of the drug leaking out of the blood vessel.

3) Inserting the needle more than once in the same area This increases vascular injury in multiple locations in the same blood vessel. Causes leakage of medicine or fluid from the blood vessels. In the position where the needle had been inserted before
4) Intravenous drug administration in the same location Administration of multiple drugs at the same time or administering drugs that have a risk of developing extravasation It causes blood vessels to become irritated from constant exposure to the drug. Exposure to higher drug concentrations and is a risky drug
5) Lack of monitoring when administering drugs using infusion therapy, which is controlled by infiltration volume and infusion rate, causing increased pressure to push drugs into the blood vessels. Risk of injury to blood vessels. Therefore, in high alert drugs, which are drugs in the vesicant agent group, which is recommended to be administered using an infusion pump, there must be guidelines for monitoring the occurrence of hypersensitivity reactions. extravasation clearly to reduce the risk of developing extravasation
6) Inappropriate monitoring of intravenous drug administration The administration of vesicant agents requires different monitoring guidelines than the administration of other drugs or fluids. This is because monitoring must be done every 1 hour in the case of drugs that are given continuously. Because there is a risk of causing blood vessel injury. Until a leak of medicine or fluid occurs, monitoring will help the patient faster and reduce the severity of the condition. extravasation

2.2.1.3 Risk factors arising from drug properties.

Type and nature of medicines or fluids given intravenously Affects the occurrence of extravasation by medicines that have a risk of causing extravasation including

1. Drugs that can directly destroy cells destroys tissue Can change DNA, including chemotherapy drugs (chemotherapeutic). The drugs destroy the transport mechanism of substances within the cell (transport mechanism), causing the cell to die and causing tissue in that area. It was continuously destroyed for a long time. which when administered through the intravenous route Exposure to blood vessels from this group of drugs for a long time or continuously will cause injury or irritation to the blood vessel tissue. And there may be leakage of medicine or fluid out of the blood vessel, damaging surrounding tissue. There is a greater risk in patients with impaired blood vessel integrity. And when the drug leaves the blood vessel, it is very severe because it destroys surrounding tissue.
2. high concentration medicine (Hyperosmolar drugs) The drug will have a high Osmolality value of more than 290 mosmol/L, causing high osmotic pressure, causing the drug to move from inside the cell out into the space between cells and causing the cell to lose its function. and medicine, which is viscous, makes it difficult to flow the drug into the blood vessels And it is a group of drugs that must be administered using a fluid flow control device. This causes the possibility of drug leakage out of the blood vessel. In the case of drugs leaking out of the blood vessels, hypotonic substances cause cells to expand and break, such as Calcium, Potassium, while hypertonic drugs cause cells to wither, resulting in cell death. Groups of drugs with high concentrations include partial parenteral nutrition (PPN), glucose, X-ray contrast media, etc.

Leakage of high concentration drugs or fluids will further damage tissue and cause tissue necrosis.)

3. Drugs that are highly acidic or alkaline (acid or alkaline drugs) where the drug has a pH less than 5.5 or more than 8.5 are potentially damaging. The drug has the effect of causing irritation to blood vessels. And when it leaks out of the blood vessel, it has the effect of destroying tissue, causing injury.
4. Drugs that cause blood vessels to expand include parenteral alimentation fluid, x-ray contrast media, calcium gluconate, KCl, $NaHCO_3$, hormone, steroids and diuretics, etc. When administered intravenously, they cause blood vessels to expand. and increases the flow of medicine through the blood vessels But this group of drugs, in addition to having the effect of expanding blood vessels, also has the effect of destroying tissue and causing irritation to the blood vessels. As a result, the drug can leak out of the blood vessel and damage the surrounding tissue of the blood vessel.
5. Drugs that cause blood vessels to constrict Both arteries (arterioles), veins (venous) and capillaries. (capillaries) When drugs are administered intravenously, there will be resistance to drug delivery. It is also a drug that must be administered using a fluid flow control device. This causes the possibility of drug leakage out of the blood vessel. And when the drug leaks out of the blood vessels, it will cause the blood vessels in the tissue in the area exposed to the drug to contract. Resulting in tissue lacking blood supply (ischemic injury) and injury. This group of drugs includes vascular regulators such as dopamine, dobutamine and adrenaline and antihistamines such as Chlorphenamine (CPM).
6. Medicines that have anticoagulant or anticoagulant effects on platelets (Anticoagulants Antifibrinolytics Antiplatelets) When there is a leak of the

drug, it will cause extravasation Or it may cause compartment injury and increase the risk of bleeding in areas where medicines leak out of the blood vessels, such as heparin alteplase (RtPA).

7. Drugs that have the effect of clogging blood vessels (venous thrombose vessels) cause the blood vessels in the area where the drug is administered to narrow, resulting in the need to use more pressure to administer the drug. A fluid flow regulator may be required. Or use pressure to give medicine by direct injection. This can cause the drug to leak out of the blood vessels.
8. Medicines that have pain relieving effects Decreases the response to pain When the drug leaks out of the blood vessel causing severe extravasation possible

2.2.2 Infiltration Scale

The Infiltration Scale is a grading system used by medical professionals to assess the severity of infiltration, which is the leakage of fluid from an intravenous (IV) catheter into the surrounding tissue.

Table 2.1 Infiltration Scale

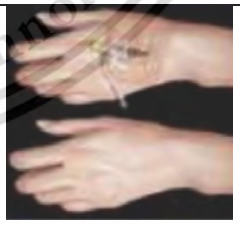
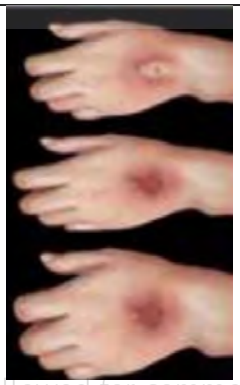
Grade	Symptom
0	No symptom
1	Skin blanched (pale) edema (swelling) less than 1 inch in any direction cool to the touch with or without pain.
2	Skin blanched edema 1 to 6 inches in any direction cool to the touch with or without pain.

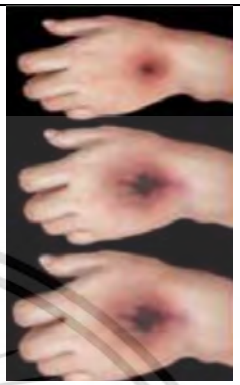
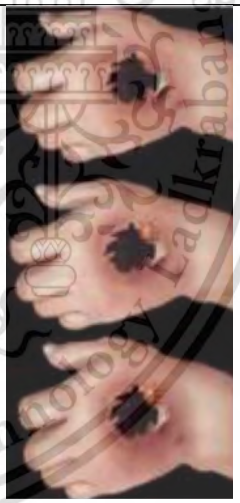
3	Skin blanched gross edema greater than 6 inches in any direction cool to the touch mild to moderate pain possible numbness.
4	Skin blanched, translucent (see-through), skin tight, leaking, discolored, bruised, swollen, gross edema greater than 6 inches in any direction, deep pitting tissue edema (swelling that leaves an indentation when pressed) circulatory impairment (reduced blood flow) moderate to severe pain infiltration of any amount of blood products, irritant, or vesicant (blistering agent).

2.2.3 Extravasation Scale

Diagnosing the level of extravasation, It is shown as in Table 12.

Table 2.2 Extravasation Scale [2]

Level	Signs	Picture
Normal	No pain, or Extravasation	
Mild	-Pale or pink skin color -There are still no blisters. -The surface temperature in the area where the solution is given is cold or warm. -There is swelling that does	

	not appear when pressed. slight pain -normal body temperature (36.5-37.5 C)	
Moderate	The color of the skin begins to change. The skin swells slightly. Hot skin temperature There is swelling, when pressed it makes a dent. Limited movement Central pain Fever, body temperature more than 37.5	
	There are dark spots around and the center is pale or red. There are blisters. The skin peels off deep into the fat layer beneath the skin. There is dead tissue and possibly bone. The skin temperature is very hot. There is a lot of swelling. Difficulty moving Fever, body temperature as high as 37.5	

2.3 Human Body Temperature

Human core body temperature is tightly regulated within a narrow range, typically between 36.5 °C and 37.5 °C (97.7 °F and 99.5 °F). However, this value exhibits physiological fluctuations throughout the day and across individuals due to several factors.

Factors Affecting Core Body Temperature:

1. Circadian Rhythm: Body temperature follows a circadian rhythm, a roughly 24-hour biological cycle. During this cycle, core temperature dips slightly in the early morning hours, followed by a gradual rise of approximately 0.5 °C (1 °F) in the afternoon and evening.
2. Physical Activity: Increased metabolic activity during exercise generates heat, resulting in a temporary elevation in body temperature. Strenuous exercise can cause core temperature to rise by several degrees.
3. Age: Newborns and young children generally have a slightly higher core body temperature range (36.4 °C to 37.2 °C or 97.5 °F to 99 °F) compared to adults.
4. Emotional State: Stress, anxiety, and even excitement can trigger minor increases in body temperature.
5. Hormonal Fluctuations: Women experience variations in core temperature throughout their menstrual cycle due to hormonal shifts.
6. Medications: Certain medications can have the side effect of raising or lowering body temperature.
7. Medical Conditions: Infections and illnesses often cause a fever, a controlled rise in body temperature that aids the immune system in combating pathogens. Conversely, some medical conditions can lead to hypothermia, an abnormally low body temperature.

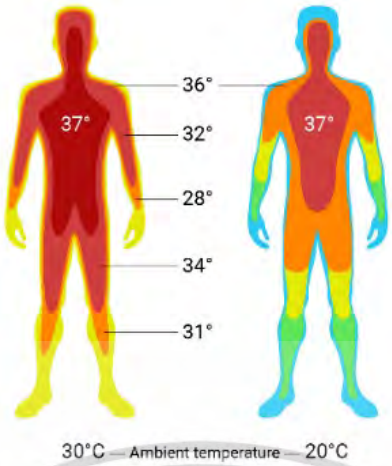


Figure 2.1 Body Temperature areas [3]

2.4 Heat Transfer

Human thermoregulation is a tightly regulated physiological process that ensures a constant core body temperature, typically around 37°C (98.6°F). This stability is critical for optimal cellular function and enzymatic activity within the body. To achieve this thermal homeostasis, the body employs three primary heat transfer mechanisms for exchange with the environment:

1. Conduction: This mode involves direct physical contact between the body and a solid object with a differing temperature. Heat flows from the warmer object (body) to the cooler object. For instance, sitting on a cold metal bench leads to heat transfer from the body to the metal, promoting a sensation of coolness. Conversely, grasping a warm surgical instrument allows heat conduction from the instrument to the hand.
2. Convection: This process involves heat transfer through the movement of surrounding fluids, primarily air or water. As warm air or water contacts the skin, it absorbs heat and rises due to convection currents. This movement is replaced by cooler fluids, facilitating continuous heat loss. Fans and air conditioning systems enhance convection by increasing air circulation, promoting a cooling effect.

Similarly, immersion in cool water during hydrotherapy promotes heat loss through convection.

3. Radiation: Unlike conduction and convection, radiation transfers heat via electromagnetic waves, specifically infrared radiation, and does not require physical contact. Our bodies continuously emit infrared radiation, and the rate of heat loss through radiation depends on the temperature difference between the body and the environment. For example, on a sunny day, our bodies absorb radiant heat from the sun, while simultaneously radiating heat to cooler objects in the surrounding environment.

These mechanisms work in concert to maintain thermal equilibrium. However, under certain conditions, the body may need to employ additional thermoregulatory strategies for heat loss. Sweating is a crucial mechanism, where sweat glands produce sweat, a watery fluid that evaporates from the skin's surface. This evaporation absorbs latent heat from the body, promoting a cooling effect.

The relative contribution of each heat transfer mechanism depends on various factors such as ambient temperature, humidity, clothing insulation level, and individual metabolic activity. Understanding these mechanisms is fundamental in various fields, including human physiology, occupational health practices, and thermal comfort considerations in building design.

2.5 Tonicity

Tonicity, in a biological context, refers to the effective osmotic pressure gradient established between a cell and its surrounding environment. It essentially describes the solution's potential to alter a cell's volume by influencing the movement of water across the semi-permeable cell membrane through a process called osmosis.

Osmosis is the net movement of water through a selectively permeable membrane driven by a difference in solute concentration. Water moves from a region of lower solute

concentration (hypotonic solution) towards a region of higher solute concentration (hypertonic solution).

Tonicity is dictated by the relative concentration of impermeant solutes, those incapable of freely crossing the cell membrane, between the extracellular solution (external fluid) and the cell's cytoplasm (internal fluid). This selective permeability of the membrane allows water molecules to pass through while restricting the passage of most solutes.

There are three key categories of tonicity:

1. Isotonic: When the external solution possesses the same solute concentration as the cytoplasm, it is considered isotonic. In this state, there is no net movement of water across the membrane, and the cell maintains its original size and shape.
2. Hypotonic: If the external solution has a lower concentration of solutes compared to the cytoplasm, it is termed hypotonic. In a hypotonic environment, osmosis drives water influx into the cell, potentially causing it to swell and even burst.
3. Hypertonic: Conversely, an external solution with a higher concentration of solutes than the cytoplasm is described as hypertonic. In such an environment, water flows out of the cell due to osmosis, leading to cell shrinkage and shriveling.

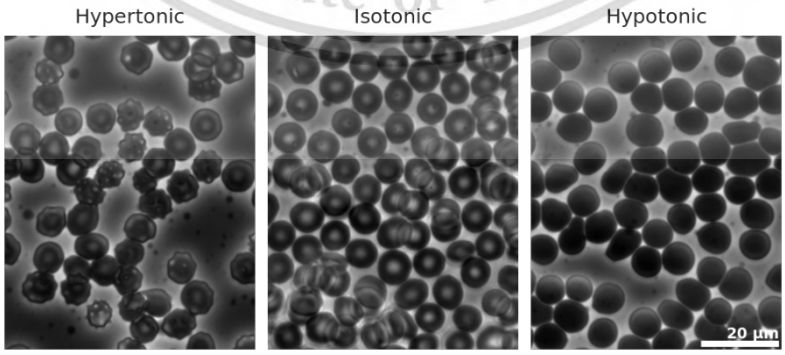


Figure 2.2 Micrographs of osmotic pressure on red blood cells [4]

2.6 Microcontroller

A microcontroller (MCU) is a tiny computer on a single integrated circuit (IC). It integrates a central processing unit (CPU), memory, and programmable input/output peripherals, enabling it to control electronic devices.

Microcontrollers are present in a wide range of devices, from simple household appliances like thermostats and microwave ovens to complex industrial robots and medical equipment. Their compact size, low power consumption, and versatility make them ideal for embedded systems applications.

Components of a microcontroller:

1. Central Processing Unit (CPU): The brain of the microcontroller, responsible for executing instructions and processing data.
2. Memory:
    1) Random-access memory (RAM): Stores temporary data used during program execution.
    2) Read-only memory (ROM): Stores the program instructions that the microcontroller executes.
3. Input/Output (I/O) peripherals: Allow the microcontroller to interact with external devices like sensors, actuators, and displays. These peripherals can be analog-to-digital converters (ADCs) for converting analog signals to digital signals, digital-to-analog converters (DACs) for converting digital signals to analog signals, timers, counters, and serial communication interfaces.

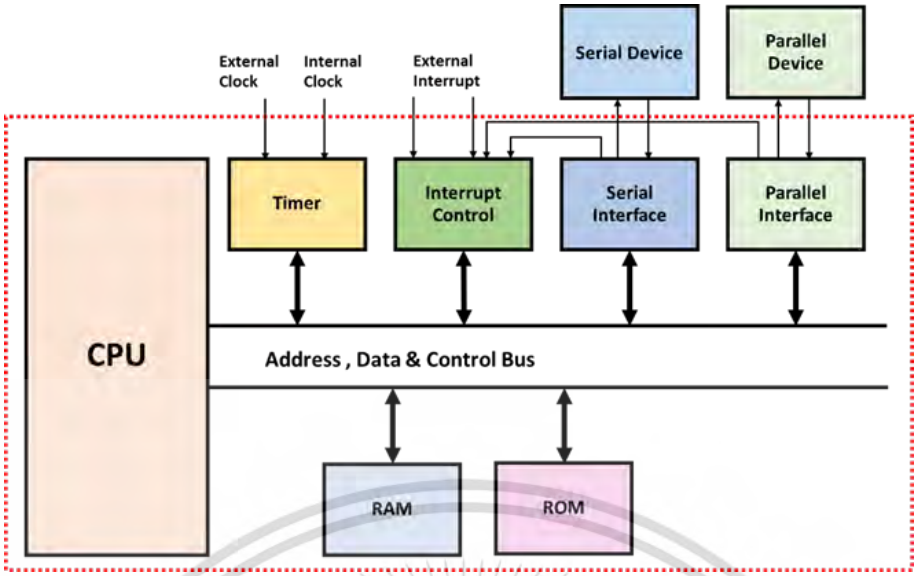


Figure 2.3 Microcontroller Architecture

2.7 ESP32 Microcontroller

ESP32 is the name of a microcontroller IC that supports wireless communication according to Wireless LAN and Bluetooth Low Energy standards, produced by Espressif® from China. The ESP32 microcontroller is a 32-bit microcontroller with a maximum clock speed of 240 MHz with SRAM main memory. On the 512 KB chip, the interesting point is that it supports WiFi at a frequency of 2.4 GHz, making it possible to immediately develop devices that need wireless connectivity. With GPIO interface for connecting additional devices as required. Featuring Tensilica LX6 internal architecture, it can process approximately 600 million instructions per second.

Features of the ESP32 microcontroller are shown in Figure 2.4.

2.7.1 Tensilica LX6 internal architectural structure

2.7.1.1 Clock signal 240 MHz

2.7.1.2 Supports external ROM connection up to 16 MB.

2.7.1.3 There is WiFi standard 802.11 b/g/n, supporting use in both Station softAP and Wi-Fi direct modes.

2.7.1.4 has built-in Bluetooth Supports use in 2.0 mode and 4.0 BLE mode.

2.7.1.5 Can process 600 million instructions per second (600 MIPS : Million Instructions Per Second)

2.7.2 Highly durable non-volatile memory

2.7.2.1 448 KB read-only memory

2.7.2.2 Internal static memory, size 512 kilobytes

2.7.2.3 Can read while writing

2.7.2.4 Can prevent program copying.

2.7.3 Characteristics of the internal working parts (Peripheral Features)

2.7.3.1 Two 64-bit timers/counters, separate prescalers and comparison mode.

2.7.3.2 There is a real time counter with a separate oscillator.

2.7.3.3 There are 16 pulsewidth modulation channels.

2.7.3.4 There are 18 12-bit analog-to-digital signal conversion channels.

2.7.3.5 There are 2 8-bit digital to analog signal conversion channels.

2.7.3.6 4 master/slave SPI serial connections

2.7.3.7 Three programmable USART serial communications

2.7.3.8 Byte-oriented 2-wire serial connection

2.7.3.9 The clock timer uses an oscillator inside the chip.

2.7.3.10 Supports connection to SD-Card.

2.7.4 Working Voltage (Operating Voltage)

2.7.4.1 Voltage 2.6 volts to 3.6 volts

2.7.5 Working temperature range (Temperature Range)

2.7.5.1 -40 degrees Celsius to 125 degrees Celsius

2.7.6 Clock signal operating speed

2.7.6.1 Clock signal 240 MHz

2.7.7 Energy consumption

2.7.7.1 Working mode Active Mode 80 milliamperes

2.7.7.2 Working mode Modem Sleep Mode 30 milliamperes

2.7.7.3 Working mode: Light Sleep Mode 0.8 milliamperes

2.7.7.4 Working mode Deep Sleep Mode 10 microamperes

2.7.7.5 Working mode Hibernation Mode 5 microamperes

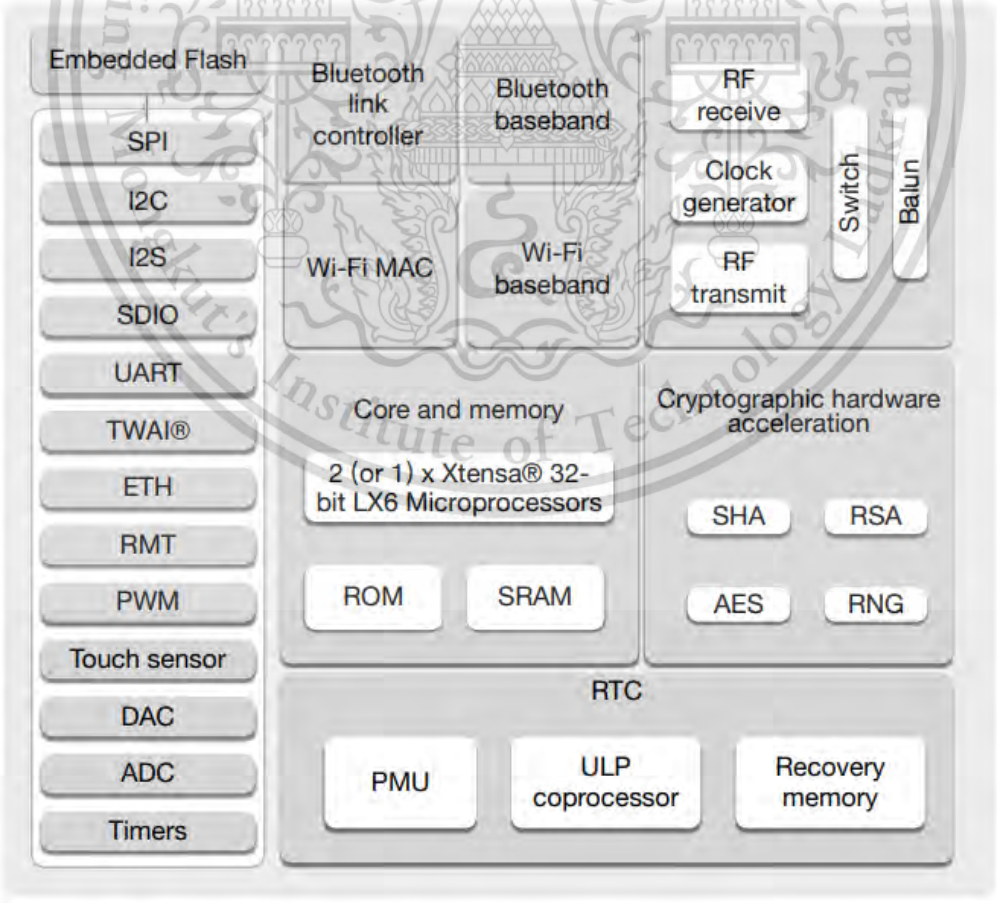


Figure 2.4 Microcontroller Architecture of ESP32 [5]

2.8 Internet of Things: IoT

The Internet of Things (IoT) is an environment in which all things can communicate and connect through both wired and wireless communication protocols. by various things There is a way to identify yourself. Able to recognize the context of the environment and can interact and work together This ability to communicate will lead to many new innovations and services. For example, home sensors can detect occupants' movements. and send signals to turn on or off light switches in various rooms with or without people The device measures the vital signs of a patient or elderly person and sends the information to medical personnel. or send a message to call rescuers or emergency vehicles, etc.

In addition, IoT will change the form and process of industrial production into a new era. Also known as Industry 4.0, it will rely on communication and collaboration between machines, humans, and data to increase decision-making power quickly and with high accuracy. All data collected from sensors that measure the device and its surroundings will be analyzed. Get results to immediately improve the production process. In addition to crossing the time limit Control system or data analysis system They may not be in the same place as the machine. But can control and order without limitations regarding location.

2.8.1 Components of the Internet of Things system

The Internet of Things has three main components:

2.8.1.1 Hardware equipment It may come in the form of computers, smartphones, tablets, and embedded devices. microcontroller or various sensor devices

2.8.1.2 Communication to connect the hardware devices in 2.5.1.1 to communicate with each other. Communications herein may be over public internet networks or within private networks. Network connectivity options range from hardwired LAN to wireless communications including 3G/4G Wi-Fi Bluetooth Zigbee Z-Wave Lora, depending on network limitations. Communication distance Baud rate and energy consumption rate

2.8.1.3 Backend Server This part is the background system that manages communication connections between hardware devices. Take care of forwarding data from source to destination. Take care of communication security. Authentication Including library or API management to facilitate the development of IoT applications. This IoT back-end system is the heart of the IoT Platform service.

2.8.2 IoT Platform is an important part in the back-end server system

which is component of the Internet of Things system. IoT Platform is a service that facilitates developers or IoT business operators without having to purchase one. No need to install the system There is no need to take care of the back-end server yourself. The IoT Platform reduces the process of developing IoT products and reduces the burden on companies producing IoT products. Currently, there are platform providers for communication to link IoT devices together. and provides tools and backend systems to facilitate the development of more than 450 IoT applications worldwide. Each service platform has its own strengths. and different service characteristics It is therefore necessary to study the strengths and limitations of each service of the platform. For developers to choose the service that suits their work and needs.

2.8.3 Components and features of the IoT Platform

The basic element that every IoT platform must have is connection management. (Connectivity Management) However, most IoT platforms in the market have additional elements to facilitate users, such as device management, data collection. Graphical data display data analysis We can classify the important components of an IoT Platform into 8 parts. However, the IoT Platform that is available in the market may not have all the components.

2.8.3.1 Connection management (Connectivity Management) is the part that manages connections between IoT devices. It is the part that is taken care of when the devices connect to the network for the first time. or when the connection is lost Or when devices move around the network or change IP addresses, the platform must ensure that data transmission continues smoothly.

2.8.3.2 Device Management is the part that manages which devices are authorized to connect to the platform. Device identity is verified to prevent unauthorized use of the device. (Authentication) There is management of which devices have rights to communicate with which devices. (Authorization) and specify details of rights at the reading or writing level and specify topics that are allowed to read or write (Access Control)

2.8.3.3 Creating rules and conditions (Rule Engine) is the part that allows users to create rules. Conditions for how to proceed when this event or information occurs This mechanism can bring Information obtained from sensors or data stored in the database to be processed on the platform side When encountering an event that meets the conditions Can send notifications or send control command or record special information According to the conditions set, for example, when the GPS sensor finds that the device has moved outside the home area, send a command to turn off all electrical devices in the home.

2.8.3.4 Data Storage (Data Storage) is the part where data is stored. The data stored may be a record of the sensor's values over time. Or it could be a data file or data that has been processed from creating rules and conditions Data storage formats can be databases, data files, and the storage part of the IoT Platform needs to be designed to support Big Data with various forms of data flowing in all the time. The database technology used can be both structured (SQL) and unstructured (noSQL). In addition, the data storage should be distributed (Distributed Storage) to spread the burden of storing large amounts of data and to be fault-tolerant.

2.8.3.5 Data Visualization is the part where raw data is displayed in a format that is easily understood by humans. It may be displayed in the form of graphs, maps, text, or other graphics. The information displayed may be raw data at that time or historical data sets. or data that has already been processed Data visualization also includes a graphical user interface. that can be used to send control commands to IoT devices. A good IoT Platform should display data. that is flexible, allowing users to customize and arrange the elements themselves and should display well on a variety of devices. both on computers and mobile devices

2.8.3.6 Data Analysis (Data Analytics) is the part that takes the raw data stored in the repository and further analyzes it to become knowledge. to learn relationships Learn behavior or to analyze the root cause of the problem or to suggest alternatives to help in decision making or to predict abnormalities in advance Tools used to analyze IoT data should be capable of handling large volumes of data. Information changes rapidly all the time. and various forms of information

2.8.3.7 Connecting to external systems (External Interfaces) In order for the system or IoT device to work with other external systems, the IoT Platform should provide a channel for importing and exporting data through the Application Programming Interface (API). or Software Development Kit (SDK) or Libraries, for example, to link data to an organization's resource planning program.(ERP) or to communicate with IoT devices that are on other IoT Platforms

2.8.3.8 Other elements on some platforms may have additional capabilities such as Generating reports in .csv .json formats, uploading firmware to IoT devices over the network. (over-the-air update) or even a tool to create a smartphone application to control IoT devices

2.8.4 IoT Platform classification view

Today, many services call themselves IoT platforms. However, each service has its own characteristics. and views of service are very different Some platforms focus on data analysis. Some The platform focuses on providing visualization services. Some platforms emphasize Supports specific IoT devices Such as platforms for Smart Home, hence the classification and classification of IoT Platform. This can be done from many angles as follows.

2.8.4.1 Application perspective for specialized work (Solution platform) compared to General use (Generic platform) IoT Platform has both generic and Supported platforms Specific areas such as Smart Home Platform, Smart City Platform, Industrial IoT Platform, Connected Car Platform and platforms that support general use, that is, there are broad basic functions for development. Select and use to develop specific applications yourself. Specialized platforms have been a concept for a long time. It is a concept of vertical development. Platform) is to provide a platform service that meets the needs Each side completely, like if it were a Smart Home The platform is designed to support Smart Home devices and supports communication standards in the home especially.

There is a control dashboard designed by Taking into account the needs of the home owner in particular While platforms that support general use It supports microcontroller devices.

In general, there are basic activation functions such as Receive, send, and collect data. The display function is also

The basics, such as the graphs, must be further customized by the developer or the person who will create them.

2.8.4.2 Public platform and private platform service angle. The concept of public platform service and

Private platform It originates from the public cloud and private cloud service models.

Meaning of public platform It is a platform where every user uses cloud resources or shared server behind the scenes The platform service manages the scope of permissions not to use. One user's service impacts other users to maximize efficiency. Service characteristics Therefore, there is a low service fee. And most of them charge service fees according to actual usage (pay-per-user).

Private platform Refers to a platform that is Determination of each user's resource area.

separated, such as separating servers and separating disk space Separate bandwidth served to each customer.

Private platform The service may be provided on a server within the customer's organization, called "on-demand" service.

On-Premise or providing services on separate servers within the cloud that the provider Providing care services

It's called Off-Premise service. Providing private platform services requires allocating and maintaining resources.

Separated, it has higher service assets than public platform-style services.

2.8.5 Classification of IoT Platforms

When these two perspectives are taken into consideration together, IoT platforms can be divided into 4 subgroups. As picture 2-6 is

2.8.5.1 Public platform For specific applications, platforms in There aren't many of these, with Samsung SmartThings and Apple HomeKit both being public platforms.

For connecting IoT devices within the home (Smart Home Platform) by both platforms Relying on being a public platform Attract smart home devices from various brands to participate. It's like creating a standard for working together between different devices.

2.8.5.2 Public platforms for general application. Platforms in this group

There are both services provided by large multinational companies and startup companies for large companies.

Providing public platform services often has a background as a Cloud Infrastructure service provider. before and having Cloud Infrastructure Being your own is an advantage. Makes it possible to provide additional services

More diverse than the platforms provided by startup companies. Platforms in this group include: Microsoft Azure IoT Hub, AWS IoT, IBM Watson IoT, NETPIE, etc.

2.8.5.3 Private platform for application of specific tasks, platform in the group

This has the largest number. Sometimes it cannot be called a platform because it sells both solutions including Hardware devices, platforms, and ready-made applications, for example, platforms in a group Industrial IoT such as Advantech, Bosch, Siemens and Smart City platforms such as Huawei.

2.8.5.4 Private platform For general applications, platforms in this group

Some of them used to be public platforms that provided services to developers all over the world. Go back and forth before you come and change.

Providing personal, enterprise-level platforms such as Xively, some of which are sales-based License Software to install and use on customer servers such as Thingworx HiveMQ and Cisco Jasper.

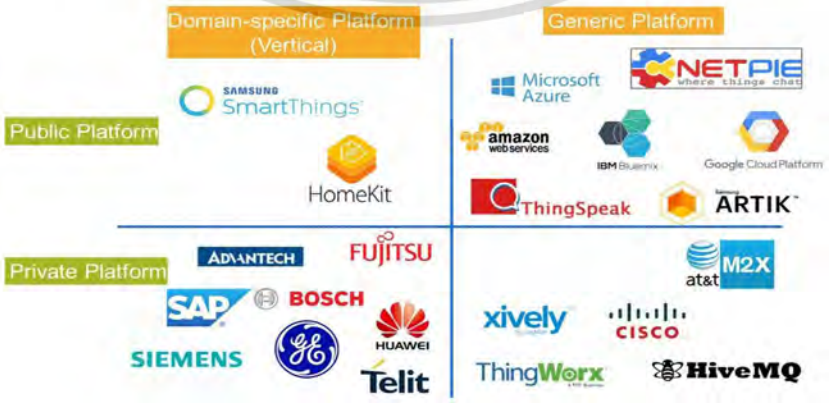


Figure 2.5 Classification of IoT platforms with examples in each group [6]

2.9 Blynk IoT Platform

Blynk establishes itself as a user-centric platform designed to streamline remote interactions within the Internet of Things (IoT) landscape. Its core functionality revolves around facilitating the control and monitoring of hardware using readily available smartphones or web browsers. Blynk achieves this through a meticulously designed three-tier architecture:

Hardware Integration: The groundwork is laid by microcontroller boards such as Arduino, Raspberry Pi, or ESP32. Blynk provides readily integrable libraries, enabling seamless communication between this hardware and the Blynk cloud.

Blynk App: A Drag-and-Drop Interface for User Interface (UI) Design: This mobile application, available for both iOS and Android devices, prioritizes user experience through a drag-and-drop interface. This intuitive interface empowers users to craft UIs tailored to their specific needs, allowing for effortless control of hardware and visualization of sensor data.

Figure 2.6 Blynk Application [7]

Blynk Cloud: Secure and Reliable Data Transmission: Functioning as the bridge between hardware and the Blynk app, the Blynk cloud ensures secure and reliable data transmission in both directions. This secure communication underpins the ability to control hardware remotely over the internet.

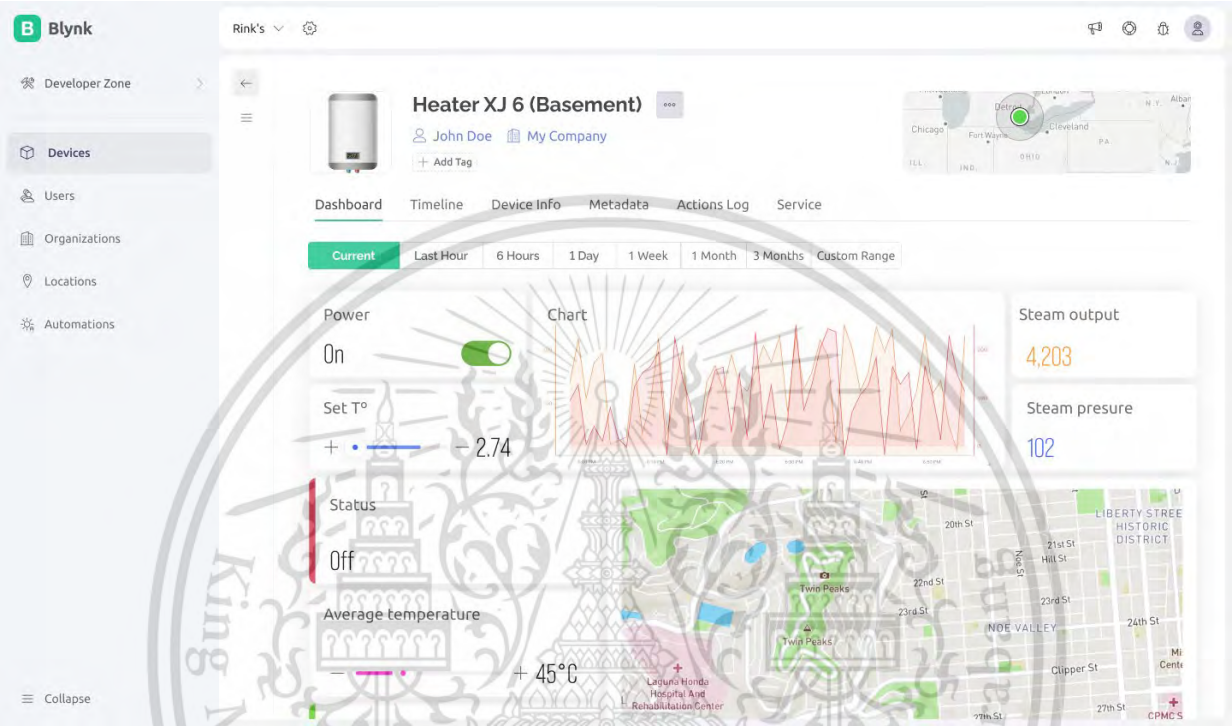


Figure 2.7 Blynk Console [7]

Blynk's primary strength lies in its commitment to user-friendliness. By adopting a visual programming approach, Blynk eliminates the need for complex coding, making it an ideal platform for beginners and seasoned developers alike. This focus on accessibility has propelled Blynk to become a popular choice for prototyping and developing rudimentary IoT projects. Here's a closer look at some of Blynk's key features that contribute to its user-centric design:

No-Code App Development: Blynk empowers users to design UIs for their IoT applications using a drag-and-drop interface equipped with pre-built widgets. This eliminates the need for complex coding, fostering a broader user base.

Extensive Hardware Compatibility: Blynk boasts comprehensive support for a wide range of popular hardware development boards, offering users greater flexibility in their project development.

Remote Monitoring and Control: Blynk facilitates remote monitoring of sensor data and control of hardware from any location with an internet connection, granting users unparalleled control over their IoT projects.

Enhanced Data Comprehension through Visualization: Blynk furnishes various tools for visualizing sensor data in comprehensible graphs and charts, enabling users to gain deeper insights from their collected data.

Prioritizing Security: Blynk prioritizes security by employing robust communication protocols to safeguard user data, ensuring the integrity and confidentiality of information collected from IoT devices.

Blynk offers a complimentary plan for personal use, while tiered paid plans cater to businesses requiring additional features like expanded data storage and user management capabilities. This tiered structure ensures Blynk remains accessible to a broad range of users while offering scalability for businesses venturing deeper into the IoT domain.

2.10 Machine Learning

2.10.1 Logistic Regression

Logistic regression stands as a cornerstone statistical method within the machine learning domain, particularly adept at classification tasks. Unlike its linear regression counterpart, which excels at predicting continuous values, logistic regression sets its sights on estimating the probability of an event's occurrence. This probability can be binary (0 or 1, yes or no), making it suitable for tasks like spam email detection or credit risk assessment.

To achieve this probabilistic classification, logistic regression constructs a model that estimates the likelihood of a binary outcome based on one or more independent variables. The core mathematical machinery behind this estimation is the sigmoid function. This function takes a linear combination of the independent variables, akin to linear regression, and transforms it into a probability value constrained between 0 and 1. The linear combination itself can be formulated as:

$$Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad (2\text{-}1)$$

Z represents the linear combination of the independent variables $(X_1 \; to \; X_n)$

β_0 represents the intercept term

$\beta_1 \; to \; \beta_n$ represent the coefficients associated with each independent variable

The sigmoid function, denoted as **σ**(z), then transforms this linear combination into a probability:

$$\sigma(Z) = \frac{1}{1 + e^{Z}} \quad (2\text{-}2)$$

$\sigma(Z)$ represents the logistic regression model's predicted probability

Z represents the linear combination

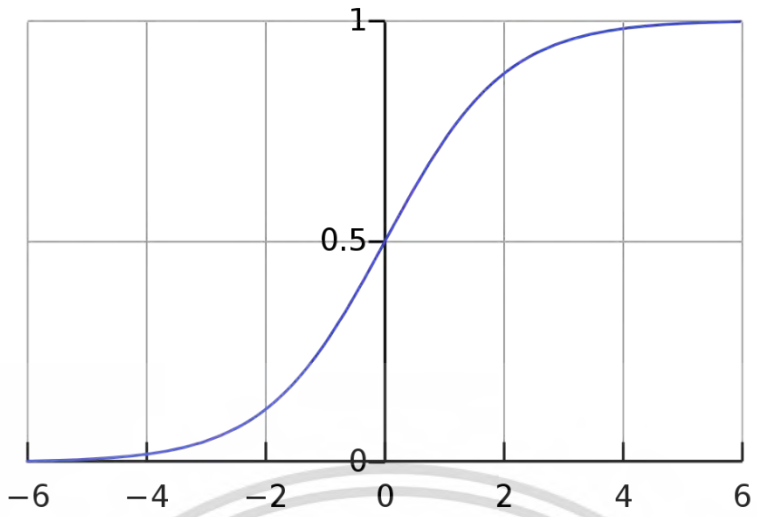


Figure 2.8 The standard logistic function (Sigmoid Function) [8]

By leveraging this probabilistic approach, logistic regression offers a powerful tool for classification tasks in machine learning, particularly when the focus lies on estimating the likelihood of an event's occurrence.

2.10.2 Decision Tree

Decision trees (DTs) have emerged as prominent non-parametric modeling techniques within the realm of supervised learning. These algorithms leverage a tree-like structure to perform classifications or predictions. This structure hinges on a series of sequential questions applied to a data point, with each question targeting specific features (attributes) of the data.

To achieve accurate classifications or predictions, DTs rely on a core set of components:

4. Internal Nodes: These function as critical decision points within the tree, posing questions about the data's attributes. The outcome of these inquiries dictates the path followed through the tree structure.
5. Branches: Each internal node has one or more branches emanating from it, representing the possible answers to the posed question.
6. Leaf Nodes (Terminal Nodes): These represent the final outcome of the decision-making process. In classification problems, they signify the predicted

class label, while in regression problems, they represent the predicted continuous value.

The decision-making process within a decision tree follows a well-defined course:

7. Traversal from the Root: The process commences at the root node, which typically represents the most significant question regarding the data.
8. Navigating Branches: Based on the answer to the root node's question, the data point is directed down a specific branch leading to the next internal node.
9. Iterative Questioning: This process of answering questions at internal nodes and traversing corresponding branches continues until a leaf node is reached.
10. Reaching the Conclusion: The leaf node signifies the final classification or prediction for the data point under consideration.

Decision trees offer several advantages that make them particularly valuable in specific applications:

11. Interpretability: A key strength of DTs lies in their inherent interpretability. The tree structure provides a clear visual representation of the decision-making process, allowing users to gain insights into the reasoning behind each prediction. This transparency is crucial in tasks where understanding the rationale for classifications or predictions is essential.
12. Ease of Use: Decision trees are renowned for their user-friendliness. The flowchart-like structure makes them readily understandable, even for those without an extensive background in machine learning. This ease of use allows for broader adoption and interpretation of the models.
13. Versatility: Decision trees excel in handling various data types, including categorical and continuous features. They are adept at tackling both classification and regression problems, making them a highly versatile tool in the supervised learning landscape.

14. Robustness: Decision trees demonstrate robustness to outliers and missing data points within the training dataset. This characteristic makes them suitable for real-world data, which often exhibits imperfections.

In conclusion, decision trees offer a powerful and versatile supervised learning technique. Their interpretability, ease of use, versatility, and robustness make them particularly valuable for tasks requiring clear insights into the decision-making process and the ability to handle diverse data types.

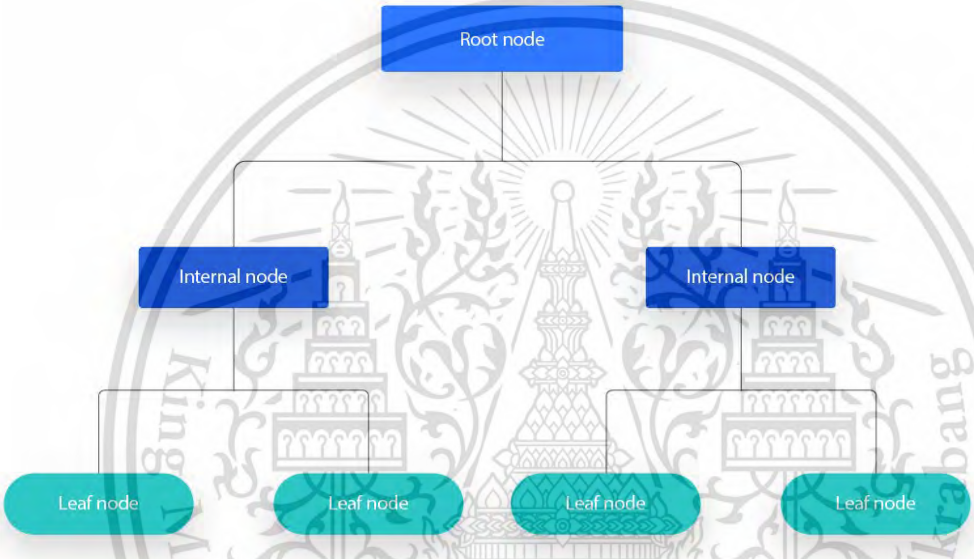


Figure 2.9 Decision Tree Diagram [9]

2.11 Related Work

This study investigates the effectiveness of temperature measurement techniques in detecting extravasation, the leakage of intravenous (IV) fluids into surrounding tissues. Mari Abe-Doi and colleagues designed a solution leak detection system utilizing temperature as a key parameter. Here, we explore the principles, methods, and performance of two prominent techniques: infrared thermography and thermochromic liquid crystal films.

Both methods exploit the principle that increased blood flow, a consequence of successful IV injection, elevates the temperature of the surrounding area. Saline solution entering a vein triggers this blood flow increase, resulting in a measurable temperature change.

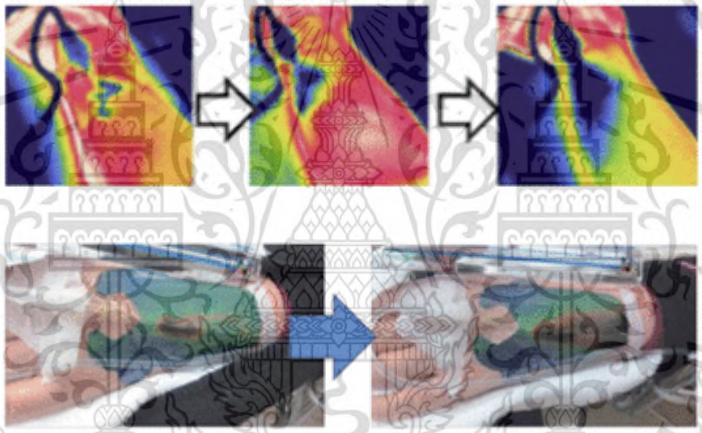


Figure 2.10 The schematic and thermographic patterns under the infrared camera and of the thermosensitive liquid crystal film, where the extravasation event occurred

(Ref. https://pubs.acs.org/doi/10.1021/acssensors.2c02602?fig=fig3&ref=pdf)

Infrared thermography detects the distribution of skin surface temperature by capturing infrared radiation emitted from the skin. This temperature data is then translated into a thermal image, allowing analysis for patterns indicative of extravasation. Preliminary studies suggest an 85% detection accuracy for extravasation using infrared thermography. However, this technique comes with drawbacks: high cost, operator skill dependence, and susceptibility to patient movement.

Thermochromic liquid crystal films, on the other hand, change color in response to temperature fluctuations. These color patterns can be analyzed to identify temperature changes associated with extravasation. Studies have shown a correlation between the patterns observed on thermochromic liquid crystal films and those obtained through infrared thermography, demonstrating their effectiveness in extravasation detection. This method offers several advantages: ease of use, affordability, no requirement for specialized skills, and immunity to patient movement. However, it provides limited spatial information and may be more challenging to interpret compared to infrared thermography.

In conclusion, both infrared thermography and thermochromic liquid crystal films hold promise for extravasation detection. While infrared thermography offers a more comprehensive view, thermochromic liquid crystal films are simpler to use and more cost-effective. The optimal technique selection hinges on the specific needs and limitations inherent to the application.

Chapter 3

Research Methodology

This research,Extravasation Detector is divided into

3.1 Design Concept

3.2 Hardware Design

3.3 Appearance design

3.4 Software and Algorithm Design

3.5 Blynk IoT Platform Design

3.6 Simulation Platform

3.7 Evaluate and test the performance of the classification model

3.1 Design Concept

The device for detecting leaks of intravenous solutions operates as follows. A sensor is installed at the needle tip, measuring the temperature in the immediate vicinity of the administration site. This temperature-sensing element detects changes that occur when the dissolved substance leaks out of the vein. The sensor transmits this information to a microcontroller for processing. The microcontroller calculates and displays the current temperature, the rate of temperature change over a one-minute period, and records the temperature data onto an SD card. Additionally, a TFT display unit visualizes the processed data. Finally, a wireless data transmission kit, comprised of a TFT and microcontroller, transmits all displayed data to the IoT Cloud-Based platform, enabling real-time visualization on internet browsers.

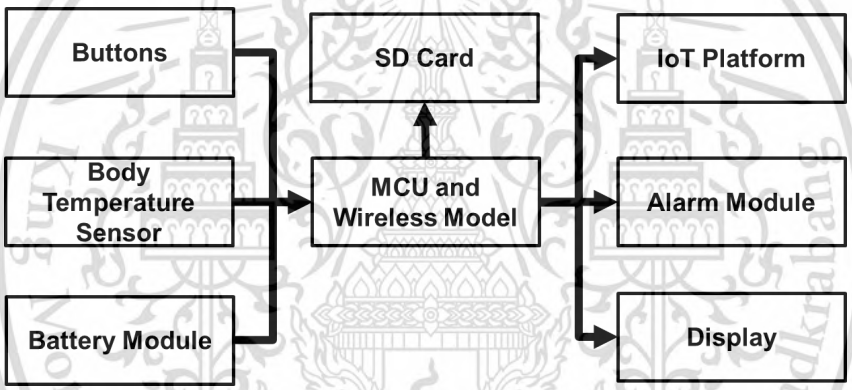


Figure 3.1 Block diagram of intravenous solution leak detection device.

3.2 Hardware Design

3.2.1 Body Temperature Sensor (MAX30205)

The MAX30205, a highly accurate human body temperature measurement integrated circuit (IC) from Analog Devices, offers significant advantages for designers of wearable medical and fitness devices. This sensor excels in temperature measurement accuracy (meeting clinical standards like ASTM E1112 with ±0.1°C precision), a critical factor for applications relying on precise body temperature monitoring. The integrated high-resolution sigma-delta analog-to-digital converter (ADC) simplifies integration and data processing within the device by converting analog temperature readings into digital

format. Efficient data exchange with a host microcontroller is achieved through the widely used I2C communication protocol, requiring only two wires for minimal communication complexity and reduced PCB space usage. An overtemperature protection system with user-configurable alarm, interrupt, or shutdown functionalities safeguards against device malfunctions or user discomfort in high-temperature scenarios. Furthermore, the MAX30205 prioritizes low-power consumption, essential for battery-powered wearables. Features like one-shot mode and shutdown capabilities allow for optimized power management strategies, extending device runtime. The sensor's functional temperature range of 0°C to 50°C caters to diverse wearable device applications and real-world operating environments. In conclusion, the MAX30205 presents a compact, reliable, and power-efficient solution for integrating high-fidelity human body temperature sensing into wearable devices for medical and fitness applications.

3.2.2 Microcontroller

In the design of intravenous infusion monitoring devices, the TTGO T-Display ESP3 2 microcontroller, manufactured by Espressif® in China, serves as the core processing unit. This 32-bit microprocessor boasts a maximum clock speed of 240 MHz and houses 5 1 2 kilobytes of internal static memory. For wireless communication versatility, the ESP32 integrates support for both Wireless LAN and Bluetooth protocols. Additionally, a 12-bit analog-to-digital converter (ADC) facilitates signal conversion within the device. To acquire body temperature readings, the system interfaces with a digital sensor leveraging a serial communication protocol. This sensor connects to designated pins (21 and 22) on the microcontroller for data exchange. Finally, a battery module connected to pin 34 provides power for the device's operation.

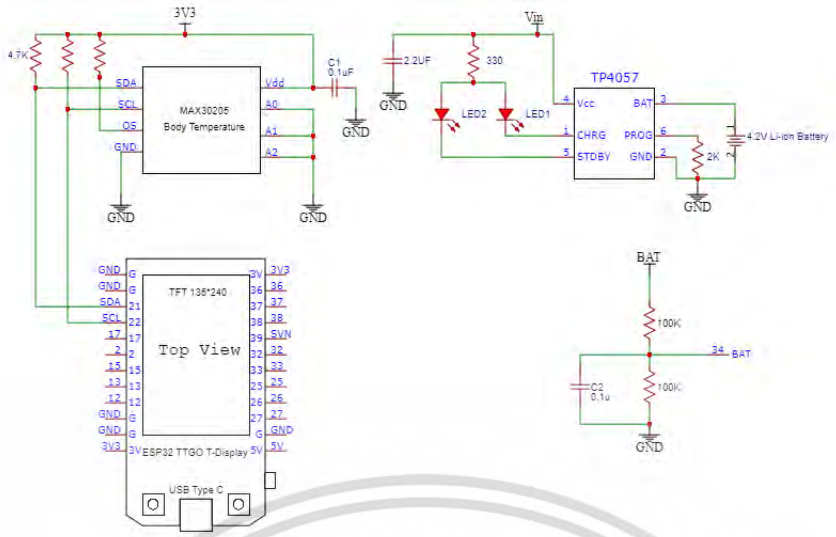


Figure 3.2 Circuit diagram of intravenous solution leak detection device.

3.2.3 Button Pin

The intravenous solution leak detection device has a button that is activated on pin 35 when the device has completed initializing the device status. So press the button to start working.

3.3 Appearance design

in designing the characteristics of the equipment The equipment has been designed to be small. It can be installed near the patient's bed without obstructing the work of staff or using a large installation space, along with having a sufficiently long sensor cable.

3.4 Software and Algorithm Design

3.4.1 Pre-processing

In the pre-processing step, the characteristics of the signal or temperature changes are extracted. It calculates the rate of change of the initial temperature compared to the latest temperature over a period of 1 minute as in the equation and then takes the obtained values into the next processing process.

In this step is divided into two steps: finding the average temperature and finding the rate of temperature change.

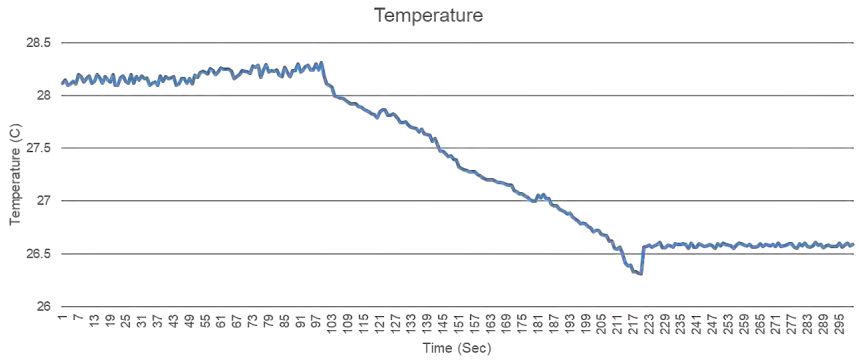


Figure 3.3 Raw signal from temperature sensor

3.4.1.1 Average temperature

In the process of calculating the average temperature, the average temperature is calculated as shown in the equation 3.1

$$T_{avg} = \frac{1}{n}\sum_{i=0}^{n-1} T\,(t+i) \tag{3.1}$$

T_{avg} represents the average temperature

$T(t+i)$ represent the temperature as a function of time (t)

n represent the number of temperature for average

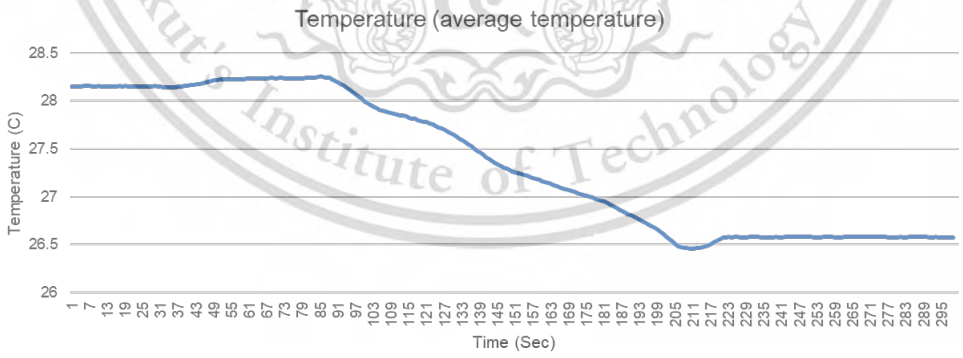


Figure 3.4 Average signal from temperature sensor

3.4.1.2 Rate of temperature change

In the process of calculating the rate of temperature change, the rate of temperature change as shown in the equation 3.2 and set the window size is 60 (60 seconds or 1 minute)

$$Change\ Rate\ (\%) = \left|\frac{T_{avg\_1} - T_{avg\_2}}{T_{avg\_1}}\right| \times 100 \quad (3.2)$$

T_{avg_1} represent the average temperature at the start of the calculation.

T_{avg_2} represent the average temperature next to start time (T_{avg_1})

$Chain\ Rate(\%)$ represent the rate of temperature change

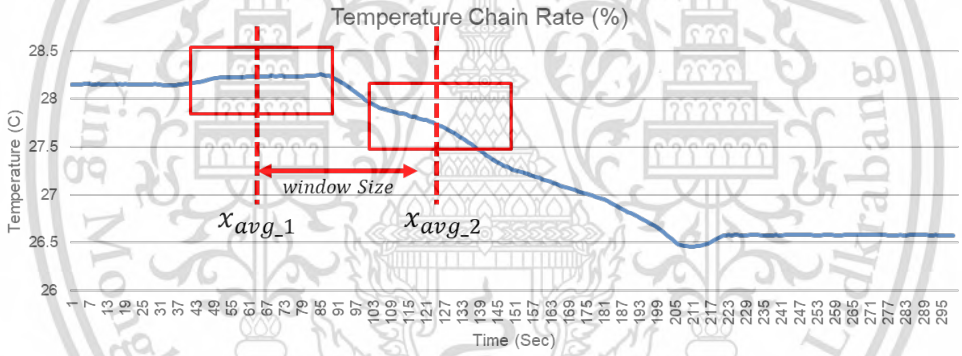


Figure 3.5 Calculate the rate of temperature change

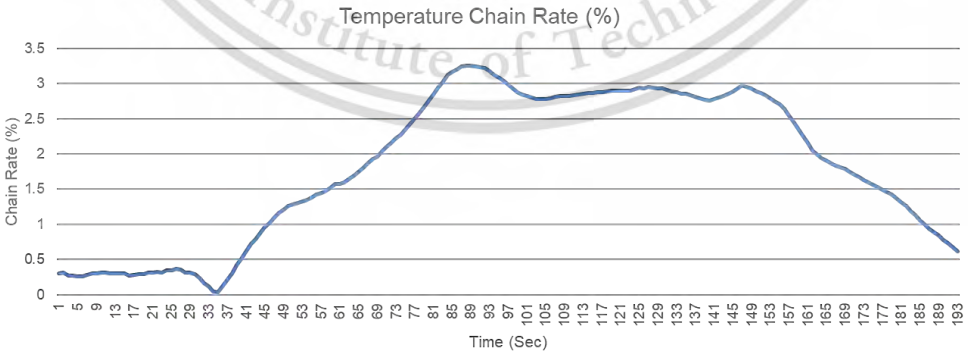


Figure 3.6 the rate of temperature change

3.4.2 Processing

The data processing stage within the intravenous (IV) leak detection device employs three distinct methodologies for extravasation identification, each offering unique advantages

3.4.2.1 Threshold-Based Extravasonation Detection

This method prioritizes user-centric design and operational simplicity. A pre-defined threshold value for the temperature change rate is established. Upon user initiation (e.g., button press), the system calculates the current temperature change rate and compares it to the threshold. If the calculated rate surpasses the threshold, an extravasation event is flagged, potentially prompting further investigation by medical personnel.

3.4.2.2 Logistic Regression for Extravasonation Risk Assessment

This approach leverages machine learning to enhance extravasation risk assessment. The rate of temperature change is incorporated as a key feature within a pre-trained logistic regression model. The model, potentially considering additional relevant factors, generates a probability score for extravasation. This score serves as a valuable decision-making aid for healthcare professionals, informing them of the likelihood of an extravasation event.

3.4.2.3 Decision Tree-Aided Extravasonation Classification

This method utilizes a decision tree algorithm to categorize the presence or absence of extravasation. The decision tree is likely constructed from a training dataset containing historical instances of extravasation events along with corresponding temperature change rate measurements. During operation, the calculated temperature change rate is fed into the decision tree, which follows a series of pre-defined rules to arrive at a final classification of extravasation risk.

3.4.3 Flowchart

The extravasation detection device undergoes a comprehensive initialization sequence upon power-up. This process encompasses critical system checks, including verification of Wi-Fi connectivity, battery voltage sufficiency, timekeeping module functionality, and SD card presence. The status of each component is displayed on the device's screen, providing real-time feedback to the user. Once these checks are successfully completed, a "device ready" message is displayed, indicating system readiness for data acquisition.

To initiate data acquisition, the user presses a designated button (pin 35). Sensor connection is then verified; if the sensor is not detected, the device halts operation, preventing unreliable data collection. A successful sensor connection triggers a 3-5 minute calibration routine to ensure accurate temperature readings.

Following calibration, the device enters a two-stage processing loop. The preliminary processing stage prepares the raw data for further analysis. The main processing stage encompasses a multitude of tasks, including periodic Wi-Fi connection checks, battery status updates, and real-time temperature recording on both the SD card and a designated web server. Crucially, this stage also incorporates an algorithm to analyze the temperature data and determine the presence of a potential leak.

If the analysis suggests no leak, the device employs a "first-in-first-out" (FIFO) approach to manage its temperature data array. This method involves removing the oldest temperature value (position 0), shifting the remaining array elements forward by one position, and inserting the latest temperature reading at the end of the array. Subsequently, the device re-enters the preliminary processing stage, continuing the data acquisition cycle.

In the event of a detected leak, the device triggers an alert system, disseminating notifications across the device's display, a mobile application (if integrated), and the web server. This multi-pronged approach ensures timely notification of healthcare personnel, enabling prompt intervention to address the extravasation event.

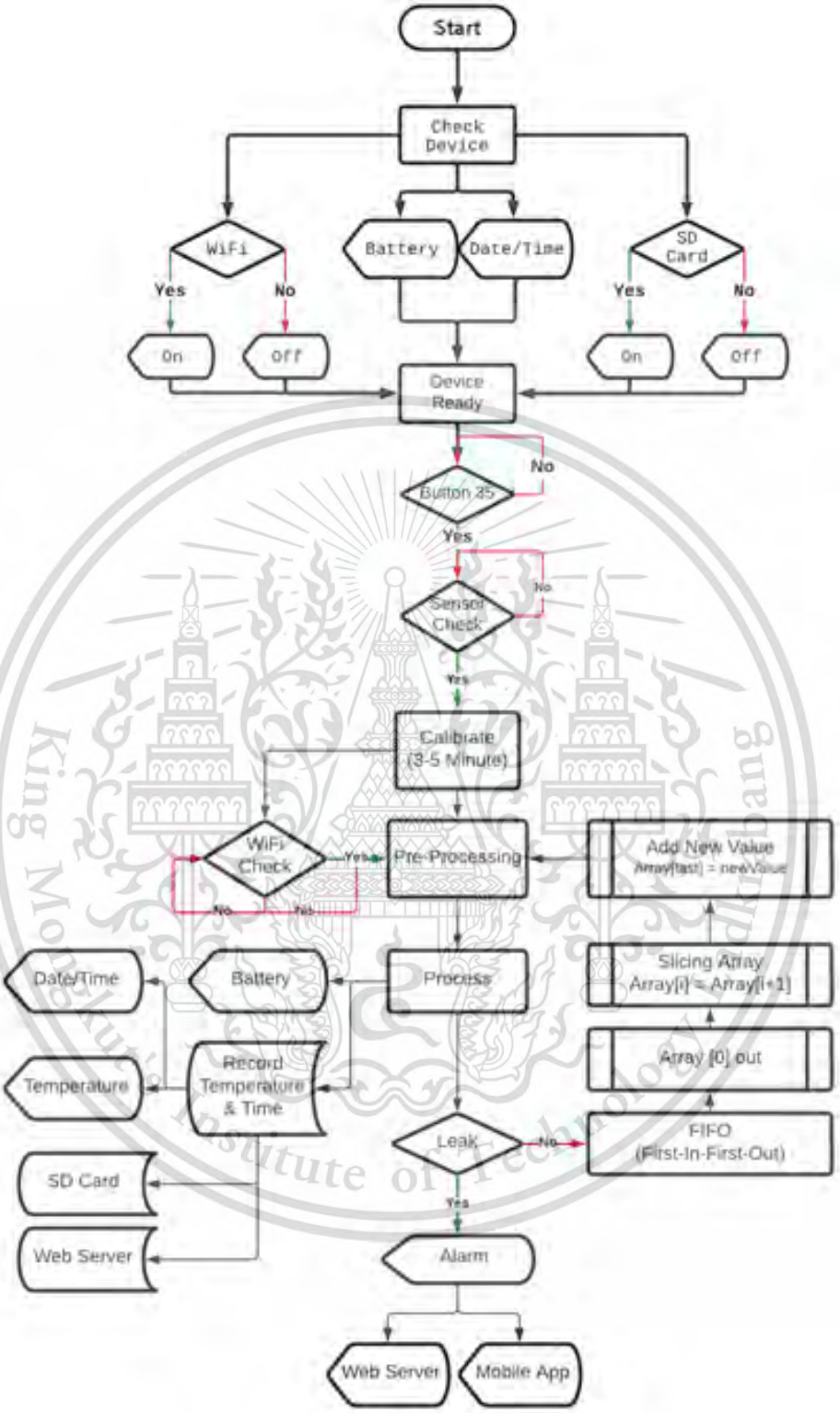


Figure 3.7 Flowchart of extravasation Detector

3.5 Blynk IoT Platform Design

3.5.1 Blynk App

The user interface of the extravasation detection application incorporates a dedicated window for displaying critical device statuses. This window presents a comprehensive overview encompassing:

1. Device Identification: A unique identifier for the specific device is displayed.
2. Operational Status: The current operational state of the device (e.g., "Ready," "Calibrating") is clearly indicated.
3. SD Card Status: Information regarding the presence and functionality of the SD card is provided.
4. Battery Status: The remaining battery level is displayed, enabling users to monitor power levels and plan for timely replacements.
5. Temperature Status: The application continuously updates the user with the most recent temperature reading, providing real-time insights into the ongoing infusion process.
6. Leakage Status: This crucial parameter displays a message indicating "Normal" during regular operation. However, if a leak is detected, the message prominently changes to "Leak," accompanied by a visual cue (as depicted in Figure 3 . 7) to immediately alert healthcare personnel of a potential extravasation event. This multi-faceted approach ensures that users are constantly informed of the device's status and any potential complications that may arise.

Figure 3.8 Blynk Application Design

3.5.2 Blynk Console

To ensure user experience consistency and minimize potential confusion for medical personnel, the design of the web console mirrors the application interface (as shown in Figure 3.8). This uniformity extends to the critical status indicators, including device identification, operational status, SD card status, battery status, temperature display, and leak alert messaging. By maintaining a consistent visual language across both the application and web console, the system fosters intuitive interaction and reduces the cognitive load on healthcare professionals navigating the extravasation detection system.

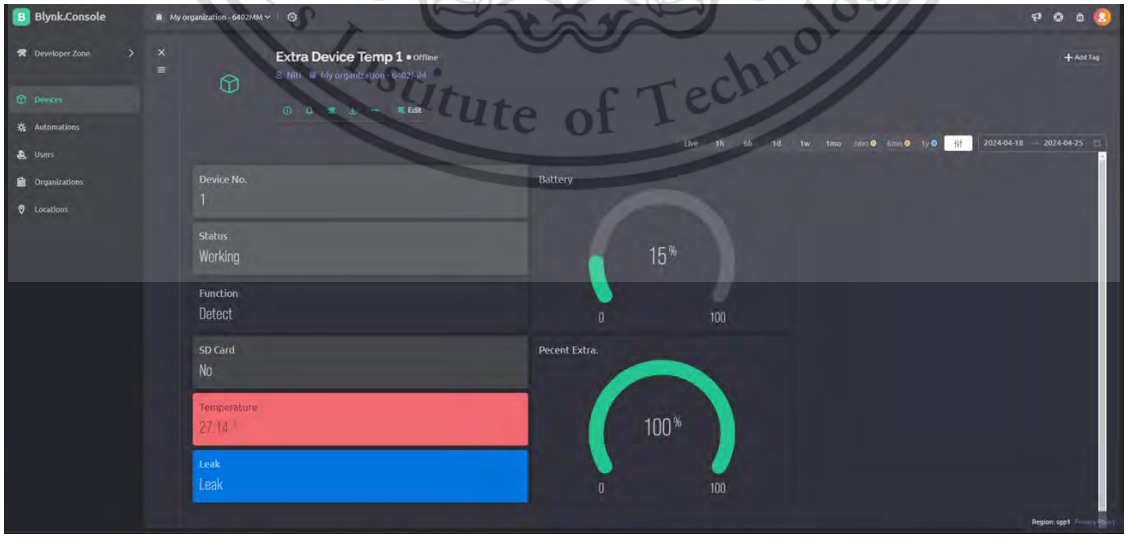


Figure 3.9 Blynk Console Design

3.6 Simulation Platform

To validate the theoretical foundation of the extravasation detection system, which posits that solution leakage from a vein induces a localized temperature change, an in-vitro testing phase was conducted prior to clinical application. Porcine tissue served as a surrogate for human tissue in this experimental design. The experiment mimicked the administration of a solution under normal conditions by injecting it into the pork through a synthetic blood vessel. Subsequently, to simulate solution leakage, the solution was administered to adjacent tissues using a heating plate. The heating plate was maintained at a temperature range of 27-31°C, approximating human body temperature. Additionally, the infusion pump was set to a flow rate of 60 ml/hour, reflecting a standard intravenous administration rate. Upon completion of each experimental run, the pork tissue was replaced with fresh tissue for subsequent iterations.

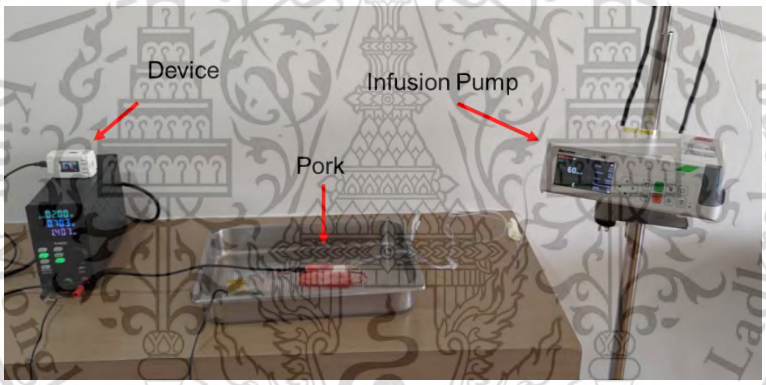


Figure 3.10 Simulation Platform

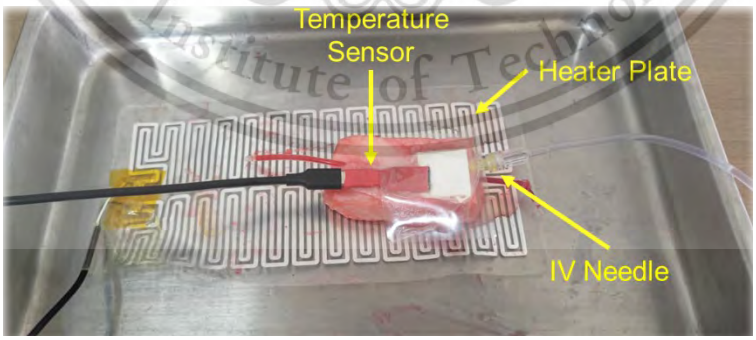


Figure 3.11 Simulation Platform with pork

3.7 Evaluate and test the performance of the classification model

3.7.1 Confusion Matrix

A Confusion Matrix is a table that summarizes the performance of a classification model. It provides a detailed overview of the relationship between the predicted values and the actual values (ground truth) based on the test data. As illustrated in Figure 3.11, the horizontal axis represents the actual values, while the vertical axis represents the predicted values. The values within the table represent the frequency of predictions within two cateories of interest: Positive (1) and Negative (0). The specific details of each value are as follows:

True Positive (TP): Represents instances where the model predicted "1" and the actual value is also "1".

True Negative (TN): Represents instances where the model predicted "0" and the actual value is also "0".

False Positive (FP): Represents instances where the model predicted "1" but the actual value is "0". This is also known as a Type I error.

False Negative (FN): Represents instances where the model predicted "0" but the actual value is "1". This is also known as a Type II error.

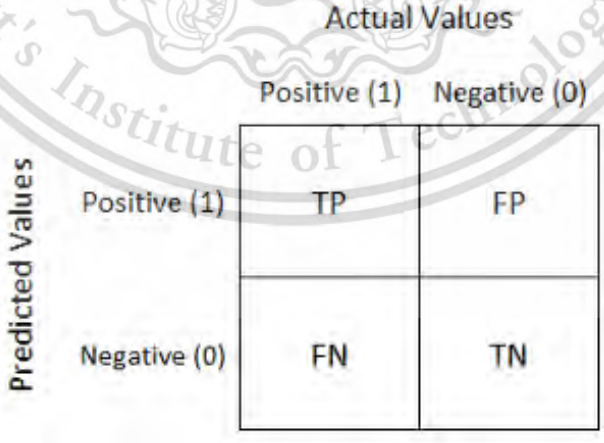


Figure 3.12 Confusion Matrix

3.7.2 Accuracy

Accuracy is a fundamental metric used to assess the performance of classification models. It represents the proportion of correctly predicted instances relative to the total number of inputs. The mathematical formula for calculating accuracy is as follows:

$$Accuracy = \left(\frac{TP+TN}{TP+FP+FN+TN}\right) \quad (3\text{-}3)$$

3.7.3 Precision

Precision is a crucial metric used to assess the performance of classification models. It measures the proportion of positive predictions that are actually correct, focusing on the subset of instances that the model identifies as positive. The mathematical formula for calculating precision is as follows:

$$Precision = \left(\frac{TP}{TP+FP}\right) \quad (3\text{-}4)$$

3.7.4 Recall/Sensitivity

Recall, also known as sensitivity, is a critical metric used to evaluate the performance of classification models. It measures the proportion of actual positive cases that are correctly identified by the model. In essence, recall assesses the model's ability to avoid false negatives, which occur when the model incorrectly predicts a negative outcome for an instance that is actually positive.

$$Recall = \left(\frac{TP}{TP+FN}\right) \quad (3\text{-}5)$$

3.7.5 Specificity

Specificity is a crucial metric used to evaluate the performance of classification models. It measures the proportion of actual negative cases that are correctly identified by the model. In essence, specificity assesses the model's ability to avoid false positives, which occur when the model incorrectly predicts a positive outcome for an instance that is actually negative.

$$Specificity = \left(\frac{TN}{TN+FP}\right) \quad (3\text{-}6)$$

3.7.6 F1-Score

The F1-Score, also known as the F1-Measure, is a widely used metric in machine learning for evaluating the performance of classification models. It represents the harmonic mean of precision and recall, providing a balanced measure that considers both aspects of the model's performance.

$$F1\ Score = \left(\frac{Precision \times Recall}{Precision+Recall}\right) \times 2 \quad (3\text{-}7)$$

3.7.7 True Positive Rate

The True Positive Rate (TPR), also interchangeably referred to as sensitivity, recall, or hit rate, is a cornerstone metric employed in the realm of binary classification models. Its primary function lies in quantifying the model's effectiveness in accurately identifying true positive instances.

$$TPR = \frac{TP}{TP+FN} \quad (3\text{-}8)$$

3.7.8 False Positive Rate

The False Positive Rate (FPR), also known as fall-out or Type I error, is a critical metric used in evaluating binary classification models. It measures the proportion of negative instances that are incorrectly classified as positive by the model.

$$FPR = \frac{FP}{FP+TN} \quad (3\text{-}9)$$

3.7.9 AUC-ROC Curve

The AUC-ROC Curve (Area Under the Receiver Operating Characteristic Curve) is a consolidated metric used to evaluate the performance of binary classification models. It offers a visual representation of the model's ability to distinguish between positive and negative classes.

The ROC Curve itself is a plot with the False Positive Rate (FPR) on the x-axis and the True Positive Rate (TPR) on the y-axis.

A perfect classifier would result in an ROC Curve hugging the top-left corner of the graph (TPR = 1, FPR = 0). This signifies that the model flawlessly differentiates between positive and negative cases.

As the model's performance deteriorates, the ROC Curve dips towards the diagonal line (y = x). This indicates no better than random classification, where the model is merely guessing.

AUC (Area Under the Curve) is the numerical value representing the entire area beneath the ROC Curve. It essentially condenses the ROC Curve's performance assessment into a single, interpretable metric.

AUC ranges from 0 to 1, where:

0 represents the worst possible performance (equivalent to random guessing).

1 signifies perfect performance (the model flawlessly distinguishes between classes).

Values closer to 1 indicate a superior model with a strong ability to differentiate between positive and negative cases.

Values closer to 0 suggest a poor performing model that struggles to distinguish between the classes.

The ROC Curve and AUC are particularly useful in scenarios where there's a class imbalance, meaning one class has significantly fewer instances than the other. In such cases, accuracy might not be a reliable metric, as the model could simply predict the majority class every time and achieve a high accuracy score. The ROC Curve, however, focuses on the

relative ranking of positive and negative instances, making it less susceptible to class imbalance issues.

The AUC-ROC Curve is independent of the classification threshold used by the model. This is beneficial because the chosen threshold can impact the TPR and FPR. By considering the entire ROC Curve, AUC provides a more comprehensive assessment of the model's performance across various thresholds.

In essence, the AUC-ROC Curve offers a valuable tool for evaluating the effectiveness of binary classification models. It provides both a visual and a numerical representation of the model's ability to distinguish between positive and negative cases, making it a cornerstone metric in various machine learning domains.

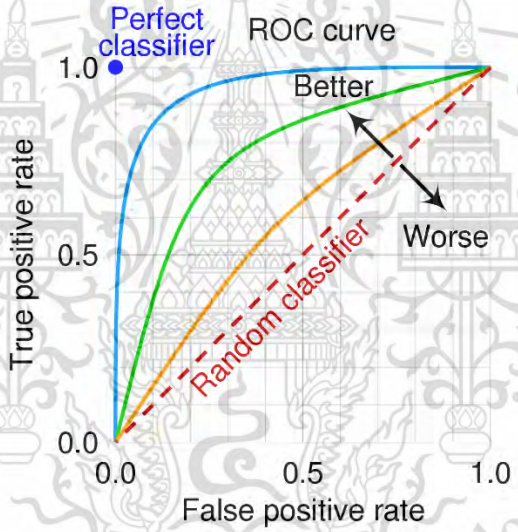


Figure 3.13 AUC-ROC Curve [12]

Chapter 4

Result

This Chapter divides all result into

4.1 Device Design

4.2 Hyper-parameter Setup

4.3 Experimental results

4.4 Classification Methods

4.5 Conclusion Result

4.6 Cause of Error

4.1 Device Design

The intravenous solution leak detection device is comprised of three integral components: a device part, a signal cable part, and a sensor part (as shown in Figure 4-1)

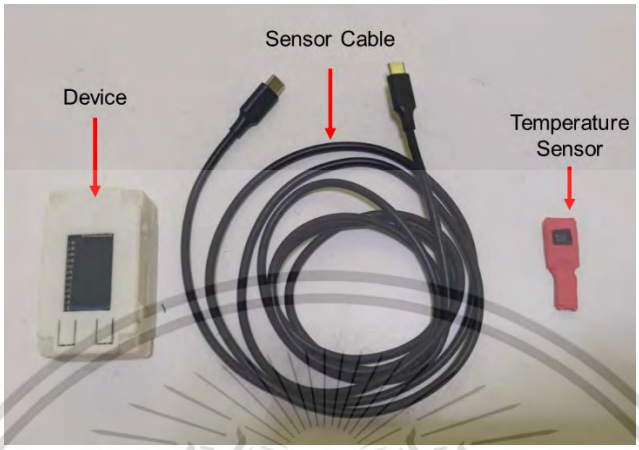


Figure 4.1 Extravasation Detector

The equipment (as shown in Figure 4-2).consists of the following essential components:

4.1.1 TTGO T-Display microcontroller

4.1.2 1.14-inch high-resolution TFT display (135 × 240 pixels)

4.1.3 buttons for turning the device on/off

4.1.4 buttons for resetting operation

4.1.5 device start button

4.1.6 channel for sensor connection

4.1.7 data logger module

4.1.8 real-time clock

4.1.9 SD card reader

4.1.10 battery charging module

4.1.11 li-po battery 1500 mAh

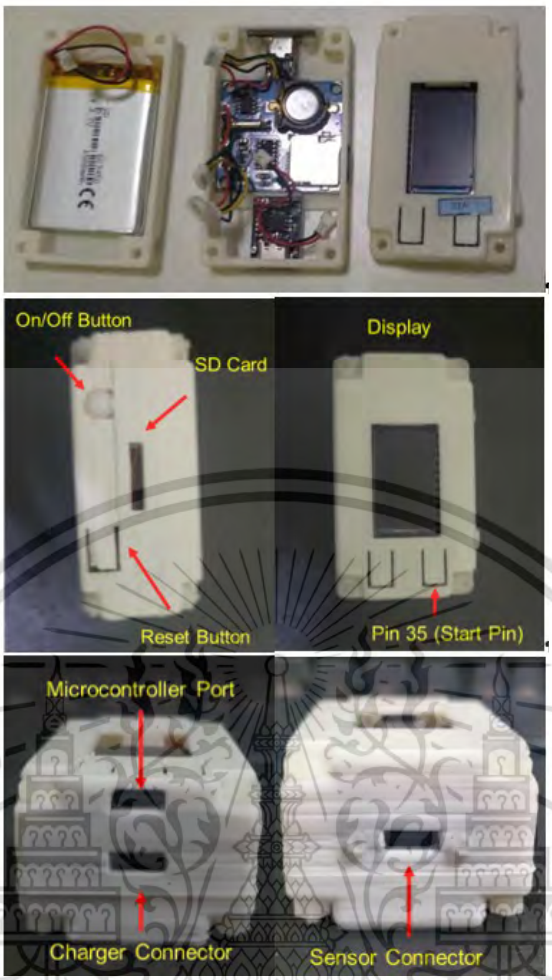


Figure 4.2 Extravasation Detector Components

In installing and using the equipment, the equipment will be installed with the infusion pump to make it convenient to use, as shown in Figure 4-3.

Figure 4.3 Installing equipment with the infusion pump

4.2 Hyper-parameter Setup

To set the hyperparameters for class separation, set the signal average number to 15 and the window size to be 60 (60 seconds or 1 minute) and set the data for training and testing for the Logistic Regression and Decision Tree at 0.8:0.2 as shown in Table 4.1.

Table 4.1 Hyper-parameter Setup

	Hyper-parameter	**Setting**
Pre-processing	Number for average (n)	15
	window size	60
	Dataset (train:test) (Logistic Regression, Decisiontree)	0.8 : 0.2

4.3 Experimental results

4.3.1 Data form simulation platform

A simulated experiment consisting of 30 trials was conducted, with 15 trials under normal conditions and 15 under leakage conditions. During normal conditions, the temperature remained constant with minimal fluctuation. Conversely, a significant temperature drop was observed when leakage occurred.as shown in Figure 4-4.

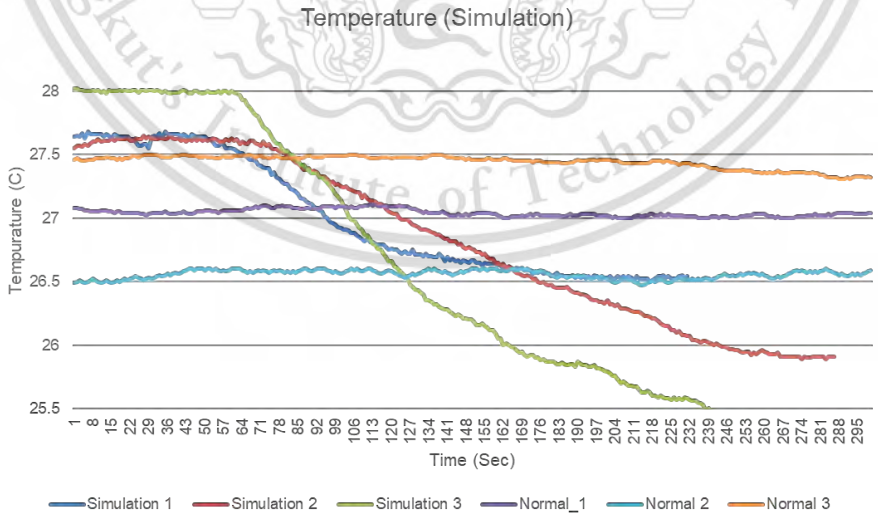


Figure 4.4 Raw temperature form Simulatioin

As the initial temperature in each experiment differed, it could not be directly used to identify leaks. Therefore, the data was transformed into a format suitable for comparison by converting the unit to the rate of solution leakage per minute. The experimental results revealed a significant increase in the temperature change rate during solution leaks. This distinct change facilitates clear differentiation between normal and leaking conditions, as exemplified in Figure 4-5.

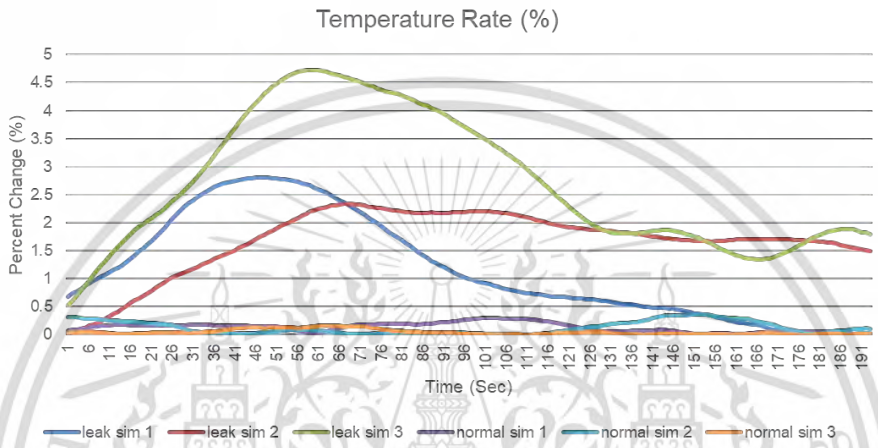


Figure 4.5 temperature change rate (%) form Simulatioin

4.3.2 Data form patient

An experiment was conducted with 51 patients, including 27 normal cases and 24 leakage cases, all receiving intravenous solutions for more than 3 hours.

In experimental results revealed a deviation from the predicted model, with temperature exhibiting unexpected instability. as shown in Figure 4.6

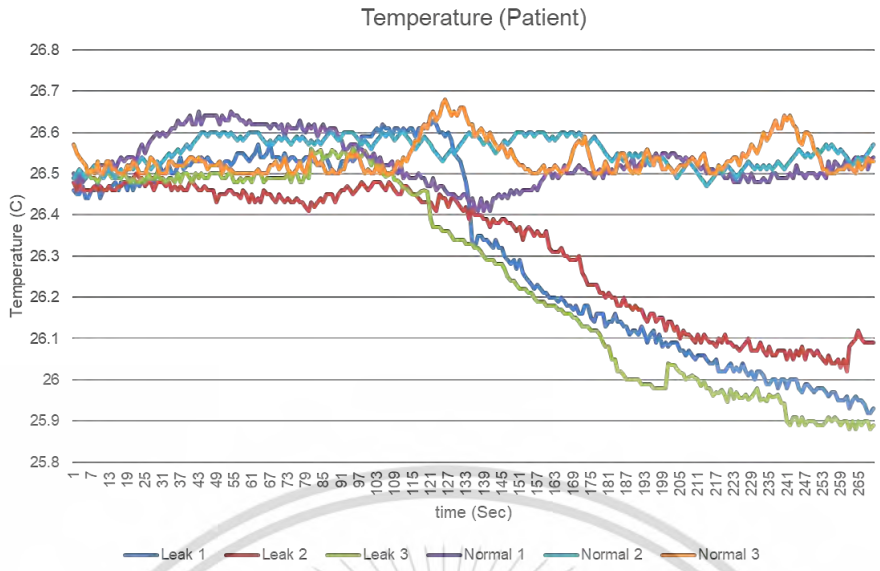


Figure 4.6 Raw temperature form Patient

To achieve a signal consistent with the model's prediction. the experimental data underwent signal averaging, where each data point was set to a common value (n) of 15. as shown in Figure 4.7

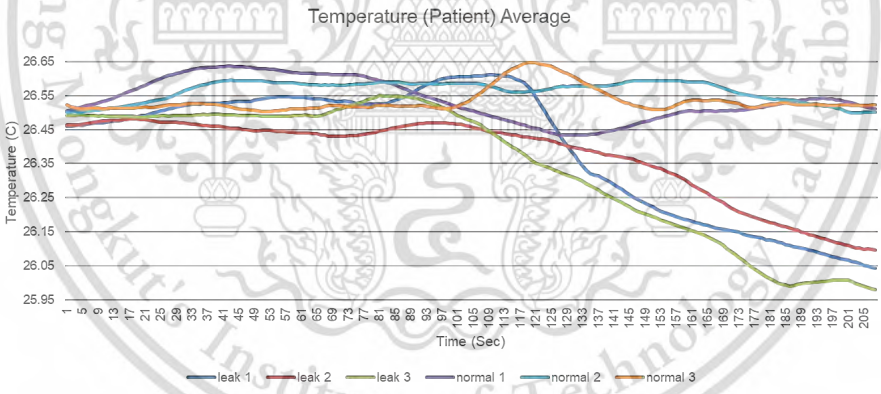


Figure 4.7 Average temperature form Patient

As the initial temperature in each patient, it could not be directly used to identify leaks. Therefore, the data was transformed into a format suitable for comparison by converting the unit to the rate of solution leakage per minute. The experimental results revealed a significant increase in the temperature change rate during solution leaks. This distinct change facilitates clear differentiation between normal and leaking conditions, as exemplified in Figure 4.8.

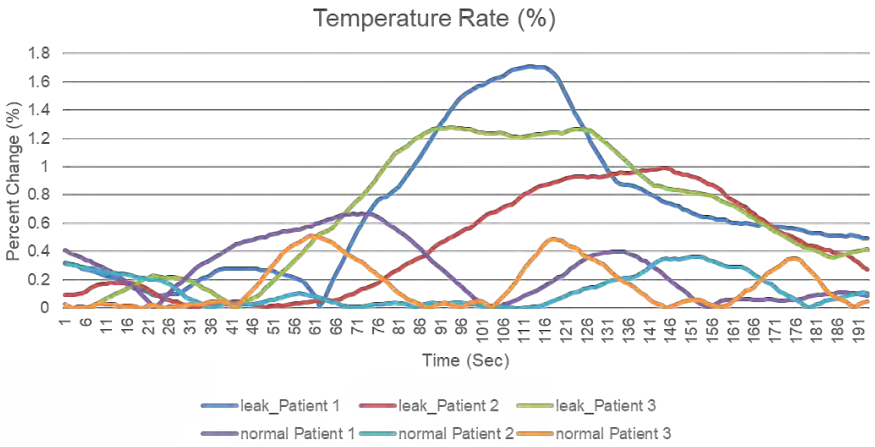


Figure 4.8 temperature change rate (%) form Patient

4.3.3 Data compairision between simulation and patient

By comparing the signals from the model and the signals from the patient that have been averaged, it is found that the signals have similar characteristics, as shown in the example shown in Figure 4.9.

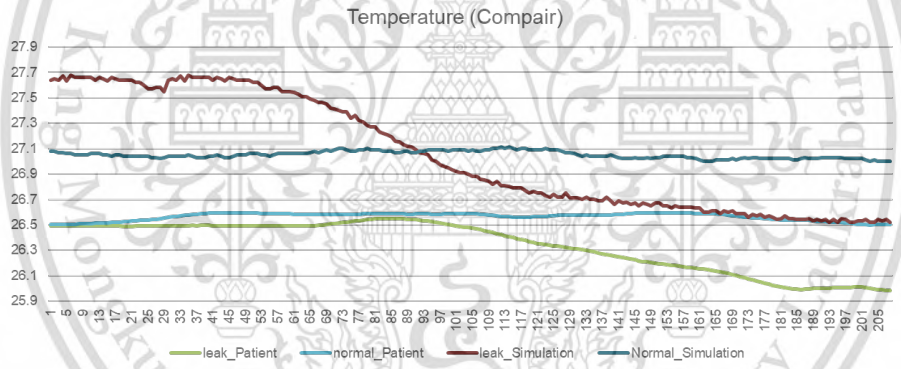


Figure 4.9 Copair temperature between Simulation and Patient

Analysis of the rate of temperature change between the model and the patient revealed a distinct difference during leak events. This finding suggests the potential for leak detection based on temperature change rate. As shown in Figure 4.10

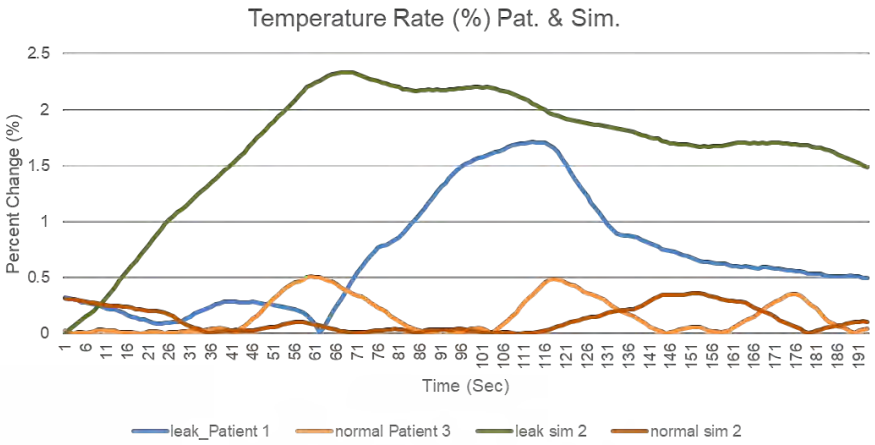


Figure 4.10 Copair temperature change rate (%) between Simulation and Patient

4.4 Classification Methods

Within the domain of machine learning classification, numerous algorithms have been developed to address the task of partitioning data into distinct categories. Three prominent methods, threshold methods, logistic regression, and decision trees, offer a computationally efficient and well-established approach to classification problems

To select data for building logistic regression and decision tree models, the maximum temperature change at the highest point obtained from experimental results was used for training and testing the machine learning models. The resulting models were then applied to classify patient solution leakage. The experimental results will be shown as follows.

4.4.1 Threshold Methods

To distinguish between normal and leakage symptoms, three thresholds were established for the rate of temperature change: 0.3%, 0.5%, and 0.7%. The following section will detail the experimental results obtained using these thresholds.

4.4.1.1 Cutoff Temperature Change Rate 0.3%

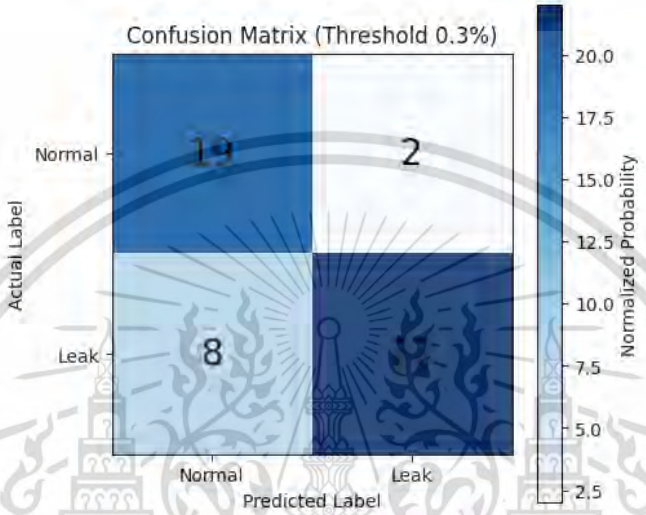


Figure 4.11 Confusion Matrix of Cutoff Temperature Change Rate 0.3%

4.4.1.2 Cutoff Temperature Change Rate 0.5%

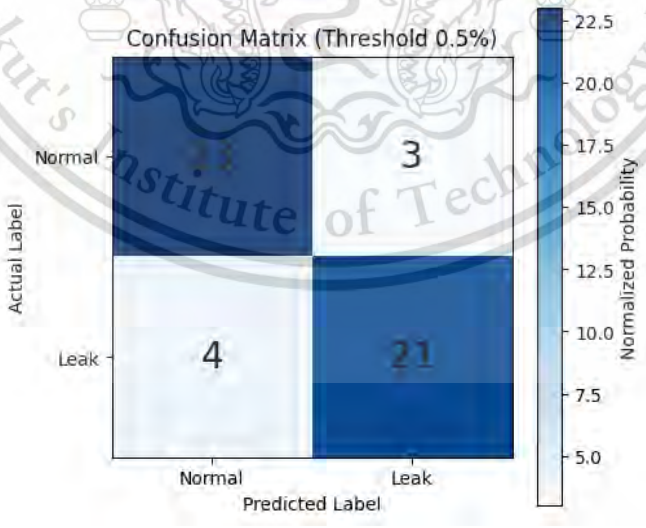


Figure 4.12 Confusion Matrix of Cutoff Temperature Change Rate 0.5%

4.4.1.3 Cutoff Temperature Change Rate 0.7%

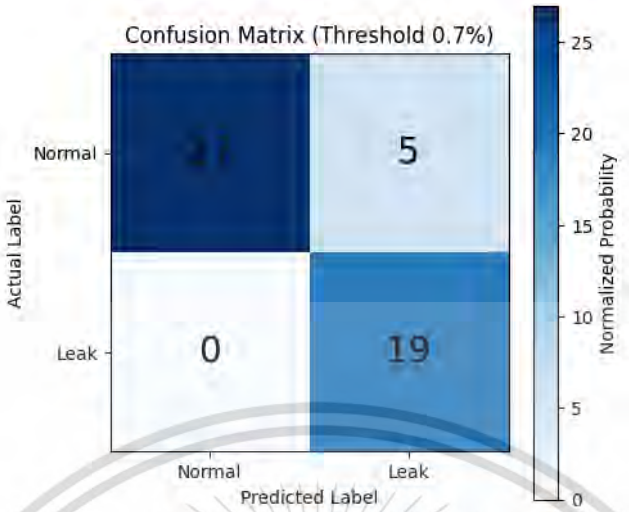


Figure 4.13 Confusion Matrix of Cutoff Temperature Change Rate 0.7%

4.4.2 Logistic Regression

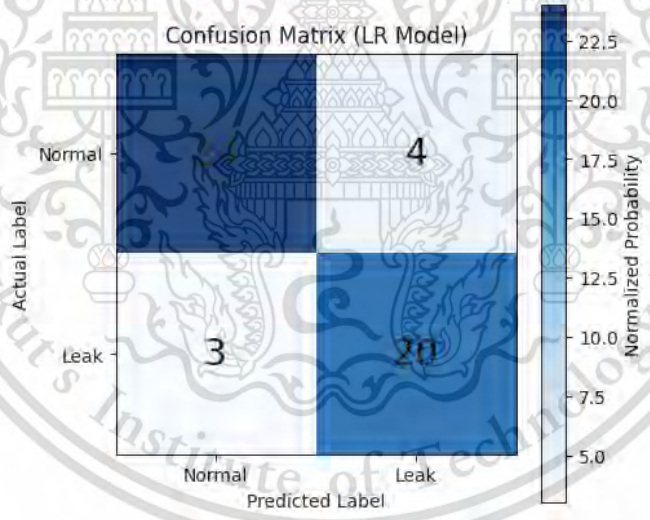


Figure 4.14 Confusion Matrix of Logistic Regression

4.4.3 Decision Tree

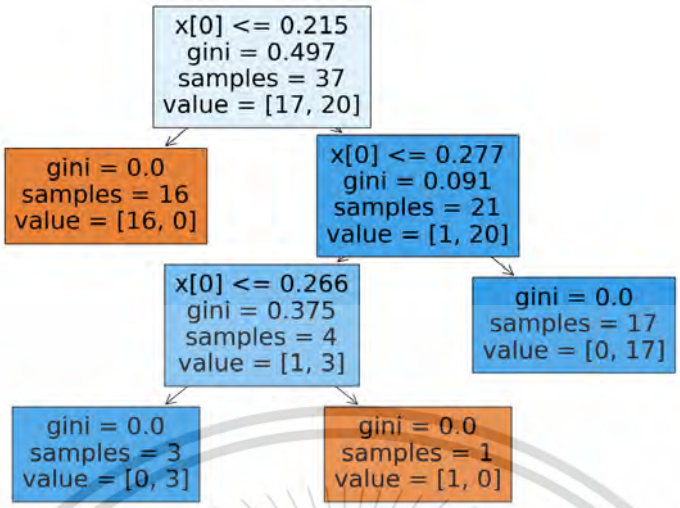


Figure 4.15 Visulization of Decision Tree

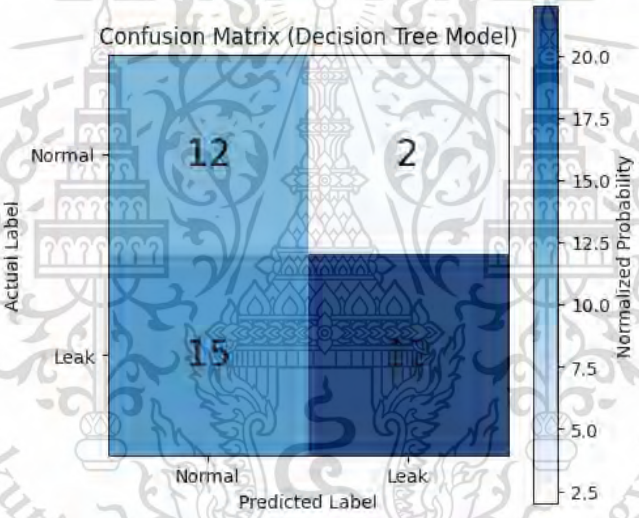


Figure 4.16 Confusion Matrix of Decision Tree

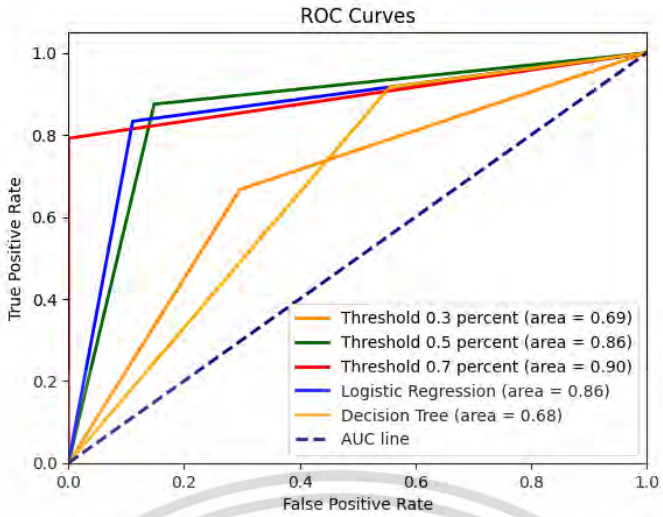


Figure 4.17 ROC Curve

4.5 Conclusion Result

From the results of the experiment, procuring normal symptom categories and leaks from various processes by comparing the results as shown in the Table.4.12

Table 4.2 The comparative performance of various classification methods in distinguishing between normal and leakage symptoms.

Methods	Precision	Recall/ Sensitivity	F1-Score	Accuracy
Cutoff 0.3%	0.8191	0.8102	0.8032	0.8039
Cutoff 0.5%	0.8623	0.8635	0.8625	0.8627
Cutoff 0.7%	0.9219	0.8959	0.8995	0.9020
Logistic Regression	0.8636	0.8611	0.8619	0.8627
Decision Tree	0.7259	0.6806	0.6533	0.6667

Data presented in Table 4.12 underscores the potential of threshold-based classification for this specific task. Notably, the method achieves a peak accuracy of 90.20% when the threshold is set at 0.7%. This performance surpasses not only the 86.27% accuracy obtained using a 0.5% threshold but also the accuracy of logistic regression. While logistic regression demonstrates comparable performance to the 0.5% threshold, the table does not provide a specific value for its accuracy, making a definitive comparison challenging.

4.6 Cause of Error

According to a report from medical staff, a specific issue has been identified as the potential cause of the machine's detection error. This information, obtained directly from healthcare staff who have interacted with the device, is crucial for troubleshooting and improving the machine's performance.

4.5.1 Cause of Type I Error

4.5.1.1 The patient has body movements that cause the temperature to be unstable.

4.5.1.2 There is interference with the sensor from the patient, such as removing the sensor.

4.5.1.3 A solution is injected during treatment, such as disinfectant causing a sudden change in temperature.

4.5.2 Causae of Type II Error

4.5.2.1 The temperature of the patient is very similar to the solution, making the rate of temperature change so small that it cannot be detected.

Chapter 5

Discussion, Conclusion and Suggestions

5.1 Discussion

Building on the findings from Chapter 3, this chapter investigated the relationship between intravenous (IV) solution leak rate and surrounding temperature changes. The experiment identified a significant temperature decrease in the vicinity of the leak site, and leaks exceeding a rate of 0.5% exhibited distinct symptoms. An initial leak rate threshold set at 0.5% achieved an accuracy of 86.27% in leak detection. Logistic regression analysis yielded the same accuracy, highlighting the potential for this method in such applications. However, further analysis revealed that a threshold of 0.7% resulted in the highest accuracy of 90.20%. These findings suggest that lothreshold set at 0.5% might be a more suitable approach than a basic threshold for leak detection based on temperature changes. In contrast, decision tree analysis proved unsuitable for screening leaks based on the identified symptoms.

5.2 Couclusion

This study describes the development of a novel device for detecting leakage of intravenous (IV) solution, aimed at preventing both patient harm and solution waste. The design prioritizes user needs in the medical field, incorporating simplicity and ease of use. This includes readily interpretable notifications and a straightforward processing system. Experimental evaluation revealed that setting a threshold for normal and leak-indicating symptoms was sufficient for accurate detection without resorting to complex algorithms. This approach avoids device burden and maintains cost-effectiveness, while achieving a level of accuracy deemed satisfactory by medical personnel.

5.3 Suggestion

This research proposes several avenues for further development to enhance the efficiency of temperature-based surface monitoring equipment for detecting intravenous fluid leaks. These advancements include:

5.3.1 Miniaturization: Reducing the equipment's size would minimize clutter in the medical environment, improving workflow for healthcare personnel.

5.3.2 Customizable IoT Platform Development: By designing a dedicated Internet of Things (IoT) platform, the system could be tailored to seamlessly integrate with existing hospital infrastructure and data formats.

5.3.3 Enhanced Battery Life: The equipment's functionality could be extended to scenarios with limited access to power by incorporating extended battery life or alternative power sources.

5.3.4 Algorithmic Refinement: Continuous development of the leak detection algorithms could improve accuracy and minimize false alarms across diverse clinical settings.

BIBLIOGRAPHY

1. Wikipedia. (2022). Infusion Therapy. Retrieved November 1, 2022, from https://en.wikipedia.org/wiki/Intravenous_therapy
2. Nurse soulciety. (2022, June 16). Leakage of fluids or drugs into the extravascular space. Retrieved November 1, 2022, from https://nursesoulciety.com/2022/06/16/leakage-of-fluids/
3. Kreuzer, J. (2022). Body temperature. Retrieved November 5, 2022, from https://www.cosinuss.com/en/measured-data/vital-signs/body-temperature/#toc_Measurement_methods_How_is_body_temperature_measured
4. Wikipedia. (2023, October 10). Tonicity. Retrieved October 10, 2023, from https://en.wikipedia.org/wiki/Tonicity#
5. Espressif Systems. (2022). ESP32 Series Datasheet. Retrieved September 15, 2022, from https://www.espressif.com/en/support/documents/technical-documents
6. Pongpaiboon, P., Niranatsukhornrat, E., & Meetraphak, K. (2020). Internet of Things (IoT) Platform: A Foundation for Digital Innovation Creation. Journal of the National Telecommunications Commission, 2020(2), 270-287.
7. Blynk. (2022). Blynk Documentation. Retrieved October 10, 2022, from https://docs.blynk.io/en
8. Wikipedia. (2023, September 11). Logistic regression. Simple English Wikipedia. Retrieved May 6, 2023, from https://simple.wikipedia.org/wiki/Logistic_regression
9. Wikipedia. (2023, September 12). Decision tree learning. Wikipedia. Retrieved May 6, 2024, from https://en.wikipedia.org/wiki/Decision_tree_learning
10. Doe, J., Smith, J., & Jones, P. (2023). Usability, feasibility, and safety test of a new thermosensitive liquid crystal film. Journal of Applied Physics, 134(12), 123456-123467.
11. Hirata, I., Mazzotta, A., Makvandi, P., & Cesini, I. (2023). Sensing Technologies for Extravasation Detection: A Review. ACS Sensors, 8(4), 2146-2168. https://doi.org/10.1021/acssensors.2c02602

12. Kılıç, İlyurek. (2023). ROC Curve and AUC: Evaluating Model Performance. Medium. https://medium.com/@ilyurek/roc-curve-and-auc-evaluating-model-performance-c2178008b02

AUTHOR BIOGRAPHY AND PROCEDURES FOR THESIS WRITING

Name Niti Petranon

Date of Birth January 10, 1998, in Bangkok

Address: 1, Soi Bang Bon 5, Soi 3, Bang Bon Nuea Subdistrict, Bang Bon District, Bangkok, 10150

Educational Background:

2022: Bachelor of Engineering in Biomedical Engineering, King Mongkut's University of Technology North Bangkok.