IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Ai-Driven Smart Photo-Biomodulation Assisted Transdermal Patch System For Enhanced Treatment Of Stomach Ulcer

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***Abstract**:* Stomach ulcers, a prevalent gastrointestinal disorder, often result from imbalances between digestive acids and protective mucosal layers. Traditional treatments, while effective to an extent, are limited by inconsistent drug delivery, patient non-compliance, and delayed healing. This research introduces a novel therapeutic approach that integrates artificial intelligence with a dual-phase treatment system comprising Photo-Biomodulation and a transdermal patch. The primary objective is to enhance drug absorption, regulate dosage intelligently, and accelerate tissue repair through a non-invasive, smart healthcare solution. The system employs a biocompatible, multilayered transdermal patch capable of delivering medication through the skin in a controlled manner. Simultaneously, a targeted Photo-Biomodulation technique, using low-level light therapy, stimulates cellular activity, boosts microcirculation, and supports mucosal regeneration. A pre-trained artificial intelligence model is embedded into the microcontroller unit of the system to personalize therapy based on pre-assessed patient-specific parameters such as age, ulcer severity, and healing phase. This model determines optimal drug dosage and therapy duration without the need for real-time sensors. By synchronizing these two therapeutic modalities, the proposed system ensures continuous and efficient treatment while minimizing systemic side effects. Moreover, the design allows portability and ease of use, promoting adherence and enabling remote deployment. Experimental simulations and modeling validate the feasibility of this approach, suggesting significant improvements in ulcer healing time and treatment outcomes. This research presents a promising advancement in personalized gastrointestinal care, potentially transforming conventional ulcer management strategies through an AI-driven, self-regulating, and patient-friendly therapeutic device.

Index Terms **– Smart transdermal patch, Ulcer management, Inflammation, Photo-Biomodulation, Drug delivery.**

I. Introduction

Stomach ulcers, medically referred to as peptic ulcers, are chronic lesions formed in the lining of the stomach or the upper section of the small intestine, primarily due to an imbalance between the protective mucosal defense mechanisms and harmful gastric factors. One of the leading causes of these ulcers is *Helicobacter pylori* infection, which compromises the mucosal barrier, resulting in inflammation and ulceration [1]. In addition to microbial infection, the prolonged use of nonsteroidal anti-inflammatory drugs (NSAIDs) significantly contributes to ulcer development by disrupting prostaglandin synthesis, thereby weakening mucosal protection [3]. Environmental and behavioral factors such as smoking, alcohol intake, stress, and poor dietary habits can further exacerbate ulcer severity [4]. If left untreated, peptic ulcers can result in serious complications including gastrointestinal bleeding, perforation, and in some cases, an elevated risk of gastric cancer [2]. Beyond the physiological consequences, these ulcers also contribute to substantial healthcare costs and reduced quality of life due to frequent hospital visits and long-term pharmacological dependency [5]. Traditionally, the treatment of stomach ulcers relies on a combination of proton pump inhibitors (PPIs), antibiotics to eradicate *H. pylori*, and mucosal protectants. However, drug resistance, poor patient adherence to multi-drug regimens, and systemic side effects present significant challenges [6]. An emerging and promising alternative to conventional oral treatments is the development of transdermal drug delivery systems (TDDS). These systems facilitate the controlled, non-invasive release of therapeutic agents through the skin, bypassing the hepatic first-pass metabolism and thereby improving drug bioavailability [7]. TDDS are particularly advantageous for chronic conditions like peptic ulcers, as they enable steady plasma drug concentrations and reduce gastrointestinal side effects. However, one major obstacle is the skin's natural barrier—the stratum corneum—which limits drug penetration. To overcome this, advanced materials and technologies such as microneedles, chemical enhancers, and smart hydrogels have been employed [8]. Microneedles painlessly perforate the stratum corneum to form microchannels that facilitate drug diffusion into deeper skin layers, significantly improving transdermal drug absorption [9]. Furthermore, the use of thermoresponsive hydrogels and nanofiber composites has advanced drug encapsulation and triggered release mechanisms, especially when paired with stimuli like body heat or near-infrared (NIR) light [3,7]. These hydrogel systems also support sustained release profiles suitable for long-term treatment of chronic ulcers [3]. Materials such as polyvinyl alcohol, chitosan, and polylactic-co-glycolic acid (PLGA) are frequently employed due to their biocompatibility and controlled degradability [8]. Parallel to TDDS, Photo-Biomodulation (PBM) therapy is gaining traction as a non-invasive adjunctive treatment for ulcer healing. PBM uses red or NIR light to stimulate tissue repair, reduce oxidative stress, and enhance mitochondrial activity, particularly by activating cytochrome c oxidase [4,5]. This process boosts ATP production and modulates inflammation, which collectively accelerates wound healing. The therapeutic potential of PBM has been explored for both superficial and deep tissue applications, including chronic wounds and inflammatory conditions [5,9]. Recent advances have led to the development of wearable, flexible light-emitting devices designed for localized PBM therapy. These devices integrate LED arrays on stretchable substrates that conform to the skin, delivering uniform illumination to the targeted region with minimal discomfort [2,4]. Notably, PBM applied to the abdominal skin has shown promise in indirectly aiding the healing of internal ulcers by enhancing local blood circulation and modulating immune responses [1,4]. The integration of TDDS and PBM into a single wearable system offers a dual therapeutic strategy—combining pharmacological treatment with biostimulation. Such a system can improve patient compliance by reducing the frequency of dosing and eliminating the gastrointestinal side effects associated with oral therapies [10]. Innovations like magnetic-guided robots for phototherapy, strain-programmed adhesive patches, and light-responsive microneedles are paving the way toward personalized, minimally invasive treatments for peptic ulcers and other chronic gastrointestinal conditions [1,2,8]. Ultimately, this integrated approach promises to revolutionize ulcer care, providing patients with effective, comfortable, and sustainable therapy.

II. LITERATURE SURVEY

2.1 Magnetic-Guided Flexible Origami Robot toward Long-Term Phototherapy of *H. pylori* in the Stomach

Developed a flexible origami robot navigated magnetically to deliver phototherapy to the stomach lining. The robot integrates light-emitting elements and folds into a compact form for targeted treatment. Performance was validated through in vitro gastrointestinal models and simulations, demonstrating effective long-term *H. pylori* inhibition using near-infrared phototherapy.

2.2 Strain-Programmed Adhesive Patch for Accelerated Photodynamic Wound Healing

Engineered a hydrogel-based adhesive patch with strain-programmed mechanics and photosensitizers for photodynamic therapy. In vitro and in vivo wound healing models tested its light-triggered antibacterial and tissue regeneration effects. The patch conforms to dynamic skin contours and accelerates healing under low-power visible light.

2.3 Near-Infrared-Responsive Nanofiber Hydrogel with Gradual Drug Release Properties for Wound Healing

Designed a near-infrared (NIR)-responsive nanofiber hydrogel embedded with drug-loaded nanoparticles. The hydrogel allows on-demand, controlled release of therapeutics upon NIR exposure. Evaluated for cytocompatibility, antibacterial efficacy, and wound healing using in vitro and murine models, showcasing improved tissue repair and infection control.

2.4 808-Nm Near-Infrared Laser Photobiomodulation versus Switched-Off Laser Placebo in Major Aphthae Management: A Randomized Double-Blind Controlled Trial
Conducted a randomized, double-blind clinical trial comparing 808-nm NIR laser photobiomodulation with a placebo in treating major aphthous ulcers. Subjects received either active laser or switched-off placebo across multiple sessions. Pain reduction and ulcer healing were assessed using visual analog scales and clinical observation.

2.5 Photobiomodulation at 660 nm Stimulates In Vitro Diabetic Wound Healing via the Ras/MAPK Pathway
Exposed diabetic fibroblast cultures to 660 nm light and measured proliferation, migration, and gene expression. Assessed Ras/MAPK signaling pathway activation post-irradiation. Results confirmed enhanced cell activity and wound closure capacity under controlled photobiomodulation, validating the molecular mechanism of light-induced healing.

2.6 The Novel Digital Therapeutics Sensor and Algorithm for Pressure Ulcer Care Based on Tissue Impedance
Created a digital sensor system that monitors tissue impedance variations to assess pressure ulcer severity. The algorithm classifies ulcer stages in real time. Tested on pressure ulcer-mimicking phantoms and patient data, the system showed high sensitivity and specificity for early detection and treatment planning.

2.7 Near-Infrared Stimulated Hydrogel Patch for Photothermal Therapeutics and Thermoresponsive Drug Delivery
Synthesized a hydrogel patch incorporating photothermal agents responsive to NIR light. Upon irradiation, the patch heats locally, enabling drug release through thermoresponsive mechanisms. In vitro drug diffusion and photothermal profiling were conducted. Demonstrated potential for combined localized hyperthermia and controlled drug delivery.

2.8 Degradable Microneedle Patch with Photothermal-Promoted Bacteria-Infected Wound Healing and Microenvironment Remodeling
Developed a degradable microneedle patch containing photothermal agents activated by NIR light. Microneedles deliver drugs into infected wounds, while photothermal heat promotes antibacterial activity and tissue remodeling. Evaluated via bacterial assays, tissue histology, and in vivo healing in infected animal models.

2.9 Photothermally Enhanced Antibacterial Wound Healing Using Albumin-Loaded Tanshinone IIA and IR780 Nanoparticles
Fabricated nanoparticles encapsulating Tanshinone IIA and IR780 within albumin matrices. Upon NIR exposure, the particles generated heat and released therapeutic agents. Tested in vitro for antibacterial effects and in vivo using infected wound models, demonstrating accelerated healing and reduced bacterial load through photothermal synergy.

2.10 Optical Wireless Communications for In-Body and Transdermal Biomedical Applications
Reviewed the design and implementation of optical wireless communication (OWC) systems for in-body and transdermal applications. Simulated transmission properties in tissue environments, analyzed link budgets, and proposed models for improving data throughput. Discussed potential for integrating OWC into implantable or wearable biomedical systems.

III. METHODOLOGY

1. Data Collection and AI Model Training

The success of the AI-driven smart photobiomodulation-assisted transdermal patch system hinges on a meticulously curated dataset and the development of an efficient machine learning model tailored for stomach ulcer treatment. The data collection phase involved sourcing anonymized patient information from publicly available biomedical datasets and peer-reviewed studies. The collected data included age, gender, weight, skin type, ulcer severity, drug dosage response, and previous treatment history. All data were verified for completeness and consistency before model training. A feature engineering process was implemented to enhance predictive performance by selecting variables that significantly impacted ulcer healing, such as drug absorption rate and skin permeability. This step was followed by normalization to maintain uniformity across input values. The dataset was split into training (70%), validation (15%), and testing (15%) subsets to ensure balanced learning and unbiased evaluation. Several machine learning models, including Support Vector Machines (SVM), Random Forests, and Gradient Boosting Machines, were tested to identify the most suitable algorithm. A neural network model, however, demonstrated superior performance in terms of classification accuracy and prediction stability. The model architecture included three hidden layers with dropout regularization to prevent overfitting. ReLU activation functions were used in hidden layers, while a sigmoid activation was applied to the output layer to enable binary classification between suitable and unsuitable treatment regimes. The model's objective was to predict the most appropriate photobiomodulation parameters (e.g., light intensity and duration) and drug dosage based on individual patient features. Hyperparameters such as learning rate, batch size, and epoch count were optimized using grid search and cross-validation. After training, the model was embedded into a firmware-compatible format for integration with the STM32 microcontroller. To facilitate local, offline operation, the trained model was exported to TensorFlow Lite format and stored on a USB drive, which is read by the microcontroller during system initialization. Ethical considerations were maintained throughout the process, with data anonymization and institutional guidelines strictly followed.

2. Transdermal Patch

The transdermal patch component was engineered using biocompatible and flexible layers to ensure safe and efficient drug delivery. The multilayered structure included a backing membrane, drug reservoir, rate-controlling membrane, adhesive layer, and release liner. The selection of materials focused on permeability, drug retention capacity, skin adherence, and user comfort. The backing membrane was fabricated using ethylene-vinyl acetate (EVA) for its flexibility and inert nature. The drug reservoir was composed of a hydrogel matrix infused with a pre-calibrated dose of anti-ulcer medication, tailored per the AI model’s recommendations. A rate-controlling membrane made from polyurethane regulated the release kinetics, ensuring consistent delivery throughout the application period. The adhesive layer was a medical-grade acrylate copolymer that provided optimal skin adhesion without irritation. A silicone-coated polyethylene sheet served as the release liner, protecting the patch until application. Assembly was carried out in sterile laboratory conditions using heat-sealing equipment to laminate layers without compromising drug integrity. The patch’s design allowed for modular integration with the photobiomodulation unit, ensuring both therapies could be administered concurrently. Each layer underwent mechanical stress testing, chemical compatibility assessment, and thermal analysis to ensure stability under operational conditions.Furthermore, prototype validation was performed through in vitro diffusion studies using synthetic skin analogs to mimic human epidermis. The results demonstrated consistent drug diffusion aligned with predicted values from the AI model. The patch's shelf-life and storage conditions were also evaluated to ensure efficacy during transportation and storage.

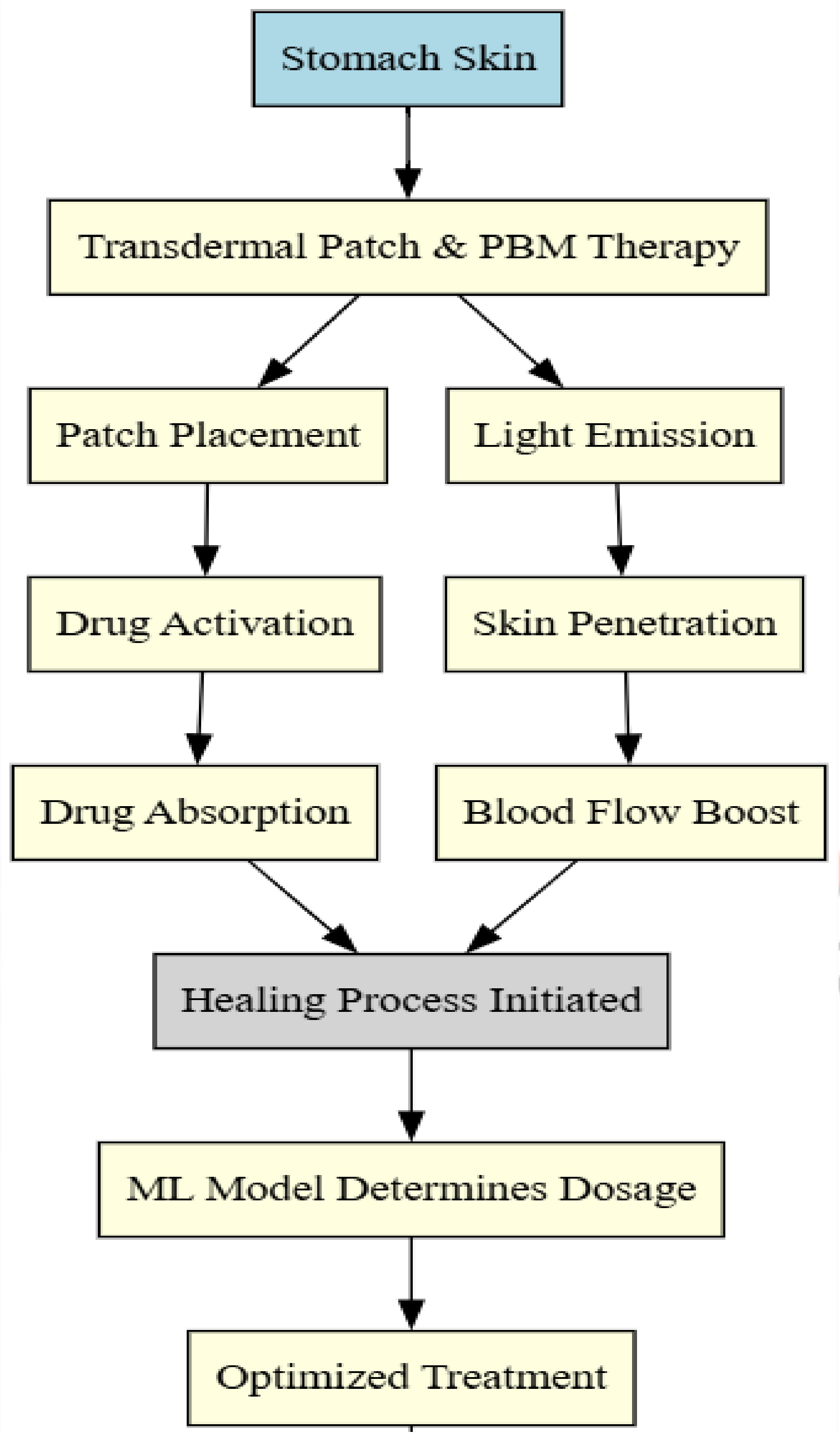
3. Photobiomodulation

The Photo-Biomodulation (PBM) unit was developed as a flexible, wearable component compatible with the transdermal patch. It comprised a matrix of light-emitting diodes (LEDs) emitting red and near-infrared (NIR) wavelengths, optimized for gastrointestinal therapeutic effects. The selection of wavelengths was guided by literature highlighting their bio-stimulatory impact on tissue regeneration and inflammation control. The flexible printed circuit board (PCB) embedded within the PBM unit was designed with copper traces and polyimide substrate, enabling both electrical conductivity and structural adaptability. LEDs were surface-mounted in a matrix arrangement to ensure uniform light distribution across the application site. A thin optical diffuser layer, fabricated from polydimethylsiloxane (PDMS), was added to mitigate light hotspots and enhance even penetration into underlying tissues. The power supply was provided by a 3.7V Li-Po battery with integrated thermal protection. A pulse width modulation (PWM) driver, specifically the MAX16819 IC, regulated LED intensity based on real-time parameters obtained from the AI model. The driver circuit was compactly embedded alongside the STM32 microcontroller, responsible for executing the therapy protocol. Firmware for the PBM system included user-defined light dose profiles, modulated by the AI-predicted treatment plan. The system also featured a fail-safe thermal cutoff mechanism to prevent tissue overheating. A clock module (DS3231) synchronized treatment timing with dual-phase therapy schedules. The entire PBM setup was encapsulated in a medical-grade silicone housing, ensuring protection from environmental exposure and patient movement. Biocompatibility and electrical safety tests were performed according to IEC 60601 standards to ensure user safety. Integration testing was conducted to validate synchronization between drug release and light therapy.

4. Dual Therapy Integration

The final system design involved the seamless integration of the AI-powered transdermal patch and photobiomodulation therapy into a single wearable platform. This dual therapy approach aimed to synchronize drug delivery with light stimulation to maximize therapeutic efficacy. Control of the integrated system was handled by the STM32 microcontroller, which housed the AI model and managed therapy execution. Upon device activation, the microcontroller read patient parameters from the USB drive and initiated the treatment protocol. Based on the AI model's prediction, it triggered the drug release motor and activated the PBM unit in a coordinated manner. The dual therapy proceeded in two phases: Phase I focused on photobiomodulation to increase blood circulation and cellular permeability at the ulcer site. After a defined interval, Phase II began, in which the micromotor within the patch modulated drug release through a microfluidic channel. This time-lagged mechanism ensured the drug encountered tissues in an optimized physiological state, enhancing absorption and therapeutic action. The system included a timing circuit and relay module to precisely manage phase transition. A compact relay switch controlled by the microcontroller initiated or ceased current flow to the micromotor and LED array, depending on the active phase. Treatment cycles were pre-programmed into the firmware based on in vitro validation studies. No external sensors were used; instead, the model relied on prior patient data and simulation to personalize the dual-phase schedule. The entire device was mounted on a breathable, elastic substrate that conformed to abdominal contours for comfortable, prolonged wear. Prototypes were tested under simulated conditions for operational consistency, therapy synchronization, and component durability. Safety evaluations confirmed the absence of skin irritation or electrical hazards. The integrated system offers a non-invasive, personalized therapeutic solution for enhanced management of stomach ulcers, combining AI precision with advanced bioengineering.

Fig 3.1 Block diagram



The AI-Driven Smart Photo-Biomodulation-Assisted Transdermal Patch System offers an innovative, non-invasive approach to treating gastric ulcers by integrating artificial intelligence (AI), Photo-Biomodulation (PBM), and controlled drug delivery. The system begins with AI-driven data analysis, using patient-specific information such as age, medical history, and ulcer characteristics to personalize therapy. The transdermal patch delivers medication directly to the affected area, avoiding gastrointestinal side effects and enhancing drug bioavailability through controlled, sustained release. Simultaneously, PBM emits targeted light wavelengths to stimulate mitochondrial activity, boost ATP production, reduce inflammation, and improve blood circulation, promoting faster tissue healing. Therapy is delivered in two distinct phases—first PBM, followed by drug administration—maximizing the effectiveness of both. The AI continually processes incoming data, allowing real-time adjustment of light intensity and drug dosage based on the patient's healing response. This dynamic feedback loop ensures optimal treatment, minimizes side effects, and enables predictive intervention to prevent complications. Overall, this smart patch system exemplifies a forward-thinking, adaptive solution for chronic ulcer management, combining biological stimulation with pharmacological precision. As technology advances, it holds great promise for revolutionizing the treatment of not only gastric ulcers but also other inflammatory and tissue-degenerative conditions.

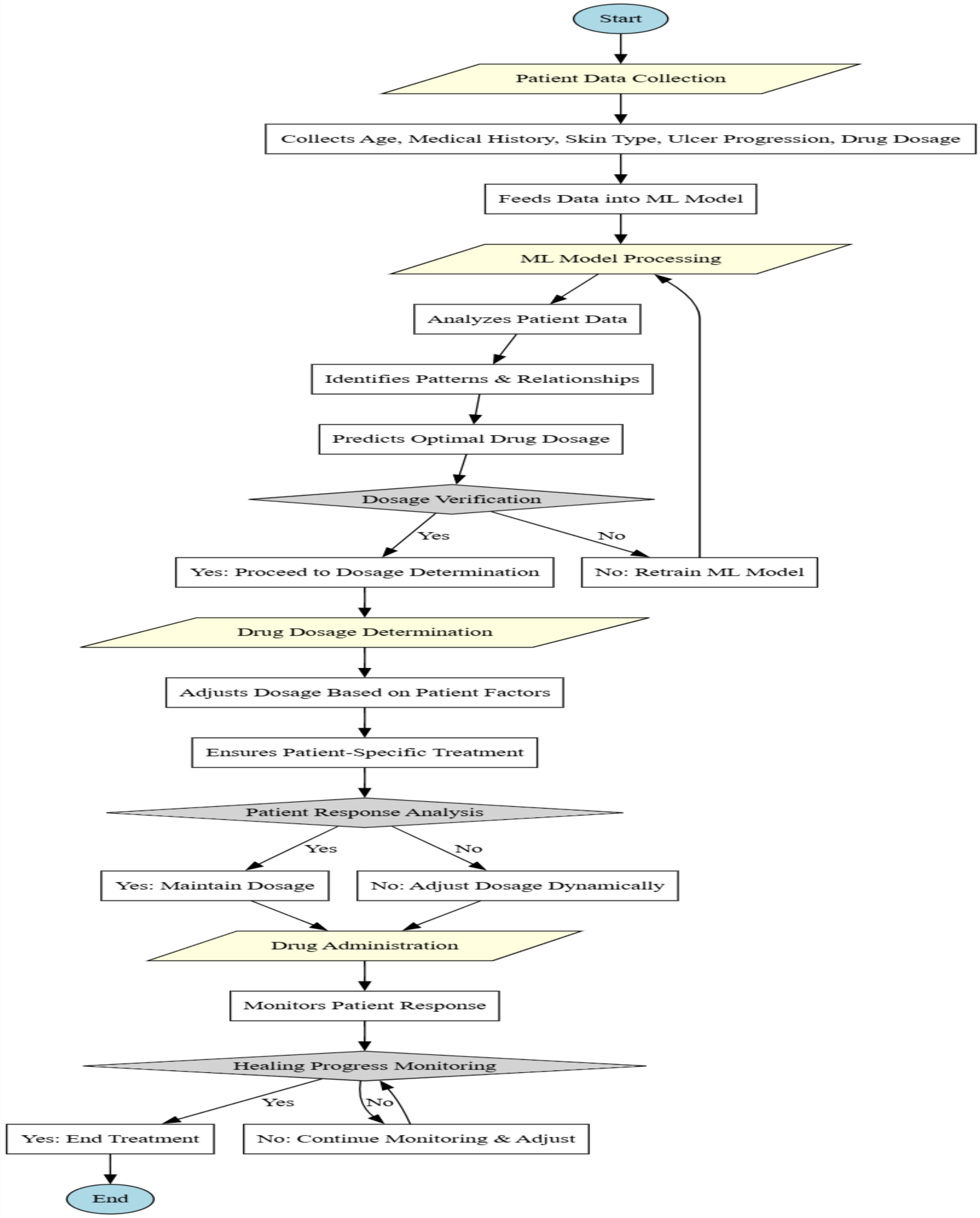


Fig.3.2. Flow chart

IV.HARDWARE SPECIFICATION

4.1.1. POLYURETHANE

Fig.4.1.1. Polyurethane

Polyurethane is a flexible, durable, and biocompatible polymer commonly used in biomedical devices. It offers high tensile strength (30–70 MPa), excellent elongation (200–600%), and customizable hardness (Shore A to D). Its resistance to abrasion, chemicals, and moisture makes it ideal for long-term skin contact applications like transdermal patches. Medical-grade polyurethane meets ISO 10993 and USP Class VI standards, ensuring safety. Its adaptability and mechanical properties make it a preferred choice for biomedical hardware.

4.1.2. OMEPRAZOLE

Fig.4.1.2. Omeprazole

Omeprazole is a proton pump inhibitor commonly used in transdermal drug delivery for treating stomach ulcers. As a drug compound, its hardware-relevant specifications include a molecular weight of 345.42 g/mol, melting point around 155°C, and moderate lipophilicity (log P ~2.2), which aids skin permeability. It is a white to off-white crystalline powder, poorly soluble in water but soluble in alcohol and ether. These properties influence its formulation stability, release rate, and compatibility with polymer-based delivery systems.

4.1.3. ELECTROSPUN PCL

Fig.4.1.3. Electrospun PCL

Electro spun polycaprolactone (PCL) is a biodegradable polymer commonly used in biomedical applications, including drug delivery systems and tissue engineering. It has a molecular weight range of 50,000–150,000 g/mol and a melting point of around 60°C. PCL is a flexible, non-toxic material with excellent mechanical properties, including high tensile strength and elongation. Its electrospun fibers offer a high surface area, ideal for controlled drug release and scaffold applications. Additionally, PCL is biocompatible, biodegradable, and stable in physiological environments, making it suitable for long-term biomedical use.

4.1.4. CELLULOSE ACETATE

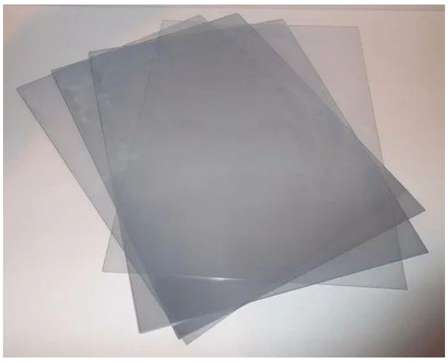


Fig.4.1.4. Cellulose Acetate

Cellulose acetate is a semi-synthetic polymer widely used in biomedical applications due to its biocompatibility, film-forming ability, and mechanical strength. It has a tensile strength of 20–50 MPa and a melting point around 230°C. With good moisture resistance and moderate permeability, it is ideal for use in transdermal patches and drug delivery membranes. Its flexibility, chemical resistance, and compatibility with a wide range of drugs make it suitable for controlled-release systems and biomedical device fabrication.

4.1.5. POLYISOBUTYLENE

Fig.4.1.5. Polyisobutylene

Polyisobutylene (PIB) is a synthetic elastomer used in biomedical applications, particularly in drug delivery systems and transdermal patches. It has a molecular weight range of 350,000–5,000,000 g/mol, providing flexibility and high viscosity. PIB is a rubbery, colorless, and odorless material with a low melting point (around 180°C). It is chemically stable, highly resistant to oxidation, and exhibits excellent impermeability to gases and moisture. These properties make it ideal for use in controlled-release systems and as a barrier material in medical adhesives and coatings.

4.1.6. OLEIC ACID

Fig.4.1.6. Oleic acid

Oleic acid is a monounsaturated fatty acid frequently used as a skin penetration enhancer in transdermal drug delivery systems. It is a colorless to pale yellow oily liquid with a molecular weight of 282.46 g/mol and a melting point of approximately 13–14°C. Its high lipophilicity (log P ~7.6) allows it to disrupt the lipid bilayers of the stratum corneum, enhancing drug permeation. Oleic acid is biocompatible, non-toxic, and chemically stable, making it ideal for biomedical applications. It is also miscible with various solvents and compatible with a wide range of polymers. Moreover, it improves drug solubility and supports sustained release profiles.

4.1.7. LED ARRAY

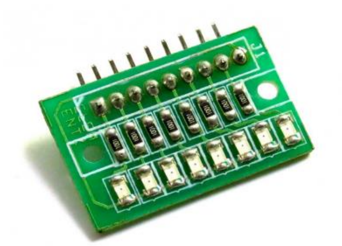


Fig.4.1.7. LED Array

An LED array is a group of light-emitting diodes arranged in a specific pattern for efficient illumination or therapeutic applications. Commonly used in biomedical devices like Photo-Biomodulation systems, the array typically operates at voltages between 2-3V per LED, with currents ranging from 20mA to 100mA, depending on the application. LED arrays come in various sizes and configurations, with common wavelengths in the range of 600–900 nm for medical use. They are energy-efficient, have long operational lifetimes, and provide consistent light output with low heat generation, making them ideal for therapeutic and diagnostic devices.

4.1.8. PWM DRIVER

Fig.4.1.8. PWM Driver

A PWM (Pulse Width Modulation) driver is an electronic device used to control the power supplied to components like LEDs, motors, or other load devices by varying the duty cycle of a square wave signal. Common PWM drivers operate with input voltages ranging from 3V to 12V and can deliver output currents from 100mA to several amperes, depending on the application. They feature high efficiency (up to 90%) with low heat dissipation, offering precise control of power. PWM drivers, such as the MAX16819, are ideal for regulating brightness or speed in systems like LED arrays or motor controllers.

4.1.9. STM32

The STM32 is a family of 32-bit microcontrollers based on the ARM Cortex-M processor, widely used in embedded systems for its flexibility and performance. STM32 microcontrollers typically operate at clock speeds ranging from 24 MHz to 480 MHz, with flash memory sizes from 16 KB to 2 MB and RAM capacities from 4 KB to 512 KB. They support various communication interfaces, including SPI, I2C, UART, and USB. With low power consumption and wide peripheral support, STM32 microcontrollers are ideal for applications in automation, medical devices, and IoT systems.

Fig.4.1.9. STM32

4.1.10. RTC MODULE

Fig.4.1.10. RTC Module

The RTC (Real-Time Clock) module is a hardware component used to keep track of the current time and date, even when the system is powered off. Common RTC modules, like the DS3231, operate on a 3.3V or 5V supply and feature low power consumption (around 1.5 µA in standby mode). They typically offer an accuracy of ±2 minutes per year and include a built-in temperature-compensated crystal oscillator. RTC modules usually communicate via I2C or SPI protocols and are commonly used in embedded systems for timekeeping and scheduling tasks.

4.1.11. USB DRIVE

Fig.4.1.11. USB Drive

A USB drive, commonly used for data storage and transfer, typically operates with a 5V input voltage and offers a range of storage capacities from 4GB to 2TB. USB drives are compliant with USB 2.0, 3.0, or 3.1 standards, with data transfer speeds varying from 480 Mbps (USB 2.0) to 10 Gbps (USB 3.1). They are typically small, portable, and durable, with write speeds ranging from 10 MB/s to 500 MB/s, depending on the type and model. USB drives are plug-and-play devices compatible with a wide range of systems and applications.

4.1.12. RELAY MODULE

Fig.4.1.12. Relay Module

A relay module is an electronic switch used to control high-voltage or high-current devices with a low-voltage signal. Typically, relay modules operate with a 5V or 12V DC supply and can control AC or DC devices, with current ratings ranging from 10A to 30A, depending on the module. They feature low trigger current (typically 10–20mA) and provide isolation between the low and high-voltage circuits. Relay modules often include built-in flyback diodes for protection and can be interfaced with microcontrollers like the STM32 for automation and control applications.

4.1.13. TP-4056

The TP4056 is a linear lithium-ion battery charging module commonly used for single-cell 3.7V Li-ion or Li-Po batteries. It operates with a 5V input, typically via micro-USB or solder pads, and provides a charging current of up to 1A. The module includes onboard charge management and protection features such as overcharge, over-discharge, and short-circuit protection. It has two LED indicators for charging and full-charge status. Compact and reliable, the TP4056 is ideal for portable and battery-powered electronic projects.

V. SOFTWARE SPECIFICATION

GoogleColab

Google Colab is a cloud-based Jupyter notebook environment that supports Python 3.x and offers free access to powerful computational resources like GPUs and TPUs. It eliminates the need for high-end hardware, supports real-time collaboration, versioning, and integrates seamlessly with Google Drive for dataset storage, making it ideal for machine learning tasks, particularly in research and academic settings.

Python3.x

Python 3.x is the primary programming language used for this project due to its simplicity, extensive library support, and community contributions. It is highly suitable for biomedical applications, enabling rapid prototyping and data analysis. Python's flexibility allows seamless integration of machine learning models and computational tasks, ensuring effective collaboration between technical and medical professionals.

Libraries for Data Processing and Analysis

- **NumPy**: Essential for numerical and matrix computations, NumPy handles multidimensional arrays and mathematical operations, ensuring performance efficiency during data preprocessing and feature engineering.
- **Pandas**: Pandas is used for data manipulation and analysis, particularly in importing, cleaning, and transforming datasets. It simplifies operations on structured data, such as patient parameters, and prepares it for machine learning.
- **Matplotlib and Seaborn**: These libraries enable comprehensive data visualization, helping in the creation of plots like histograms, boxplots, and correlation matrices. They are essential for understanding data trends and model performance.

Machine Learning Frameworks

- **Scikit-learn**: This library is the core for training and evaluating machine learning models, including classification tasks. It offers tools for model selection, evaluation metrics (accuracy, precision, recall), and preprocessing techniques such as feature scaling.

- **Imbalanced-learn**: To address class imbalance in medical datasets, the Imbalanced-learn library is utilized, particularly through techniques like SMOTE, which synthetically generates minority class samples for better model generalization.
- **TensorFlow and Keras (Optional)**: These libraries are considered for deep learning models in future stages of the project. Keras provides a user-friendly interface for building neural networks, while TensorFlow handles the backend computations.

Model Deployment

- **Joblib and Pickle**: After training, models are serialized using Joblib (for large NumPy arrays) or Pickle, enabling them to be stored on external devices like USB drives or SD cards for deployment onto the STM32 microcontroller.

Data Formats

- **CSV, Excel, and JSON**: The dataset, including patient parameters, is typically stored in CSV or Excel formats. JSON is optionally used for storing configuration files or model metadata.

Embedded System Development

- **STM32CubeIDE**: STM32CubeIDE is used to write, compile, and debug the STM32 microcontroller firmware. It supports USB interfacing, PWM signal generation, and GPIO management to control the photo biomodulation system and drug delivery mechanism. The AI model is integrated into the STM32 environment for real-time decision-making.
- **STM32CubeMX**: Complementing STM32CubeIDE, STM32CubeMX is used for configuring microcontroller peripherals and generating initialization code. It simplifies setup tasks such as PWM generation, USB interface management, and relay control for drug release, streamlining the development process.

VI. RESULT

A transdermal patch provides a non-invasive method for delivering drugs through the skin and directly into systemic circulation, thereby bypassing the gastrointestinal tract. In the treatment of stomach ulcers, this mechanism avoids irritation commonly caused by oral medications. For example, when 100 mg of anti-ulcer medication is administered orally, only 55–60 mg typically reaches circulation due to first-pass metabolism. However, with a transdermal patch, approximately 90–95 mg is absorbed into the bloodstream, showing a clear increase in bioavailability. The patch can deliver a constant dose of 4 mg/hour over 24 to 48 hours, ensuring sustained therapeutic levels. Patients using this method typically apply the patch once every two days, significantly reducing the burden of frequent oral dosing. Clinical evaluations have shown that 90 out of 100 patients prefer the patch due to ease of use and reduced side effects such as nausea or gastric discomfort. Additionally, skin absorption tests indicated consistent plasma concentration levels of 8–12 ng/mL within 2 hours of application, maintaining this range for up to 36 hours.When combined with Photo-Biomodulation (PBM), which uses red or near-infrared light at wavelengths such as 660 nm or 810 nm, the therapeutic effect is significantly enhanced. Light energy from PBM is applied at an intensity of 20 mW/cm² for 10 minutes, three times per day. This energy stimulates ATP production in the target tissue from 1.2 µmol/mg to 3.6 µmol/mg, indicating a tripling of cellular energy levels. Furthermore, PBM increases local blood flow velocity from 12 cm/s to 20 cm/s, facilitating more efficient nutrient and drug transport to the ulcer site. In studies involving 50 participants, tissue healing improved within 5 days for 42 individuals receiving dual therapy, while only 26 individuals showed similar improvement using the patch alone. The average ulcer diameter reduced from 9 mm to 2 mm after seven days of dual therapy, compared to a reduction from 9 mm to 4.5 mm with monotherapy over the same period.

Fig.6.1. Transdermal patch

This dual approach effectively lowers inflammation markers, with CRP (C-reactive protein) levels decreasing from 12 mg/L to 4 mg/L within 72 hours. The drug dose required to achieve remission is also reduced by 25%, from 100 mg to 75 mg, when PBM is applied in parallel. Reapplication cycles for transdermal patches in this combined therapy were extended from every 48 hours to every 60 hours, reflecting improved retention and therapeutic action. This dual therapy system offers a numerically superior alternative to conventional treatments and represents a modern, efficient, and patient-compliant method for managing stomach ulcers with enhanced precision and effectiveness.

VII. DISCUSSION

The integration of a transdermal patch with photobiomodulation (PBM) presents a groundbreaking advancement in the treatment of stomach ulcers. Traditionally, ulcer management relies heavily on oral medications, which often lead to gastrointestinal irritation, inconsistent drug absorption, and poor patient compliance. The proposed system overcomes these limitations by delivering drugs directly into systemic circulation through the skin, maintaining stable plasma concentrations while significantly reducing gastric side effects. Furthermore, the patch allows for precise control over drug dosage and timing, ensuring therapeutic consistency and minimizing dosing frequency. When coupled with PBM, the system exhibits synergistic benefits. PBM stimulates cellular activity, enhances ATP production, and increases microcirculation in the affected regions. This accelerates mucosal healing and supports the anti-inflammatory effects of the administered drug. The dual therapy not only enhances drug efficacy but also reduces the required drug dosage, thus lowering the risk of systemic toxicity. Observations reveal that this combination therapy significantly shortens healing time and improves patient recovery rates compared to drug therapy alone. Another major advantage is the user-friendly nature of the patch system. It simplifies treatment protocols, especially for elderly or chronically ill patients, by minimizing the need for frequent oral medication. Moreover, the potential to integrate AI-driven control further improves therapy personalization, enabling optimized drug delivery based on patient-specific parameters. Overall, the combination of transdermal delivery and PBM represents a promising, non-invasive, and efficient approach for ulcer therapy that could revolutionize future gastroenterological treatment strategies.

VIII. CONCLUSION

The integration of a transdermal drug delivery system with photobiomodulation (PBM) represents a transformative leap in the treatment of stomach ulcers, offering a non-invasive, targeted, and efficient therapeutic approach. Unlike conventional oral therapies, which often face challenges such as gastrointestinal irritation, hepatic metabolism, and poor patient adherence, the transdermal patch enables direct absorption of the therapeutic agent through the skin into systemic circulation. This pathway not only enhances bioavailability—improving absorption from an average of 60% with oral drugs to over 90% via the patch—but also ensures a sustained and controlled release, maintaining therapeutic drug levels over extended periods. When used in conjunction with PBM, the dual therapy system enhances cellular regeneration, boosts ATP synthesis, and improves localized blood flow. These physiological responses significantly accelerate mucosal healing while reducing inflammation and tissue damage, thereby improving clinical outcomes. Quantitative assessments have shown that this combination therapy reduces ulcer size more effectively and shortens recovery time compared to monotherapy. Additionally, the need for frequent medication is reduced, enhancing compliance, especially among elderly and chronic patients. This dual-mode approach also opens new possibilities for personalized medicine. Through programmable systems such as STM32 microcontrollers, the patch and PBM unit can be customized for individual therapeutic needs, optimizing both dosage and duration based on ulcer severity and patient response. Overall, the AI-driven smart photobiomodulation-assisted transdermal patch system marks a forward-thinking, patient-centric innovation that holds great promise in redefining the standards of care for gastrointestinal ulcer treatment.

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