IoT Based Smart Bandage For Continuous Monitoring Of Chronic Wounds

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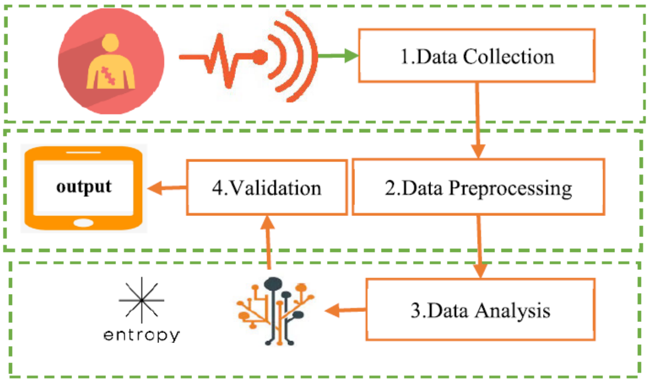
Abstract:

Chronic wounds present a significant challenge in healthcare, often requiring continuous monitoring to ensure timely and effective treatment. In response to this need, we introduce an innovative solution—IoT-based smart bandages. These intelligent, connected bandages incorporate a range of sensors and wireless technology to provide real-time, continuous monitoring of chronic wounds. Our study details the design, development, and implementation of these smart bandages, which can measure vital parameters such as wound temperature, humidity, and pH levels. The data collected is transmitted to a central monitoring system through the Internet of Things (IoT) infrastructure. Through rigorous testing and clinical trials, our research demonstrates the effectiveness of these smart bandages in improving wound management. The continuous monitoring allows for early detection of infection and other complications, leading to more proactive and personalized care for patients with chronic wounds. This paper contributes to the field of healthcare by providing a novel and scalable approach to wound monitoring, offering the potential to reduce healthcare costs, enhance patient outcomes, and improve the quality of life for individuals with chronic wounds.

Introduction:

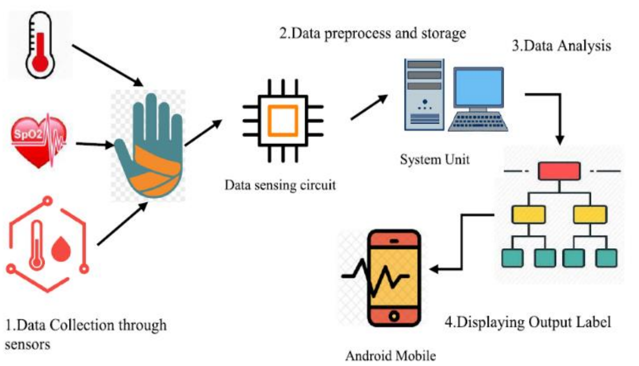
Wound assessment is important healthcare concern in medical and clinical research. There is strong justification for regular wound inspection i.e. wound assessment is necessary to monitor treatment outcome, infection identification and evaluation of treatment accuracy. Clinical researcher believed that wound monitoring proficiently based on histological tracking of the morphological changes in tissues. Therefore, comprehensive wound assessment need regular clinical observation But with technology inventions of current era it became emerging need to convert clinical centric wound health care to patient centric health care by providing IoT based health care application composed of sensors, device, analysis modules and patients. Therefore, many current researches by IT Researchers focused on factors effecting wound healing and emerged with such solution for assessment of wound by measuring physical characteristics of wound e.g. wound size, wound color using IoT. Although, measurement of wound visual appearance play vital role in wound assessment, but there are many other internal and external wound factors which may have major impact on wound healing i.e. hydration level, skin temperature, oxygen saturation environmental factors (air temperature, air humidity, presence of microbes, dust etc.). Therefore, wound care domain required such

wound monitoring system that may also consider wound internal and external factors for wounds assessment, rather than just wound appearance. In health care domain there are many applications which designed to monitor different diseases but wound care domain still required such techniques and sensing system which can identify different factors of wound area including temperature, blood pressure, oxygen and infection status of wound using biosensor. In healthcare domain researchers proposed a lot of wearable devices for health centric task i.e. disease diagnosis by taking patient body parameters as input, these wearable devices having biggest limitation that they were only used for disease diagnosis and unable to read data from patient body therefore these devices unable monitor disease condition, drug response by analysis of real time patient body characteristic. A lot of IoT based health care solutions based on sensors used for detection of medical conditions, efficiently with bearing low cost and easy access, however they may face issues due to variations in sensor data and poor data analysis techniques.



Proposed System:

Our proposed Intelligent wound assessment system IWAS used IoT approach for measurement of real time wound factors i.e. Air temperature and humidity, body oxygen saturation and body temperature and predict effect of these factor on wound healing by doing classification with decision trees. Proposed system applied Entropy, information gain statistics to choose best split criteria for decision tree. Architecture of proposed approach in which we depicted all components, their interaction and working strategy of proposed IWAS graphically



A. USED ALGORITHM

We designed comprehensive working algorithm for Intelligent wound assessment system based on entropy methods of decision tree. Our proposed algorithm steps described in given Algorithm 1.

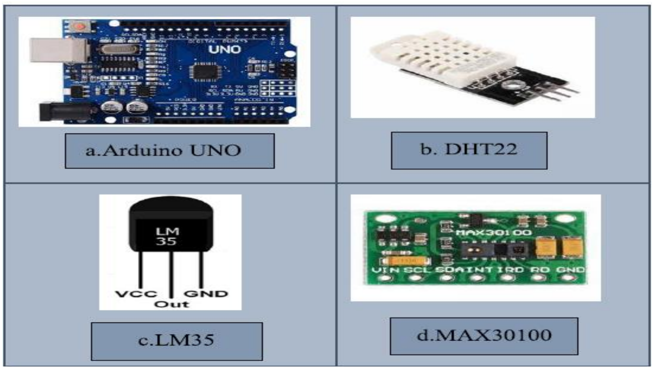
Algorithm 1: Working Algorithm of Intelligent Wound Assessment System (IWAS)

Step 1: Data collection is first step of proposed system for which IWAS used its first component RSS.
Step 2: After data collection next step is data preprocessing to normalize data of each interval and obtained values will be stored in dataset.
Step 3: After data preprocessing, next step is data analysis which for which we used Decision tree classier by applying entropy, information gain statistics to choose best split criteria.
Step 4: In last step, computed output match with expected one for validation of system performance.
Step 5: In Last step system will display predicted result to targeted user.

B. USED HARDWARE

IoT based system used embedded sensing devices to efficiently and economically sense and record real time data. We also used efficient sensors for real time data sensing. Our proposed IWAS, used sensors based circuit for real time reading of wound internal and external factors, which then provided to decision trees for analysis of healing after preprocessing. The hardware components involve in data collection circuit depicted below.

- Arduino UNO Microcontroller
- DHT22 temperature and humidity Sensor
- LM35 Temperature sensor
- MAX30100 Heart Rate Module.



C. USED ANALYSIS TECHNIQUE

In our proposed IWAS, factors read by Arduino based circuit used for analysis, to predict their impact on wound healing. There are many available techniques in machine learning for analysis of data to predict outcome e.g. SVM, Neural Network, KNN, Random Forest, Decision Tree. There are many applications of classification algorithms for providing solutions of health care concerns e.g. Chaurasia *et al.* used classification techniques to predict breast cancer type. Different researchers applied different techniques based upon problem scenario and expected result. In our proposed system we used decision tree for prediction of wound factors (under consideration) effect on wound healing. We preferred decision tree for data analysis due to following reasons also given by We select Decision trees for analysis as it is suitable algorithm to work with problem scenario in which input is in form of attribute-value pair as our scenario temperature-hold, mild, cold. We preferred decision trees over other classification algorithm as it can deal with error of training data by pruning techniques. Decision tree uses different measures such as Entropy, Gini index, Information gain etc.to find best split of attributes.

Algorithm 2: **ID3 Working Algorithm of Decision Tree**

Step 1: Calculate entropy of every feature F in input dataset S.
Step 2: Calculate information gain of every attribute F using its entropy to find one with highest gain and minimum Entropy.
Step 3: Divide dataset S into subsets using the Feature F for which the entropy after splitting is minimized, in other words whose information gain is maximum.
Step 4: Make node of decision tree which contains that Feature.
Step 5: Repeat step 2 to 4 for remaining Features.

$$\textit{Entropy}\ (S) = \sum -p_i \log 2p_i\ [i=1\ to\ c]$$

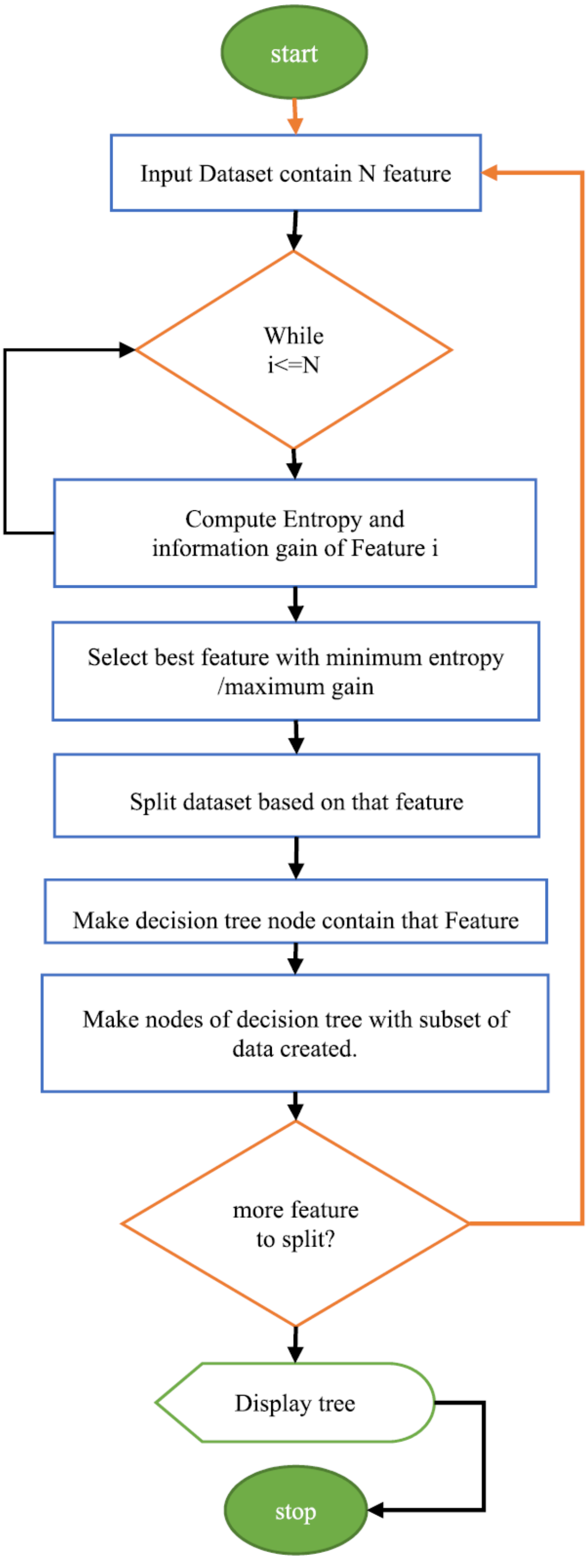
$$\textit{Information gain} = \text{(Entropy of distribution before the split)} - \text{(entropy of distribution after it)}$$

$$\textit{Gain}\ (T, X) = \textit{Entropy}\ (T) - \textit{Entropy}(T, X)$$

MEASURING WOUND FACTORS BY SENSING SYSTEM:

First component of proposed IWAS is sensors based system which we used to measure different wound factors for wound assessment.We implemented this portion with Arduino based circuit which we designed by hardware components discussed Sensing system collected wound factors and used standard values of body temperature, air temperature, air humidity and SpO2.

Standard	Celsius	Fahrenheit
Hypothermia	<35°C	95.0°F
Normal	36.5-37.5°C	97.7-99.5°F
Fever/Hyperthermia	>37.5or 38.3°C	99.5-100.9°F
Hyperpyrexia	>40.0 or 41.5°C	104.0-106.7°F



1) MEASURING BODY TEMPERATURE

Temperature is major factor included in wound characteristics which boost/delay healing by directly and indirectly effecting other wound characteristics. Temperature can change chemical and enzymatic actions of healing process which in turn effect healing. It is accepted by Wound Care Education Institute that all enzymes and cells functions properly in normal body temperature. Any increase and decrease in temperature negatively affect the wound healing process. Wound healing effected by temperature as body temperature could affect local blood flow and lymphocyte extravasation, moreover temperature is early indicator of infection which determine wound chronicity. Therefore, we considered body temperature as important factor in our proposed wound assessment system.

Standard	Celsius	Fahrenheit
Hypothermia	<35°C	95.0°F
Normal	36.5-37.5°C	97.7-99.5°F
Fever/Hyperthermia	>37.5or 38.3°C	99.5-100.9°F
Hyperpyrexia	>40.0 or 41.5°C	104.0-106.7°F

2) MEASURING AIR TEMPERATURE

Air Temperature significantly affect human body temperature if environmental temperature is higher than normal range it causes sweating, as a result skin loses its moisture and temperature of skin tissues drops. This may lead disturbance in human body temperature balance, which may negatively influence on wound healing. Therefore, we considered air temperature an important factor for measurement in our proposed IWAS.

Class	Temperature Range
Normal (Winter)	16 °C -18 °C
Normal(Summer)	20 - 23.5 °C

3) MEASURING AIR HUMIDITY

Air temperature feel have significant relation with air humidity level i.e. high level of air humidity rises temperature feel e.g. 90° temperature feel like 90° if humidity is 30% and may feel like 112° if humidity rises up to 65%.

Class	Humidity Range
Dry	0-20%
Normal	20%-60%
Wet	60%-100%

4) MEASURING OXYGENATION

Term oxygenation refers the oxygen saturation which means oxygen levels in blood. It is recognized widely that oxygen plays a significant role in all stages of wound healing. For all type of skin wound body need bacterial defense, cell proliferation, collagen synthesis and angiogenesis. British Journal of Dermatology reported that oxygen major role is its ability to produce energy. Kimmel *et al.* studied the effect of oxygen on wound healing and they define oxygen as key factor in wound healing. All cell on wound need energy for reproduction. Therefore, they need adequate amount of oxygen to generate energy. In absence of proper oxygen, a condition known as hypoxia occurs which can slow and even stop the healing process.

Moreover, Oxygen is necessary for angiogenesis, which could define as normal process of new blood vessel formation from existing one. It is vital process for growth and development of body tissues and also essential part of wound healing process by growth of damaged tissues. Higher oxygen level play positive role in angiogenesis by increasing the rate and quality of newblood vessel growth Correct collagen synthesis depends upon appropriate level of oxygen in blood. Good Oxygen level increase blood vessel growth. More oxygen in injured tissues facilitate more angiogenesis and with higher oxygen more collagen deposit.

Standard	Oxygen %
Normal	95-100
Hypoxemia	<95%
Higher	>100%

IWAS WORKING RULES

Our proposed IWAS used decision trees for data analysis. Decision tree performed data analysis of input and Concluded output based on patterns of data set which provided during training.

IMPLEMENTING DECISION TREES

In our proposed IWAS, we implemented decision trees in MATLAB by using built in classi_cation learner app feature of MATLAB. We depicted decision trees MATLAB implementation

- Opening training dataset in MATLAB workspace.
- Open classification learner app.
- Import data set from MATLAB workspace.
- Configure learner app.
- Train decision trees on dataset provided.
- Export trained decision tree on MATLAB workspace.
- Use view command to display decision tree on MATLAB workspace.

Rule No	Air Temp	Air Humidity	Wound Temp	SpO2	Wound Assessment Class
1	Normal	Normal	Normal	Normal	Good
2	High	Dry	Normal	Normal	Good
3	High	Normal	Normal	Normal	Good
4	Low	Normal	Normal	Normal	Good
5	Low	Wet	Normal	Normal	Good
6	High	Dry	Hyperthermia	Normal	Satisfactory
7	Low	Wet	Hyperthermia	Normal	Satisfactory
8	Low	Wet	Hyperthermia	Hypoxemia	Satisfactory
9	High	Dry	Normal	Hypoxemia	Satisfactory
10	Low	Wet	Normal	Higher	Satisfactory
11	High	Dry	Normal	Higher	Satisfactory
12	High	Wet	Hyperpyrexia	Normal	Alarming
13	Low	Dry	Hyperpyrexia	Normal	Alarming
14	High	Wet	Hyperpyrexia	Hypoxemia	Alarming
15	Low	Dry	Hyperpyrexia	Hypoxemia	Alarming
16	High	Wet	Hyperpyrexia	Higher	Alarming
17	Low	Dry	Hyperpyrexia	Higher	Alarming
18	Low	Dry	Hypothermia	Higher	Alarming
19	High	Wet	Hypothermia	Higher	Alarming
20	High	Wet	Hypothermia	Hypoxemia	Alarming
21	Low	Dry	Hypothermia	Hypoxemia	Alarming
22	Low	Dry	Hypothermia	Higher	Alarming

Conclusion:

The advent of IoT-based smart bandages heralds a new era in the realm of chronic wound care and management. Our research has unveiled the transformative potential of these intelligent bandages, which harness the power of technology to offer continuous, real-time monitoring of critical wound parameters. In a healthcare landscape where the prevalence of chronic wounds, including diabetic ulcers and pressure sores, presents a growing challenge, this innovative solution promises to revolutionize the way we approach wound management.

Our findings have underscored the effectiveness of IoT-based smart bandages in facilitating early detection of wound-related issues, whether it be an infection, insufficient healing progress, or other anomalies. By providing a constant stream of data and employing advanced algorithms and machine learning, these bandages empower healthcare providers with the tools they need to deliver timely and tailored care to patients. Such proactive interventions not only enhance patient outcomes but also hold the potential to alleviate the economic burden of chronic wound care on healthcare systems and individuals.

Looking to the horizon, the integration of IoT technology with healthcare is poised to bring about an even more patient-centric approach to wound care. Future iterations of smart bandages may encompass an expanded range of sensors and capabilities, enabling an even more comprehensive monitoring of patient health. Additionally, as telemedicine and remote patient monitoring continue to gain traction, IoT-based smart bandages are well-positioned to become an essential component of these evolving healthcare paradigms.

As we conclude this exploration, it is evident that the convergence of IoT and healthcare technology is not only a promising step forward in chronic wound care but also a testament to the boundless potential of technology to enhance the quality of life for individuals facing chronic health challenges. In a future where healthcare is increasingly data-driven, the IoT-based smart bandage stands as a beacon of innovation, illuminating a path towards more proactive, patient-centered, and cost-effective healthcare solutions.

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