Heat stroke prediction: a perspective from the internet of things and machine learning approach

Lim Ke Yin, Sumendra Yogarayan, Siti Fatimah Abdul Razak, Umar Ali Bukar, Md Shohel Sayeed
Faculty of Information Science and Technology, Multimedia University, Melaka, Malaysia

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ABSTRACT

With the increasing occurrence of heat-related illnesses due to rising temperatures worldwide, there is a need for effective detection and prediction systems to mitigate the risks. Heat stroke, a life-threatening condition occurs when the body's temperature exceeds 104 °F (40 °C). It can happen due to prolonged exposure to temperatures. When the body struggles to cool itself down adequately. The internet of things (IoT) and machine learning (ML) are two advancing technologies that have the potential to revolutionize industries and enhance our lives in numerous ways. Currently, monitoring devices are primarily used to diagnose when individuals suffering from heatstroke are at the location. This paper delves into the exploration of utilizing the IoT and ML algorithms to predict heat strokes. It reviews existing studies in this field, focusing on how IoT has been deployed and the application of machine learning techniques. The research aims to define the integration of IoT devices and ML algorithms that has a great potential to detect and predict heat-related illnesses such as heat stroke at an early stage.

Corresponding Author:

Sumendra Yogarayan
Faculty of Information Science and Technology, Multimedia University
Jalan Ayer Keroh Lama, 75450 Melaka, Malaysia
Email: sumendra@mmu.edu.my

1. INTRODUCTION

One of the news from New Straits Times on 13 May 2023 have reported that number of hot weather-related cased is subject to increase because of the present heat season which is predicted to last till August mentioned by Lukanisman Awang Sauni, Malaysia Deputy Health Minister [1]. On 14 May 2023, one of the Philippine's cities, Diplolog reported have reached 47 °C in the afternoon, which is the danger category and more likely to cause heat-related illness if continued sun exposure [2]. In Singapore, the number of cases related to heat injury has increased compared to past few months due to the high temperature in mid-May [3]. As many countries have reported high environment temperature which can lead to high risk of getting heat-related illness. Internet of things (IoT) refers to a network of interconnected physical devices embedded with sensors, software, and connectivity capabilities to exchange data and interact with the environment. These devices can range from everyday objects like household appliances to complex systems such as industrial machinery or smart cities [4]–[7]. IoT enables the collection and sharing of real-time data, enabling remote monitoring, control, and automation of various processes [8], [9]. On the other hand, machine learning (ML), is a subset of artificial intelligence that focuses on algorithms and statistical models that allow computers to learn from data and make predictions or take actions without being explicitly programmed. ML algorithms analyze datasets to identify patterns, relationships, and insights, and use that knowledge to make accurate predictions or decisions [10], [11].

In the context of heat-related illness prediction, IoT and ML can significantly contribute to improving early detection and prevention. IoT devices equipped with sensors can continuously monitor environmental temperature, humidity, and individual health parameters such as body temperature, heart rate, or sweat levels. The collected data can be processed and analyzed using ML algorithms to identify patterns and correlations between these variables and the occurrence of heat-related illnesses. By leveraging these insights, predictive models can be developed to issue early warnings and alerts to individuals at risk, allowing them to take preventive measures such as seeking shade, hydrating, or cooling down. At the same time, number of cases of getting heat-related illness and the hospital admission can be reduced. Thus, in this work, we explore the use of IoT devices and machine learning algorithms in the context of heat stroke prediction. The rest of the paper is organized as follows. Section 2 presents the related works. Section 3 includes the existing works of IoT and ML. Section 4 discusses on the research gaps. Finally, the paper is concluded in section 5.

2. RELATED WORKS

Heat stress is an initial stage of heat stroke. Heat stress often develop in exercise in a warm environment or without exercise but expose to excessively warm environment. The difference between heat exhaustion, heat stroke and heat stress are that heat stress may not affect the core body temperature to turn high, the individual who have heat stress will remain the normal range of core body temperature. The symptom of heat stress is feeling discomfort and showing decreased exercise performance. Other than that, symptoms like physiologic strain in feeling muscle cramps or severe thirst [12]–[14]. Heat exhaustion is also one of the heat-related illness which possibility get confuse with heat stroke. Heat exhaustion will have a symptom of mild dehydration with the core body temperature between 38.3 °C and 40 °C without central nervous dysfunction [15], [16]. Heat exhaustion often result from strenuous exercise with exposition of high environment temperature which resulting in heavy sweating. Sweating is a mechanism in human body for cooling down when the core body temperature is raising. While if a person overexercise or long period expose in warm and humid environment, the body might have difficulties to produce enough sweat to cool down the body temperature, this may result in having heat-related illness and more seriously life-threating; heat stroke. Heat exhaustion can be a precursor to heat stroke if a person with heat exhaustion is not well treated, whereas there is also possible to have heat stroke without getting heat exhaustion [17], [18]. The elderly, those with high blood pressure, and those who labor in hot environments are most likely to get heat exhaustion, according to the centers for disease control and prevention (CDC) in the United States [19]–[21].

Core body temperature elevated above 40 °C or 104 °F and have a sign of central nervous system dysfunction like coma, seizures, encephalopathy can be considered an occurrence of heat stroke for a person. Heat stroke is one of the life-threatening heats related illnesses which categorize into classic heat stroke also known as non-exertional heat stroke and exertional heat stroke [22]–[24]. Classic heat stroke frequently affects vulnerable populations, such as the elderly. Vulnerable groups might include people who have comorbid conditions like hypertension, heart disease, kidney illness, obesity, diabetes, dementia, and alcoholism. This group of populations may result in classic heat stroke mainly because of the poor heat-dissipation mechanisms or in others word, they have difficulty in adjusting heat exposure and heat strain. Classic heat stroke happens while at rest without skeletal muscle heat production involvement [25]–[28]. Exertional heat stroke often results from strenuous physical exertion among healthy person. Exertional heat stroke often but not necessarily occurs in high temperature environment. The absences of prompt treatment may lead to 33% mortality [29]. With the combination of strenuous exercise, hot environment, clothing, and other factors may lead to rapid and unusual raise in core body temperature which will cause exertional heat stroke and central nervous system abnormalities [30]–[32].

Exertional heat stroke often develops in individual like laborers, athletes, soldiers, military personnel, and individual who perform rigorous activities as part of an occupation [18], [33], [34]. For athletes, one of the risk factors for having exertional heat stroke is the individual perform beyond his/her physiological capability under over motivation from coaches. Other than that, drug or alcohol can also put an individual in the risk of getting exertional heat stroke [35]–[38]. Table 1 shows the comparison of heat stress, exhaustion and stroke. Apart from that, although core body temperature and skin temperature are different with the ratio of 0.9/0.1, but the increase of skin temperature may also reveal the increase of core body temperature [39]. According to Amit *et al.* [40], skin temperature have a significant increase in the high environment temperature and humidity condition compare to others low environment temperature and humidity condition tested. This can be used to infer that skin temperature is a useful attribute for evaluating heat-related illness too. Table 1 shows the difference between heat stress, exhaustion and stroke.

Table 1. The difference between heat stress, exhaustion and stroke

Heat stress	Heat exhaustion	Heat stroke
Normal core body temperature	Core body temperature between 38.3 °C and 40 °C	Core body temperature above 40 °C
Muscle cramps, severe thirst	Headache, vomiting, nausea, fatigue, dizziness, cold, ataxia, diarrhea	Loss of conscious, delirium, confusion, coma, seizures, agitation
-	Heavy sweating and dehydration	Hot and dry skin

3. EXISTING WORKS

3.1. Internet of things

Javed *et al.* [41] has presented a wristband IoT device to detect heat stroke. The research includes Arduino Nano as the microcontroller and sensors such as body temperature (MLX90614), blood oxygen level sensor (Sp02) and environmental temperature and humidity (SHT75) to collect the data. The integration of the components includes global system for mobile communications or global positioning system (GSM/GPS) module for sending alert messages to the caretakers through mobile numbers. Similarly, Son *et al.* [42] described using similar concept of wristband for detecting heat stroke. The development includes Arduino Nano along with heartrate sensor from World Famous Electronic. In addition, NodeMCU microcontroller with ESP8266 Wi-Fi built-in module was presented in research [42]. Different body temperature sensor, environment temperature and humidity sensor were used and pulse sensor amped was used instead of using blood oxygen level sensor. Digital humidity and temperature (DHT22) sensor were used to collect data. For data gathering, the linear monolithic (LM35) body temperature sensor was positioned on the inner side of the wrist. All the sensors output will be compared among them to get the exact impact of heat wave.

Lin *et al.* [43] distinguished that the wearable device was proposed as an IoT device for heat stroke detection while all the sensors' data collected will send to back-end system for heat stroke risk analysis using LoRa technology. The back-end system will record user's physiological data, physical condition and environmental information. In addition, a warning will be displayed through light-emitting diode (LED) and buzzer based on the risk of getting heatstroke. Apart from that, Karmani *et al.* [44] developed hand glove as an IoT device to create a heatstroke early-warning system. Arduino board with Wi-Fi module is used as a microcontroller. other than that, body temperature sensor, pulse sensor and breath sensor are used in this Research also. All the real time sensor data are collected and categorize into different condition status. Machine learning algorithm like decision tree is used in the prediction part. Nearby hospital and family members will receive message if the condition status is alert mode. Lastly, Venugopal and Dudhe [45] using Arduino Uno, body temperature sensor (LM35) and GSM/GPS module to build an IoT based advance heat stroke alarm system. The reminder message will send to user and his/her family members if the body temperature increases to 40 °C and above. Table 2 shows the comparison of existing method of IoT devices. Table 2 shows the comparison of existing works using IoT for heat stroke.

Table 2. The comparison of existing work using internet of things for heat stroke

References	Method applied	Microcontroller	Modules/sensors
[41]	Wristband	Arduino Nano	GSM/GPS MLX90614 SHT75 SpO2
[42]	Hand Glove	Arduino Uno	Wi-Fi Bluetooth Temperature Pulse Breath
[43]	Wristband	Node MCU ESP8266	Pulse DHT22 LM35
[44]	Wearable Device	Arduino Nano	Bluetooth LoRa Heartrate MLX90614 SHT35 Grove-GSR
[45]	Wearable Device	Arduino Uno	GSM/GPS Bluetooth LM35

3.2. Machine learning

First, Hirano *et al.* [46] used some machine learning algorithm like logistic regression, support vector machine, random forest and XGBoost for mortality prediction for heat-related illness. "Heatstroke study" database in Japan was used in this system for machine learning prediction. The highest accuracy was applying XGBoost algorithm with the 95.3% accuracy, followed by 92.4% accuracy which is random forest, 84.8% accuracy for logistic regression and the lowest 84.3% accuracy which is support vector machine. Instead of getting database as the dataset, studies [47] and [48] conducted survey for data collection. In [47], 1,200 persons did the survey but only 231 persons fulfilled the criteria of heat-related illness (HRI) spectrum. Decision tree algorithm was applied in it with the accuracy of 93.6%. On the other hand, Roy *et al.* [48] collected data through ventilation survey for prediction of heat stress in underground mine environment. Then, two machine learning algorithm like random forest and artificial neural network (ANN) were used in this system. High accuracy of 99.73% and 99.93% had achieved in random forest and artificial neural network respectively. Wang *et al.* [49] collected daily case numbers of heat stroke in several places in China from 2012 to 2014 summer periods. Then, random forest algorithm has been applied to predict heat stroke occurrence for heatwave in China. ANN algorithm was applied in study [50] with national oceanic and atmospheric administration (NOAA) global summary of day data for dew point, humidity and heat index prediction. Table 3 shows the comparison of existing works using machine learning for heat stroke.

Table 3. The comparison of existing work using machine learning for heat stroke

References	Dataset	Machine learning algorithm	Accuracy
[46]	Heatstroke study database in Japan	Logistic regression (LR) Support vector machine (SVM) Random forest (RF) XGBoost	84.80% 84.30% 92.40% 95.30%
[47]	Survey 1200 persons encountered; 231 persons fulfilled the criteria of HRIs spectrum	XGBoost	93.60%
[48]	Daily case numbers of heat stroke in Shanghai, Chongqing, Wuhan, Jinan, Ningbo, Hefei and Shaoxing from the summer periods of 2012 to 2014	Random forest (RF)	Not Disclosed
[49]	NOAA's Global Summary of Day data	Artificial neural network (ANN)	Not Disclosed
[50]	Collection of data through ventilation survey.	Random forest (RF) Artificial neural network (ANN)	99.73% 99.93%

4. DISCUSSION

4.1. Internet of things

One common approach was to deploy Arduino boards as microcontrollers for wearable devices. These devices used sensors such as heart rate or pulse wave, body temperature, and environmental temperature and humidity to detect heat-related illnesses. However, the requirement of multiple sensors attached to the wearable device made it inconvenient for users. To enhance user-friendliness, it is important to explore alternative approaches that minimize the number of sensors required and improve the overall wearability of the devices. Additionally, optimizing the selection and placement of sensors on wearable devices is crucial to ensure effective and non-intrusive monitoring. Additionally, further investigation into advanced machine learning techniques is necessary to enhance the predictive capabilities of IoT-based heat stroke detection systems, moving beyond simple threshold-based approaches.

4.2. Machine learning

Machine learning algorithms such as random forest (RF), artificial neural network (ANN), XGBoost, logistic regression (LR), and support vector machine (SVM) have been used in existing methods related to heat-related illness. However, these approaches mainly focus on analyzing the number of heat-related illness cases or specific populations, such as workers, through existing datasets or surveys rather than utilizing data from sensors in wearable devices. By studying these machine learning approaches applied to heat-related illness, the data obtained from wearable devices can be improved. Instead of solely setting certain thresholds to alert users, machine learning techniques can be employed to analyze hidden patterns and provide more accurate prediction statuses. Combining lightweight wearable devices with machine learning enables enhanced early detection and prediction, yielding more precise results.

5. CONCLUSION AND FUTURE WORK

In conclusion, the integration of IoT devices and ML algorithms has the potential to detect and predict heat-related illnesses such as heat stroke at an early stage. Existing studies in this field have provided insights and methodologies for developing systems. However, there are still areas that require further research. It is crucial to improve the wearability and user-friendliness of devices by minimizing the number of sensors used and optimizing their placement. Additionally, applying advanced ML techniques can enhance the accuracy and predictive capabilities of heat stroke detection systems. By combining these advancements, we can develop efficient systems for early detection and prediction of heat-related illnesses, ultimately reducing cases and hospital admissions. Future research should prioritize addressing these research gaps while exploring the potential of IoT devices and ML in heat stroke prediction to enhance public health and safety.

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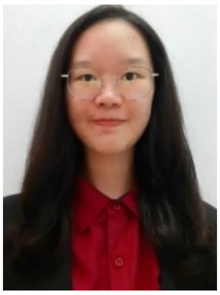
BIOGRAPHIES OF AUTHORS



Lim Ke Yin is a Bachelor of Computer Science (Hons) student in Faculty of Information Science and Technology, Multimedia University (MMU), Melaka, Malaysia, majoring in artificial intelligence. Her research interests include machine learning, internet of things and embedded devices. She can be contacted at: 1181203338@student.mmu.edu.my.

Sumendra Yogarayan is a Senior Lecturer in the Faculty of Information Science and Technology, Multimedia University. He graduated from Multimedia University (MMU) with a Doctor of Philosophy (PhD) in Information Technology in 2023 and a Master of Science in Information Technology in 2019. He currently holds the positions of Deputy Chairperson for the Center of Intelligent Cloud Computing (CICC) and Program Co-Coordinator for Data Communication and Networking (DCN). He is a MBOT Professional Technologist since 2020 and a member of International Association of Engineers since 2022. His research and teaching interests includes intelligent transportation system, wireless communication, ad hoc networks, machine learning, internet of things, embedded device and sensors. He can be contacted at email: sumendra@mmu.edu.my

Siti Fatimah Abdul Razak is an Assistant Professor at the Faculty of Information Science and Technology, Multimedia University. She graduated from Multimedia University (MMU) with a Doctor of Philosophy (Ph.D.) in Information Technology in 2018 and a Master of Information Technology (Science and System Management) in 2004. She is also an active member of the Centre for Intelligent Cloud Computing. Her research interest includes vehicle safety applications, the internet of things, rule mining, information systems development, and educational technology. She can be contacted at email: fatimah.razak@mmu.edu.my.

Umar Ali Bukar received the B.Sc. degree in business information technology with concentration in e-commerce research and strategy from Greenwich University, U.K., the M.Sc. degree in computer network management from Middlesex University, Dubai, and the Ph.D. degree from the Department of Software Engineering and Information Systems, Faculty of Computer Science and Information Technology, Universiti Putra Malaysia, Malaysia. He is currently a postdoctoral research fellow with the Centre for Intelligent Cloud Computing (CICC), Faculty of Information Science and Technology, Multimedia University, Malacca, Malaysia. His contributions have published in prestigious peer-reviewed journals and international conferences. His IT career has included work on several niche projects, with responsibilities ranging from teaching, research, and analysis. His research interests include crisis informatics, data analytics, text analysis, machine learning, and SLR. He can be contacted at email: uabukar@tsuniversity.edu.ng.

Md. Shohel Sayeed has been a member of Multimedia University since 2001, and now he serves as a professor of the Faculty of Information Science and Technology. His research works have been accepted by journals such as IEEE Transactions on Pattern Analysis and Machine Intelligence (TPAMI), International Journal of Pattern Recognition and Artificial Intelligence (IJPRI), Discrete Dynamics in Nature and Society (DDNS). Several of his findings have been presented in a number of well recognized IEEE conferences such as ICSP2006, ICIAS2007, ITSIM2008, CSECS2009 and ITSIM2010. He has been appointed technical paper reviewer for Journal of Pattern Recognition Letters, IEEE Transaction on Neural Networks, IEEE Transactions on Automation Science and Engineering, Journal of Computer Methods and Programs in Biomedicine and International Journal of Computer Theory and Engineering. His research interests include biometrics, image processing, signal processing, big data analytics, soft computing, artificial intelligence, machine learning, deep learning and data mining. He can be contacted at email: shohel.sayeed@mmu.edu.my.