Journal of Medical Devices Technology Vol. 5, No. 1, (2026) 6-10

Journal of Medical Devices Technology
jmeditec.utm.my

Original Research

Vital Signs and Hydration Monitoring for Military Application Via GSM Module

Hussain Youssef Hashim Karira [1], Maheza Irna Binti Mohamad Salim [1,2*]

[1] Department of Biomedical Engineering and Health Sciences, Faculty of Electrical Engineering, University Teknologi Malaysia, 81310 Johor Malaysia
[2] Diagnostics RG, Health and Wellness Research Alliance, Universiti Teknologi Malaysia, 81310 Johor Malaysia

ARTICLE INFO

Article History:
Received 13 April 2026
Accepted 24 June 2026
Available online 30 June 2026

Keywords:
Vital signs,
Oxygen saturation,
Skin moisture monitoring,
Wearable sensors,
GSM communication,
Military health,
Remote monitoring,
Photoplethysmography (PPG)

ABSTRACT

Health and readiness are critical for military personnel operating in demanding and extreme environments. Conditions such as hypoxia and dehydration-related physiological changes can adversely affect soldiers' performance and safety. These situations highlight the need for continuous physiological monitoring during military operations. This study presents a cost-effective, GSM-integrated wearable system for monitoring blood oxygen saturation (SpO2), heart rate, body temperature and skin moisture conditions in real time. The proposed system utilizes an ESP32 microcontroller integrated with a MAX30102 sensor and a capacitive Moisture Click sensor, with remote alerts transmitted via a GSM communication module to facilitate timely medical intervention. Performance evaluation involving five healthy subjects demonstrated that the MAX30102 sensor produced SpO2 readings between 97% and 99%, with a maximum deviation of ±1.33% relative to the MX450 Patient Monitor. Temperature and heart rate measurements exhibited deviations of within ±0.5°C and ±5 bpm, respectively. In addition, the Moisture Click sensor successfully differentiated three skin moisture conditions, namely very dry, dry and hydrated, with classifications comparable to those obtained using the Corneometer CM 825. The GSM module also demonstrated reliable data transmission over varying distances. These findings highlight the potential of low-cost wearable technologies for supporting physiological monitoring and enhancing situational awareness in military environments.

INTRODUCTION

The defense of a nation relies on military personnel who must operate under extreme and often hostile environmental conditions that impose substantial physiological stress. These include prolonged physical exertion, hypoxic exposure at high altitudes, thermal extremes and restricted access to hydration or medical support. Such stressors can induce adverse physiological states, particularly hypoxia and hypovolemia (dehydration-related), which compromise cardiovascular stability, autonomic regulation and overall human performance. Recent studies demonstrate that inadequate tissue oxygenation, if not detected early, can lead to functional deterioration and increased risk of mission-critical failure (Cheng et al., 2024).

In parallel, dehydration remains a critical concern in military and high-performance environments, as it disrupts fluid balance, reduces circulatory efficiency and impairs thermoregulation. Even mild dehydration has been associated with fatigue, reduced physical endurance and cognitive decline, thereby affecting operational readiness. Recent advances in non-invasive monitoring technologies highlight the importance of early detection of dehydration through continuous physiological sensing, to enable timely intervention in field conditions (Belabbaci et al., 2025).

Despite growing advancements in wearable health technologies, current systems remain insufficient for

* Maheza Irna Mohamad Salim (maheza@utm.my)

Diagnostics RG, Health and Wellness Research Alliance, Universiti Teknologi Malaysia, 81310 Johor Malaysia

deployment in military settings. Existing devices often lack multimodal sensing capability, exhibit limited integration of physiological parameters and fail to provide actionable real-time insights under operational constraints. Recent analyses emphasize that while wearable biosensors can measure parameters such as heart rate variability, temperature and metabolic indicators, most systems are still fragmented and not optimized for comprehensive physiological monitoring in dynamic environments (Sipos et al., 2025; Vo and Trinh, 2024). Furthermore, emerging smart wearable systems highlight the need for improved integration, robustness and adaptability for real-world applications beyond controlled laboratory conditions (Zhou et al., 2025).

Recent developments in wearable biosensor technologies have demonstrated significant progress toward non-invasive, continuous health monitoring. Advances include multimodal sensing platforms integrating optical, electrochemical and capacitance-based techniques, as well as Internet-of-Things (IoT)-enabled systems for real-time data transmission and analysis (Vo and Trinh, 2024; Shahzad et al., 2024; Ajami and Teimouri, 2015). In particular, hydration monitoring technologies based on bioelectrical and capacitive sensing approaches have shown strong potential for continuous, real-time assessment of physiological status, although challenges remain in accuracy and field validation (Belabbaci et al., 2025). Moreover, recent military-focused studies highlight the growing importance of integrated wearable biosensors capable of monitoring physiological and metabolic states in extreme operational environments (Sipos et al., 2025).

In response to these limitations, this study proposes the development of a wearable, precision-oriented monitoring system that integrates capacitance-based hydration sensing with optical physiological measurements and wireless communication capability via a Global System for Mobile Communications (GSM) module. The system is designed to continuously monitor key physiological parameters, including oxygen saturation (SpO2), heart rate, body temperature and skin hydration. By enabling real-time monitoring and remote data transmission, the proposed device aims to facilitate early detection of physiological distress and support timely intervention in austere and high-risk battlefield environments. This approach aligns with current research trends toward integrated, multimodal wearable systems that enhance operational performance, resilience and soldier safety.

MATERIALS AND METHOD

System Architecture

The proposed wearable device employs an ESP32-WROOM-E microcontroller as the central processing unit, selected for its robust performance and wireless capabilities. The system architecture features two primary data acquisition modules: the MAX30102 sensor, which facilitates measurement of peripheral capillary oxygen saturation (SpO2), heart rate and temperature through an I2C interface; and a capacitive Moisture Click sensor, which quantifies skin hydration via analog signal outputs. The Moisture Click sensor measures skin capacitance, reflecting stratum corneum hydration, which is used in this study as an indirect indicator of hydration status. For remote data transmission, the design integrates a SIM800L GSM module interfaced with the ESP32 via UART communication. Importantly, this GSM module is powered by an independent 3.7V LiPo battery, thereby ensuring uninterrupted and reliable cellular connectivity critical for real-time data transfer.

Software Implementation

System software was developed using the Arduino Integrated Development Environment (IDE), with specialized libraries (MAX30102_I2C.h, FDC2214.h, SIM800L.h and Software Serial.h) integrated to synchronize data collection. The microcontroller then processes raw biometric data and translates capacitance readings into actionable hydration percentages (0% for very dry skin, 50% for dry skin and 100% for completely hydrated skin). When parameters exceed predefined safety thresholds, the system seamlessly triggers the SIM800L module, which transmits automated SMS alerts to designated medical personnel.

The MAX30102 sensor was connected to the ESP32 using I2C (address 0x57, with SDA on pin 21 and SCL on pin 22) through the DFRobot_BloodOxygen_S_I2C library. This library provides pre-processed output values directly, including SpO2 (%), heart rate (bpm) and die temperature (°C), which are retrieved every 4 seconds using the getHeartbeatSPO2() and getTemperature_C() functions. No calibration code was added at the user level, as the module manages signal processing on its own.

Performance Testing

To validate the accuracy of the proposed system, simulated field testing was conducted involving five healthy student volunteers aged between 18 and 45 years. Participants were required to provide informed consent and exhibit varying baseline skin moisture levels to facilitate the evaluation of the capacitance sensor. Individuals with a history of cardiovascular or respiratory disorders, skin conditions at the sensor placement site, or those taking medications that could affect heart rate or SpO2 measurements were excluded from the study. In addition, participants who had consumed caffeine or engaged in strenuous physical activity within 30 minutes prior to testing were excluded to ensure baseline stability.

The outputs of the MAX30102 sensor for SpO2, heart rate, and temperature were directly compared with those obtained from an industry-standard MX450 Patient Monitor. The sensor was configured according to the manufacturer's specifications and operated using the standard signal processing algorithm provided in the MAX30102 library, without applying any additional calibration factors. For each participant, three consecutive measurements were recorded simultaneously from both the prototype system and the reference monitor at one-minute intervals to allow sensor stabilization. The average of the three measurements was subsequently used for comparison and analysis to improve measurement reliability and minimize random fluctuations.

To evaluate the hydration monitoring function, the prototype capacitance sensor (Moisture Click MIKROE-3084) was benchmarked against the clinical-grade Corneometer CM 825. Epidermal capacitance was assessed under three controlled skin conditions, namely very dry, dry and fully hydrated. For each condition, three sequential measurements were performed with one-minute intervals between readings. During these intervals, the sensor probe was briefly removed from the skin to minimize microclimate occlusion and sweat accumulation, thereby reducing the likelihood of artificially elevated capacitance measurements.

Finally, the GSM module was evaluated in terms of transmission stability and alert consistency under varying communication distances.

Ethical Considerations

All experimental procedures involving human participants in this study were conducted in accordance with established ethical standards for biomedical research. The study protocol adhered to the principles outlined in the Declaration of Helsinki for research involving human subjects. Prior to participation, all individuals were provided with detailed information regarding the study objectives, procedures and potential risks and informed consent was obtained in writing. Participation was voluntary and subjects were allowed to withdraw at any stage without consequence. All collected data were anonymized to ensure participant confidentiality and privacy. No invasive procedures were involved and the wearable system was designed to operate within safe, non-harmful physiological limits.

RESULT

Development of the Prototype

The prototype was designed as a wearable multi-sensor system to continuously monitor the vital signs and hydration status of military personnel in real-time. The system architecture is divided into three primary stages: data acquisition (input), processing and remote transmission (output). The core of the system is an ESP32 microcontroller, which serves as the central processing unit orchestrating all hardware components.

For data acquisition, the system relies on two specialized sensors. A MAX30102 sensor interfaces with the ESP32 via I2C to measure oxygen saturation (SpO2), heart rate and skin temperature. Simultaneously, a capacitance-based Moisture Click sensor is utilized to evaluate skin moisture levels as an indirect indicator of dehydration status. To enhance system efficiency and prevent sensor cross-interference, the ESP32 microcontroller implements a time-multiplexed acquisition strategy: each sensor is individually activated, data is captured over a fixed sampling interval, the sensor is deactivated and control is passed sequentially to the next peripheral in the polling cycle.

Once acquired, the physiological data is processed by the ESP32 and transmitted via USB to a connected PC, where it is further analyzed and displayed in real-time. Subsequently, the data is forwarded via a UART interface to a SIM800L GSM module. Powered by an independent 3.7V LiPo battery, the GSM module leverages cellular networks to deliver automated SMS alerts containing real-time sensor readings to remote medical personnel. When any monitored parameter exceeds predefined critical thresholds, an alert is dispatched immediately, enabling timely clinical intervention without reliance on Wi-Fi infrastructure, as illustrated in Fig 1.

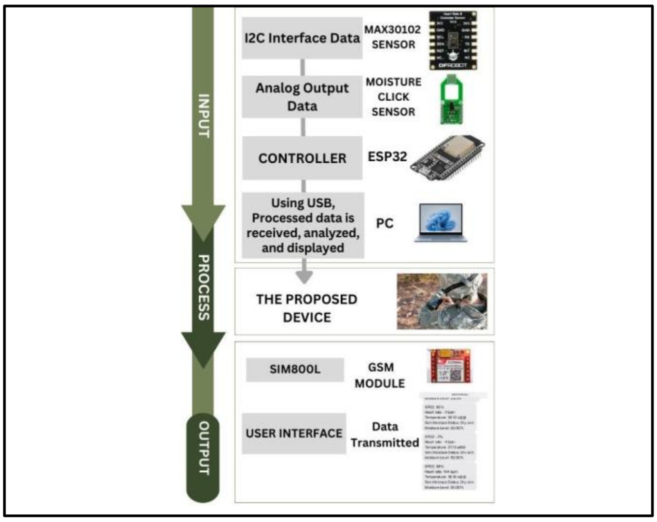

Fig 1 Block diagram of the proposed real-time vital signs and hydration monitoring system

Performance Testing Result

Vital Signs Sensor Validation

The performance of the integrated MAX30102 sensor with that of the clinical-grade MX450 Monitor. The developed device accurately tracked SpO2 levels and heart rates across diverse subject profiles, with only minor acceptable deviations in superficial temperature readings, which were attributed to the distinct calibration techniques used for temperature measurement in each device.

Table 1 Comparison between MAX30102 and MX450 Patient Monitor (mean value)

Name	Sensor Type	SpO2 (%)	Heart Rate (bpm)	Temperature (°C)
SUBJECT 1	DF Robot Sensor	98.33	107.33	31.33
	MX450 Monitor	98.67	104.00	34.17
SUBJECT 2	DF Robot Sensor	98.33	76.33	30.90
	MX450 Monitor	98.33	80.67	32.17
SUBJECT 3	DF Robot Sensor	99.00	83.33	35.18
	MX450 Monitor	98.67	88.00	33.30
SUBJECT 4	DF Robot Sensor	99.00	87.00	32.70
	MX450	99.00	90.00	34.25

	Monitor			
SUBJECT 5	DF Robot Sensor	97.00	114.67	30.62
	MX450 Monitor	98.33	111.00	31.87
Mean Absolute Error (MAE)		0.40	3.80	1.76

As indicated in Table 1, the SpO2 mean absolute error (MAE) of 0.40% and the heart rate MAE of 3.80 bpm fall within the tolerances of ±2% and ±5 bpm established by ISO 80601-2-56, respectively, confirming that they are clinically acceptable. The temperature MAE of 1.76°C is due to the physiological difference between peripheral skin temperature (measured by the MAX30102) and core body temperature (measured by the MX450), which typically ranges from 2 to 5°C at distal sites because of vasoconstriction and decreased blood flow. This is a recognized limitation of peripheral wearable sensors and does not suggest a calibration error.

Hydration Sensor Validation

The Moisture Click sensor effectively distinguished between critical hydration states. As shown in Table 2, the capacitance-based percentage readings closely aligned with the Astronomical Units (AU) generated by the Corneometer CM 825, confirming its high sensitivity and robustness for monitoring combat-induced dehydration.

Table 2 Shows Comparison between Moisture Click and Corneometer CM

Sensor	Readings		
Moisture Click 3084 (%)	0	50	100
	Very dry Skin	Dry Skin	Hydrated
Corneometer CM 825 (AU)	0-30	30-45	Above 45

GSM Transmission Performance

To evaluate the SIM800L GSM module's transmission reliability, SMS alert delivery was tested across varying distances under simulated field conditions without Wi-Fi connectivity. The module was triggered by threshold-exceeding values of SpO2, heart rate, temperature and hydration and the success of each alert transmission was recorded. According to Table 3, the module demonstrated reliable and effective SMS delivery at all tested distances, validating its appropriateness for remote military health monitoring uses. The offline cellular functionality of the SIM800L allowed for continuous communication, even in simulated environments without infrastructure, with no data loss noted during transmission.

Table 3 GSM Module Transmission Performance

Test Number	Distance	Environment Condition	SMS Received	Transmission Status
1	10	Indoors	Yes	Success
2	50	Indoors	Yes	Success
3	100	Outdoors	Yes	Success
4	300	Outdoors	Yes	Success

DISCUSSION

The results demonstrate the feasibility of employing cost-effective, commercially available sensors for demanding military applications. The MAX30102 sensor, which measures blood oxygen saturation, body temperature and heart rate, together with the Moisture Click sensor for skin hydration monitoring, exhibited good agreement with clinical reference devices. These findings suggest that changes in physiological parameters associated with conditions such as hypoxia and reduced skin hydration can be detected in a timely manner, thereby providing valuable information for early intervention in battlefield settings.

The differences observed between the prototype and the MX450 Patient Monitor may be partly attributed to the distinct sensing and calibration approaches employed by the two systems. The MAX30102 sensor was operated using the manufacturer's recommended configuration and signal processing algorithm without additional calibration coefficients, while the MX450 Patient Monitor utilizes clinically calibrated measurement techniques optimized for medical applications. To enhance measurement reliability, three consecutive readings were acquired and averaged prior to comparison with the reference device. Consequently, the prototype demonstrated satisfactory agreement with the MX450 Patient Monitor, with slight deviations in temperature measurements expected because the proposed system estimates superficial skin temperature rather than core body temperature.

Additionally, the hydration monitoring subsystem developed in this study does not directly diagnose systemic dehydration but rather provides an indication of changes in epidermal moisture based on capacitance measurements. Since the capacitive Moisture Click 3084 sensor is sensitive to transient factors such as perspiration, environmental humidity and local skin conditions, methodological controls were implemented to minimize false readings. Measurements were acquired while participants were at rest and the sensor probe was briefly removed between intervals to prevent sweat accumulation and microclimate formation at the skin–sensor interface. Furthermore, three consecutive measurements were obtained and averaged to reduce measurement variability. Consequently, the hydration sensor should be regarded as an auxiliary screening tool rather than a definitive indicator of systemic dehydration. Future enhancements may incorporate additional physiological and environmental parameters to improve the specificity and robustness of dehydration assessment.

The successful integration of the GSM (Global System for Mobile Communications) module also addresses a major limitation of current military wearables, which often struggle to transmit physiological data reliably over long distances in austere environments. By facilitating rapid medical response through automated alerts, the system directly addresses evacuation and triage challenges frequently highlighted in battlefield after-action reviews (Carius et al., 2022). In terms of communication performance, the SIM800L module demonstrated reliable SMS delivery at all tested distances without data loss. This finding is consistent with previous studies emphasizing the importance of infrastructure-independent communication for real-time remote monitoring in harsh environments. Compared with short-range Bluetooth-based systems such as the Hidalgo EQ02 and Nonin Onyx II, the proposed GSM-based approach enables long-range alert transmission without requiring local Wi-Fi networks or portable base stations, thereby providing a significant operational advantage for field military applications (Patil et al., 2023).

CONCLUSION

This study presented a portable, low-cost wearable system for real-time monitoring of physiological parameters and skin moisture conditions in military personnel. By integrating the ESP32 microcontroller, MAX30102 optical sensor and a capacitance-based Moisture Click sensor within a GSM communication framework, the system demonstrated satisfactory agreement with reference devices and reliable remote alert transmission under varying operational conditions. The findings highlight the potential of commercially available sensors for supporting physiological monitoring and enhancing situational awareness in resource-constrained military environments.

Nevertheless, the skin moisture subsystem should be regarded as an auxiliary indicator rather than a definitive measure of systemic dehydration, as environmental factors and perspiration may influence capacitance measurements. Future work should focus on expanding the sensor array, improving LiPo battery efficiency, incorporating GPS tracking and data encryption and integrating additional physiological and environmental parameters to enhance the robustness and specificity of hydration assessment, thereby further aligning the platform with contemporary defense technology requirements.

ACKNOWLEDGEMENT

The authors would like to thank Department of Biomedical Engineering and Health Sciences for the facilities provided to conduct the research

REFERENCES

Ajami, S., & Teimouri, F. 2015. Features and application of wearable biosensors in medical care. *Journal of Research in Medical Sciences*. 20(12), 1208–1215. https://doi.org/10.4103/1735-1995.172991

Belabbaci NA, Anaadumba R, Alam MAU. 2025. Recent Advancements in Wearable Hydration-Monitoring Technologies: Scoping Review of Sensors, Trends and Future Directions. *JMIR Mhealth Uhealth*. 13:e60569. doi: 10.2196/60569

Carius, B. M., et al. 2022. Battlefield Vital Sign Monitoring in Role 1 Military Treatment Facilities: A Thematic Analysis of After-Action Reviews from the Prehospital Trauma Registry. Military Medicine. 187(1-2), e28-e33.

Cheng, C., Ganguly, S., Li, P., & Tang, X. 2024. Detecting Hypoxia Through the Non-Invasive and Simultaneous Monitoring of Sweat Lactate and Tissue Oxygenation. Biosensors, 14(12), 584. https://doi.org/10.3390/bios14120584

Patil S. S, Patil A. B. and Mali A. S. 2023. "Soldier tracking & health monitoring system using GSM and GPS system," *Journal of Emerging Technologies and Innovative Research (JETIR)*, 10(10):g185–g191. Available: https://www.jetir.org/papers/JETIR2310521.pdf

Shahzad, S., Iftikhar, F. J., Shah, A., Rehman, H. A., & Iwuoha, E. 2024. Novel interfaces for internet of wearable electrochemical sensors. RSC Advances. 14, 36713–36732. https://doi.org/10.1039/D4RA07165D

Sipos, D., Vészi, K., Bogár, B., Pető, D., Füredi, G., Betlehem, J., & Pandur, A. A. 2025. Physiological State Monitoring in Advanced Soldiers: Precision Health Strategies for Modern Military Operations. *SciSci*, 7(4), 137. https://doi.org/10.3390/sci7040137

Vo, D.-K., & Trinh, K. T. L. 2024. Advances in Wearable Biosensors for Healthcare: Current Trends, Applications and Future Perspectives. *BiosensorsBiosensors*. 14(11), 560. https://doi.org/10.3390/bios14110560

Zhou L, Guess M, Kim KR, Yeo WH. 2024. Skin-interfacing wearable biosensors for smart health monitoring of infants and neonates. Commun Mater. 5(1):72. https://doi.org/10.1038/s43246-024-00511-6