Review Article

The Fabrication of Electronics Wearable Bracelets and approach to telecommunications: A Review

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Abstract: This research aims to develop an innovative and easy-to-use fetal heart rate monitoring bracelet for pregnant women. The design of this bracelet involves various electronic aspects, including signal acquisition using optical sensors (Ultrasound Doppler, ECG, or PPG), signal processing with a microcontroller and efficient algorithms to eliminate noise and detect heart rate, as well as data display and communication via LCD screen, LED indicator, or Bluetooth connection. The power aspect is an important consideration in the selection of the right battery and power management. The design of the bracelet considers ergonomics and safety for pregnant women and fetuses. Testing and validation are carried out thoroughly, including functionality testing and clinical trials. This research also considers ethical aspects, such as data privacy and information reliability. By integrating all these aspects, it is hoped that this research can produce a prototype fetal heart rate monitoring bracelet that is accurate, safe, and comfortable to use, thus contributing to improving maternal and child health. Wearable Bracelet must-have comfort factors components consisting of Size & Dimensions, Device Weight, Strap Material, Thickness, Flexibility, Component Distribution, Edges & Corners, and Skin Ventilation. From the intructables' sample results the comfort level is 52.5%, while the tool created by Puput Dani Prasetyo has a comfort level of only 50%. And this needs to be increased to >90%.

Keywords: battery degradation, current distribution, temperature rise, electrochemical model, sensitivity analysis.

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1. Introduction

Currently, wearable technology has emerged as a revolutionary force in the electronics industry, bridging the gap between human capability and digital connectivity. Among these innovations, wearable bracelets have gained significant prominence due to their non-invasive nature, user-friendly interfaces, and versatile applications, various technologies such as BLE, WiFi, and LoRa have become part of the current development of Wearable Devices. These devices represent the convergence of miniaturized electronics, telecommunications, and human-centered design principles, offering unprecedented opportunities for personal health monitoring, seamless connectivity, and enhanced productivity. Wearable Devices have been made as flexible as possible as well as Nordic-IoT devices that combine with BLE.

The fabrication of electronic wearable bracelets involves intricate processes that combine advanced materials science [1,2,3], wearable bracelets combined with telecommunications, precision engineering, and innovative manufacturing techniques. Modern wearable bracelets integrate complex electronic components including microprocessors, sensors, wireless communication modules, and energy storage solutions within compact, lightweight, and often flexible form factors. The challenge lies not only in miniaturizing these components but also in ensuring their durability, energy efficiency, and comfort during prolonged usage, A super lightweight version is used for patient comfort, The previous development used a medium-sized ZigBee in the wrist area, with a pulse sensor.

Figure 1. Functionality of Wearable Bracelet Device for Health Monitoring

Telecommunications plays a pivotal role in extending the functionality of wearable bracelets beyond simple data collection and processing. Through various wireless communication protocols such as Bluetooth, Wi-Fi, NFC, and cellular connectivity, these devices can transmit and receive data in real time, enabling them to serve as extensions of smartphones, gateways to the Internet of Things (IoT), and nodes within broader telecommunications networks. This connectivity transforms wearable bracelets from standalone gadgets into integral components of our increasingly interconnected digital ecosystem. The intersection of wearable technology and telecommunications presents unique challenges and opportunities that necessitate innovative approaches [4,5,6]. These include optimizing power consumption for wireless data transmission, ensuring secure and private communication channels, maintaining connectivity in various environments, and developing user interfaces that balance functionality with simplicity. As these technologies continue to evolve, they promise to revolutionize how we interact with digital information and services [7,8,9], making technology more personal, intuitive, and seamlessly integrated into our daily lives. Figure 1 shows in detail the Wearable Bracelet for Health Monitoring with different types of sensors.

2. Literature Review

2.1 *Flexible Electronics Theory*

The development of wearable bracelets is fundamentally grounded in flexible electronics theory, which addresses the mechanical, electrical, and thermal properties of materials that can undergo deformation while maintaining functionality. This includes the study of elastic moduli, strain limits, and fatigue behavior of conductive materials under repeated flexing conditions typical in wearable applications. The miniaturization required for wearable devices relies heavily on thin-film deposition theories, including physical vapor deposition (PVD) and chemical vapor deposition (CVD) models. These theories explain the growth mechanisms, adhesion properties, and electrical characteristics of nanometer to micrometer-scale films used in sensor arrays and circuit pathways.

Modern wearable fabrication increasingly incorporates additive manufacturing theories, particularly related to multi-material printing and embedded electronics [10,11,12]. These theoretical approaches model the interaction between substrate materials and functional inks, curing mechanisms, and the integration of electronic components within printed structures. For devices with direct skin contact, biocompatibility theories become essential. These include models predicting material degradation in the presence of sweat, mechanical irritation thresholds, and allergenic potential based on polymer chemistry and surface characteristics [13,14,15].

2.2 *Telecommunication for Wearable Bracelet*

The telecommunications capability of wearable bracelets relies on wireless propagation theories that account for the unique challenges of body-worn devices. These include path loss models specific to body area networks (BANs), accounting for body shadowing effects, multipath propagation, and reflection/absorption characteristics of human tissue. Power constraints in wearable devices have led to the development of theoretical frameworks for energy-aware communications, including duty-cycling optimization, transmission power control algorithms, and energy-harvesting models that predict available power from ambient sources [16,17,18].

Theoretical models describing optimal network architectures for wearable devices include star, mesh, and hybrid topologies that balance reliability, latency, and energy consumption. Protocol theories address the unique challenges of intermittent connectivity, prioritized data transmission, and graceful degradation under resource constraints. The privacy-sensitive nature of data collected by wearable bracelets necessitates theoretical frameworks for lightweight cryptography, physical layer security, and secure key exchange in resource-constrained environments.

The fabrication of electronic wearable bracelets represents a complex systems integration challenge requiring theoretical models that address the interaction between multiple subsystems: Comprehensive models that simultaneously address electrical, thermal, mechanical, and sometimes chemical behaviors are essential for predicting device performance. These models account for thermal dissipation from electronic components, mechanical stress distribution during flexing, and electromagnetic interference between closely packed components. Theoretical approaches to user interface design for wearable devices must account for limited display real estate, alternative input methods, and contextual awareness. These include models for gesture recognition, haptic feedback optimization, and glanceable information presentation [19,20,21,22]. Advanced wearable bracelets rely on theoretical frameworks for sensor fusion and context inference, including probabilistic models that derive higher-level information (activity type, user state) from raw sensor data, often using Bayesian networks or hidden Markov models.

Theoretical approaches to seamless operation across multiple communication technologies (Bluetooth, Wi-Fi, cellular) include vertical handoff algorithms, media-independent handover frameworks, and quality-of-service preservation models during transitions between networks. Distribution of processing between the wearable device, smartphone, and cloud services follows theoretical models of computational offloading that optimize for energy efficiency, latency, and reliability based on network conditions and processing requirements.

The transformation of raw sensor data into actionable information follows theoretical frameworks for data compression, feature extraction, and anomaly detection that maximize information content while minimizing transmission bandwidth and energy requirements. Theoretical models exploring energy harvesting from body motion, temperature differentials, and ambient RF sources to create self-sustaining wearable systems. Theories describe materials that intrinsically perform sensing, computation, or communication functions without discrete electronic components, including models of neuromorphic materials and programmable matter. As components shrink toward fundamental limits, quantum mechanical models become increasingly relevant for describing electron transport, tunneling effects, and potential quantum communication protocols. Theoretical frameworks describe the interface between electronic systems and biological processes, including bioelectric signal detection, biofeedback mechanisms, and biomarker sensing through minimally invasive approaches. This theoretical framework provides a foundation for research into the fabrication of electronic wearable bracelets and their telecommunications capabilities, highlighting the multidisciplinary nature of the field and the complex interplay between materials science, electronics engineering, telecommunications theory, and human factors.

3. Method

This research employs a mixed-methods approach combining experimental design, prototyping, and performance evaluation to investigate the fabrication of electronic wearable bracelets and their telecommunications capabilities. The methodology is structured in four sequential phases, with each phase building upon the findings of the previous one.

3.1 Material Selection and Characterization

The Materials Screening process is Flexible Substrate Selection, which is a systematic evaluation of potential substrate materials including thermoplastic polyurethane (TPU), polydimethylsiloxane (PDMS), and polyimide films. Next is to conduct Parameter Testing namely Flexibility (bend radius testing), durability (cyclic mechanical stress testing), and biocompatibility (ISO 10993 standard testing). In addition, Conductive Materials Assessment or Evaluation of silver nanoparticle inks, carbon-based conductive materials, and liquid metal alloys for circuit lines. In addition, Analytical Techniques namely Scanning electron microscopy (SEM), atomic force microscopy (AFM), and four-point probe resistivity measurements. In addition, Material-Component Compatibility Analysis, i.e. Interface Characterization i.e. Assessment of adhesion strength between electronic components and flexible substrates. The next parameter is Thermal Behavior, which is Differential scanning calorimetry (DSC) to determine the coefficient of thermal expansion and compatibility. Environmental Stability Testing, which is exposure to controlled humidity (10-95% RH), temperature cycles (-10°C to 50°C), and artificial sweat solutions to simulate real-world usage conditions.

3.2 Fabrication Process Development

It is important in the Fabrication process to consider Circuit Design and Optimization, as well as Circuit Layout Design which is Computer-aided design (CAD) of flexible circuit layouts optimized for wearable form factors. The simulation process also includes Electromagnetic Simulation which is Finite element analysis (FEA) to simulate electromagnetic performance and identify potential interference. In addition to simulation, it also uses Circuit Design, namely Power Management Circuit Design, which is the development of low-power circuits with sleep mode and adaptive power scaling.

Then enter the Fabrication stage. Fabrication requires special techniques, examples of Fabrication Techniques include Printing Methods, namely Evaluation of screen printing, inkjet printing, and aerosol jet printing for conductive traces. Then pay attention to Process Parameters Optimization, which is a Design of Experiments (DOE) approach to optimize printing parameters (viscosity, substrate temperature, curing conditions). Next is Component Integration, which is the development of methods to attach rigid components (microcontrollers, sensors) to flexible substrates, including anisotropic conductive film (ACF) bonding and low-temperature soldering.

The last but not least factor is Encapsulation Techniques i.e. Assessment of conformal coating methods including parylene deposition, UV light curable polymers, and medical grade silicone encapsulation. Since the sensor is not just a single sensor, there is a need for Sensor Integration, namely Sensor Selection and Calibration, namely Integration of accelerometers, gyroscopes, optical heart rate sensors, temperature sensors, and electrodermal sensors (EDA). The next factor is Sensor Placement Optimization, which is experimental sensor positioning that is optimal for signal quality and user comfort. And also Calibration Protocols, which is the development of sensor calibration procedures to ensure the accuracy and repeatability of measurements.

3.3 Telecommunications System Implementation

The Telecommunication System is one of the foundations in building this research, there are several key parameters used including Communication Protocol Selection, namely Protocol Evaluation Comparative analysis of Bluetooth Low Energy (BLE), Zigbee, ANT +, and NFC protocols, The complete parameters used in the Health Monitoring Bracelet are described in Table 1. Then Evaluation Metrics namely Power consumption, data rate, range, latency, and robustness in body-worn scenarios. Interference Testing is Controlled RF environment testing to evaluate performance in the presence of common interference sources.

In the process of sending data to Wearable Devices, Antenna Design, and Optimization are required, Antenna parameters include Antenna Geometries, namely the Design and fabrication of compact antennas compatible with wearable form factors, including meandered monopoles, printed dipoles, and patch antennas. Antenna parameters can also be analyzed using CST Software. Simulation and Validation include Electromagnetic simulation using the method of moments (MoM) or finite-difference time-domain (FDTD), followed by network analyzer measurements of fabricated antennas. Then On-Body Performance, namely Characterization of antenna performance when worn on different body locations, accounting for body effects on radiation patterns and efficiency.

Furthermore, in telecommunication systems, system integration is also known. Communication System Integration puts forward Protocol Stack Implementation which is the development of an efficient protocol stack optimized for the resource limitations of wearable devices. Other than that is Power Optimization, which is the implementation of adaptive duty cycling, transmission power control, and context-aware connection management. Last but not least is Security Implementation which is the integration of lightweight encryption, a secure boot process, and a secure key storage mechanism.

Table 1. Comparison of Telecommunication Technologies for Health Monitoring Bracelet

Parameters	LoRa	ZigBee	WiFi	BLE
Reach	2-15 km	10-100 meter	30-100 meter	10-50 meter
Power Consumption	Very Low (µA)	Low (mA)	High (+100 mA)	Very Low (µA)
Battery Life	2-10 year	6 month – 2 year	Several hours - 1 day	6 months - 3 years
Data Transfer Speed	0.3-50 kbps	20-250 kbps	1-150 Mbps	125 kbps-2 Mbps
Latency	High (1-10 second)	Low (<100 ms)	Very Low (<10 ms)	Low (6-30 ms)
Cost of Implementation	Intermediate-High	Intermediate or medium	Low	Low
Setup Complexity	High (need gateway)	Medium	Low	Very Low
Object Penetration	Very Good	Good	Medium	Medium
Interference	Low	Medium	High	Low-Medium
Antenna Size	Big	Small	Medium	Very Small

3.4 Integration System and Evaluation

At this stage, the prototype stage is already under development. Prototype Development consists of Iterative Prototyping i.e. Progressive prototype development from breadboard to flexible PCB to final form factor. Form Factor Optimization i.e. Anthropometric studies to determine the optimal bracelet dimensions for different user populations. And Manufacturing Process Development i.e. Establishment of a repeatable manufacturing process suitable for small batch production.

Not only hardware but also software needs to be tested, so it needs to go through the Performance Evaluation process which consists of Electrical Performance Testing i.e. Characterization of power consumption, battery life, processing capabilities, and sensor accuracy. Mechanical Reliability Testing i.e. Flexibility testing (10,000+ cycles), drop testing, and water/sweat resistance testing with IP67 standard. Telecommunications Performance i.e. Field testing of data transmission reliability, range, and durability in various environmental conditions. And Thermal Management Assessment i.e. Infrared thermography during operation to identify potential hot spots and validate thermal design.

The next evaluation is seen from the user's side, or User-Centered Evaluation. It consists of Usability Testing which is a structured user study with defined tasks and standardized usability metrics (System Usability Scale). Wearability Assessment which is a comfort evaluation using standardized questionnaires and physiological measures of skin irritation. And Long-term User Study i.e. extended usage trials (2-4 weeks) with daily usage logs and periodic interviews to assess real-world performance and user acceptance.

Furthermore, Data Analysis Methods, consisting of Performance Data Analysis, including Statistical Analysis i.e. Descriptive statistics, ANOVA, and regression analysis to evaluate performance metrics across different design iterations. Reliability Analysis i.e. Weibull Analysis for failure prediction and identification of reliability bottlenecks. And Power Profile Analysis i.e. Time domain and frequency domain analysis of power consumption patterns to identify optimization opportunities.

In addition, in Telecommunications Data Analysis, there are several parameters that are key, including Signal Quality Metrics, namely Bit error rate (BER), packet delivery ratio (PDR), and signal-to-noise ratio (SNR) under various operating conditions. Network Performance includes throughput, latency, and jitter analysis using controlled test scenarios and real-world usage data. Then Coverage Mapping is a spatial analysis of signal strength and connection reliability to validate coverage requirements. The next process is the Validation and Verification Method. System Validation entails Requirements Verification, which is the systematic testing of established functional and non-functional requirements. Standards Compliance i.e. Verification of compliance with relevant standards including FCC regulations for RF devices, Bluetooth SIG certification requirements, and applicable medical device standards if health monitoring is included. Comparative Benchmarking is the comparison of performance against commercial wearable devices in controlled tests. Finally, In Telecommunications Validation, the components analyzed include Protocol Analyzer Testing, which is the use of special equipment to verify the correctness of the protocol implementation. Interference Resilience is controlled testing in an RF anechoic chamber with calibrated interference sources.

Moreover, Real-world validation required Field testing in environments representing actual use cases, including indoor/outdoor scenarios and various levels of population density. For example, in measuring the signal strength (-dBm) of the telecommunication device used against obstacles and distance. Furthermore, this comprehensive methodology provides a structured approach to the development and evaluation of electronic wearable bracelets with a specific focus on their fabrication processes and telecommunications capabilities. The multi-phase research design enables systematic investigation of materials, fabrication techniques, telecommunications strategies, and overall system performance. In detail, Figure 2 shows the Wearable Bracelet System with various steps and connectivity.

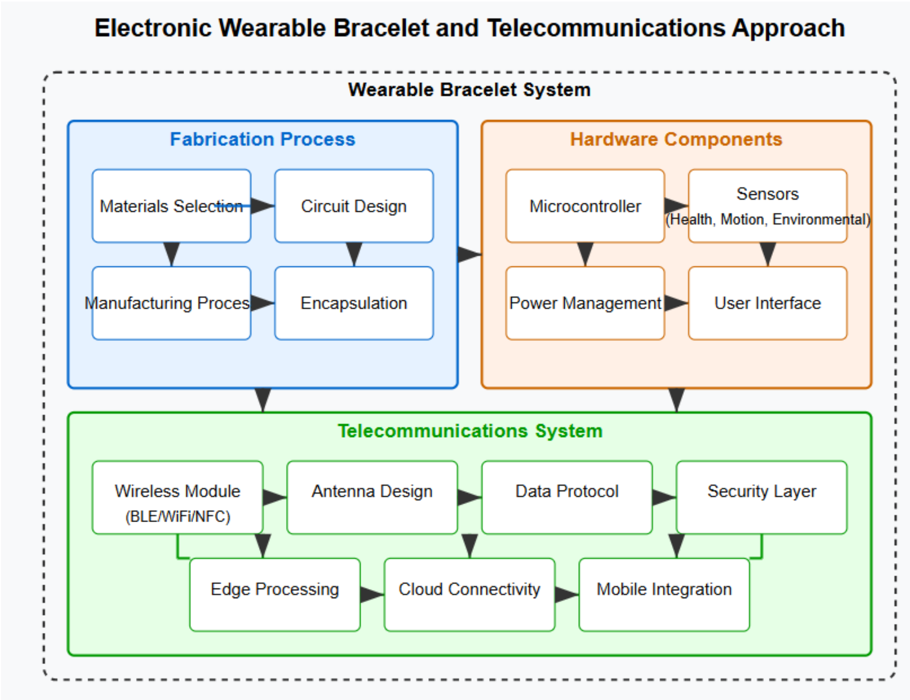


Figure 2. Wearable Bracelet System

4. Result and Discussion

Furthermore, Figures 3 and 4 are DIY examples of using 3D Software to personally create a Wearable Bracelet device that will be used to place electronic components inside, including batteries and case settings that are neither too large nor too small, so that electronic components cannot fit and be placed appropriately. 3D designers must take into account various sides, including the dimensions of the Microcontroller to be used so that it is not too large or small MCU dimensions including batteries and other components. The smaller the size of the MCU and other electrical components including integrated sensors, the more comfortable it is for patients or users to use.

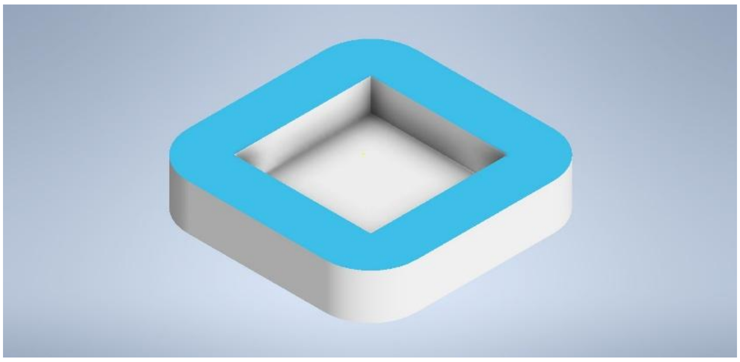


Figure 3. Fabrication for Electronics Wearable Bracelet

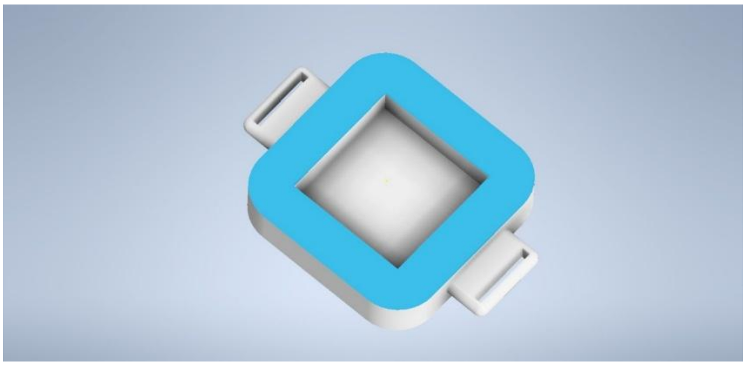
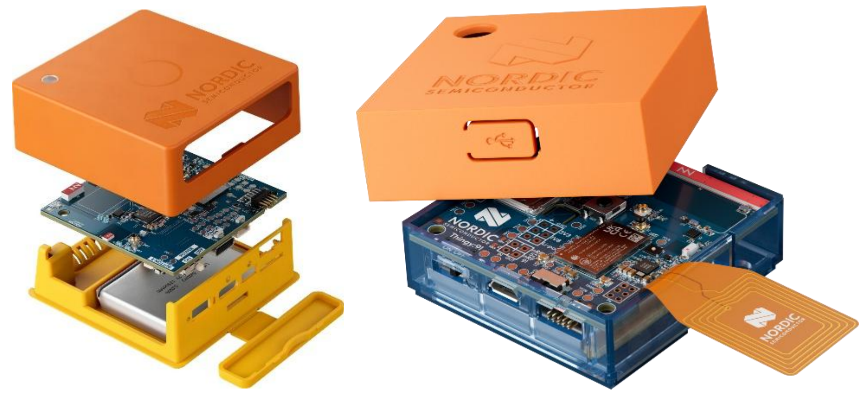


Figure 4. Fabrication for Electronics Wearable Bracelet



(a) (b)

Figure 5. (a, b) Nordic casing (*source*: nordicsemi.com and nordicsemi.jp)

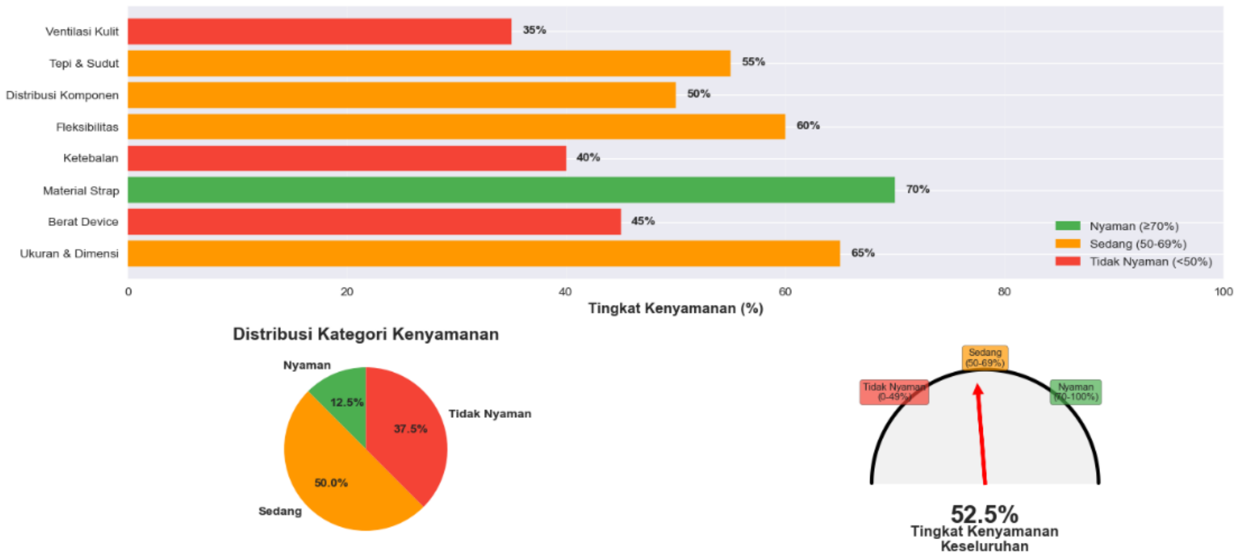
Furthermore, Figure 5 is one of the shapes of the Nordic casing and how the hardware inside is placed and sized appropriately, next is to fit the elastic band that will be used for the patient, in addition to showing the sensor configuration and patient comfort features. Sensors configuration includes Heart Rate using a PPG Sensor (photoplethysmography), temperature sensor using a Non-Contact IR Sensor, Motion using a 3-axis accelerometer, and SPO2 using a Dual-wavelength optical sensor. Next, the patient comfort factor consists of several features including Smart Alerts (Gradual intensity), Sleep mode (minimal disturbance), skin temperature monitoring (prevent overheating), and Activity-aware adjustments. Moreover, from the data in Table 1, the overall comfort score is 6.5/10 to 8.3/10 with improvement.

Table 2. Comfort level for patients (1-10)

Aspects	Current Score	Potential Score
Weight/Size	8/10	9/10
Ergonomics	6/10	8/10
Skin Contact	5/10	8/10
Heat Management	6/10	8/10
Mobility	7/10	9/10
Aesthetics	7/10	8/10

Figure 6. DIY of Wearable Bracelet for Health Monitoring (*source:* instructables.com/HealthBand)

Figure 6 is a DIY Wearable Bracelet from instructables which is also made by combining various Microcontrollers and sensors to monitor human health. Just like the previous discussion that Weight or Size determines the comfort level of the patient, because the movement of the patient or user is too frequent, an End-Devices that is small and light is needed, without reducing the essential factor, i.e., health monitoring system. Wearable Bracelets must have comfort factors components consisting of Size & Dimensions, Device Weight, Strap Material, Thickness, Flexibility, Component Distribution, Edges & Corners, and Skin Ventilation.



Faktor	Score	Analisis Berdasarkan Gambar	Rekomendasi Perbaikan
Ukuran & Dimensi	65%	Cukup besar, mungkin mengganggu gerakan	Desain lebih compact dan ergonomis
Berat Device	45%	Terlihat berat dengan banyak komponen	Gunakan material lebih ringan
Material Strap	70%	Strap fleksibel, tampak comfortable	Pertahankan kualitas material
Ketebalan	40%	Sangat tebal, menonjol dari pergelangan	Redesign untuk profil lebih tipis
Distribusi Komponen	50%	Komponen terpusat, tidak merata	Distribusi komponen lebih merata
Ventilasi	35%	Tertutup rapat, kurang sirkulasi udara	Tambahkan lubang ventilasi

Figure 7. Wearable Health Device Comfort Factor Analysis on DIY Device Figure 6

Moreover, there is another mode that can be analyzed for its comfort level for patients, namely the DIY Wearable Bracelet for Health Monitoring LoRa as shown in Figure 8. This Wearable Bracelet device is rather large due to the antenna factor and also the casing is too large, for Telecommunication devices used is LoRa type ES920LR with a Frequency of 920 MHz which is included in the LPWAN devices category in the Asian region used in Japan. Next, Figure 9 is the comfort analysis of this DIY Wearable Bracelet.

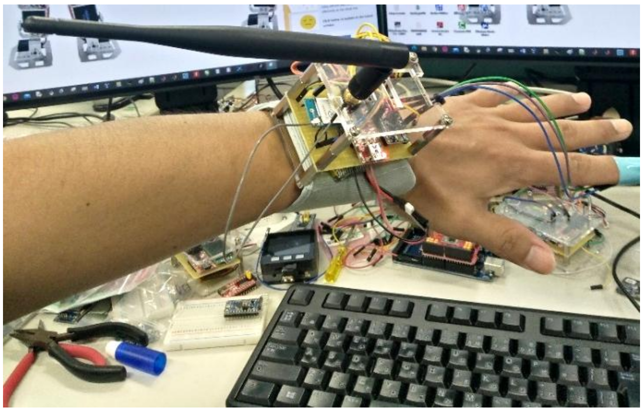
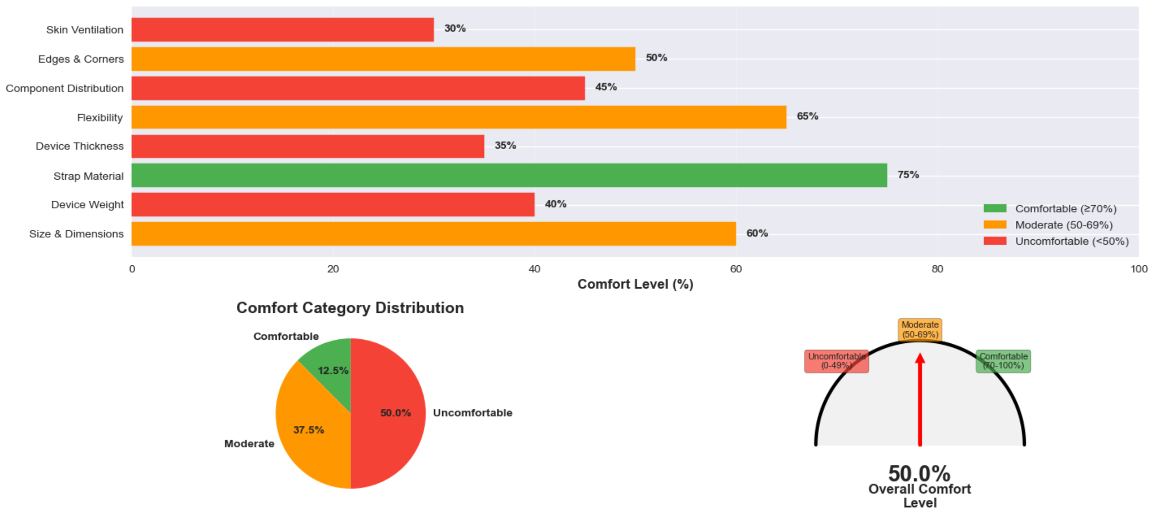


Figure 8. DIY of Wearable Bracelet for Health Monitoring LoRa based (*source:* Puput Dani Prasetyo Adi, BRIN Researcher)



Factor	Score	Analysis Based on Visual Observation	Improvement Recommendations
Size & Dimensions	60%	Bulky design, may hinder natural movement	Develop more compact and ergonomic design
Device Weight	40%	Heavy with multiple components and wires	Use lightweight materials, optimize components
Strap Material	75%	Flexible straps, appears comfortable	Maintain current strap quality
Device Thickness	35%	Very thick profile, prominent on wrist	Redesign for thinner, low-profile form factor
Flexibility	65%	Some flexibility but rigid components	Increase joint flexibility, add soft interfaces
Component Distribution	45%	Components clustered, uneven weight distribution	Distribute components more evenly
Edges & Corners	50%	Some sharp edges visible on device housing	Round edges, smooth all contact surfaces
Skin Ventilation	30%	Enclosed design, poor air circulation	Add ventilation holes, breathable materials

Methodology: Assessment based on visual analysis of ergonomic factors, device size, component distribution, and comparison with comfortable wearable device standards

Figure 9. Wearable Health Device Comfort Factor Analysis on DIY Device Figure 8

Moreover, the device created by Puput Dani Prasetyo Adi has a comfort level of all the previous parameters described in Figure 9, the Overall Comfort Level is 50% with a

Moderate Category. Factors with Lowest Scores consisting of Skin Ventilation 30%, Device Thickness: 35%, and Device Weight: 40%. Primary Recommendations include Reducing device thickness for lower profile design, Optimizing component distribution to reduce weight and bulk, Adding a ventilation system for better skin comfort, Smooth edges and corners to prevent pressure points, and Consider modular design for better adaptability. Next, the Comfort Classification is as follows: Comfortable factors (1): Strap Material, Moderate factors (3): Size & Dimensions, Flexibility, Edges & Corners, Uncomfortable factors (4): Device Weight, Device Thickness, Component Distribution, Skin Ventilation, the conclusion is The device shows Moderate comfort level requiring significant improvements. The focus areas are Device thickness, weight distribution, and ventilation system.

5. Conclusion

The current health monitoring system has switched from a static to a dynamic system, meaning that it is very easy for users to get data dynamically and in real-time. For example, a runner does not need to carry a device with large dimensions, but only a small 11x40 mm watch on the wrist. In terms of sales systems, watch-shaped monitoring technology is currently widely circulated in the market, but something that needs to be considered and needs to be continuously developed is the system by the Research and Development (RnD) team, especially the telecommunication division for the development of warning and real-monitoring systems with different telecommunication devices such as LoRa Module, which has different capabilities from WiFi and BLE Module, and other devices as shown in Table 1. Wearable Bracelets must have comfort factors components consisting of Size & Dimensions, Device Weight, Strap Material, Thickness, Flexibility, Component Distribution, Edges & Corners, and Skin Ventilation. From the intractable sample results the comfort level is 52.5%%, while the tool created by Puput Dani Prasetyo has a comfort level of only 50%. And this needs to be increased to >90%.

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