

# **Intelligent Health Monitoring Device Data Analysis: From Data Collection to Health Insights**

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#### Abstract

The integration of smart wearable and home health monitoring devices marks a new epoch in health management, offering deep insights through real-time data. This study seeks to convert this collected health data into actionable personalized assessments and recommendations, enhancing health management efficacy.

Utilizing literature review, case analysis, and data analysis, the research initially describes smart devices' capabilities and data gathering techniques. It then concentrates on data processing methodologies, statistical analysis, and machine learning, examining the translation of these into usable health insights.

The study reveals that smart devices offer continuous health data, enabling the identification of individual trends and risks through data analysis. Personalized assessments can boost engagement and adherence to health plans. Yet, it acknowledges challenges in data privacy, technological synthesis, and user adoption, proposing solutions like fortified security, interface optimization, and enhanced analytical accuracy.

In conclusion, the research highlights the potential of data analysis in advancing personalized health management and recommends future explorations, such as refining algorithms, bolstering privacy safeguards, and setting regulatory benchmarks.

**Keywords:** smart health monitoring devices, data analysis, personalized health assessment, real-time data, health management

#### 1. Introduction

#### 1.1 Research Background

Smart wearable and home health monitoring devices, propelled by digitalization and personalized healthcare, are increasingly integral to health management. These devices utilize high-precision sensors and advanced data processing to monitor real-time physiological parameters like heart rate and blood pressure, offering valuable personal health data.

• **Popularization**: Advances in technology and reduced costs, along with heightened health consciousness, have made smart devices like smartwatches and blood glucose monitors common, enhancing accessible and affordable health monitoring.

- Health Management Potential: Beyond real-time data, these devices analyze and predict health trends for early intervention, such as alerting to heart issues or identifying sleep disorders through continuous monitoring.
- Personalized Medicine: Device-collected data supports personalized medicine, offering tailored prevention and treatment plans based on individual lifestyles and genetics, diverging from traditional generic medical approaches.

**Social and Economic Impact**: Widespread adoption of smart health monitors aids in reducing healthcare costs and improving service accessibility, especially in remote areas, and promotes healthier lifestyles for better public health.

• Challenges and Opportunities Coexist: Despite their potential, these devices face challenges including data accuracy, privacy protection, technology integration, and regulatory compliance, which this study aims to address.

#### 1.2 Research Significance

The growing prevalence of smart health monitoring devices highlights the importance of data analysis in personalized health management. This study underscores the pivotal role of data analysis in converting raw device data into actionable health insights.

- **Personalized Health Management**: Data analysis extracts individual health trends from extensive monitoring data, enabling the provision of customized health assessments and enhancing the effectiveness and user engagement of health management plans.
- Advancement of Preventive Medicine: Ongoing data analysis allows for the early identification of health risks, advancing preventive medicine, reducing disease incidence, and optimizing resource allocation.
- Enhancing Health Awareness: Presenting data analysis results intuitively raises user health awareness, encouraging proactive participation in self-health management.
- Technological Integration and Innovation: Data analysis technology

development has spurred technological integration and innovation in health monitoring devices, with machine learning and AI making devices smarter in data processing and health assessment.

• **Regulatory and Ethical Considerations**: The expanding role of data analysis in health assessment brings regulatory and ethical concerns to the fore, emphasizing the need for data accuracy, privacy protection, and standardization.

In essence, data analysis in smart health monitoring devices promises to elevate personal health management quality and efficiency while fostering medical industry innovation. This study will delve into how data analysis technology meets these goals and assess its practical application potential and challenges.

# 2. Overview of Smart Health Monitoring Devices

### 2.1 Device Types and Functions

The rapid development of smart health monitoring devices has brought a variety of tools for personal health management. These devices, through advanced sensors and computing power, can monitor and analyze users' health data, providing real-time feedback and recommendations. Here are some common types of devices and their functions in the market:

- Smartwatches and Fitness Trackers: Smartwatches are not just timekeeping devices; they integrate functions such as heart rate monitoring, sleep tracking, and step counting, providing comprehensive activity and health data for users. Some high-end smartwatches also have blood oxygen saturation detection and electrocardiogram (ECG) functions to monitor heart health.
- Glucose Monitoring Systems: For diabetic patients, Continuous Glucose Monitoring Systems (CGM) offer a painless and continuous way to track blood sugar levels. These devices can send real-time blood sugar data to the user's smartphone or receiver, helping users adjust their diet and insulin dosage in a timely manner.
- Smart Scales: Smart scales go beyond simple weight measurement; they can

analyze body fat percentage, muscle mass, water content, and other body indicators. By synchronizing with smartphone apps, smart scales provide users with long-term body change trends and health recommendations.

- Sleep Monitors: Sleep monitors assess sleep quality by monitoring users' breathing patterns, heart rate, and turnover frequency at night. These devices help identify sleep disorders, such as sleep apnea, and provide methods to improve sleep quality.
- **Blood Pressure Monitors**: Home blood pressure monitors allow patients with hypertension to conveniently monitor blood pressure changes at home. Some smart blood pressure meters can wirelessly synchronize data to the user's mobile devices, facilitating the tracking and management of blood pressure levels.

The main functions of these smart devices lie in providing real-time data monitoring and health trend analysis. They transmit data to the user's mobile devices or cloud platforms through wireless connections, allowing users to understand their health status at any time and take action based on the results of data analysis.

#### 2.2 Data Collection Methods

Data collection methods of smart health monitoring devices are diverse, each targeting specific physiological parameters or health indicators. Here are the main ways and types of health data collection by devices:

- Sensor Technology: Smart devices are equipped with various biosensors, such as heart rate sensors, blood pressure sensors, and blood oxygen sensors, which can capture users' physiological data in real-time. For example, Photoplethysmography (PPG) sensors are commonly used in smartwatches and fitness trackers to monitor heart rate by measuring the optical changes caused by blood flow.
- Wireless Connectivity: Devices connect to the user's smartphone or other receiving devices through wireless technologies such as Bluetooth and Wi-Fi, enabling real-time data transmission. This wireless

synchronization not only facilitates users to view data anytime but also provides convenience for further data analysis and storage.

- User Input: In addition to automatically collected physiological data, some devices also allow users to manually enter health-related information, such as diet, exercise, and emotional state. These data, combined with sensor-collected data, provide a more comprehensive view of the user's health status.
- Environmental Monitoring: Some smart devices also integrate environmental monitoring functions, such as measuring ambient temperature, and UV index. humidity, These environmental data, combined with users' physiological data, help analyze the impact of external environmental factors on health.
- Long-term Tracking and Trend Analysis: One of the advantages of smart health monitoring devices is the ability to track health data over the long term. By continuously collecting data, devices can analyze users' health trends, such as weight change trends and improvements in sleep quality.
- Data Integration: Advanced smart devices and applications can integrate data from different devices, providing comprehensive users with health reports. This data integration helps discover associations between different health indicators, such the as relationship between exercise and sleep quality.

The data collection methods of smart health monitoring devices provide rich raw materials for personalized health management. How to effectively use these data and transform them into valuable health insights through scientific analysis is the focus of this research.

#### 3. Data Analysis Methods

# 3.1 Data Preprocessing

Before the data generated by smart health monitoring devices can be transformed into health insights, it must go through a rigorous data preprocessing phase. Data preprocessing is a key step in data analysis, ensuring the quality and accuracy of the data, which directly affects the results and reliability of subsequent analyses.

- Data Cleaning: Data cleaning involves identifying and correcting errors and inconsistencies in the data. For example, due to temporary sensor failures or improper user operation, monitoring data may contain outliers or anomalies. Data cleaning steps include removing or correcting these erroneous data to ensure the accuracy and usability of the dataset.
- Standardization: Users of smart devices may use the devices at different times and in different environments, leading to differences in the dimensions and magnitudes of the collected data. Data standardization is the process of converting data from different sources and types into a unified format or scale for easy comparison and analysis. For instance, standardizing data from various indicators such as steps and heart rate to the same measurement standard helps in comprehensively assessing the user's health status.
- Missing Value Treatment: In the long-term health monitoring process, data missingness is a common issue. Missing value treatment is an important task in preprocessing, including identifying patterns of missing data missingness, (such as random systematic missingness) and adopting appropriate methods for treatment, such as interpolation, mean replacement, or deletion of missing data. Correctly handling missing values is crucial for the maintaining integrity and effectiveness of the data analysis results.

Through data preprocessing, the quality of the data can be significantly improved, laying a solid foundation for subsequent statistical analysis and machine learning modeling. In addition, preprocessing steps also help to reduce the complexity of the data and improve analysis efficiency.

#### 3.2 Statistical Analysis and Machine Learning

After data preprocessing, statistical analysis and machine learning become key techniques for mining the value of data from smart health monitoring devices. These methods can reveal patterns, trends, and associations behind the data, providing a scientific basis for personalized health assessments and recommendations.

- Statistical Analysis: Statistical analysis is the foundation for understanding data distribution and characteristics. Descriptive statistics provide measures of the central tendency and dispersion of data, such as mean, median, standard deviation, etc. Inferential statistics allow population the inference of characteristics from sample data, including hypothesis testing and estimation of confidence intervals. Correlation analysis and regression analysis are used to explore the relationships between different health indicators.
- Machine Learning Algorithms: Machine learning algorithms can learn from historical data and predict future trends. Supervised learning algorithms, such as Support Vector Machines (SVM), decision trees, and neural networks, can be used for classification and regression tasks, such as predicting users' health risk levels or estimating physiological Unsupervised indicators. learning algorithms, such as cluster analysis and Principal Component Analysis (PCA), help discover natural groupings in data and reduce data dimensions.
- Feature Engineering: Feature engineering is an important step in improving the performance of machine learning models. It involves extracting meaningful features from raw data, such as periodic patterns in time series analysis or abnormal patterns in user behavior. Selecting and constructing appropriate features is crucial for the accuracy and generalization ability of the model.
- Model Evaluation and Optimization: Model evaluation is an important link in understanding the performance and reliability of the model. Methods such as cross-validation and confusion matrices are used to evaluate the model's accuracy, sensitivity, and specificity. Model optimization improves the model's performance by adjusting different parameters, selecting

algorithms, or using ensemble learning methods.

• Application Examples: For instance, by using machine learning algorithms to analyze heart rate and activity data, one can identify an individual's cardiovascular health risks. By monitoring sleep patterns and cycles, one can assess users' sleep quality and provide improvement suggestions.

By combining statistical analysis and machine learning techniques, this study aims to develop an efficient data analysis process to extract valuable health insights from the complex data collected by smart health monitoring devices.

#### 4. From Data to Health Insights

#### 4.1 Data Interpretation

Data interpretation converts raw monitoring data into actionable health insights, essential for personalized health assessments.

- **Pattern Recognition**: Identifies exercise and sleep patterns from heart rate and sleep data.
- Anomaly Detection: Employs statistical and machine learning to flag potential health concerns like abrupt heart rate changes.
- **Risk Assessment**: Evaluates health risks by considering weight, body fat, and exercise data, particularly for cardiovascular diseases.
- Health Trend Analysis: Analyzes long-term data to track health trends and inform adjustments.
- **Personalized Feedback**: Provides tailored recommendations based on data, from daily activities to medical advice.
- **Data Visualization**: Utilizes charts and dashboards for intuitive understanding of health status.

#### 4.2 Health Assessment Models

These models are crucial for quantifying individual health status through integrated data analysis.

- Multi-Parameter Comprehensive Assessment: Integrates various health parameters for a complete health overview.
- Predictive Models: Uses historical data

to forecast health trends and predict risks.

- **Personalized Risk Assessment**: Customizes risk evaluation based on individual characteristics.
- **Dynamic Updating Mechanism**: Updates models with new data for current health assessments.
- **User Engagement**: Encourages active participation through visual feedback.
- **Professional Medical Integration**: Enhances models with professional medical insights for diagnosis and treatment.

#### 4.3 Personalized Recommendation Generation

The final step in applying data analysis, focusing on customized health advice.

- **Data-Driven Recommendations**: Offers advice derived from data analysis, like increasing physical activity.
- **Real-Time Feedback**: Adjusts recommendations for timeliness based on current user data.
- **Behavior Change Strategies**: Supports gradual adoption of healthy behaviors with goal setting and tracking.
- Comprehensive Multi-Source Data: Ensures recommendations are well-rounded by incorporating diverse data.
- User Interface Interaction: Ensures the interface is user-friendly and allows for personalization of recommendations.
- **Professional Medical Guidance**: While based on data, advises consulting professionals for major health decisions.

#### 5. Case Study

#### 5.1 Selection of Specific Cases

This study examines a popular smartwatch as a case study to understand the practical application of data analysis in smart health monitoring.

- **Case Device Description**: The smartwatch features health monitoring capabilities like heart rate, sleep, physical activity, and stress level tracking, providing a continuous health data stream for daily wearers.
- Data Collection: Equipped with sensors,

the watch collects real-time data, automatically synchronizing it with the user's smartphone app, eliminating the need for complex user operations.

- Data Analysis Process: The app includes tools to process and visually present data, utilizing color coding to distinguish between normal and abnormal heart rate ranges.
- **Personalized Health Reports**: Advanced analysis within the app generates personalized reports on sleep quality, exercise efficiency, and long-term health trends, offering users valuable insights.
- User Engagement: The app allows users to set health goals and receive personalized recommendations and incentives based on their goals and tracked data.
- **Privacy and Data Security**: With a focus on privacy and security, the smartwatch and app employ industry-standard encryption for secure data storage and transmission.
- Challenges and Solutions: The device faces challenges such as ensuring data accuracy and protecting user privacy. Solutions involve advanced algorithms for data accuracy and transparent privacy policies with user control options.

This case study illustrates the role of data analysis in personalized health management, highlighting the pathways and challenges for effective health monitoring.

# 5.2 Result Analysis

This section evaluates how data analysis transforms and provides valuable insights in the selected smart health monitoring device case study.

- Data Accuracy Verification: The smartwatch's data accuracy was confirmed by comparing it with traditional medical devices, ensuring reliable health insights.
- Health Trend Identification: Analysis exposed health trends like exercise habits and sleep quality from long-term data, helping users track health changes.
- Risk Prediction: Statistical and machine

learning models predicted health risks, such as cardiovascular issues, based on heart rate variability and activity data.

- Effectiveness of Personalized Recommendations: Personalized health advice from the smartwatch, tailored to user data, was assessed for effectiveness through feedback and health improvements.
- User Behavior Change: Data analysis positively influenced user behavior, with many adopting healthier lifestyles as indicated by insights.
- Challenges and Opportunities: The analysis highlighted challenges in data interpretation and user acceptance, alongside opportunities for improvement through tech innovation and education.

**Comprehensive Assessment**: While data analysis offers practical insights, optimizing accuracy, interface design, services, and security is crucial for realizing its full potential.

# 6. Challenges and Opportunities

#### 6.1 Technical Challenges

Data analysis for smart health monitoring devices faces several key technical challenges alongside proposed solutions:

- Data Quality and Integrity: Monitoring devices may collect noisy or incomplete data. Advanced signal processing and data cleaning, along with interpolation techniques, are used to address these issues.
- Data Privacy and Security: Given the sensitivity of health data, end-to-end encryption, anonymization, and secure storage are essential. Compliance with regulations like GDPR is also mandatory.
- Data Interpretability: Complex machine learning models require explainable AI (XAI) for transparent decision-making, aided by data visualization for user comprehension.
- **Real-Time Data Processing**: The need for immediate analysis of streaming data calls for efficient processing systems like Apache Kafka or Apache Storm.

- Model Generalizability: To ensure models perform well across various datasets, cross-validation and ensemble learning techniques are implemented, with continuous model updates for adaptability.
- User Interface and Experience: For user-friendly interfaces, design incorporates intuitive charts and simplified metrics, offering customized views to meet diverse user needs.
- Interdisciplinary Integration: Collaboration across medicine, data science, and engineering is fostered through team integration and ongoing education to tackle complex problems comprehensively.

#### 6.2 Privacy and Security

With the widespread application of smart health monitoring devices, issues of privacy protection and security of health data are becoming increasingly prominent. Here are several key points that must be taken seriously in data analysis:

- Data Encryption: To protect the security of user data during transmission and storage, strong encryption standards must be adopted. End-to-end encryption technology ensures that only authorized users can access the data.
- **Anonymization**: Anonymize personal information during data analysis and sharing, removing or replacing data that can identify personal identity to reduce the risk of privacy leakage.
- Access Control: Implement strict access control mechanisms to ensure that only authorized healthcare professionals and the user themselves can access sensitive health data. Role-Based Access Control (RBAC) is a common solution.
- Legal Compliance: Providers of smart health monitoring devices and services must comply with relevant data protection laws and regulations, such as the EU's General Data Protection Regulation (GDPR) or the US HIPAA regulations.
- **Informed Consent**: Before collecting and processing user data, explicit informed consent from users must be obtained. Transparent privacy policies

and user agreements help users understand how their data is used and protected.

- Data Breach Prevention: Establish data breach prevention and response mechanisms, including regular security audits, vulnerability scans, and risk assessments, as well as rapid response plans in the event of a data breach.
- Education and Training: Educate users about data privacy and security to raise awareness for personal information protection. At the same time, provide regular privacy and security training for professionals who handle data.
- Technical Updates and Maintenance: As technology develops and new threats emerge, regular updates and maintenance of security measures are necessary. This includes software updates, security patches, and hardware upgrades.

By comprehensively considering these privacy and security measures, it can be ensured that smart health monitoring devices not only provide health management services but also protect users' sensitive data from threats.

#### 7. Discussion

# 7.1 Application Prospects of Data Analysis in Health Management

The application prospects of data analysis in the field of health management are broad, heralding the arrival of an era of personalized and precise healthcare. Here are several key prospects for the application of data analysis in health management:

- Personalized Health Management **Plans**: Data analysis makes it possible to customize health management plans on individual physiological based characteristics, lifestyle habits, and health history. By deeply understanding personal health data, more effective disease prevention and health promotion strategies can be designed.
- **Predictive Health Management**: Using machine learning and artificial intelligence technologies, data analysis can predict health risks and disease development trends. Predictive health management helps to take early intervention measures to reduce the

incidence of diseases.

- **Precision Medicine**: Data analysis supports the realization of precision medicine by analyzing patients' genetic information, lifestyle, and environmental factors, providing personalized treatment plans to improve treatment effectiveness and reduce unnecessary medication side effects.
- **Population Health Analysis**: At the population level, data analysis helps to identify public health issues and health inequalities. This can provide a basis for public health policy formulation and resource allocation, promoting the improvement of the overall population's health level.
- Technological Integration and Innovation: With the development of the Internet of Things, wearable devices, and remote monitoring technologies, data analysis will be more seamlessly integrated into all aspects of health management. Technological innovation will further improve the accuracy of data collection and the depth of analysis.
- User Participation and Empowerment: The application of data analysis will increase users' understanding and control of their health, making users the primary responsible party for their own health management. Through easy-to-understand data analysis results and health recommendations, users can make wiser health decisions.
- Cross-disciplinary Cooperation: The application of data analysis in health management will promote cross-disciplinary cooperation between medical professionals, technologists, policymakers, and patients. This cooperation helps to develop more comprehensive health management solutions to address complex health challenges.

#### 7.2 Assessment of Existing Data Analysis Technologies

Existing data analysis technologies have made significant progress in the field of health monitoring and still need a comprehensive assessment of their effectiveness, limitations, and development potential.

- **Technical Effectiveness**: Data analysis, particularly machine learning and deep learning, has validated its effectiveness in detecting health trends and providing tailored health advice, crucial for complex data set processing.
- Data Quality and Accuracy: The reliability of data analysis outcomes hinges on the quality of collected data, emphasizing the importance of accurate data collection and robust preprocessing techniques.
- User Acceptance and Participation: User experience is pivotal, influenced by interface design, data clarity, and personalized recommendation relevance, which collectively shape user acceptance of data analysis technology.
- **Privacy and Security**: Ensuring data analysis technology adheres to privacy regulations and allows user control over personal information is fundamental to safeguarding data security.
- Technical Accessibility and **Cost-effectiveness**: The technology should be both accessible and economically viable across various environments to facilitate broad health promotion.
- Technical Integration and Compatibility: When assessing existing technology, its integration capabilities and compatibility with other health information systems should be considered. Technology should be able to seamlessly exchange data with electronic health record systems, mobile devices, and wearable technology.
- Future Development and Innovation Potential: Finally, the assessment should focus on the future development and innovation potential of existing technology. With technological advancements, such as more advanced algorithms, more powerful computing capabilities, and more advanced sensor technology, data analysis technology is expected to achieve higher accuracy and broader applications.

A comprehensive assessment shows that existing data analysis technology has great

potential in the field of health management, but it still needs continuous optimization and improvement to meet the growing needs of health monitoring.

#### 7.3 Outlook for Future Research Directions

As data analysis technology continues to advance in the field of health management, future research will open up new horizons and possibilities. Here are some prospects for future research directions:

- Development of Advanced Analysis Algorithms: Future research will focus on developing more advanced data analysis algorithms to improve predictive accuracy and the relevance of personalized health recommendations. Deep learning and other artificial intelligence technologies will continue to play an important role in this field.
- Expansion of Interdisciplinary Research: Encourage interdisciplinary research methods that combine knowledge from fields such as medicine, data science, psychology, and sociology to fully understand the complexity of health data and develop more comprehensive health management solutions.
- Data Integration and Interoperability: Research will focus on improving the integration and interoperability between different data sources, enabling data from various smart devices and medical systems to be seamlessly integrated, providing patients with more coherent care.
- User Participation and Customization: Future research will place greater emphasis on user participation and customized experiences, developing systems that can adapt according to user feedback and behavior to improve user satisfaction and health outcomes.
- **Research on Ethical and Legal Issues**: With the development of technology, research on ethical and legal issues will also become a focus, ensuring that the application of data analysis technology complies with ethical standards and laws and regulations, protecting personal privacy and data security.

**Technology**: Research will explore how to make data analysis technology more widely available and accessible, especially for people in resource-limited and remote areas, ensuring the fair distribution of health management tools.

- **Real-time Monitoring and Immediate Feedback**: Future research will focus on real-time health monitoring and immediate feedback systems so that users can understand their health status and take action in a timely manner.
- **Preventive Health Management**: Strengthen research on preventive health management, using data analysis technology to predict health risks and develop early intervention strategies to reduce the incidence of diseases.
- Application of Technology in Specific Populations: Research the application of data analysis technology in specific populations (such as the elderly, chronic disease patients) and how to adjust the technology to meet the unique needs of these groups.

Through these research directions, data analysis technology in the future is expected to achieve greater breakthroughs in the field of health management, bringing profound benefits to individual and public health.

#### 8. Conclusion

This study has in-depth explored the application of data analysis in smart health monitoring devices for personalized health management, revealing its key role in improving the accuracy of health monitoring, promoting disease prevention, and enhancing users' health awareness.

- Main Findings: The study found that smart health monitoring devices, by collecting continuously users' physiological and activity data, provide rich raw materials for data analysis. Through effective data preprocessing, statistical analysis, and machine learning techniques, these data can be into valuable transformed health insights, including personalized health assessments and customized recommendations.
- Popularization and Accessibility of
- Importance of Data Analysis: The

importance of data analysis in health management is reflected in its ability to process and interpret large amounts of complex health data, identify health trends and potential risks, and provide decision support for users and healthcare professionals.

**Potential Value**: The data analysis of smart health monitoring devices not only has the potential to improve individual health conditions but also provides new perspectives for public health research, disease management, and the optimization of medical resource allocation.

- **Technology and Ethics**: The study also points out that while data analysis technology is developing rapidly, it must be carried out under the premise of ensuring data privacy and security. Compliance with laws, regulations, and ethical standards is a prerequisite for realizing the potential of technology.
- Future Outlook: Looking ahead, the further development of data analysis technology will depend on algorithm innovation, interdisciplinary collaboration, and increased user participation. At the same time, the popularization and accessibility of the technology are also key to its widespread application in the field of health management.

**Final Thoughts**: Integrating the analysis and case studies of this research, we believe that data analysis of smart health monitoring devices is an important tool for achieving personalized health management. By continuously optimizing technology, strengthening user education, and improving regulatory compliance, smart health monitoring devices will play an increasingly important role in the future health management system.

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