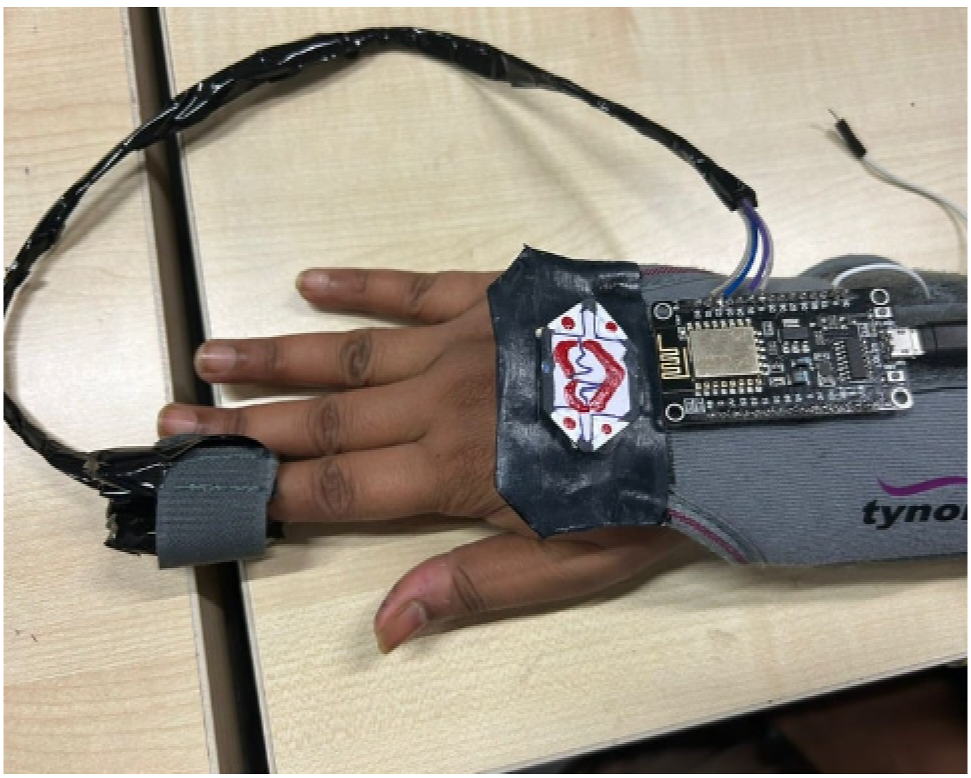
Design and Development of VariScan: A Continuous Heart Rate Variability Monitor



AMAN RANJAN 2021376
MEGHA IIITD 2021337

Supervisor: Sujay Deb

ABSTRACT

Heart Rate Variability (HRV), which represents how the autonomic nervous system controls the heart, is an essential marker of cardiovascular health. Even though HRV is important, it is still difficult to continuously and accurately monitor the technologies available today since they are frequently invasive or imprecise.

This project presents VariScan, a device that offers precise and instantaneous HRV monitoring. With the help of the MAX30102 sensor and the NodeMCU ESP8266 for WiFi-based transmission and data collecting, VariScan uses optical readings to obtain precise heart rate data. The design and development process of VariScan, including hardware integration, data gathering strategies, and data processing techniques that improve the precision and dependability of HRV readings, are covered in this.

INTRODUCTION

The physiological phenomenon known as heart rate variability, or HRV, is the change in time between successive heartbeats. The autonomic nervous system (ANS), which reacts to the body's states of stress, rest, and recuperation, controls it. Because it offers a non-invasive window into the heart's capacity to react to different stressors, heart rate variability (HRV) is significant as a health indicator. Low variability may point to weariness, stress, or underlying medical conditions, whereas high variability denotes a healthy and responsive nervous system. As a result, measuring HRV can be an essential tool for evaluating stress levels, cardiovascular health, and general well-being.

The primary goal of developing VariScan is to create an advanced, accessible tool for continuous HRV monitoring. Traditional methods often involve complex and cumbersome equipment that is not suitable for everyday use.

VariScan aims to overcome these limitations by employing a compact, non-invasive design that utilizes infrared (IR) technology. The device captures heartbeats via an IR sensor, accurately measuring the time intervals between each beat. This data is then used to calculate the differences in these intervals, providing real-time insights into HRV. Through accurate and timely HRV analysis, VariScan hopes to enable people to proactively manage their heart health by making this technology accessible and easy to use. This novel method advances not only personal health monitoring but also advances general research and comprehension of the dynamics of cardiovascular health.

LITERATURE REVIEW

1. **Heart Rate Variability: An Old Metric with New Meaning in the Era of using mHealth Technologies for Health and Exercise Training Guidance. Part One: Physiology and Methods**

   This paper discussed time domain and frequency domain for measuring HRV followed by different sensors and types of devices one can use, like Photoplethysmography (PPG), Pulse Oximeter, and ECG. Later, it discussed how the Autonomic Nervous System controls HRV.

2. **Heart rate variability: A review**

   The paper discussed the interplay between the sympathetic and parasympathetic nervous systems. It also highlighted that Heart rate (HR) is a nonstationary signal; its variation may contain indicators of current disease or warnings about impending cardiac diseases.

   This paper has discussed the various applications of HRV and different linear, frequency domain, wavelet domain, and nonlinear techniques used to analyze the HRV.

PROCEDURE

1. Hardware Selection and Integration

NodeMCU ESP8266:

Purpose: Provides the core processing unit of VariScan, enabling WiFi connectivity for real-time data transmission to remote servers or cloud storage. This feature is critical for continuous monitoring and accessibility of data.

Integration: Connected with other components via a breadboard and jumper wires, programmed using the Arduino IDE for managing sensor data and network communications.

MAX30102 Sensor:

Purpose: This optical sensor measures changes in blood volume through IR and red light absorption, which is pivotal for detecting heartbeats and calculating R-R intervals.

Integration: Mounted on a finger clip or wristband, it captures blood flow data, which is then processed to determine heart rate and variability.

9V Rechargeable Battery:

Purpose: Powers the entire device, ensuring portability and continuous operation without external power sources.

Integration: Connected to the NodeMCU and sensor setup to provide a stable power supply.

2.Data Collection

Procedure:

- Participants are instructed to wear the VariScan device on their finger or wrist.
- The MAX30102 sensor continuously captures the IR and red light intensity, which correlates with blood volume changes as the heart pumps blood.
- Data points are collected in real-time, including timestamps and light intensity values.
- This raw data is transmitted via WiFi to a designated server, where it is logged for further analysis.

Settings and Duration:

Data collection is initially conducted in controlled environments, with trials running for 5 minutes to ensure consistency across different conditions and participants.

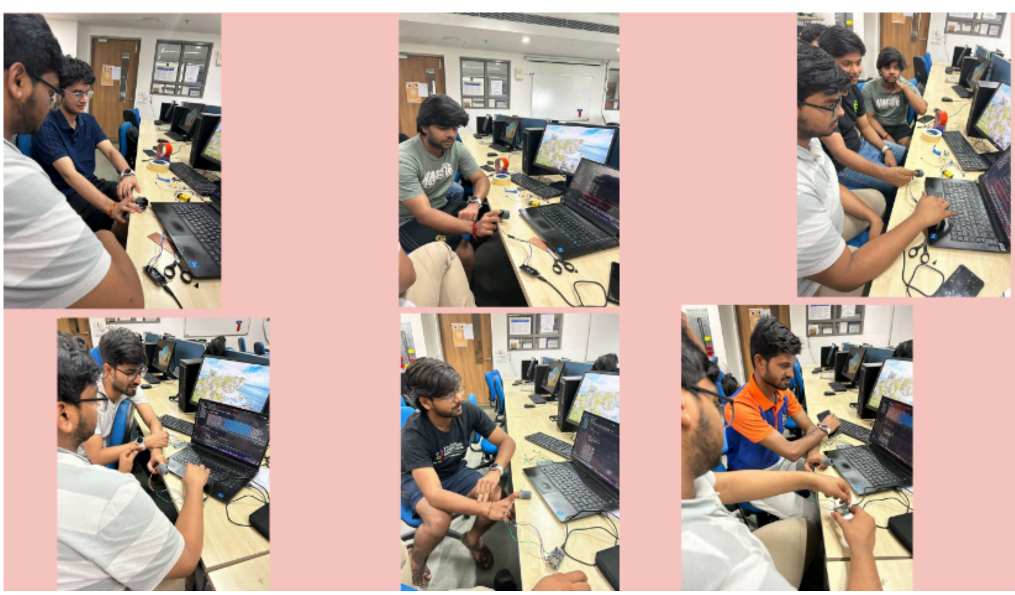


Fig. Collection of data

3. Data Preprocessing

Steps:

- Format Standardization: Raw data received from the sensor is standardized into a structured format (timestamps, IR intensity, red light intensity).
- Noise Reduction: Filters are applied to the raw sensor data to remove any artifacts caused by motion or ambient light interference.
- Segmentation and Calibration: Data is segmented into individual heartbeats, and calibration is performed to align the sensor readings with known standards.

```
Time: 247417 IR: 95302.00 Red: 69156.00
Time: 247518 IR: 95445.00 Red: 69112.00
Time: 247618 IR: 94287.00 Red: 68932.00
Time: 247737 IR: 94963.00 Red: 69115.00
Time: 247837 IR: 95338.00 Red: 69184.00
Time: 247937 IR: 95587.00 Red: 69287.00
Time: 248057 IR: 95956.00 Red: 69429.00
Time: 248156 IR: 96202.00 Red: 69544.00
Time: 248257 IR: 95444.00 Red: 69266.00
Time: 248376 IR: 95791.00 Red: 69439.00
Time: 248476 IR: 96061.00 Red: 69512.00
Time: 248576 IR: 96164.00 Red: 69563.00
Time: 248716 IR: 96439.00 Red: 69633.00
Time: 248855 IR: 96584.00 Red: 69611.00
Time: 248955 IR: 95414.00 Red: 69310.00
Time: 249075 IR: 95828.00 Red: 69450.00
Time: 249175 IR: 96157.00 Red: 69533.00
Time: 249275 IR: 96242.00 Red: 69589.00
Time: 249375 IR: 96492.00 Red: 69665.00
Time: 249494 IR: 96691.00 Red: 69705.00
Time: 249594 IR: 95928.00 Red: 69384.00
Time: 249694 IR: 95769.00 Red: 69437.00
Time: 249773 IR: 95979.00 Red: 69472.00
Time: 249854 IR: 96263.00 Red: 69528.00
```

Format1

1	Time	IR	Red
2	103593	1935.0	2194.0
3	103692	1877.0	2185.0
4	103812	1891.0	2199.0
5	103893	1934.0	2218.0
6	103993	2400.0	2258.0
7	104093	6887.0	3464.0
8	104193	12665.0	9436.0
9	104293	45748.0	40143.0
10	104373	55689.0	45796.0
11	104474	88484.0	62851.0
12	104573	92431.0	63503.0
13	104674	93282.0	63626.0
14	104773	93548.0	63669.0
15	104873	93943.0	63854.0
16	104974	94669.0	64080.0
17	105075	96214.0	64514.0
18	105174	95452.0	63830.0
19	105254	91904.0	63025.0
20	105354	90122.0	62675.0
21	105455	91388.0	63213.0

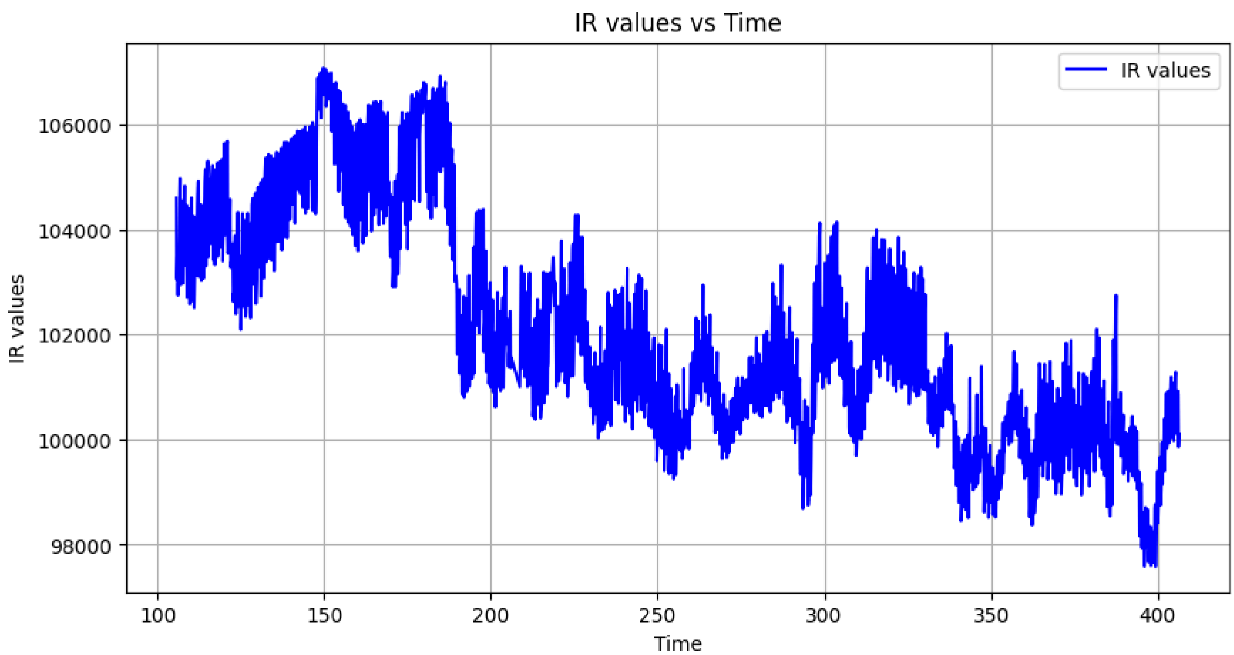
Format2

4. Data Analysis

Graph Generation:

We generate graphs representing IR intensity vs. time and red light intensity vs. time.

These graphs provide visual insights into the variations of IR and red light intensities over time.



Peak Detection:

- Using the generated graphs, we identify peaks corresponding to significant changes or spikes in intensity.
- The difference between consecutive peak timestamps represents the RR interval, providing valuable information about heart rate variability over time.

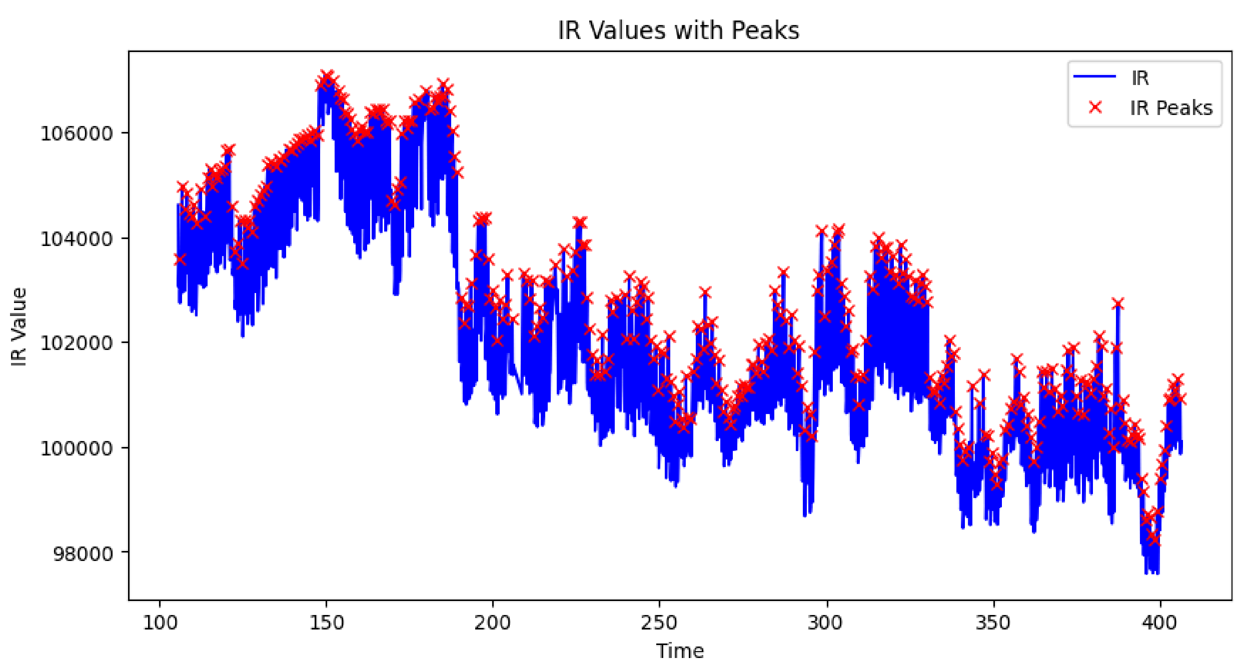


Fig.Peak Detection for the IR values (for a time interval of 5 min)

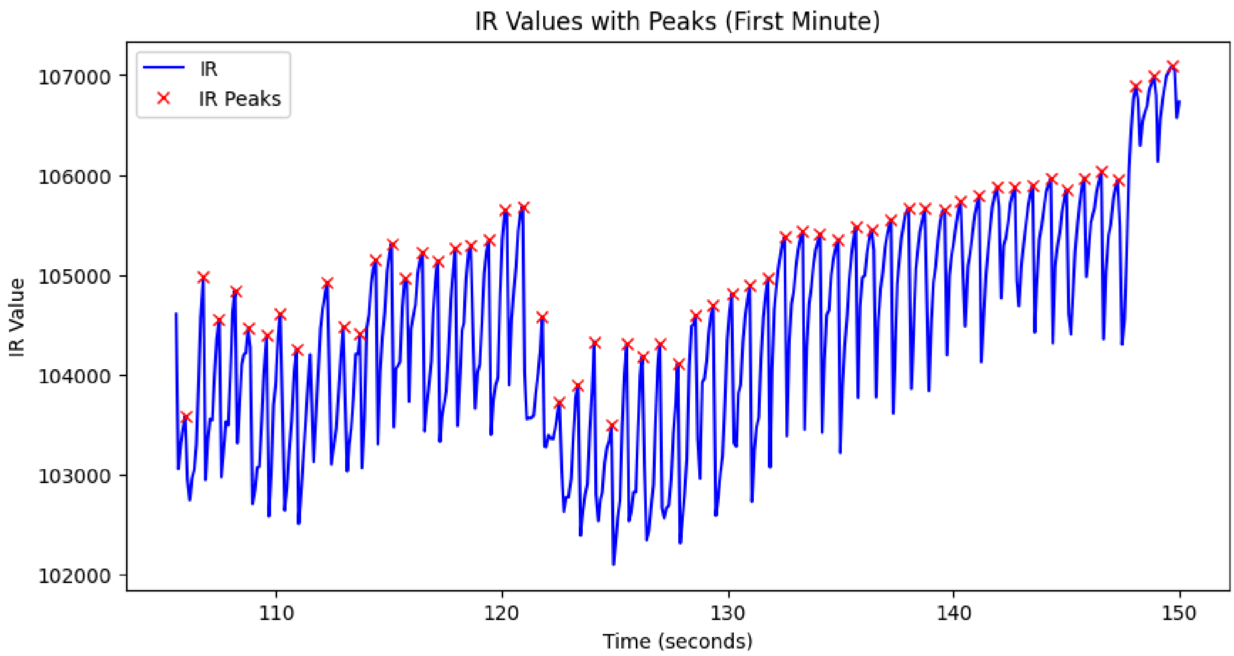


Fig.Peak Detection for the IR values (for a time interval of 50 seconds)

RR Interval Calculation:

Peaks in the IR intensity graph are identified, each representing a heartbeat. The time difference between consecutive peaks is calculated, providing the RR intervals.

HRV Metrics:

HRV metrics such as RMSSD (Root Mean Square of Successive Differences) are calculated using the RR intervals. These metrics provide insights into the autonomic nervous system's activity and overall heart health.

$$\mathrm{RMSSD} = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N-1} (RR_{i+1} - RR_i)^2}$$

- RRi is the i-th RR interval,
- NN is the total number of RR intervals.

DATA

Name	Gender	Age	Height(inches)	Weight(kg)	BPM(watch)	Calculated BPM	RMSSD	ln(RMSSD)
Test1	M	21	74	69	76	81	86.48	4.45
Test2	M	21	71	80	92-94	85	106.70	4.67
Test3	M	22	69	100	90	89	453.47	6.11
Test4	F	22	61	63	88	84	59.02	4.07
Test5	M	21	65	65	82,83	82	102.74	4.63
Test6	M	22	67	53	87,89	84	73.867	4.3
Test7	M	20	68	75	80,61,55,72	70	146	4.9
Test8	M	19	64	70	88,96	88.4	189.81	5.24
Test9	M	19	69	66	79,78,87	73	188.76	5.24
Test10	M	19	68	50	55,64	63	318.33	5.76
Test11	M	22	69	100	74,80	74.97	288.85	5.66
Test12	M	33	67	65	78,85,72,77,74	75.8	212.61	5.35
Test13	M	21	5'10	75+	88	87.3	588.78	6.37

RESULTS

1. Data Accuracy and Reliability

Heartbeat Detection:

The MAX30102 sensor effectively captured the pulse waveforms corresponding to each heartbeat. The sensor's ability to detect changes in blood volume using IR and red light provided clear and consistent data, allowing for precise measurement of RR intervals.

RR Interval Consistency:

The RR intervals measured during the trials showed consistency with medically established norms when compared to traditional ECG measurements. This confirms the reliability of the optical sensor approach used in VariScan.

2.HRV Analysis

RMSSD Calculation:

Calculated RMSSD values for each participant varied, reflecting individuals' natural differences in autonomic nervous system activity.

Higher RMSSD values generally correlated with periods of rest or low stress, while lower values were observed during stress or physical activity.

Graphical Representations:

Graphs plotting IR intensity vs. time and RR intervals clearly illustrated the heart rate variability. Peaks in these graphs corresponded accurately to the detected heartbeats, and the variability in these peaks reflected the expected HRV patterns.

3. Participant-Specific Outcomes

Test Subject Examples:

Test 3: Showed an exceptionally high RMSSD value, indicating a high rate variability and potentially robust cardiovascular health.

Test 6: Due to errors in data transmission (marked as "ERROR"), the results for this participant were inconclusive, highlighting the need for further refinement in VariScan's data transmission reliability.

4. Device Performance

User Feedback:

Participants reported that the device was comfortable to wear and did not interfere with everyday activities, suggesting good user compliance and practicality for continuous monitoring.

Technical Performance:

The WiFi connectivity feature functioned well, with most data successfully transmitted in real-time to the server, except in isolated cases like Test6, where improvements could be made.

CONCLUSION

The results from the VariScan trials provide strong evidence of its capability to accurately and reliably monitor heart rate variability. While slightly less accurate than traditional ECG, the use of an optical sensor proved sufficient for non-clinical settings, offering a practical solution for everyday HRV monitoring. The successful implementation of real-time data transmission and analysis demonstrates VariScan's potential as a valuable tool for personal health monitoring and broader clinical applications. Future enhancements will improve data transmission reliability and expand device testing to more diverse populations to further validate its effectiveness and adaptability.

REFERENCES & RESEARCH PAPERS

1. https://imotions.com/blog/learning/best-practice/heart-rate-variability/
2. https://elitehrv.com/normal-heart-rate-variability-age-gender
3. https://www.researchgate.net/publication/6687018_Heart_rate_variability_A_review
4. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6141929/
5. Chatgpt for the report and some coding-related help