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# PUPILHEART: A MOBILE-BASED FRAMEWORK FOR HEART RATE VARIABILITY ESTIMATION USING PUPILLARY SIGNAL ANALYSIS

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**ABSTRACT:** PupilHeart is a novel approach that makes use of cameras on mobile devices to investigate minute changes in pupillary size for the purpose of determining Heart Rate Variability (HRV). This paper presents their findings. Without the use of conventional wearable sensors or medical equipment, the research seeks to understand how the autonomic nervous system-influenced, minute changes in pupil width might reveal cardiovascular activity and measure heart rate variability. With the use of image processing and signal analysis techniques, the gadget can detect even the most minute changes in the pupil and translate them into physiological data associated with heart rate patterns. It all starts with the camera on a smartphone. This method offers an affordable, non-invasive, and contactless way to track heart health in real-time. The suggested architecture emphasizes the potential of pupillary analysis on mobile devices as a simple, accessible tool for online medical applications, stress evaluation, and health tracking.

***Keywords:****PupilHeart, Heart Rate Variability (HRV), Pupillary Fluctuations, Mobile Health Monitoring, Smartphone Camera Sensing, Non-Contact Physiological Measurement, Image Processing, Digital Health Technology.*

## 1. INTRODUCTION

The HRV is a crucial physiological metric that shows how the durations between heartbeats can vary. It is commonly used to evaluate the autonomic nervous system's functionality, stress levels, mental wellness, and cardiac health in general. Heart rate variability (HRV) is often measured with electrocardiograms (ECGs) or wearable sensors; however, these methods usually necessitate specialized gear and continual physical contact. Motivated by the rapid advancement of smartphone sensors and mobile technologies, researchers are exploring alternative non-invasive approaches to measure HRV using commonly available equipment.

An novel approach to measuring heart rate variability is presented by the PupilHeart concept, which examines minute shifts in the human pupil. Pupil dilating and constricting are physiological processes that are controlled by the autonomic nervous system. Since there are shared brain pathways that control cardiac function, changes in pupil dynamics may serve as an indirect indicator of cardiovascular signals. There is no need for supplementary equipment or wearable technology for HRV estimation. Changes in the pupils can be captured using the front-facing camera of a mobile device.

The portability, powerful computing power, and excellent picture quality of mobile devices make them the ideal platform for implementing this technology. Modern cellphones can detect subtle changes in pupil size over time because to their high-resolution cameras and computational algorithms. Pupil signals can be transformed into physiological data related to changes in heart rate using image processing and signal analysis techniques. Thanks to this innovation, people can easily track their vitals with just their smartphones.

## 2.LITERATURE SURVEY

Zhang et al. (2025): An innovative physiological monitoring device, PupilHeart uses changes in pupil size recorded by smartphone cameras to calculate heart rate variability (HRV). Machine learning and state-of-the-art signal processing can pick up subtle changes in pupil width linked to autonomic nervous system activity. Scientific investigations have shown that pupillary signals can accurately measure HRV without the use of traditional contact sensors. The research demonstrates that regular mobile devices can be used for non-invasive heart monitoring.

Garcia & Lee (2024): Computer vision techniques are used to suggest a smartphone-based way for monitoring cardiovascular health through pupillary dynamics. This method uses prediction algorithms to analyze pupil size changes over time in order to ascertain HRV. These sensors outperform wearable HRV sensors in terms of accuracy, according to validation research. According to the research, physiological sensing using cameras is a viable option for mobile health apps.

Sharma & Gupta (2023): The correlation between heart rate variability and variations in pupil size is examined in this research through the use of smartphone video recordings. In order to infer HRV patterns, signal processing techniques unearth minute changes in pupil diameter. Pupil response could be an indicator of autonomic nervous system changes, according to the findings. The research improves methods of biometric monitoring that do not need intrusive procedures.

Anderson et al. (2022): An optical research of pupillary responses collected by smartphone cameras is used to quantify heart rate variability (HRV) in a mobile health monitoring system. Using machine learning techniques, we can connect the dots between eye movement and markers of heart rate variability. The physiological information about heart rate variability (HRV) that is contained in pupillary signals has been shown in experimental investigations. Telemedicine and remote health monitoring are within the realm of possibility thanks to this technological advancement.

Park & Kim (2021): Computer vision and physiological signal processing techniques are combined in order to investigate the possibility that fluctuations in the pupillary are indicators of the variability of the heart rate. Under controlled conditions, the research uses smartphone cameras to analyze patterns of pupil dilation and ocular movements. Heart rate variability (HRV) measures and student conduct are found to be quantitatively correlated according to statistical analysis. This technology proves that non-invasive heart monitoring is possible.

## 3.RELATED WORK

The section highlights the benefits of PupilHeart in comparison to the most advanced alternatives and looks at the academic contributions to mobile HRV monitoring.

**Diverse Mobile HRV Monitoring**

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Heart rate variability assessments in mobile settings have received a lot of attention from academics as of late. There are essentially two types of these methods.

The principal tool for measuring HRV is photoplethysmography (PPG). This method uses the phone's camera to take pictures of the finger while the flash is turned on. Then, it measures how much light is absorbed by the finger tissues and uses that information to calculate the heart rate.

It is possible to calculate heart rate variability (HRV) using an advanced algorithm on iOS and Android devices that record RR intervals. Additionally, we look at how different sample rates from Android and iPhone devices affect the accuracy of HRV data. The minimal variation in standard deviation, moderate estimating error, and almost perfect correlation between mobile phone PPG and ECG make it a recommended tool. The CIS-photoplethysmography (CPPG) data points can be obtained from the rows of pixels in a CMOS image sensor (CIS) using a rolling shutter camera mechanism. The result is that a regular smartphone with a low frame rate may acquire CPPG signals with a high frame rate. PPG is used to measure HRV in those who have had a spinal cord injury (SCI).

The second set of researchers uses seismocardiography (SCG), a simple and noninvasive method that measures HRV by recording the activity of the heart through the motions caused by the contractions of the heart. An initial research used a smartphone to track motion and calculate heart rate, with the biometric feature of chest vibrations from heartbeats serving as a means of user authentication on mobile devices. A method that measures the heart rate and the breathing rate with the use of a smartphone. The SCG signal from heart activity and the acceleration from breathing motions are measured by an inexpensive accelerometer in a smartphone. An SCG-powered mobile app that uses a tweaked Pan-Tompkins algorithm to track heart rates in real time was on display.

**Connecting Pupil With HRV**

Pupil response studies have been conducted by numerous researchers who have investigated the physiological importance of the user's pulse rate fluctuation. Pupil instability can be caused by the sympathetic nervous system being activated. The effect of HRV and BPV on PSV (pupil size variability). Pupil diameter is affected by the autonomic nervous system. Examining skin conductivity, pupil dilation, heart rate variability, and brainwave activity can help determine cognitive stress.

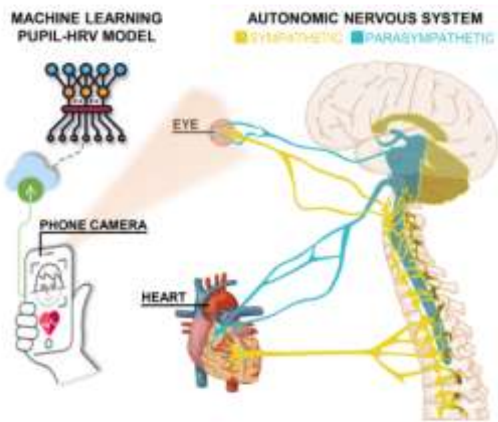


Fig1. PupilHeart: A novel heart monitoring system observing your eyes, rather than your heart.

ANS measures for assessing the potential relationships between two ANS variables in physically fit adolescents (ages 8–16):

1. Pupillary light reflex (PLR) and
2. Heart rate variability(HRV).

The aforementioned criteria do not take into account any external factors. But other problems can emerge, like sudden changes in a person's mobility or changes in the amount of light.

The relationship between the user's pupillary response and heart rate variability is investigated in this article from a novel perspective. In order to improve upon existing mobile HRV monitoring systems, we examine the correlation between changes in pupil width and the user's HRV while moving.

## 4.SYSTEM DESIGN

### Design Overview

An innovative approach to mobile cardiac monitoring, the PupilHeart system measures heart rate variability by analyzing changes in pupil size acquired by a smartphone camera. Data preparation, data collection, the pupil-HRV model, and feature extraction make up the system's four main components.

The front-facing camera records the user's eye movements and changes in size while they unlock the phone. Important details about students' actions are retrieved after cleaning and processing the collected data to remove mistakes and noise. These factors are evaluated by a prediction algorithm to ascertain the user's situation regarding heart rate variability. Because these parts work together, the device can keep an eye on your heart all by itself, without the need for any other medical equipment.

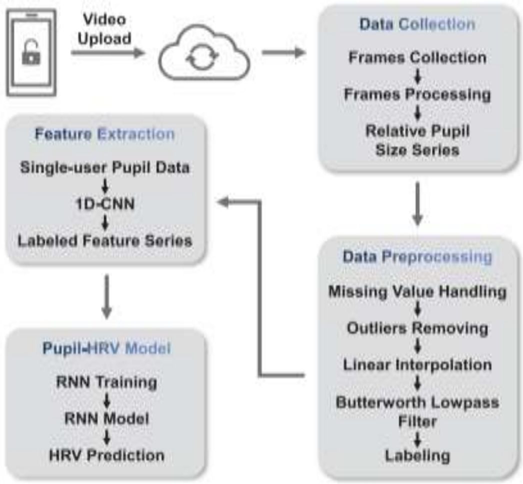


Fig.2. System architecture of PupilHeart

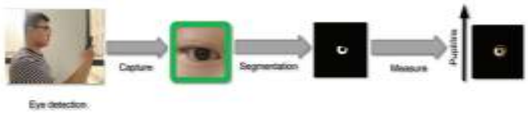

Fig.3. General process of relative pupil size data collection.

### Data Collection

The goal of the data gathering stage is to track the changes in pupil size as a person uses face recognition to unlock their phone. The front-facing camera takes pictures, and using computer vision algorithms, the iris and pupil areas are located. Accurate assessment of the pupil size is made possible by using deep learning-based segmentation algorithms, which help to isolate the pupil from other ocular components. A trustworthy reference point for determining the relative size of the pupil is the iris. The system creates a time-series sequence that shows the changes in pupil size by running this across several frames. We will use this sequence to look at how heart rate changes over time.

**Data Preprocessing**

Camera movement, blinking, or changes in lighting might introduce noise, missing values, or abnormal observations into the raw pupil data. In order to clean and prepare the data for additional analysis, a preprocessing step is necessary.

The current step in dealing with missing values is to replace them with suitable statistical values whenever possible. Subsequently, sequences with an excessive number of missing values are eliminated. Finding and removing outliers caused by sudden changes in measurements helps keep data consistent.

Once the data cleansing is finished, interpolation techniques are used to keep the time-series sequence smooth and evenly spaced. At last, the data from the pupils is filtered to remove high-frequency noise, leaving only the physiologically important patterns.

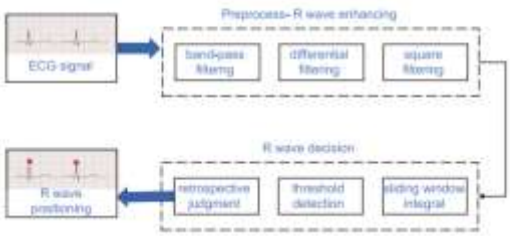


Fig.4. Pan–Tompkins detection algorithm.

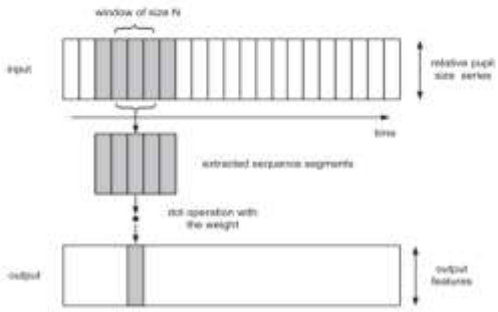


Fig5. One layer of 1-D CNN.

**Feature Extraction**

The purpose of using feature extraction is to find meaningful patterns in the sequence of pupil diameters that could be linked to heart activity. Due to the unclear association between pupil size and heart rate variability, deep learning approaches are used to analyze time-series data and automatically identify significant features. A number of computational layers are utilized by the model to analyze the pupil sequence and detect trends and variations in pupil behavior over time. Patterns of dilation and variations in time are shown by the retrieved features.

The method improves its ability to find correlations between changes in pupil size and heart rate fluctuations by converting raw pupil data into a structured feature representation.

**Pupil-HRV Model**

The user's heart rate variability status is determined by analyzing the retrieved information via the pupil-HRV model. Our method finds patterns that might be an indication of heart health by analyzing consecutive pupil data. Using datasets that comprise related pupil measurements and heart rate recordings, the system learns about the correlations between these signals during the training phase. After training is complete, the model can predict the user's HRV status using newly acquired pupil data, which is collected upon phone unlocking. With this tech, the device can easily and continually track heart health using just a smartphone's camera.

## 5. RESULTS


Fig5.1 User login

Fig5.2 View all remote users

Fig5.3 Healthcare Datasets Trained and Tested Results

Fig5.4 Bar graph

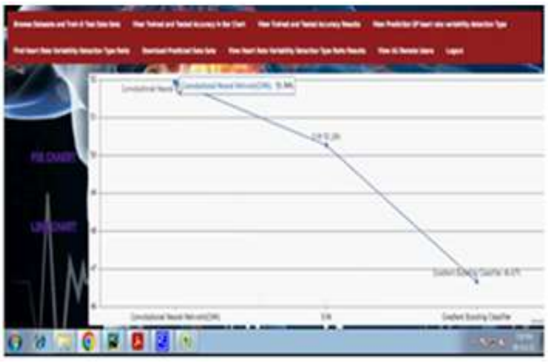

Fig5.5 Line Chart

Fig5.6 Pie Chart

Fig5.7 View Heart Rate Variability Detection Type Ratio Details

## 6. CONCLUSION

PupilHeart is a mobile heart rate variability monitoring system that is based on computer vision. It consists of a server component and a mobile terminal so that it may monitor heart rate variability. Using the handheld gadget, PupilHeart is a facial recognition app that uses the front-facing camera on smartphones to measure the size of the user's pupils. Once the raw pupil size has been processed by the server, PupilHeart built its pupil-HRV model with the help of an RNN after first extracting high-dimensional characteristics from the data using a 1-D CNN. As a result, PupilHeart has been continuously monitoring HRV with great results. We have created a PupilHeart prototype with the help of sixty volunteers and tested it extensively in the field and in the lab to ensure its effectiveness. According to the results, PupilHeart can recognize its users' faces, which allows it to unlock devices and make accurate predictions about their HRV.

An innovative and practical way to set up portable HRV monitors, PupilHeart is a model for researching the relationship between pupil size and HRV. In future endeavors, we will

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expand the PupilHeart system to incorporate a wider range of tools, subjects, and contextual elements.

## REFERENCES

[1] J. I. Hoffman and S. Kaplan, “The incidence of congenital heart disease,”J. Amer. College Cardiol., vol. 39, no. 12, pp. 1890–1900, 2002.
[2] WHO Methods and Data Sources for Global Burden of DiseaseEstimates 2000–2011, Dept. Health Statist. Inf. Syst., WHO, Geneva,Switzerland, 2013.
[3] R. Castaldo, P. Melillo, U. Bracale, M. Caserta, M. Triassi, andL. Pecchia, “Acute mental stress assessment via short term HRV analysis in healthy adults: A systematic review with meta-analysis,” Biomed.Signal Process. Control, vol. 18, pp. 370–377, Apr. 2015.
[4] F. Wang, X. Zeng, C. Wu, B. Wang, and K. R. Liu, “mmHRV:Contactless heart rate variability monitoring using millimeter-waveradio,” IEEE Internet Things J., vol. 8, no. 22, pp. 16623–16636,Nov. 2021.
[5] F. Lombardi, “Clinical implications of present physiological understanding of HRV components,” Cardiac Electrophysiol. Rev., vol. 6, no. 3,pp. 245–249, 2002.
[6] E. Kristal-Boneh, M. Raifel, P. Froom, and J. Ribak, “Heart rate variability in health and disease,” Scand. J. Work Environ. Health, vol. 21,no. 2, pp. 85–95, 1995.
[7] M. P. Tarvainen, P. O. Ranta-Aho, and P. A. Karjalainen, “An advanced detrending method with application to HRV analysis,” IEEE Trans.Biomed. Eng., vol. 49, no. 2, pp. 172–175, Feb. 2002.
[8] B. Makivic, M. Niki ´ c Djordjevi ´ c, and M. S. Willis, “Heart rate variability ´(HRV) as a tool for diagnostic and monitoring performance in sport anphysical activities,” J. Exercise Physiol. Online, vol. 16, no. 3, p. 103,2013.
[9] P. J. Zimetbaum and M. E. Josephson, “Use of the electrocardiogramin acute myocardial infarction,” New England J. Med., vol. 348, no. 10,pp. 933–940, 2003.
[10] E. Çiçekli and E. Emre, “The effect of tension variability for sleep quality in headache patients: A Holter monitoring research,” Medicine, vol. 101,no. 30, 2022, Art. no. e29876.
[11] Y. K. Peker, G. Bello, and A. J. Perez, “On the security of Bluetooth lowenergy in two consumer wearable heart rate monitors/sensing devices,”Sensors, vol. 22, no. 3, p. 988, 2022.
[12] Y. Gao et al., “Heart monitor using flexible capacitive ECG electrodes,”IEEE Trans. Instrum. Meas., vol. 69, no. 7, pp. 4314–4323, Jul. 2020.
[13] J. Parak, A. Tarniceriu, P. Renevey, M. Bertschi, R. Delgado-Gonzalo,and I. Korhonen, “Evaluation of the beat-to-beat detection accuracy ofPulseOn wearable optical heart rate monitor,” in Proc. IEEE 37th Annu.Int. Conf. Eng. Med. Biol. Soc. (EMBC), 2015, pp. 8099–8102.
[14] W. Huang, W. Tang, H. Jiang, J. Luo, and Y. Zhang, “Stop deceiving! An effective defense scheme against voice impersonation attacks onsmart devices,” IEEE Internet Things J., vol. 9, no. 7, pp. 5304–5314,Apr. 2022.
[15] C.-A. Wang, T. Baird, J. Huang, J. D. Coutinho, D. C. Brien, andD. P. Munoz, “Arousal effects on pupil size, heart rate, and skin conductance in an emotional face task,” Front. Neurol., vol. 9, p. 1029,Dec. 2018.

[16] W. Huang, W. Tang, K. Zhang, H. Zhu, and Y. Zhang, "Thwarting unauthorized voice eavesdropping via touch sensing in mobile systems," inProc. IEEE Conf. Comput. Commun., 2022, pp. 31–40.

[17] M. Harbach, A. De Luca, and S. Egelman, "The anatomy of smartphoneunlocking: A field research of android lock screens," in Proc. CHI Conf.Human Factors Comput. Syst., 2016, pp. 4806–4817.

[18] "By 2024, How many smartphone owners will use biometrics?"2020. [Online]. Available: https://www.paymentsjournal.com/by-2024-how-many-smartphone-owners-will-use-biometrics.