RESEARCH ARTICLE

Automated Packed Cell Volume Analyzer

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Abstract: Packed Cell Volume (PCV), or hematocrit, is a crucial indicator of red blood cell concentration in blood, essential for clinical diagnostics. Traditional PCV measurement methods are manual, require significant blood volumes, and are unsuitable for remote or resource-limited areas. This project presents the development of a fully automated, portable PCV analyzer that minimizes blood sample volume while delivering accurate results. The system consists of a compact centrifuge driven by a 12V DC brushless motor and controlled by a Raspberry Pi. After centrifugation, a Raspberry Pi Camera Module 2 captures high-resolution images of the separated blood layers. These images are processed using a custom-trained YOLO machine learning model hosted on a Flask API to identify and measure the red cell and plasma layers. The PCV value is calculated from the proportional heights of these layers and automatically uploaded to a Firebase database. A React Native mobile application enables real-time access to the results. The system achieved an average accuracy of 97.67 % compared to commercial hematology analyzers (Sysmex), confirming its clinical reliability. Key technical challenges, such as image clarity and sample holder stability, were overcome using high-definition imaging. This project demonstrates the potential of cost-effective, automated PCV measurement solutions to improve healthcare access in decentralized and resource constrained environments. Future developments aim to explore non-centrifugal, ultrasound-based measurement techniques.

Keywords: Packed Cell Volume, Raspberry Pi, YOLO model, Automated Diagnostics, Portable Centrifuge

INTRODUCTION

Packed Cell Volume (PCV), also known as hematocrit, is a fundamental parameter in hematology that quantifies the proportion of red blood cells (RBCs) in whole blood. It plays a crucial role in diagnosing and monitoring a wide range of clinical conditions, including anemia, dehydration, polycythemia, and other hematological disorders. Accurate determination of PCV is essential for guiding appropriate medical interventions and treatment plans.

Conventional PCV measurement techniques involve manual centrifugation of blood samples followed by visual inspection of the separated layers in capillary tubes. While simple in concept, these methods are time-consuming, require trained personnel for interpretation, and are prone to human error [1]. Moreover, laboratory-grade hematology analyzers, though highly accurate, are expensive, bulky, and often inaccessible in remote or low-resource healthcare settings. This limits the availability of reliable PCV testing at the point of-care, particularly in field operations, rural clinics, and mobile health services.

Addressing this gap, the present project proposes the design and development of a portable, fully automated PCV analyzer capable of delivering fast and reliable results with minimal user intervention. The system integrates several key technologies: a Raspberry Pi-controlled compact centrifuge to separate blood components efficiently; a high-resolution camera for capturing post-centrifugation images.

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YOLO-based machine learning model for automated image analysis. The PCV value is calculated based on the relative height of the RBC and plasma layers and transmitted to a Firebase cloud database. A React Native-based mobile application provides real-time access to test results, enhancing usability in decentralized healthcare environments.

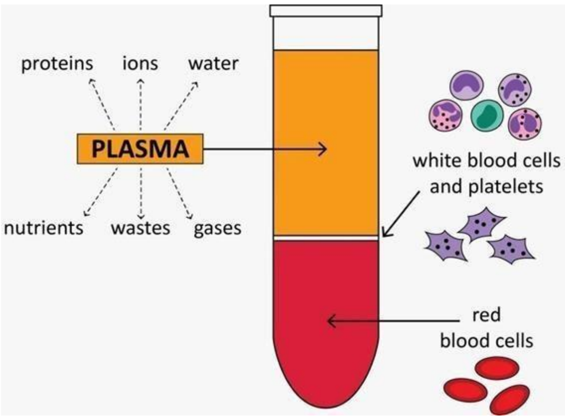

Figure 1: Centrifuged Sample

This innovative approach aims to create an affordable, compact, and user-friendly PCV analyzer suitable for point-of-care applications. By automating the entire testing process and enabling IoT connectivity, the device eliminates the need for complex laboratory equipment and skilled technicians, making accurate hematological analysis more accessible and scalable. Furthermore, the system's accuracy is benchmarked against commercial analyzers (Sysmex), demonstrating its clinical reliability.

This project highlights the transformative potential of embedded systems, machine learning, and IoT technologies in developing low-cost, automated diagnostic solutions to improve healthcare delivery in resource-constrained environments

METHODOLOGY

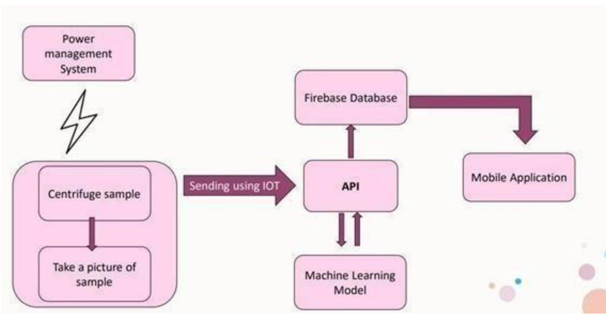

Figure 2: Overall Architecture

To develop a user-friendly and portable PCV analyzer, we divided the system into four key parts: power management, centrifuge operation, image processing, and data handling via a mobile app. Each part was carefully designed to be low-cost, compact, and optimized for use in field conditions.

A. Power Management System Design

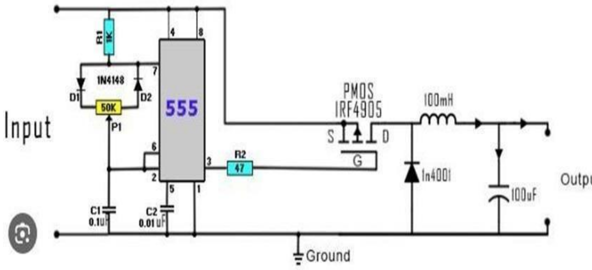

Figure 3: Buck Converter

To make the PCV analyzer truly portable and usable in remote or off-grid locations, a reliable and energy-efficient power system was essential. The design focused on using renewable energy, battery storage, and intelligent voltage regulation to keep the device lightweight and self-sustaining.

At the heart of the system is a 12V, 4Ah rechargeable battery, which acts as the primary power source for all components. This battery is charged using solar power through a custom-built buck converter circuit. The converter is designed to step down the higher voltage from the solar panel to a safe level suitable for charging the battery. To achieve this, a 555-timer IC is used to generate a pulse-width modulation (PWM) signal, which controls an IRF4905 PMOS transistor acting as a high-efficiency switch.

This setup allows the system to manage power intelligently and only what's needed is used. For example, during image capture, the camera flash LED is activated briefly and then turned off to save power. Once the battery is charged, power is distributed through two lines: a 7805-voltage regulator supplies a stable 5V for the Raspberry Pi and camera module, while a direct 12V connection powers the centrifuge motor through an L298N motor driver.

We also carefully designed the system to handle voltage fluctuations and to minimize energy waste. Based on calculations, the battery can provide power for about 1.4 hours of continuous operation under full load.

This is more than enough for multiple test cycles in one session, even in places where grid electricity isn't available.

B. Compact Centrifuge System Implementation

To make the PCV analyzer both portable and affordable, we built a compact centrifuge system from the ground up. Traditional lab centrifuges are bulky, expensive, and not designed for point-of-care use-especially in rural or low-resource settings [2]. Our goal was to create a reliable, small-scale alternative that could perform the same task: separating red blood cells from plasma in a capillary tube.

At the heart of our design is a 12V brushless DC motor, known for its smooth operation, low noise, and long lifespan. We mounted this motor onto a PVC foam board chassis, which is lightweight, sturdy, and easy to work with. This setup helped us keep the device compact without sacrificing stability.

Motor control is handled by a Raspberry Pi 2 Model B, which sends signals to an L298N motor driver. These signals adjust the motor speed 3000RPM using pulse-width modulation (PWM) [3]. When activated, the centrifuge gradually ramps up its speed and spins the sample for around five minutes. LED indicators provide visual feedback, so users know when the process begins and ends. A custom 3D-printed rotor securely holds the capillary tubes in place to prevent misalignment or wobbling. The result is a stable, reliable, and low-cost centrifuge suitable for field deployment.

B. Automated Image Processing & PCV Calculation

After the centrifuge finishes spinning the blood sample, the next step is to measure the red blood cell (RBC) level accurately. Traditionally, this is done manually by visually inspecting the capillary tube and estimating the RBC percentage, a method that can be slow and prone to human error. To improve both speed and accuracy, our system automates this process using image analysis and machine learning [4].

A Raspberry Pi Camera Module captures a 1920 × 1080 pixels-resolution photo of the blood-filled capillary tube right after centrifugation. This photo clearly shows the separate layers: the red blood cells at the bottom and the plasma on top. Once captured, the image is sent via Wi-Fi to a nearby Flask server, which handles the processing.

There, we use a YOLOv8 object detection model-trained [5], [6] using 20 images of real samples to locate and measure the RBC and plasma layers. It draws bounding boxes using a manual annotation protocol and calculates the PCV using a simple formula:

$$\text{PCV (\%)} = \frac{RBC\ Height}{RBC\ Height + WBC\ Height} * 100$$

Figure 4: Bounded sample

The result, along with the annotated image and timestamp, is uploaded to Firebase and displayed in real-time through a mobile app. This automated approach eliminates human error and provides fast, consistent results even in low resource settings.

C. Data storage and Mobile Application integration

To make the PCV analyzer more user-friendly and connected, we developed a simple yet effective mobile application that works alongside the device. After the PCV is calculated, the result along with the annotated image and time stamp is automatically uploaded to the Firebase Realtime Database. This allows the data to be securely stored in the cloud and accessed from anywhere [7], [8].

We built a mobile app using React Native, which supports both Android and iOS platforms. The app fetches the data from Firebase and presents it in a clean, easy-to-read format. Users can view their PCV history, see visual charts, and even zoom in on the analyzed image with the detected red and plasma layers.

This mobile integration adds real-time accessibility and supports better record-keeping for both patients and healthcare workers. It also sets the foundation for future features like multi-user access, doctor integration, and long-term health monitoring.

RESULTS AND DISCUTION

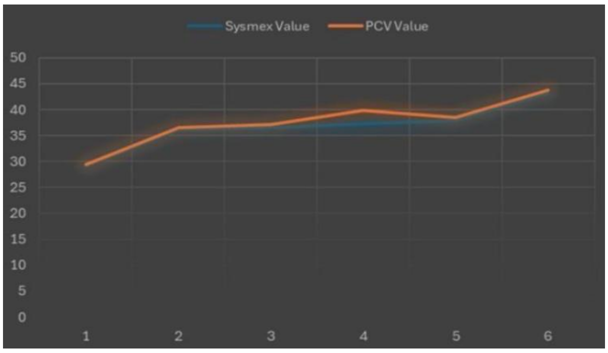

Figure 5: Comparison of PCV Values from Sysmex and Developed Analyzer with Accuracy curve

To evaluate the performance and accuracy of the automated PCV analyzer, we conducted tests using six different blood samples. Each sample was processed using our system and analyzed with a standard laboratory hematology analyzer (Sysmex), which served as the benchmark. The PCV results from both methods were compared to assess accuracy. Our system achieved an average accuracy of 97.67 % across all samples. In most cases, the difference between the automated PCV value and the lab result was less than 1.5 %, which falls well within acceptable clinical limits. This level of accuracy demonstrates the system's reliability, especially considering it operates in non-laboratory environments. Here, the error with the capillary tube filled with blood about 1/4 of the way up was 6.79 %. This may be due to the small data set we used.

Table 1: Comparison of PCV values from Sysmex and developed analyzer with accuracy

Sysmex Machine	PCV Analyzer Value	Relative Error	Accuracy
29.2 %	29.5 %	1.03 %	98.97 %
36 %	36.5 %	1.39 %	98.61 %
36.5 %	37.1 %	1.64 %	98.36 %
37.3 %	39.9 %	6.79 %	93.03 %
37,9 %	38.8 %	1.58 %	98.42 %
43,2 %	43.2 %	1.39 %	98.61 %
Average Value			97.67 %

Minor discrepancies observed were mainly due to image quality issues such as shadows or misalignment of the tube during capture and occasional variance in the motor speed. However, these did not significantly impact the final PCV calculations.

The processing time from centrifugation to result display was approximately 7 – 8 minutes, making the device suitable for point of care diagnostics where quick turnaround is essential. All test results, including the captured images and bounding boxes, were correctly stored in firebase and successfully retrieved via the mobile app.

Overall, the results validate that the proposed system is not only accurate but also practical for real-world use. Its portability, automation, and real-time mobile integration offer a significant advantage for use in rural clinics, mobile health units, or emergency situations where traditional lab equipment is unavailable.

CONCLUSION

This research successfully demonstrates the feasibility of a portable, automated PCV analyzer tailored for use in low resource and field environments. By integrating a compact centrifuge system, Raspberry Pi-based control, high resolution imaging, and YOLO-based machine learning, we were able to deliver a device capable of accurately measuring Packed Cell Volume with minimal human intervention. The system's average accuracy of 97.67%, when benchmarked against commercial hematology analyzers, confirms its potential for clinical use. Additionally, real-time data transmission through Firebase and intuitive access via a mobile application positions this solution as a powerful tool for decentralized healthcare delivery.

The challenges of image clarity, motor control, and power management were met with practical engineering solutions, including precision 3D printing and a solar-charged power system. Our design strikes a balance between affordability, portability, and performance, opening new possibilities for diagnostic services in rural clinics, mobile health units, and emergency response scenarios. Future iterations may explore ultrasound-based methods for even more compact and non-invasive applications. Ultimately, this project emphasizes the transformative potential of embedded systems and machine learning in democratizing access to essential medical diagnostics.

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