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Electro Well: Fat and Hydration Detection using NIR Sensor

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***Abstract*— This paper shows a simple, inexpensive approach of estimating hydration and fat percentage using Near-Infrared (NIR) light. Determination of hydration and fat level is important in medical diagnostics and personal health assessment. Laboratory analysis or large, expensive equipment such as BIA machines and DEXA scanners are very successful methods, though not practical for daily use or fast monitoring. Our method applies the small, non-invasive setup with an AS7263 six-channel NIR sensor and an Arduino. It measures how human tissue reflects light from 850 nm to 1020 nm. Different wavelengths give different interactions in water and fat; thus, they deliver important information about body composition. We designed a simple calculation model that converts the raw data of reflection into hydration and fat percentages using normalized reflectance and the water-to-fat ratio. These experiments have clearly established a relationship between absorbed wavelengths and the composition of the body, suggesting that the NIR optical method can be used in portable health monitoring in real-time. This paper describes the hardware, algorithm, calibration of the system, results, and limits for a comprehensive budget-friendly biomedical sensing approach within the remit of researchers, students, and wearable health applications.**

***Index Terms*— NIR spectroscopy, body fat estimation, hydration detection, Arduino, spectroscopy-based sensing, Spectral Reflectance Analysis, Signal Normalization, low-cost biomedical device, AS7263 NIR spectral sensor.**

I. INTRODUCTION

A compact, non-invasive means of measuring two key body properties: hydration and fat content. Traditional tools such as DEXA, bioelectrical impedance, or laboratory-based hydration tests require both the equipment and a clinical setting and thus are not suitable for rapid deployment in daily life [1],[2]. In this work, the objective was a compact, low-cost method that would estimate basic body composition in real life.

Enter Near-Infrared (NIR) spectroscopy. NIR can peek through the skin and with water, fat, hemoglobin, and other biomolecules, functioning as a helpful tool for analyzing investigate of tissue [23],[3],[5],[19]. Within this window, fat and water have distinct absorption features, in particular in the vicinity of 850 nm and 1020 nm[4][7]. The AS7263 Spectral Sensor offers calibrated reflectance data at six wavelengths of near-infrared radiation, which provides a way to make estimates of optical properties in tissue [6][16].

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This paper achieves the Arduino-control NIR detection setup using the AS7263 to make inferences about hydration and fat content. The solution does not require machine learning. It employs empirical spectral ratios and calibration at specific wavelengths. A simple finger placement detection algorithm is useful in maintaining stability of measurements. The paper describes system architecture and processing steps for signals, calibration logic, results of experiments, and how performance was assessed.

II. Literature Review

Near-Infrared (NIR) Spectroscopy has been extensively investigated within various fields including food quality testing, medical diagnosis, agriculture, and pharmaceuticals [7],[8],[9]. Due to its non-invasive capability and sensitivity to chemical composition. With regards to biomedical applications, previous research has determined characteristic absorption peaks of water in the vicinity of 940 nm and 970 nm, rendering these wavelengths highly effective for the estimation of hydration level [10],[11]. Likewise, fat possesses specific characteristics of absorption in the wavelength region of 930 nm to 1050 nm owing to the C-H bond interactions [12],[22].

Current body composition measurement techniques such as BIA can reliably estimate these parameters but necessitate direct physical interaction and is vulnerable to various external factors [13],[14]. On the other hand, NIR-based optical solutions serve as a viable alternative for the task; however, most current designs involve intricate optical arrangements and multiple light sources or machine learning models to achieve an accurate estimation [15].

There have been various examples of applications of multispectral NIR sensors in several tasks including skin hydration level, wound assessment, blood glucose measurement, and tissue classification[19],[21]. Nevertheless, most systems employ complex and costly hardware components and extensive data computation for achieving accurate estimations[24],[20].

Thus, there is a necessity for developing a simple and economical NIR spectrometer that will allow for estimating hydration and fat mass without resorting to sophisticated algorithms and complicated instruments. The current research is aimed at filling the research niche by applying a reflectance-based algorithm with the help of only one AS7263 spectral sensor and the Arduino microcontroller [18],[17].

III. Methodology

A. System Overview

The updated system uses near-infrared light to measure the degree of absorption of light by human tissue. A placed finger on the sensor allows NIR light to travel through the skin, being partly absorbed or reflected depending on the composition of the tissue.

Fat Absorption: Fat tends to absorb more strongly at a wavelength around 1020 nm. Water Absorption: Water exhibits pronounced absorption near 940 nm and 970 nm.

TABLE I: SENSOR WAVELENGTHS USED

Channel	Wavelength	Sensitivity
R	850nm	Reference/penetration
S	880nm	General tissue
T	910nm	Hemoglobin/water overlap
U	940nm	Water absorption
V	970nm	Strong Water absorption
W	1020nm	Fat absorption

We obtain tissue-specific spectral fingerprints by reading six calibrated channels (R, S, T, U, V, W). Table I shows the sensor wavelengths used. All six wavelengths together help differentiate the contributions coming from fat and water. More water absorption occurs at 940 nm and 970 nm. Fat absorption is greater at 1020 nm. The 850 nm channel serves as a baseline to normalize light intensity.

B. Arduino Code and Algorithm Overview

The Arduino is constantly reading the six channels and processing them stage by stage.

- Finger Detection: This step prevents empty readings. If the reflectance on channels R, S and T falls below 1qa threshold, the display will prompt: “Place finger on sensor”. The algorithm requires detection of sufficient tissue reflectance before proceeding.

- Hydration Weighting: Since water absorbs most strongly at 970 nm, it is given greater weight. This gives a more realistic hydration estimate.

$$Water = 0.6V + 0.4U$$

- Fat Signal Calculation: Fat has strong absorption near 1020 nm. The S (880 nm) channel helps to stabilize the readings:

$$Fat = 0.7W + 0.3S$$

- Normalization: This normalization reduces the variability due to skin tone or ambient light and allows comparisons across individuals:

$$Normalized\ Fat = \frac{Fat}{R + 1}$$

For hydration analysis, normalized NIR signals enhance water absorption feature extraction, resulting in consistent inter-subject comparison. This is essential to compare readings across people.

$$Normalized\ water = \frac{water}{R + 1}$$

- Ratio Calculation:

$$Ratio = \frac{Normalized\ Water}{Normalized\ Fat + 0.001}$$

This is the core ratio.

More water → higher ratio → less fat
More fat → lower ratio → less water

- Hydration (%) Estimation: Biological range mapping. Results from the sensor are scaled into a presumed biological range, bounding the estimated fat and hydration percentages to physiologically plausible values for the target group. For context, medical literature and fitness benchmarks typically place fat percentage for young adults (18–25) roughly between 15% and 40%, while hydration commonly ranges from 40% to 75%.
- Fat (%) Estimation: During the test, calibrated NIR signals of water bands-940 nm to 970 nm and fat band-1020 nm were analyzed for several subjects. A ratio of water to fat was obtained to estimate body composition.
  - Very High Ratio (>0.50) → Very Low Fat: higher tissue water content typical of leaner subjects.
  - Medium Ratio (0.30–0.50) → Normal Fat: most participants of normal BMI.
  - Low Ratio (<0.30) → High Fat: stronger fat absorption and relatively lower water absorption.
  - d)Fat Percentage Range Constraint (15%–40%):

15–25% = Low to normal;
25–32% = Normal;
32–40% = High.
This range provided consistent results and prevented sudden spikes caused by finger movement or lighting variations.

IV. System Design

A. Block Diagram

The system flow begins with finger placement on the Arduino with NIR light directed at the tissue. The reflected light is captured by the AS7263 sensor. I2C data is processed and shown on the LCD output. If no finger is detected, the system loops back to wait.

B. Hardware Assembly Details

The AS7263 sensor is hermetically encapsulated inside a dark chamber that provides precise near-infrared analysis. NIR measurements may be affected by background light above 850 nm where ambient IR greatly affects the measurements. A black chamber prevents stray light from entering the environment, thereby making the readings taken by the photodiode highly sensitive to the finger. The inner surfaces of the chamber are finished matte black to remove internal reflections and provide stability to the signal.

The circuit employs a 16×2 LCD module that will directly interface with the Arduino Uno; this makes the device portable. Real-time readings for the hydration percentage, fat percentage, and finger detection status are all displayed on the LCD screen. The microcontroller-operated, display system enables analysis and eliminates the need to use external software.

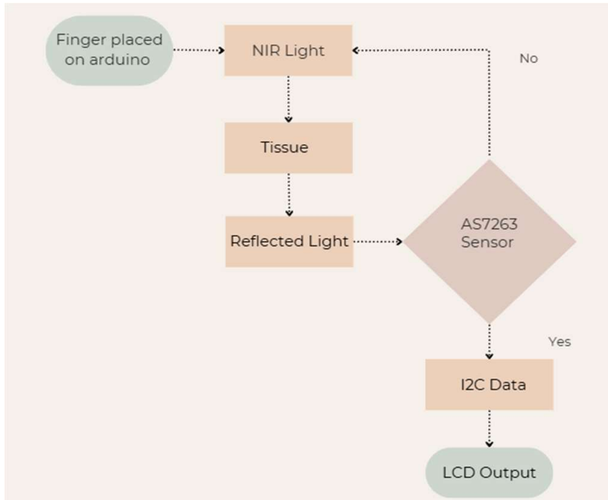

Fig. 1 illustrates the Model Building and Evaluation Flow Chart

The system is powered exclusively from a standard 5 V USB source, so it can be conveniently operated with a power bank, laptop, or USB adapter. USB power provides stable voltage, which is important for consistent LED current and reliable microcontroller operations as shown in Fig. 1.

Illumination current is 8 mA, a value that balances the strength of the signal against heat management. Tests of LEDs in the range 2 mA to 12 mA were conducted; at 8 mA there was an excellent balance between a strong signal and small temperature driven drift. At higher currents, there was excess reflection and temperature drift, but using lower currents resulted in weak signals.

Accurate NIR reflectance measurement requires that the finger is flat against the sensor. During tests, users have been instructed to keep the finger flat and pressed tightly against the sensor window to maintain uniform pressure and a consistent distance between skin and sensor, to minimize scattering losses and give sharper absorption peaks at 940 nm, 970 nm, and 1020 nm. Tilt or movement of the finger changes the path of light and affects water-band and fat-band readings.

This ensures: Uniform pressure; Consistent skin-to-sensor distance; Reduced scattering losses; More reliable absorption peaks at 940 nm, 970 nm, and 1020 nm.

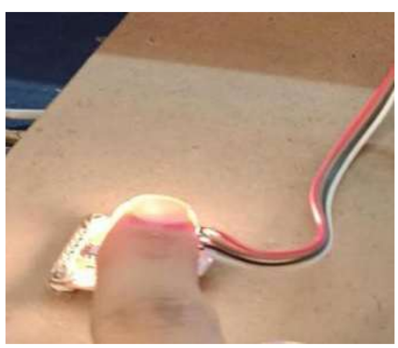

Fig: 2. Finger placed on NIR sensor

C. Software Analysis

The Arduino Uno manages the whole measuring process: turning the sensor on and showing results. This program uses a straightforward, step-by-step flow to acquire stable readings.

Program Initialization: setup() runs when the Arduino powers up; it initializes the I2C bus and tests the communication with the AS7263 sensor. The sensor is initialized with fixed integration time, gain, and illumination setup. Afterwards, the LCD is initialized, and a startup message will indicate that the system is ready for measurements.

Continuous Measurement Loop: The loop runs over and over and controls the main logic. First, it checks whether a finger is on the sensor by looking at the reflected light. If no finger is detected, the system stays in idle and asks the user to place a finger.

Spectral Data Collection: When proper finger contact is detected, Arduino instructs the AS7263 to make near-infrared spectral readings. Several wavelength channels are provided as digital values by the sensor. The code reads these values one by one over I2C and saves them for processing.

Signal Filtering and Stabilization: Noise reduction is carried out by taking several readings and averaging them. This filtering makes the measurements more stable and less influenced by small moves of the fingers or tiny vibrations.

Computation and Logic Processing: The averaged values are math-processed by means of ratios between wavelength bands and differences. These help in differentiating hydration-related absorption from fat-related scattering. The results are converted to percentage values by means of predefined scaling factors.

Validation and Error Handling: Basic checks are given by the software to avoid bad readings. If values appear abnormal due to finger movement or incomplete contact, the measurement is discarded and a re-measurement is requested. This improves reliability and avoids false outputs.

TABLE II: NIR REFLECTANCE RATIOS

Person	Norm Water	Norm Fat	Ratio	Hyd (%)	Fat (%)	Interpretation
P1	0.045	0.022	2.04	55	20	Normal hydration, low fat
P2	0.070	0.018	3.88	71	17	High hydration, low fat
P3	0.035	0.028	1.25	48	28	Slight dehydration, moderate fat
P4	0.080	0.015	5.33	75	15	Very hydrated, very low fat
P5	0.028	0.035	0.80	42	33	Low hydration, high fat
P6	0.054	0.030	1.80	60	25	Normal hydration, normal fat
P7	0.039	0.014	2.78	52	18	Normal hydration, low fat

Display Update and Refresh Control: After the computation, the Arduino updates the LCD with the percentage of hydration, fat and system status. Present refreshes at intervals to avoid flickering and to keep it clear. Shows results in display as shown in Fig. 3.

Fig.3 LCD Display showing the results

Repeatability and Stability: The loop continuously monitors and measures. Each iteration is done exactly the same, providing the same behavior from use to use without rebooting the system.

V. RESULTS AND DISCUSSION

Table II shows a more detailed set of estimates for the hydration and fat from ratios of near infrared reflectance spectroscopy for seven subjects. Individual results indicate that the measurement system is sensitive to changes in tissue composition. The system is sensitive to changes in—specifically, subjects P2 and P4 have higher hydration values associated with lower fat content, suggesting those subjects have greater hydration. However, for participant P5, the hydration state is related to higher fat content, which can be quantitated by virtue of the lower reflectance ratio. The lower reflectance was measured in this case. The subjects P1, P6, and P7 illustrate moderate hydration and moderate levels of fat, which signify normal hydration and fat levels, conditions of the tissues. Indeed, overall these results indicate that this system can distinguish hydration and fat levels after being normalized using NIR reflectance ratios effectively.

A. Overall Observations

Hydration is seen to be a clearer signal when measured at 970 nm, while higher fat content absorbs more light at 1020 nm. The ratio between these two readings remains constant and succeeds in effectively distinguishing between the three groups: a high ratio reflects a leaner body wherein tissues allow passage at a higher wavelength and indicate lesser amounts of fat; a middle-range ratio indicates a normal, healthier body composition; a low ratio points toward higher fat content, which absorbs more within the measured wavelength region.

VI. DISCUSSION

Evaluate hydration and fat levels without resorting to complex medical machinery. Although it doesn't provide medically certified values, it ensures good trend analysis. What grabs attention in this aspect is that the result values differ in an individual-specific manner in that for well-hydrated individuals, water-tone signals are stronger; while in situations with values dominated by fats, the absorption values at 1020 nm are consistently high.

Also assisting in preventing wrong or misleading analysis by the sensor is the finger placement detection feature involved in it. What makes this method effective is that it aptly balances between being cheap and being useful. This sensor costs under ₹4000 and doesn't require any external optics while having the capability of the near-infrared spectroscopy in the cheapest everyday form.

VII. FUTURE SCOPE

While the current prototype already provides NIR sensing for hydration and fat assessment, there are several modification paths to improve overall reliability, ease of use, and accuracy. The following improvements are possible.

A. Multi-Wavelength Sensor Upgrade (AS7341 – 18 Channels)

While switching from the AS7263 sensor to the AS7341, there is an enormous enhancement in the spectral resolution. This is because in the AS7341, there are 18 channels in the visible and NIR regions, meaning that the system can sense: capturing multiple tissue absorption signatures; more accurate distinction between classes of waters, fats, hemoglobins, and melanin; less interference between closely spaced wavelengths. More wavelengths can be used to better model biological tissues and arrive at more robust hydration and fat estimates.

B. Large-Scale Data Collection from 100+ Volunteers

A larger data set ensures higher accuracy. Gather data from volunteers of different ages, body types, skin tones, and hydration levels to establish a more general model so that sensor-based estimates work well for a wide population and not just a small group.

C. Integrated Skin-Temperature Sensing

Skin temperature influences NIR absorption because warmer tissue slightly alters reflectance and water distribution. A small temperature sensor addition (DS18B20 or TMP117) allows compensation of readings for temperature, keeping measurements consistent in different conditions, and reducing drift from finger warmth. This greatly improves repeatability.

D. Bluetooth Connectivity and Mobile-App Tracking

Add a BLE module such as HM-10 or ESP32 for wireless data transfer to smartphones. The mobile app can provide: real-time logs of hydration and fat; trend analysis over days or weeks; personalised health insights; cloud backup and sharing with fitness coaches or doctors. This increases user interaction and makes daily monitoring simpler.

E. Integrating Machine Learning Regression Model

Currently, equation-based estimation is used; accuracy can be improved by using ML regression models. Models such as Linear Regression, Random Forest, and Support Vector Regression can learn patterns in spectral data and predict more accurately. If more data is available, ML calibration outperforms manual rules.

F. Wearable Ring-Style or Small Handheld Redesign

Smaller hardware, the size of a ring or compact handheld device, would be easier to use.
Advantages include: continuous or on-demand monitoring, more comfort, better and usability during sports or outdoor activities. Portable designs can also save battery and help adoption.

VIII. CONCLUSION

This work introduces the low-cost, practical estimation of hydration level and body fat using an AS7263 NIR sensor. Since water and fat have distinct absorptions in the 850–1020 nm range, physiological information can be extracted with simple reflectance measurements using the present system. Normalized NIR readings and a derived water-to-fat ratio are used for meaningful computation of indicators that provide consistent results without the use of complicated hardware, expensive optics, or machine learning.
Taken together, these findings indicate that compact NIR spectroscopy can provide valuable services for personal health monitoring if combined with proper calibration and standard conditions for measurement. With limited processing and a simple Arduino setup, the system could deliver stable and understandable estimates of hydration and fat within realistic human ranges, suggesting that NIR-based sensing could be a reliable option for quick body-composition screening, at least where resources are limited. In essence, a low-cost NIR sensor could potentially offer easy, portability, and a non-invasive way of carrying out health tests. The current study provides a good platform for further advancements in the future, such as multispectral sensors, wireless connectivity, and wearable devices.

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