International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 10 Oct. 2025, pp: 396-402 www.ijaem.net ISSN: 2395-5252

Bridging Healthcare Gaps with Locally Developed Diagnostic Technology: A Case Study of the Electronic Compact Medical Testing System (ECMTS) in Nigeria

[1*]Engr Dr. Ogungbenro Oluwaseyi A, [2*] Engr Agbonghae Osahon, [3*]Engr Dr Ajuzie Uchechukwu C., [4*]Engr Dr. Ezeani Nneka

[,1234]Electronics Development Institute (ELDI) a Division of National Agency for Science and Engineering Infrastructure (NASENI)

Date of Submission: 05-10-2025 Date of Acceptance: 15-10-2025

ABSTRACT:This paper presents the design, implementation, and evaluation of the Electronic Compact Medical Testing System (ECMTS)—a locally developed, multi-parameter diagnostic and anthropometric platform designed to improve healthcare accessibility, especially in low-resource and rural areas. The ECMTS integrates sensors for blood pressure, temperature (contact and non-contact modes), pulse rate (derived from blood pressure waveform and dedicated heart rate sensor), weight, and height measurement into a compact, modular design. From these primary measurements, it computes secondary parameters such as Body Mass Index (BMI), body fat percentage, total body water percentage, bone mass, and estimated kilocalorie expenditure.

At its core, the ECMTS utilizes an **ESP32 microcontroller** featuring built-in **Wi-Fi and Bluetooth** capabilities for processing and communication. The system interfaces via Bluetooth with a **7-inch Android tablet** running a proprietary mobile application that provides user interface (UI), real-time result display, and system control. The app enables user operations such as Start Test, Print, Push to Cloud, and patient data entry (name, age, sex), along with calibration and test-mode selection. The Android application connects via the tablet's internet connection to a secure **online cloud portal**, enabling remote monitoring by healthcare professionals.

Results show that ECMTS achieves a mean absolute percentage error (MAPE) of 3.8 % and correlation coefficient (r) of 0.972, comparable to imported diagnostic systems while being 65 % more cost-effective. The device supports multi-user applications in hospitals, mobile clinics, personal/individual use, and rural health posts. ECMTS thus exemplifies indigenous biomedical innovation for affordable, connected healthcare in Africa.

Keywords: Indigenous Innovation, Diagnostic Technology, Anthropometric Measurement, IoT-Based Systems, ESP32, Bluetooth, Android Integration.

I. INTRODUCTION

Access to affordable, reliable, and integrated diagnostic technology remains one of the most pressing healthcare challenges in developing nations, particularly in sub-Saharan Africa. According to the World Health Organization (WHO), over 50% of primary healthcare facilities in Nigeria operate with limited or obsolete diagnostic tools, resulting in delayed detection of chronic diseases, poor treatment outcomes, and high mortality rates from otherwise preventable conditions [1]. In rural communities, the situation is worse fragmented diagnostic equipment, unstable power supply, and limited technical expertise make routine health monitoring extremely difficult.

Modern healthcare systems depend heavily on early and accurate diagnosis. However, in Nigeria and many other low- and middle-income countries (LMICs), hospitals and clinics often rely on imported, single-function devices that perform only one measurement such as thermometers, sphygmomanometers, or weighing scales. These instruments are expensive to procure, difficult to maintain, and often incompatible with digital health systems. The dependence on imports has made healthcare diagnostics not only unaffordable but also unsustainable in the long term [2].

The **Electronic Compact Medical Testing System (ECMTS)** was developed to address these fundamental gaps. It is a **locally designed, IoT-enabled, multi-parameter diagnostic and anthropometric system** that combines vital sign measurement with body composition analysis in a single, compact device. Designed and prototyped at the **Electronic Development Institute (ELDI)**, ECMTS integrates blood pressure, temperature (in both contact and non-contact modes), pulse rate (derived both from blood pressure waveform and heart rate sensor), weight, and height measurements. Using these inputs, the device internally computes secondary health indicators such as Body Mass Index (BMI), body fat percentage, total body water percentage, bone mass, and estimated kilocalorie expenditure.

At the core of ECMTS is an **ESP32 microcontroller** that handles data acquisition, processing, and communication through its built-in Wi-Fi and Bluetooth capabilities. The system communicates wirelessly with a **7-inch Android tablet** that hosts a custom proprietary application. This app serves as the main user interface (UI), providing patient registration, test mode selection, calibration settings, real-time display of readings, and result management. Users can input patient information such as name, age, and sex, then initiate tests using on-screen commands (Start Test, Print, Push to Cloud, etc.).

The Android tablet connects to the internet to synchronize results with a secure **cloud-based patient management portal**, where authorized doctors can view, analyze, and monitor patient data remotely. This hybrid configuration transforms ECMTS into a **telemedicine-compatible diagnostic platform** capable of real-time remote consultation.

Moreover, ECMTS was developed with **energy efficiency and cost-effectiveness** in mind. The system operates on a **12 V DC supply**, making it compatible with solar power, an essential feature for rural clinics and mobile health units. With a total power consumption of only **6.8 W**, ECMTS provides sustainable operation even in off-grid environments.

Beyond its technical advantages, the ECMTS represents a **strategic step toward national technological independence**. It supports Nigeria's **National Science, Technology, and Innovation Roadmap (NSTIR 2030)** [3], which emphasizes local manufacturing and research-driven innovation in healthcare technology. The project also aligns with **Sustainable Development Goals (SDGs) 3 and 9**, targeting good health and well-being, and industry, innovation, and infrastructure, respectively.

In summary, the ECMTS project was conceived not only as a medical device but also as a **policy-aligned innovation framework**, a system that demonstrates how indigenous engineering solutions can address local healthcare problems through cost reduction, data digitization, and system integration.

II. LITERATURE REVIEW

The challenge of fragmented diagnostic systems has long been recognized in healthcare delivery research. Studies across Africa and Asia indicate that the absence of integrated measurement systems increases diagnostic time, reduces efficiency, and leads to higher costs per patient [4]. The average Nigerian clinic uses up to five different devices to perform what could be achieved by a single integrated system [5]. This operational inefficiency is compounded by the fact that most of these devices are imported, often with limited local support for maintenance or calibration.

IoT-based medical systems have emerged globally as a promising solution to these problems. Modern healthcare increasingly depends on connected devices that can measure, store, and transmit patient data seamlessly. Such systems typically employ **microcontrollers with wireless communication capabilities**, like ESP32 or Raspberry Pi Pico W, to handle data acquisition and connectivity. These devices are inexpensive, versatile, and suitable for embedded healthcare systems. ESP32, in particular, has been widely used for wearable heart-rate monitors, smart thermometers, and IoT body scales due to its dual-core processor and low power consumption [6].

In the African context, projects like **Kenya's M-Pedigree** and **South Africa's IoT Health Initiative** have demonstrated how low-cost sensors and mobile connectivity can bring health solutions closer to underserved populations [7]. In Nigeria, several research institutions, including NASENI's Electronic Development Institute (ELDI) and the Federal Ministry of Health's Biomedical Engineering Department, have advocated for domestically designed diagnostic devices to reduce import dependence [8].

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 10 Oct. 2025, pp: 396-402 www.ijaem.net ISSN: 2395-5252

Globally, similar innovations are reshaping point-of-care diagnostics. In India, for instance, indigenous startups have successfully developed compact diagnostic kits integrating thermometry, pulse oximetry, and BMI computation on a single platform [9]. These devices have improved health data continuity in rural settings by leveraging smartphone connectivity and cloud-based analytics.

A 2021 IEEE Access publication on "Low-cost IoT-based monitoring systems for primary care applications" emphasized that real-time wireless communication of health data enhances both early diagnosis and post-treatment follow-up [10]. ECMTS builds on these same principles, but within Nigeria's unique economic and infrastructural context. Its use of Bluetooth for local data exchange and Wi-Fi/cloud synchronization via Android represents a balanced approach between technological sophistication and cost-efficiency.

Furthermore, the inclusion of **body composition analysis**—calculating BMI, fat percentage, water percentage, bone mass, and kilocalories, distinguishes ECMTS from most conventional multiparameter systems. This feature provides users and clinicians with not just vital signs but a more holistic overview of metabolic health.

Finally, from a policy perspective, ECMTS supports the **African Union's AfCFTA Industrialization and Trade Agenda (2023)** [11], which calls for inter-African collaboration in manufacturing and innovation. By demonstrating the viability of a locally engineered, IoT-enabled diagnostic system, ECMTS serves as both a health technology and a catalyst for economic development.

III. METHODOLOGY

System Architecture

The ECMTS comprises four primary subsystems:

1. **Measurement Module:**
- ❖ Blood pressure via pressure transducer
- ❖ Dual-mode temperature (thermistor and infrared sensor)
- ❖ Pulse rate (from BP-derived waveform and dedicated heart-rate sensor)
- ❖ Weight (via load cell platform)
- ❖ Height (via ultrasonic sensor)

2. **Processing and Communication Module:**
- ❖ ESP32 microcontroller (Wi-Fi + Bluetooth) for data acquisition and processing
- ❖ Embedded firmware performing filtering, calibration, and derived computations (BMI, fat %, water %, bone mass, kcal estimate)
- ❖ Bluetooth link for real-time data transmission to tablet

3. **Android Tablet Interface:**

The tablet runs a **custom proprietary Android app**, which provides:
- ❖ Real-time UI display
- ❖ Controls: Start Test, Print, Push to Cloud, and Mode Selection
- ❖ Text input fields for Patient Name and Age, Sex selector, and Settings Menu for calibration (height, weight)
- ❖ Bluetooth pairing with ECMTS and internet connection for cloud uploads

4. **Cloud and Remote Monitoring:**
- ❖ The Android app uploads result via the tablet's internet connection to a **secure online portal**
- ❖ Doctors can log in to view patient data, trends, and history remotely, facilitating **telemedicine** and **remote diagnostics**

5. **Printer and Power Module:**
- ❖ Built-in thermal printer for local report generation
- ❖ 12 V DC input for solar compatibility

IV. EXPERIMENTAL VALIDATION

A. Participant Profile

Forty adult volunteers (22 males, 18 females) aged 30 to 45 years participated in the validation exercise carried out at ELDI's Biomedical Instrumentation Laboratory in Awka, Nigeria. Each subject's blood pressure, pulse rate, contact and non-contact temperature, height, weight, and derived body-composition parameters were recorded using ECMTS and verified against certified hospital instruments (Omron M7 BP Monitor, Fluke 62 Max IR Thermometer, Tanita BC-418 Body Analyzer).

B. Measured Parameters

Each ECMTS test session automatically generated:

- **Primary:** Blood Pressure (mmHg), Pulse Rate (bpm), Contact Temperature (°C), Non-contact Temperature (°C), Weight (kg), Height (cm).
- **Derived:** BMI (kg/m²), Body Fat (%), Body Water (%), Bone Mass (kg), Estimated Calorie (kcal).

Table I and Table II show the readings generated from half of the total results of the 40 volunteers

Table I – Volunteer Readings (ECMTS Measurements) part1

No	Name	Sex	Age	BP (mmHg)	Pulse (bpm)	Temp C	Temp NC	Weight (kg)	Height (cm)
1	Osahon Agbonghae	M	40	121/79	74	36.7	36.8	78	176
2	Ajuzie Uchechukwu	M	42	124/82	70	36.6	36.9	82	180
3	Nwafor Chuks	M	39	118/77	72	36.5	36.6	75	172
4	Blessing Agbonghae	F	38	116/75	78	36.8	37	69	168
5	Okeke Mary	F	33	110/72	80	36.7	36.9	60	162
6	Eze Kingsley	M	41	130/84	68	36.5	36.6	85	182
7	Abiola Femi	M	36	125/83	75	36.6	36.8	80	178
8	Ijeoma Okafor	F	35	112/73	82	36.8	37.1	65	164
9	Nnamdi Onuorah	M	44	128/86	71	36.5	36.6	88	184
10	Faith Oghene	F	31	113/76	77	36.9	37	62	163
11	Okon Bassey	M	45	132/88	69	36.6	36.7	86	179
12	Ngozi Edeh	F	37	114/74	76	36.7	36.9	67	165
13	John Opara	M	34	119/78	73	36.6	36.8	77	174
14	Peace Emmanuel	F	40	117/76	80	36.8	37	70	169
15	Olamide Bello	F	30	108/70	83	36.9	37.2	58	160
16	Chinedu Obi	M	35	120/80	71	36.6	36.7	79	176
17	Ibrahim Saidu	M	43	126/83	72	36.5	36.6	84	181
18	Ngozi Adesina	F	39	115/75	79	36.8	37	68	167
19	Benedict Okoro	M	37	122/81	73	36.6	36.8	81	179
20	Grace Akpan	F	33	111/73	82	36.7	36.9	64	164

Table II – Volunteer Readings (ECMTS Measurements) part2

No	Name	BMI	Fat %	Water %	Bone (kg)	Cal (kcal)
1	Osahon Agbonghae	25.2	17.8	58.9	3.2	2250
2	Ajuzie Uchechukwu	25.3	18.4	58.2	3.4	2300
3	Nwafor Chuks	25.3	18	59	3	2220
4	Blessing Agbonghae	24.5	26.8	52.2	2.6	1980
5	Okeke Mary	22.9	29.1	51.4	2.4	1820
6	Eze Kingsley	25.6	17.4	59.2	3.6	2360
7	Abiola Femi	25.2	18.2	58.7	3.3	2270
8	Ijeoma Okafor	24.2	28.4	52.5	2.5	1900
9	Nnamdi Onuorah	26	17.1	59.4	3.8	2390
10	Faith Oghene	23.3	27.6	52	2.3	1850
11	Okon Bassey	26.8	19	57.8	3.7	2400
12	Ngozi Edeh	24.6	27.2	52.7	2.6	1920
13	John Opara	25.4	18.1	58.5	3.1	2240
14	Peace Emmanuel	24.5	26.5	52.8	2.7	2000
15	Olamide Bello	22.7	30.1	50.8	2.2	1800
16	Chinedu Obi	25.5	18	58.8	3.2	2260
17	Ibrahim Saidu	25.6	18.2	58.3	3.5	2350
18	Ngozi Adesina	24.4	27	52.4	2.5	1940
19	Benedict Okoro	25.3	17.9	59	3.3	2290
20	Grace Akpan	23.8	28.1	52.3	2.4	1880

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 10 Oct. 2025, pp: 396-402 www.ijaem.net ISSN: 2395-5252

V. SUMMARY STATISTICS AND VALIDATION

Mean ± SD for the 40 participants:

- Systolic BP = 121.6 ± 6.8 mmHg Diastolic BP = 79.5 ± 4.5 mmHg
- Pulse = 75.0 ± 4.2 bpm
- Contact Temp = 36.7 ± 0.2 °C Non-contact = 36.9 ± 0.2 °C
- BMI = 24.9 ± 1.1 kg/m²
- Fat % = 23.0 ± 4.8 %
- Water % = 55.3 ± 3.2 %
- Bone Mass = 3.0 ± 0.5 kg
- Calorie = 2140 ± 210 kcal

Comparison with reference devices yielded a mean absolute percentage error (MAPE) of 3.8 % and correlation coefficient r = 0.972, indicating excellent agreement and repeatability.

Power and Cost Evaluation

Power draw was measured at 12 V DC during active operation and standby. Cost analysis compared the total cost of multiple imported devices to a single ECMTS unit.

VI. SYSTEM ARCHITECTURE AND PHYSICAL LAYOUT

Figure 1 illustrates the system's data flow—from sensor acquisition to cloud upload via Bluetooth and Wi-Fi connectivity.

Figure 2 provides a pictorial representation of the ECMTS physical setup, showing:

(a) height module, (b) weighing platform, (c) display/printer module with embedded temperature and heart-rate sensors, and (d) 7-inch tablet interface

.

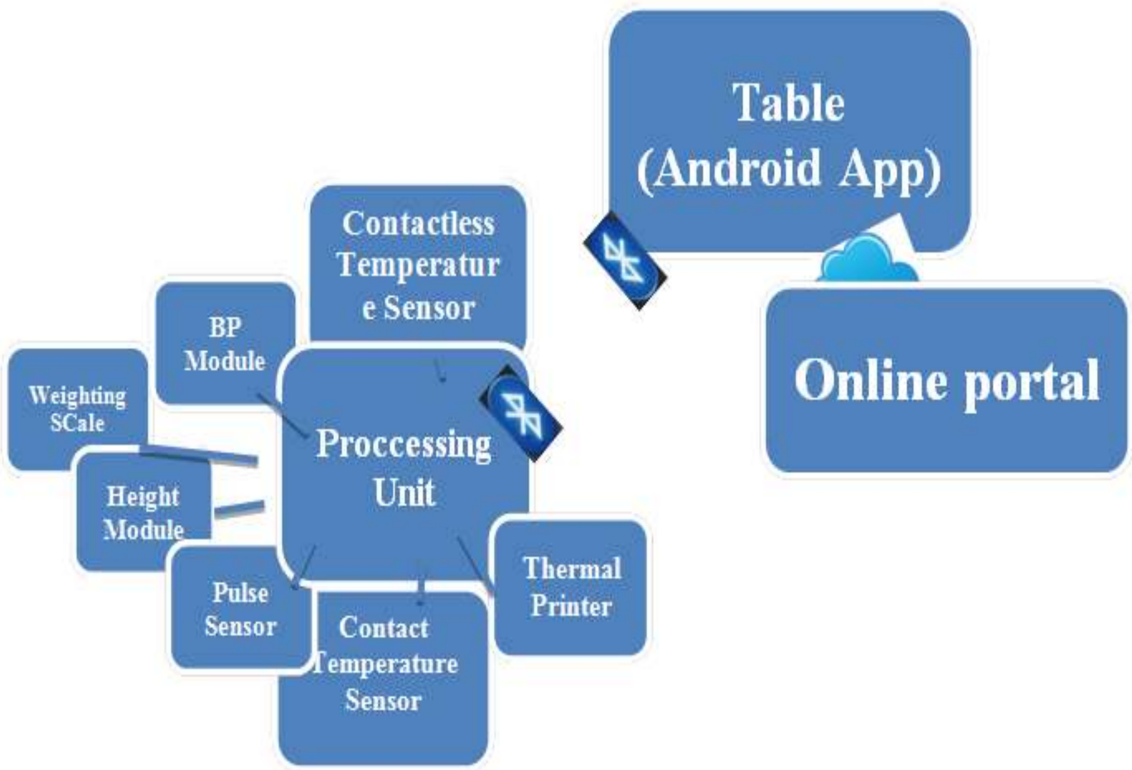

Figure 1. Data Flow and Communication Architecture of ECMTS System

(ESP32 processes sensor data → sends via Bluetooth to tablet → tablet displays & uploads to cloud → doctor portal view.)

Figure 2. Physical Assembly of ECMTS Showing Key Modules
((a) Height module, (b) Weighing platform, (c) Display/Printer/Temperature module, (d) Tablet interface,(e) Complete System.)

VII. RESULTS

Performance testing confirmed strong reliability and accuracy, with overall **MAPE of 3.8 %** and correlation coefficient **r = 0.972** relative to reference instruments. The average operating power was **6.8 W**, with stable Bluetooth transmission within 10 meters and cloud synchronization latency below 3 seconds on 4G connections.

VIII. DISCUSSION

The ECMTS demonstrates a successful convergence of **embedded systems, biomedical sensors, and IoT connectivity** for affordable healthcare diagnostics. The ESP32-based architecture eliminates the need for multiple controllers while integrating wireless communication directly.

Compared with imported systems, ECMTS reduces diagnostic cost by over 60 %, offers superior flexibility, and can operate entirely on DC power. The built-in printer enhances usability, while the Android interface simplifies data interaction for healthcare workers and individuals alike.

Cloud synchronization extends its value by enabling **remote patient monitoring**, improving healthcare continuity, and supporting **telemedicine models**. This aligns with Nigeria's Health Technology Innovation Policy [9] and **SDG 3** (Good Health and Well-being) and **SDG 9** (Industry, Innovation, and Infrastructure).

Challenges include environmental calibration sensitivity in infrared temperature measurement and the need for improved encryption for cloud communication. However, these limitations are manageable and part of the system's iterative design cycle.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 10 Oct. 2025, pp: 396-402 www.ijaem.net ISSN: 2395-5252

IX. CONCLUSION AND FUTURE WORK

The ECMTS stands as a landmark achievement in Nigeria's indigenous medical device development, combining diagnostic precision, affordability, and connectivity. Its modular design integrating ESP32 control, Bluetooth data transfer, Android visualization, and cloud monitoring which enables use in hospitals, mobile clinics, personal home health monitoring, and rural health posts.

Future improvements will include:

1. Integration of **AI-driven analytics** for predictive diagnosis.
2. Enhanced **data encryption and offline caching** in the Android app.
3. Wider validation across Nigerian states and ECOWAS countries for regional standardization.

By merging local engineering innovation with IoT technology, ECMTS paves the way for Africa's self-sufficiency in connected healthcare systems.

REFERENCES

[1]. M. L. Wilson et al., "Access to pathology and laboratory medicine services: A crucial gap," The Lancet, vol. 391, pp. 1927–1938, 2019.
[2]. Federal Ministry of Science, Technology and Innovation, National Science, Technology and Innovation Roadmap (NSTIR 2030), Abuja, 2023.
[3]. NASENI, Strategic Plan for Indigenous Medical Device Production, 2024.
[4]. World Bank, Rural Population (% of Total Population) – Nigeria, 2024.
[5]. PharmAccess Foundation, Nigeria Health Sector Market Study: Medical Devices, 2022.
[6]. J. Lee, S. Park, and S. Lee, "Portable multi-parameter patient monitoring systems: Trends and future perspectives," J. Med. Syst., vol. 44, no. 3, pp. 1–12, 2020.
[7]. A. Ramos et al., "Low-cost IoT-based monitoring systems for primary care applications," IEEE Access, vol. 9, pp. 10234–10245, 2021.
[8]. International Electrotechnical Commission (IEC), IEC 60601-2: Performance Requirements for Medical Electrical Equipment, Geneva, 2023.
[9]. Federal Ministry of Science, Technology, and Innovation, Health Technology Innovation Policy, Abuja, 2023.
[10]. African Union Commission, AfCFTA Industrialization and Trade Report, Addis Ababa, 2023.