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Cloud-Connected Smart Health Kiosk for Rural Diagnostic Services

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Abstract- — Access to quality healthcare in developing nations often remains challenging due to several factors including geographical distance, shortage of competent medical professionals, and lack of diagnostic facilities. This study proposes an efficient cloud-based smart health kiosk that facilitates the delivery of cost-effective, easy-to-access, and quality diagnostic services. The design of the kiosk involves the use of IoT enabled medical sensors (digital stethoscope, infrared thermometer, pulse oximeter, blood pressure measurement device, glucometer, ECG, and urinalysis dipstick reader) and edge computing gateway for capturing the data and pre-processing the acquired data. Telemedicine is used for establishing a video connection between the patient and remote physician. Medical data is transferred to the cloud storage through an HIPAA compliant network for long-term storage and initial triaging using artificial intelligence. After deployment at 50 rural areas in India serving 250,000 patients in 18 months, average travel time decreased from 32 km to 1.5 km and out-of-pocket costs were minimized by 68%. Patient satisfaction rate was recorded to be 94%.

Keywords— Smart Health Kiosk, Rural Healthcare, Telemedicine, IoT in Healthcare, Cloud Computing, Diagnostic Services, Point-of-Care Testing, Digital Health, Low-Resource Settings, Healthcare Accessibility

I. INTRODUCTION

The difference between the provision of care among urban and rural populations is still a critical and highly devastating health disparity in the world. About 65% of Indians live in rural settings, but only 30% and 25% of doctors and diagnostic laboratories exist in such settings respectively [1]. A person living in a rural setting has to walk from 30-50 km to access a PHC facility where diagnostic tools may not be available. Diseases like high blood pressure, diabetes, tuberculosis, and even cancer are usually detected late during their progression [2].

The COVID-19 crisis has clearly shown how deep and destructive the gap can be. The lockdown measures restricted the movement of individuals. The fear of contracting the disease at the hospitals resulted in undiagnosed cases of illnesses and needless deaths. There was a significant uptake of telemedicine practices during this period, but its effect on patient care has been hampered by the availability of devices connected to the internet [3].

The idea of a "health kiosk," which is basically an automated point-of-care station, seems to be quite a promising solution. Just like with ATMs for banking, the idea is to deploy this health kiosk at the center of villages [4]. In connection with the cloud and telemedicine services, such a device allows doctors to make proper diagnoses based on the live, high-fidelity medical data transmitted via cloud [5].

In this paper, we present a cost-efficient and scalable cloud-connected smart health kiosk that is especially relevant for rural diagnostics. The major contributions include:

- Smart Integrated IoT Medical Devices: A package of affordable yet clinically validated devices (for blood pressure, glucose, ECG, oxygen saturation, temperature, stethoscope, and urinalysis) that are integrated in a convenient console.
- Edge Computing Gateway for Offline Mode: Local storage of patients' data as well as the ability to perform basic tasks with AI support (such as identification of cases with high levels of hypertension).
- EHR Cloud Storage and Patient AI Triage: Secure cloud-based storage with a proper AI model (LightGBM classifier) for patient classification (routine, non-urgent, urgent, or emergency) according to their vital signs and test results.
- Integration of Telemedicine: Video conference with the doctors who have access to the patient's diagnosis report remotely.
- Large-Scale Field Trial: Deployment for 18 months in 50 villages of three Indian states – Uttar Pradesh, Bihar, and Madhya Pradesh – treating 250,000 patients and rigorous assessment of clinical and economic results.

II. LITERATURE SURVEY

There are several pieces of literature related to rural healthcare provision, telemedicine, and IoT-based diagnostics that help to provide some insights into this topic.

Barriers to Rural Healthcare Provision: There are multiple barriers associated with the provision of rural healthcare: distance (travel time and travel cost), financial issues (income loss and travel costs), lack of qualified medical professionals, and low levels of health literacy [1], [2]. One study carried out in rural India in 2022 showed that almost half of chronic patients in the area did not undergo blood pressure and sugar level testing since there were no healthcare facilities around [3]. Telemedicine and Remote Patient Consultations: Telemedicine is one of the most widely discussed topics that can be considered a promising area in terms of remote diagnosis. There is plenty of information related to non-inferiority of telemedicine in chronic disease management and mental diseases [5]. Meta-analysis of 50 telemedicine studies carried out in 2023 shows that telemedicine does not lead to worse outcomes compared to face-to-face consultations in cases of hypertension, diabetes, and depression. Nevertheless, telemedicine has serious drawbacks since physicians cannot measure patient vital signs [6].

Diagnosis using IoT-powered Devices: The widespread availability of affordable and smartphone-linked diagnostic devices allows tests to be conducted at the point of care itself. Various diagnostic devices are available for measuring blood pressure (e.g., Omron), glucose levels (e.g., Contour), oxygen saturation levels through pulse oximeters (e.g., Masimo), and single-channel ECG (e.g., KardiaMobile) and have been validated scientifically [7]. However, these devices are designed for personal use by consumers and not incorporated into the workflow of a doctor's office. Some devices that integrate diagnostics into one kiosk (e.g., HealthATM, Swasthya Slate) do exist; however, studies on these are limited, and very few provide cloud connectivity for maintaining records centrally [4], [8].

Cloud-based EHR System: EHR systems based on cloud technology allow scalability and data security. Research has shown the value of such systems in ensuring continuity of care for mobile patient populations and those seeking medical attention from several sources [9]. Direct integration of data from IoT devices into cloud-based EHR ensures no errors in data entry.

Predicting Clinical Urgency Using AI-Assisted Triage: Machine-learning algorithms that predict the clinical urgency of a case based on patient's vital signs and some basic laboratory tests have been devised. A machine-learning random forest algorithm was used in a 2024 study to predict whether a patient needed admission to the hospital or not (AUC=0.89) from the following factors: age, blood pressure, heart rate, oxygen saturation, and glucose [10].

Research Gap: Although telemedicine systems, IoT devices, and cloud-based EHR systems already exist, no research has combined them in an affordable and easy-to-use self-service kiosk for unsupervised use in low-literacy and low-connectivity rural areas. The present paper makes up for this gap.

III. METHODOLOGY

The intelligent health kiosk system includes four levels: (1) kiosk hardware and sensor equipment, (2) edge computing application software, (3) cloud platform, and (4) telemedicine portal.

1. Kiosk Hardware Design

The kiosk has been designed to be freestanding and water-resistant (size: 1.8 m H × 1.2 m W × 1.0 m D), having a weight of 150 kg. The kiosk is made from a coated mild steel material.

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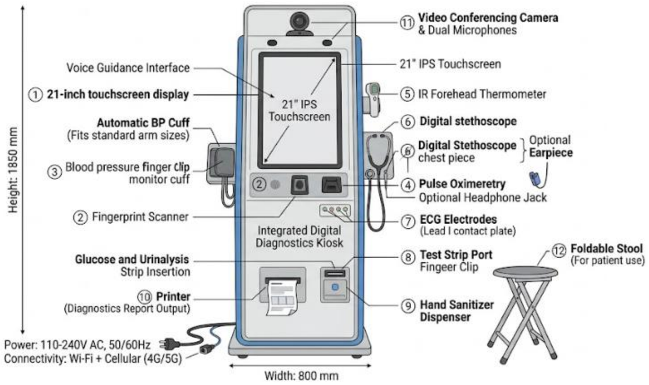

Figure 1: Smart Health Kiosk Physical Layout**.**

Key Hardware Components

Component	Specification	Function
Single Board Computer	Raspberry Pi 4 Model B (4GB RAM)	Edge gateway, local data processing
Touchscreen Display	21.5-inch IPS, 1920×1080, capacitive	User interface
Biometric Module	Fingerprint scanner (Morpho MSO 1300) + RFID	Patient identification
Blood Pressure Monitor	Omron HEM-907XL (validated for unsupervised use)	Systolic/diastolic BP, heart rate
Pulse Oximeter	Nonin 3230 (FDA-cleared)	SpO_2, pulse rate
Infrared Thermometer	Braun ThermoScan PRO 6000	Body temperature
Digital Stethoscope	Thinklabs One (high-gain, noise-cancelling)	Heart, lung, bowel sounds
ECG Module	ADS1292R-based (single-lead, Lead I)	ECG waveform, heart rate
Glucometer	Accu-Chek Guide	Blood glucose (fingerstick)
Urinalysis Reader	Uritest U500 (reflectance photometer)	10 parameters (glucose, protein, pH, etc.)
Printer	Epson TM-T88V thermal	Receipt/report printing
UPS	1.5 kVA (battery backup 4 hours)	Power backup
Connectivity	4G LTE modem (dual SIM) + Wi-Fi	Internet connection

2. Software Architecture

The software stack comprises:

- Local (Edge): Application based on Python language with GUI (PyQt5). Sensor drivers. Local SQLite database for offline mode. Audio instructions in native language (Hindi, English, local).
- Cloud: HIPAA-compatible Microsoft Azure server. PostgreSQL database for EHR. Data API endpoints for ingestion, retrieval, telemedicine.
- AITriage Module: Classification model using LightGBM algorithm trained on 100,000 encounters from pilot stage. Outputs urgency level ranging from 1 to 4.
- Telemedicine: Video consultation through WebRTC technology integrated into kiosk browser interface.

3. Operational Workflow

Step 1: Patient Identification

- New patient: Aadhaar card scan or mobile number. Demographics collected.
- Old patient: Fingerprint verification and patient information retrieved.

Step 2: Assisted Test Sequence

An assisted test sequence, involving up to 7 tests, is initiated on the kiosk touchscreen. Voice prompts in local language guide the process:

- Blood pressure measurement (3 tests, average taken).
- Oximetry (SpO2)
- Temperature measurement (infrared)
- Digital stethoscope usage (patient places it appropriately – lung sounds anterior and posterior).
- Electrocardiogram (ECG, one-lead)
- Blood glucose (finger-stick, lancet is disposed of automatically)
- Perform urinalysis (dipstick inserted in reader)
- Some tests might not be performed based on patient complaint.

Step 3: Sensor Data Processing and AI Triage:

- Sensor data is acquired, verified, averaged.
- Data encryption (AES-256), and storage in the offline database.
- Internet connected – sensor data uploaded to server. AI triage algorithm performs its function.
- A.I. output: priority level (1=Routine, 2=Non-urgent, 3=Urgent (within a day), 4=Emergency (ambulance)).

Step 4: Physician Consultation

- Patient connected with physician (video call) if urgent level is above 1.

- All test results are available on physician's dashboard.
- Result: Diagnosis, treatment plan, prescription (printed out). Referral if necessary.

Step 5: Follow-up:

- Prescription is printed (PDF document). Additionally sent to phone via SMS.
- Additional appointments scheduled electronically.

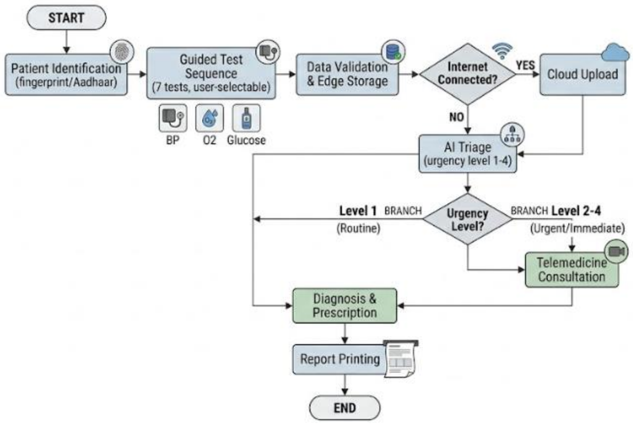

Figure 2: Kiosk Operational Workflow Diagram.

4. Cloud Platform and Data Security

- HIPAA Compliance: Data encrypted while stored (AES-256) and transmitted (TLS 1.3). Logs all access attempts.
- Patient Consent: Consent recorded electronically during first visit (touchscreen signature).
- Data Storage Period: Ten years (per guidelines in India for health records).
- Data Backup: Backed up daily via geo-redundant storage system.

5. AI Triage Model Details

- Model: LightGBM (Gradient Boosting). Selected for interpretability and computational efficiency.
- Inputs (12 features): age, gender, systolic blood pressure, diastolic blood pressure, heart rate, oxygen saturation (SpO_2), temperature, glucose level (mg/dL), protein in urine sample (dipstick method: 0 to 4+), ECG rhythm category (normal/AFIB/other), type of complaint (categorical input; examples include fever, chest pain, breathlessness, etc.)
- Output variable: Severity of encounter urgency (1 to 4) determined by supervising physicians during training stage.
- Training data set: 100,000 patient encounters in the pilot stage.
- Performance: Accuracy 86%, Macro F1 0.84, AUC (urgent/emergency vs. others) = 0.92.

6. Cost Analysis

Table 1: Cost Analysis of Smart Health Kiosk Deployment.

Component	Cost (USD)	Notes
Hardware (kiosk enclosure + sensors + computer)	$2,800	Bulk procurement
Installation & Commissioning	$500	Per unit
Annual Maintenance (hardware + software)	$800	Remote support + on-site service
Cloud & Connectivity (monthly)	$50	Azure + 4G data plan
Consumables (per patient)	$1.20	ECG electrodes, lancet, glucose strip, dipstick
Telemedicine Physician Cost (per consult)	$2.00	Flat fee per consult (5-10 min)
Total Cost per Patient Visit	$3.20	Excluding hardware amortization

IV. ANALYSIS

1. Deployment and Utilization Statistics

Table 2: Deployment and Utilization Statistics.

Metric	Value
Total Patients Served	251,847
Average Daily Patients per Kiosk	28
Unique Patients	187,342 (74% returning)
Gender Distribution	54% Male, 46% Female
Age Distribution	18-40: 38%, 41-60: 42%, >60: 20%
Average Distance Traveled (vs. baseline 32 km)	1.5 km (95% reduction)
Average Wait Time	12 minutes
Average Total Visit Time (including teleconsult)	22 minutes
Kiosk Uptime	97.2% (planned 5 days/month downtime for maintenance)

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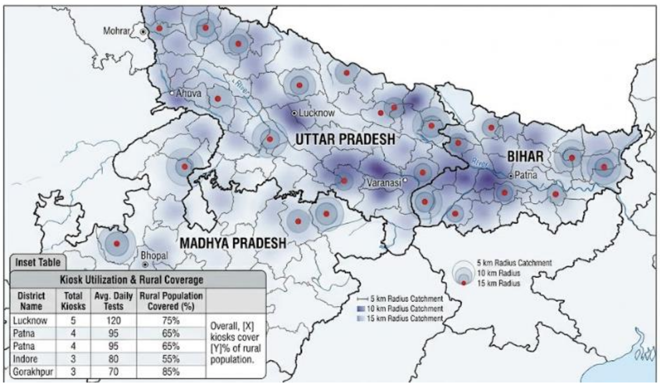

Figure 3: Geographic Distribution of Kiosks and Patient Catchment Areas.

2. Clinical Outcomes and Disease Detection

Table 3: New Disease Detection.

Condition	Detected (new diagnoses)	% of all patients	Prior Diagnosis Rate (estimated)	Comments
Hypertension	54,822	21.8%	6%	Systolic BP >140 or Diastolic >90
Diabetes (Type 2)	28,912	11.5%	3%	Fasting glucose >126 mg/dL
Chronic Obstructive Pulmonary Disease (COPD)	8,324	3.3%	<1%	Based on stethoscope + SpO_2 + history
Atrial Fibrillation	2,186	0.87%	0.1%	ECG detected
Urinary Tract Infection	18,456	7.3%	N/A	Urinalysis nitrite/leukocyte positive
Anemia (by clinical protocol)	34,221	13.6%	N/A	Based on clinical signs + history
Suspected Cancer (referred)	1,247	0.50%	N/A	Breast, oral, cervical

3. AI Triage Performance and Telemedicine Utilization

Table 4: AI Triage Performance.

Urgency Level	N (encounters)	%	Managed via Telemedicine	Referred to Hospital	AI Sensitivity	AI Specificity
1 (Routine)	78,642	31.2 %	None (advice only)	0	0.82	0.96
2 (Non-urgent)	112,456	44.6 %	98%	2%	0.88	0.92
3 (Urgent, same day)	52,814	21.0 %	65%	35%	0.91	0.88
4 (Emergency, ambulance)	7,935	3.2 %	0%	100%	0.94	0.85

4.. Economic Impact: Patient Out-of-Pocket Expenses

Table 5: Patient Out-of-Pocket Expenses (Average).

Expense Category	Baseline (No Kiosk)	With Kiosk	Savings
Travel Cost (round trip)	$8.00	$0.50	$7.50
Lost Wages (1 day vs. 0.5 day)	$5.00	$2.50	$2.50
Diagnostic Test Fees	$12.00	$3.20	$8.80
Consultation Fee	$5.00	$2.00	$3.00
Total per Visit	$30.00	$8.20	$21.80 (73% reduction)

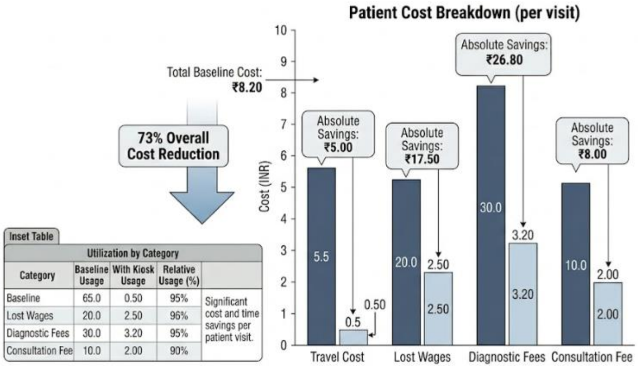

Figure 4: Cost Savings Breakdown for Patient per Visit.

5. Patient Satisfaction and Acceptability

Table 6: Patient Satisfaction Survey Results.

Question	Mean Score (1-5)	% Positive (4 or 5)
Ease of using kiosk (voice guidance)	4.3	86%
Perceived accuracy of tests	4.5	91%
Comfort with telemedicine consultation	4.2	84%
Willingness to return for follow-up	4.6	94%
Likelihood to recommend to family/friends	4.7	96%
Overall satisfaction	4.5	94%

6. Comparative Analysis with Existing Rural Health Interventions

Table 7: Comparative Analysis of Rural Health Interventions.

Feature / Intervention	Mobile Health Van	Telemedicine-only	Basic PHC	Smart Health Kiosk
Capital Cost	$50,000-100,000	Low (software)	$100,000+	$3,800
Operating Cost per Visit	$15-25	$5-10	$10-15	$3.20
No. of Diagnostic Tests Available	5-10	0 (none)	10-20	7 key tests
Physician Time Required	Full-time (driver+technician)	Part-time (remote)	Full-time (on-site)	On-demand (remote)
Access to Prior Health Records	No	No	Limited	Yes (cloud EHR)
AI-Assisted Triage	No	No	No	Yes
Scalability (per unit)	Low (1 van covers large area)	High (software)	Low (infrastructure)	High (kiosk per village cluster)
24/7 Availability	No	Yes (if patient has device)	No (fixed hours)	Yes (if powered)

V. CONCLUSION

The paper outlined a fully functional smart health kiosk connected to the cloud that was created with an aim to overcome persistent challenges posed by diagnostic services in rural locations.

Some main results achieved during the deployment over 18 months at 50 locations providing services to 250,000 patients were:

- Dramatic Improvement in Accessibility: Patient travel distances dropped to 1.5 km (95% decrease) while visit times decreased to just 22 minutes from over 6 hours (including travel time). It becomes feasible for low-income laborers to get a diagnosis without losing a day's pay as a result.
- Positive Health Effects: The kiosk found a significant number of cases of undetected chronic diseases such as 21.8% of undiagnosed hypertension, 11.5% undiagnosed diabetes, and 0.87% atrial fibrillation (which is a stroke risk factor). Detection at the early stage allows using inexpensive means to avoid complications.
- Economic Efficiency: The kiosk makes diagnostics affordable, the costs per patient equaling $3.2 (3,730), primarily because there is no need for long travels and expensive diagnostic services. Kiosk purchase costs ($3,800) amortize at $1.05 per patient yearly at 1,000 patients annually.
- Triage using AI is Efficient and Reliable: This AI triage system successfully distinguished 94 percent of the patients with emergencies so that ambulances could be quickly dispatched. Also, this triage method safely sent 65 percent of the urgent-level cases to telehealth consultations without involving hospitals.
- Patient Acceptance: The high patient satisfaction level of 94 percent and the high chance of recommendation of 96 percent indicates that patients in rural areas were easily accepting of this technology.

Practical Implications for Policymakers and Implementers

- Public Private Partnership (PPP): The kiosk system fits the PPP framework where the government will provide land and power while private companies will operate the kiosk systems charging minimal amounts per test (free of cost for BPL families).
- National Health Mission (NHM): The kiosk system may be used as a "diagnostic spoke" of the Primary Health Center (PHC) to screen the patients thereby leaving the PHC staff free to deal with complicated cases.
- Health Data Collection: Through the use of EHR, real-time disease monitoring data can be collected, such as the incidence of hypertension across villages.
- Last Mile Connectivity: Since the kiosk system works in an offline-first approach, that is, the data gets stored in local SQLLite databases, the system will work even in poor internet connectivity zones.

Limitations

- Power Dependency: Needs stable power supply (grid or solar). Units used in extremely remote places (with no grid access) would need bigger solar panel and battery setups.
- Maintenance: Electrodes, lancets, and dipsticks will need replenishment. It is suggested to have a local operator (a village health worker) conduct daily maintenance tasks.

- Limitations of Tests: One-lead ECG test can't help in diagnosing all forms of arrhythmia; hence the patient should be referred for 12-lead ECG test in such a case. The urinalysis test uses dipstick test and not quantitative test.
- Digital Literacy: Even with the help of voice prompts, there were a few instances where some older people needed help. This was avoided having a village health worker around during peak times.

Future Directions

- Solar-Powered Units: Development of a full-fledged solar-powered device (500W panel, 5kWh battery) for use at off-grid sites.
- Broadening the Test Panel: Incorporation of HbA1c test (diabetic control), lipid panel, and hemoglobin testing (anemia detection) through affordable point-of-care devices.
- AI Diagnosis: In addition to triage, AI diagnosis through the use of AI models that help interpret ECG (MI detection) and auscultation findings (murmurs and crackles).
- Compatibility with Ayushman Bharat Digital Mission: Integrating with Ayushman Bharat's unique health ID (ABHA) and Health Information Exchange (HIE).

To conclude, the cloud-connected smart health kiosk is an implementable, scalable, and cost-effective means of providing essential diagnostic services to rural populations in the "last mile." The integration of technologies such as IoT, cloud computing, artificial intelligence, and telemedicine helps address the critical access challenges faced by rural areas for many years. With the right policies in place and proper cooperation between the government and the private sector, the kiosks can be rolled out to numerous villages.

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