International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 10
***Article Received:** 25 July 2023 **Revised:** 12 September 2023 **Accepted:** 30 September 2023*

Exploring Portable Multi-Modal Telehealth Solutions: A Development Approach

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Abstract: In the realm of medical healthcare, standard modules are typically utilized in the design of both healthcare units and diagnostic devices. Despite the similarity in operational modes across sensory devices, variations exist in data retrieval methods. Consequently, researchers often develop distinct devices tailored for specific diagnostics. Given that sensors commonly operate in either digital or analog modes, the development of a versatile device capable of supporting multiple sensor types is both feasible and desirable, particularly in resource-constrained settings. The key challenge in such device development lies in software implementation and sensor calibration, ensuring accurate calculation of sensor values. Body statistics encompass various parameters, some directly detected by sensors in real-time, while others require calculation based on standardized procedures such as time-based averaging or differential value analysis. To address these challenges, we propose a system designed to facilitate the execution of multiple functional algorithms on a single device, triggered as needed and based on demand. This research study elucidates the methodology for handling diverse processes on demand and delineates multiple operational procedures pertinent to healthcare devices..

Keywords: *Tele-healthcare, IoHT, IoMT, IoT*

I. INTRODUCTION

In today's world, hospital visits can be pricey, especially for those living in remote areas where travel costs add up. With the ongoing Covid-19 pandemic, people are understandably wary of in-person appointments due to the risk of infection. Instead, many are opting for prescription drugs. Fortunately, advancements in healthcare technology like video conferencing offer a solution by allowing patients to consult with their doctors remotely. This not only saves time and money for both patients and healthcare providers but also streamlines operations in hospitals and clinics. These tools also enable better patient monitoring and recovery management. In summary, telemedicine presents a win-win scenario for all involved

The power of networks enables individuals to enhance healthcare accessibility, reaching more people in need. Telemedicine emerges as a potent tool, facilitating preventive healthcare and contributing to long-term well-being, particularly beneficial for those constrained by business obligations or residing in remote areas. Telemedicine holds promise in optimizing healthcare delivery, enhancing effectiveness, and improving efficiency. While research in this domain is still evolving, promising advancements are evident. For instance, remote monitoring of vital signs among cardiac patients has demonstrated reductions in mortality risk and hospital admissions, ultimately enhancing their quality of life. The availability of telemedicine services assures patients of receiving optimal care, addressing various treatment and rehabilitation needs. Notably, telemedicine offers a viable solution for mental healthcare, eliminating barriers that traditionally hinder access to such critical medical services.. [1], [2], [3].

Providing healthcare facilities in remote or rural areas poses significant challenges, particularly in setting up automated diagnostic machines. Establishing critical care units for home-bound patients or basic care units for periodic patients at multiple locations entails considerable costs and logistical challenges. A viable solution to overcome these hurdles is the deployment of portable tele-healthcare units for initial diagnosis. However, monitoring various body parameters and statistics presents another challenge due to their diverse nature and the need for different measurement methods. Managing multiple

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instruments for individual parameters requires numerous wireless connections, power sources, and standard operating procedures, leading to reduced feasibility and acceptability. While advancements in manufacturing offer potential solutions, assessing the acceptance and usability of such devices on a large scale is essential. This research aims to propose and develop a portable yet multi-functional medical device capable of diagnosing various body parameters such as temperature, heart rate, ECG, and oxygen levels sequentially. Additionally, the device facilitates sharing of data with consulting hospitals or doctors for further treatment suggestions using IoT technologies. Furthermore, the portable device aims to provide different categories of data for analysis by various stakeholders, including patients, doctors, healthcare organizations, and device manufacturers..

II. BACKGROUND

2.1 Tele-healthcare system

Telemedicine refers to the utilization of virtual platforms and technology to disseminate health information, preventive measures, care, and comprehensive treatment. It stands as one of the fastest-growing sectors within the medical field, encompassing a broad spectrum of services. Narrowly defined, telemedicine entails the remote management of medical care through electronic interfaces. It diverges from traditional phone-based delivery methods. In practice, the majority of telemedicine services occur between healthcare professionals, often catering to rural, international, or specialized patient populations. Conversely, patient-to-physician telehealthcare is a burgeoning industry, characterized by direct-to-consumer services where patients engage with doctors remotely..

There are three main types of healthcare: synchronous, asynchronous, and remote care. Synchronous healthcare involves the real-time transmission of medical information, enabling live conversations between patients and doctors for immediate treatment. An example of synchronous care is the Facilitated Virtual Visit (FVV), where a patient in one location with diagnostic equipment communicates with a doctor in a different location via remote control (e.g., medical assistants, nurses), who collect objective measurements using devices like digital stethoscopes, thermometers, and pulse oximeters and transmit the data to the service providers. Asynchronous telemedicine, on the other hand, utilizes "store-and-forward" technology. Here, patients or doctors gather medical information, images, and reports and send them to specialist doctors for diagnosis and treatment at a later time. Remote patient care involves continuous monitoring of a patient's clinical condition, either through direct patient care or by reviewing tests and remote images. Emerging technologies, such as mobile apps on devices, are expanding the possibilities for telehealth.. [4][5][6].

For effective telemedicine, participants must have reliable Internet access, typically requiring a strong and stable broadband connection. This often means having access to at least fourth-generation (4G) or long-term evolution (LTE) standard mobile communications technology to ensure smooth video transmission and overcome bandwidth limitations. As broadband infrastructure continues to develop, telemedicine usage is becoming more widespread.

Doctors typically initiate telehealth services by evaluating the specific needs that can be addressed through telemedicine, such as reducing travel time, cutting costs, or accommodating busy schedules. Partnerships with technology firms can facilitate seamless integration. Telemedicine services can be delivered in four main ways: through live video consultations (synchronous), store-and-forward methods (asynchronous), remote patient monitoring, and via mobile healthcare devices..

A) Store and forward

Store-and-forward telemedicine entails gathering medical data, such as medical images or biosignals, and transmitting this information to a doctor or medical specialist for assessment at a later time, without the need for both parties to be present simultaneously. Specialties like dermatology, radiology, and pathology are well-suited for asynchronous telemedicine. It is advisable to have a properly organized medical record, preferably in electronic format, as part of this data transfer process. In the 'store-and-forward' approach, clinicians rely on medical history reports and audio/video information in place of a physical examination..

B) Remote monitoring

Remote monitoring, also referred to as self-monitoring or testing, allows medical professionals to oversee a patient's health remotely using various technological devices. This approach is commonly employed for managing chronic diseases or specific conditions like heart disease, diabetes mellitus, or asthma. Such services have been shown to yield similar health outcomes to traditional in-person patient encounters, often resulting in greater patient satisfaction and potential cost-effectiveness. Examples include home-based nocturnal dialysis and enhanced joint management.

C) Real-time interactive

Electronic consultations are facilitated through interactive telemedicine services, enabling real-time interactions between patients and healthcare providers. Video conferencing has been utilized across a broad spectrum of clinical disciplines and settings for purposes

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such as management, diagnosis, counseling, and patient monitoring.

2.2 Sensory Technology in Tele-healthcare

Typically, sensory-based model works in three major stages Data extraction, Data processing, and Data presentation sequentially. We defined and presented (See figure 1.0) these three stages as following;

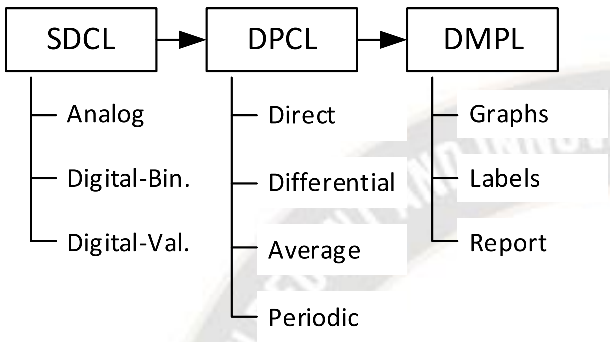

Figure 1.0: Sensory statistics monitoring

SDCL (Signal to Data Conversion Layer): Sensors are primarily categorize in A. analog presenting variable value in pre-defined minimum and maximum ranges, B. digital binary value with true or false state in series, and C. digital unit based real-world values.

DPCL (Data Processing and calculation Layer): depending upon the sensor value extracted and the working principle of medical procedure for parameter calculation or processing, methodologies are categorize in following category. A) Direct sensor extracted value as a result, B) Differential value between two or more timestamped values of pre-condition and post-conditions scenarios, C) averaging value from defined time period or defined number of samples, and D) periodic sensor value reading to monitor the progressive variations in parameters.

DMPL (Data Management and Presentation Layer): presenting sensory data has globally accepted standards and methods where single instant and current values are typically present or display on labels with right visibility and readability. The series of value with relative changes and with respect to time are present in graphical patterns and finally multiple value with multiple sub-fields are present in row or column pattern known as reports.

As a part of the research and study, we studied different medical sensors and its working principle along with time sensitivity and resultant type. Table 1.0 presented the comparison between selected sensors based on defined parameters. It also stated that typically medical parameters are either acceptable in interval of pre-defined time on demand or need to extract on real-time basis in critical conditions. In delayed mode, medical device could be detachable to body and connect on demand, and in real-time mode medical devices needs to connect all the time does not matter how long it took to recover. For example, patient in ICU monitored for real-time throughout the treatment time.

Parameters	Interval	Interval Level	Result type
Temperature / Humidity	Delayed	Mid	Direct
Spo2 / Oxygen	Delayed	Low	[Avg.:Samp.] / Min
Blood Pressure	Delayed	High	Differential
Heart Rate (BPM)	Real-time	Instant	[Avg.:Samp.] / Min
ECG / EEG / EMG	Real-time	Instant	Variable Data Patterns

Table 1.0: Executional comparing of medical sensors

Different parameters are tested using supportable sensors and processing unit, to understand the acceptable frequency or interval between two readings. We also tested the need of singular direct reading or batch of reading from sensor to generate the final result. Considering the hardware design and the primary processing unit or microcontroller in such a hardware are typically single threaded program and running in an infinite loop until exiting the programs. This makes it difficult to control execution flow as it depends upon the processors clock speed and control through defined or desired delay in execution.

As medical parameter calculations has a different methods of direct, averaging, or the sampling methodologies it becomes difficult to run multiple functionality as the hardware firmware either works in continues delayed flow or continuous counter controlled flow. For example in direct approach, temperature sensor gives is instant resultant value. Heart rate sensor gives pulse trigger as a input which needs to calculated as number of pulse per minute so it is based on averaging. Blood pressure sensor gives resistive pressure from muscles after applying the external pressure hence real blood pressure value calculated as differential changes in pressure values. It state that sensor alone cannot give final resultant value rather it may need calculation and processing approach on sensor input. We proposed a multiple functionality with single execution at a time approach. This will enable single hardware to perform multiple operations and serves multiple functionality on demand at different time. With this approach system, design could be singular and make it more generic to operate, transport, and maintain easily with minimum cost.

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III. PROPOSED SOLUTIONS

The proposed solution involves designing and developing a portable, multi-functional system for diagnosing medical parameters and sharing statistics among remote homecare patients. This comprehensive system comprises a sensory unit, a display unit, a processing unit, and both USB wired and Bluetooth wireless communication modules. To ensure portability, the system is designed to operate on low voltage, enabling it to be powered by a DC battery power supply. An overview of the system is illustrated as blocks in Figure 2.0..

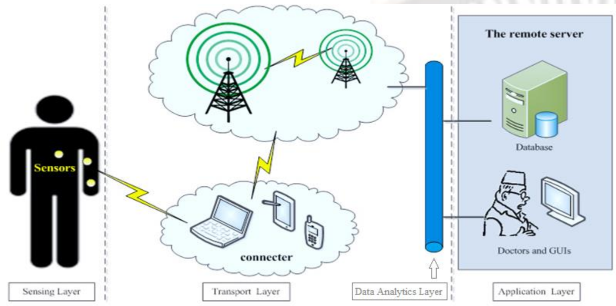

Figure 2.0: System architecture

Following are primary sensory component are used in system. *(Any of the module used is not medical grade and not a medical device and is not intended to be used as such or as an accessory to such nor diagnose or treat any conditions. These are designed for proof of concept testing purpose).*

MAX30102: This sensor is highly versatile, capable of measuring body temperature in addition to monitoring heart rate and blood oxygen levels. The digital pulse oximeter and heart rate sensor is an electronic device that gauges a person's heart rate by detecting the difference between oxygen-rich and oxygen-poor blood. Moreover, this device can also assess the concentration of oxygen in the blood. Manufactured by Analog Devices, the sensor includes two LEDs (one infrared and one red), a photodetector, optics, and a low-noise signal processing unit to accurately detect pulse oximetry (SpO2) and heart rate (HR) signals

AD8232 ECG Sensor: This sensor is a cost-effective board used to measure the electrical activity of the heart. This electrical activity can be charted as an ECG or Electrocardiogram and output as an analog reading. ECGs can be extremely noisy, the AD8232 Single Lead Heart Rate Monitor acts as an op-amp to help obtain a clear signal from the PR and QT Intervals easily.

DS18B20 Temperature Sensor: This sensor follows single wire protocol and it can be used to measure temperature in the range of -67oF to +257oF or -55oC to +125oC with +-5% accuracy. The range of received data from the 1-wire can range from 9-bit to 12-bit. Because, this sensor follows the single wire protocol, and the controlling of this can be done through an only pin of Microcontroller.

HX710B Blood Pressure Sensor: Blood pressure refers to the force exerted by blood against the walls of arteries as it is pumped throughout the body by the heart. With each heartbeat, the heart contracts, pushing blood through the arteries, thereby creating pressure. Blood pressure is typically measured using two numbers: the systolic pressure, which reflects the pressure during heartbeats, and the diastolic pressure, which indicates the pressure when the heart is at rest between beats..The sensor module comprises a high linearity pressure sensor and an ultra-low power, 24-bit analog-to-digital converter (ADC) with internally calibrated coefficients. This module delivers precise digital values for both pressure and temperature, offering various operation modes to optimize conversion speed and current consumption. It utilizes a high-precision AD sampling chip and incorporates a 0-40KPa air pressure sensor, with the capability to connect to a 2.5mm hose for air pressure detection **Primary objective of the proposed system**

A. The proposed system will consist of a multi-layered architecture with various functionalities tailored to different types of users. Figure 1.0 depicts the different layers within the system, each undergoing its own research and development phase. It is imperative that the system meets medical-grade standards to ensure readiness for deployment and ease of use for various user groups. The system is designed with four primary user categories in mind: 1) Patients, 2) Doctors or hospitals, 3) Device manufacturers, and 4) Medical associations. The primary objective of the proposed system is to

B. Design and development of the remote and real-time patient monitoring and diagnosis support system.

C. Sensory-based body area network connected to cloud servers to get the real-time patient information with timestamping.

D. Deploying multiple nodes in real field to get the dataset for further analysis and future action planning.

E. Concluding the need, feasibility and the acceptance of such a system by multiple survey.

IV. IMPLEMENTATION

The proposed model, as depicted in Figure 3.0, showcases a compact, portable design with wire-connected sensor modules. The central processing unit comprises a display unit, USB wired and Bluetooth wireless communication units, control unit, and sensor unit. The system operates in

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four main modes: A) Temperature reading, B) Heartbeat and Oxygen reading, C) Blood Pressure reading, and D) ECG reading. Users can switch between and work in any selected mode at any given time, transitioning to the next mode as needed. There is no predetermined sequence for mode operation; users can exit and start any mode at their discretion .An LCD display indicates the current working mode and the sensor input reading of the selected mode. Users can navigate between different modes using a left-side switch, while a right-side switch allows them to enter or exit the selected mode. Upon entering a mode, the system activates and begins reading from the specific selected sensor. If the sensor is improperly connected to the body, the system will display abnormal readings or an error message. The central unit can be connected to a computer system via USB cable, allowing users to view readings on computer software (refer to Figure 5.0), or paired with an Android mobile phone via Bluetooth for monitoring readings on a mobile application (refer to Figure 6.0). Additionally, the computer software enables data uploading to a central cloud web service for further analysis and treatment advice from relevant medical professionals. Each hardware unit is assigned a unique serial number identity and connected to the respective service provider, doctor, or hospital server. A web-based application can then access and display patient information, including timestamps, in graphical and reporting formats (refer to Figure 7.0 (A) & (B)). This enables doctors to monitor statistics and provide further treatment or medication recommendations. (The research scope primarily focuses on hardware design and development, hence the limited functionality presented in the software model serves as proof of concept.)

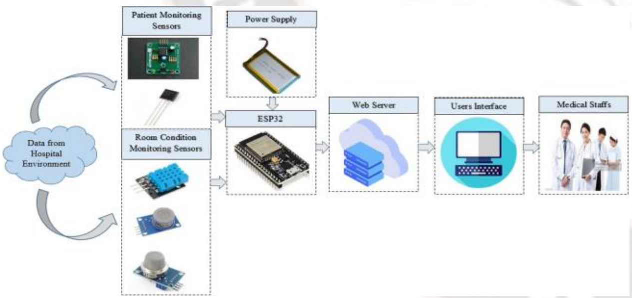

Figure 3.0: Portable hardware

As depicted in Figure 4.0, the patient utilizes various sensors connected to the body. These sensors are meticulously designed and selected to ensure precise connection without any electrical hazards or side effects. Patients have the flexibility to connect all sensors simultaneously or as needed. The temperature, heartbeat, and blood pressure sensors are reusable and easy to use, requiring no additional supplements. However, the ECG sensor requires connection to the body through single-use gel-based electrodes, which are low-cost and available for bulk purchase. The cable sizes for each sensor are designed to provide a feasible connection length, allowing for comfortable seating or sleeping postures. Attention to product design and engineering aspects enhances the acceptability of the product in real-world environments. We have successfully tested the functionality of the system with different modes, both randomly and on-demand.

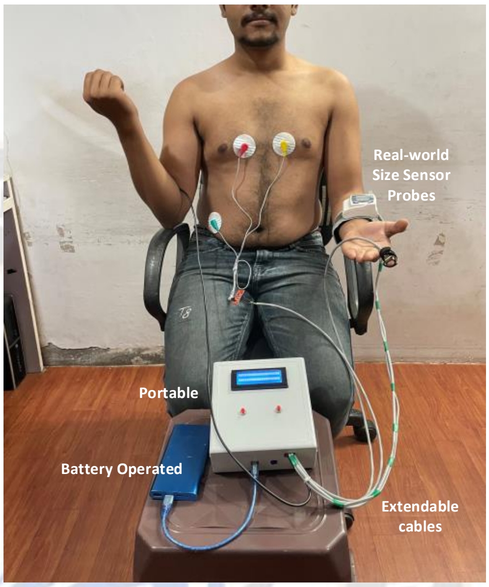

Figure 4.0: Patient live connected and using the proposed system

The computer software (refer to Figure 5.0) retrieves data from the hardware via serial communication using a USB cable and presents the incoming data in graphical format, including labels and graphs. Parameters such as temperature, heartbeat, and blood pressure display instant and latest readings in label format, focusing solely on the current reading. For ECG data, which follows standard flow and patterns, the software presents the incoming readings in a graphical series format, clearly depicting the ECG signal pattern. Additionally, the software enables patients or users to upload data to a central cloud server for further analysis. Users can also select the communication port if connected to different USB ports on the computer. In the future, this port selection functionality could potentially be replaced with automatic hardware detection mode.

The Android mobile application (refer to Figure 6.0) provides a quick overview of body parameter statistics from the hardware in graphical format. This application is specifically tailored for temperature, heartbeat, and blood pressure sensors via a Bluetooth serial link. However, if connected through GPRS or Wi-Fi internet link, the application can be enhanced to display and monitor real-time patient statistics from remote locations, contingent upon internet connectivity availability.Implementing a real-time remote monitoring system poses its own set of challenges and issues, particularly concerning live

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connectivity and data reliability. Various researchers are currently working on addressing these challenges to develop a real-time live patient monitoring system over the internet.

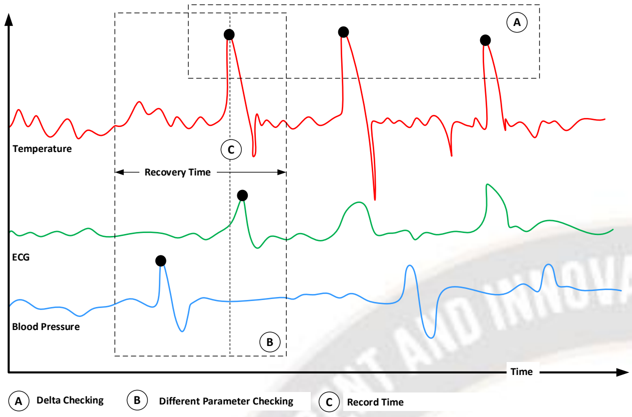

Figure 5.0: Computer software for real-time data monitoring

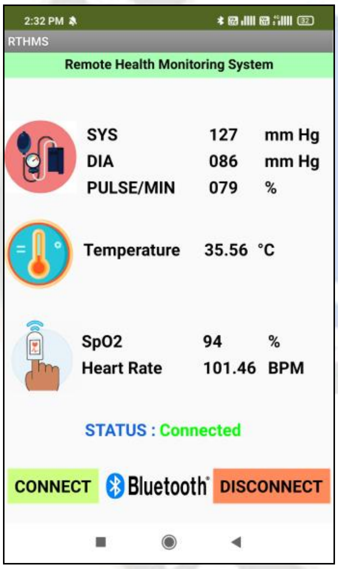

Figure 6.0: Android mobile app for real-time data monitoring

The web application is centrally designed, developed, and deployed for all connected users. Upon accessing the application, users are first presented with a list of all available patients (refer to Figure 7.0 (A)). Valid and authenticated users, such as doctors or hospital administrators, can view this populated list and select a patient to access their uploaded body statistics along with the timestamp of the session. Once a patient is selected, the web application displays the details of the parameters for the chosen patient (refer to Figure 7.0 (B)). The entire hardware infrastructure, computer software, mobile application, and web application can be further extended to be monitored and analyzed by various authorities, including doctors, government agencies, device manufacturing authorities, and others.

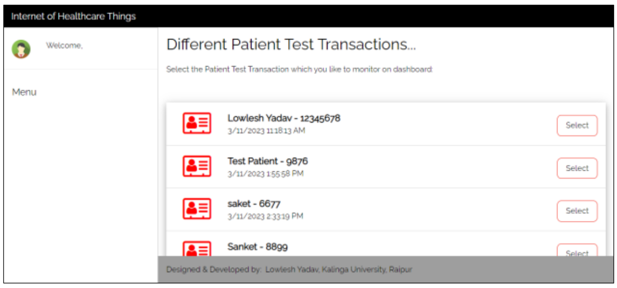

Figure 7.0 (A): Web based application displaying uploaded patient list

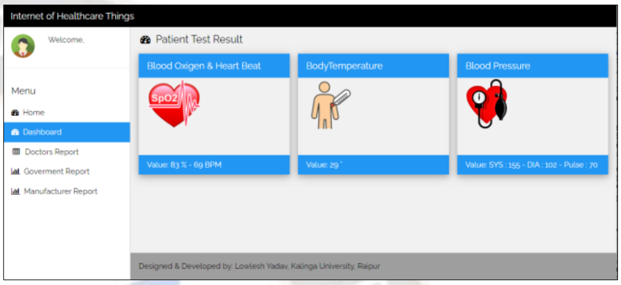

Figure 7.0 (B): Web based application displaying selected patient uploaded statistics with timestamp.

V. CONCLUSION

The scope of the proposed system involves implementing a real-time monitoring system for remote patients in rural areas, particularly focusing on elderly and disabled patients, utilizing wireless technology. With the emergence of IoT technology, the utilization of the latest IoT advancements may enhance the applicability and effectiveness of the proposed remote monitoring system. IoT-based health monitoring offers several benefits, including increased independence and mobility for elderly, sick, and physically or mentally disabled patients. Additionally, it reduces stress for family members and doctors by providing immediate alerts and enabling prompt reactions to emerging issues. We have successfully tested and implemented the proposed system, conducting trials with over 50 volunteers to assess hardware feasibility and acceptability. Our findings indicate that the system performed as expected and delivered accurate results.

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