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# Design and Implementation of a Polymer-Integrated IoT-Based Smart Intravenous Fluid Monitoring System for Patient Safety

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***Abstract***

*The intelligent healthcare systems rely more and more on the advanced materials and Internet of Things (IoT) technologies to improve patient safety, patient-centeredness, timeliness of care, clinical efficiency. This paper presents a polymer-enhanced IoT enabled automatic IV Fluid Level monitoring and notification system. The novel system is based on the use of polymer-encapsulated load-cell sensors and polymer-packaged electronic modules, which allow biocompatibility, long-term stability and easy sterilisation in medical environments. Its weight-based sensing approach continuously monitors the liquid level of remaining IV fluid in bottles, and provides timely alerts wirelessly to healthcare personnel. The proposed system has been verified by experiments with great reliability and accuracy in liquid-level estimation as well as good sense-and-notify ability to avoid potential hazards including backflow, air embolism and operator errors. The integration of polymer with IoT-enable sensing illustrates the potential value of functional polymers in new generations of smart medical devices. Additionally, the system allows real-time logging of data and remote access via a cloud interface, ensuring that it can be easily integrated into hospital information systems. Due to the low power aspects and a scalable architecture, it can be rolled out in multiple wards with only minor maintenance work. The proposed system minimizes the requirement of manual supervision, and thereby reduces staff workload as well as improves patient comfort. In summary, this is a practical approach for reliable, cheap and smart infusion monitoring in contemporary healthcare environments.*

**Keywords:** Polymers, IoT, smart healthcare, intravenous fluid monitoring, load cell sensor, patient safety

## INTRODUCTION

In modern health care system, intravenous (IV) fluid therapy is one of the most commonly practiced and vital clinical procedure. It is vital for giving patients fluids, electrolytes, glucose, saline solutions, blood and other things through different body parts in a variety of medical environments including accident and emergency departments, intensive care units (ITU), recovery areas after surgery, and treatment centres. Despite wide availability and apparent straightforwardness, IV infusion requires constant and accurate control of the volume of fluid administered to ensure patient safety as well as therapeutic efficiency. A lack of timely monitoring of IV fluid levels may lead to serious complications including air embolism, venous backflow (reversed flow), clotting, infections, and in extreme cases death.

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In usual case, IV fluid level is required to be manually monitored by nurses, ward personnel or the caretakers who occasionally check an extent of residual of the solution in bottles/bags. Nevertheless, long term, real time manual monitoring is infeasible in high workload clinical settings such as hospitals with a small nurse ratio to patient number. Human factors (e.g., tiredness, multitasking and negligence) might cause the delay of bottle change, or an overlook to disconnect a drained IV line. Such challenges highlight the urgent need for automated, reliable and real-time monitoring tools that can offer support to healthcare providers and reduce their reliance on manual intervention.

The rise of the IoT in times of digital healthcare has also led to the development of IoT-enabled medical monitoring systems, which is well received by the community. The IoT technologies provide the real-time data acquisition, processing and wireless communication in monitoring patient-related parameters without human intervention. When it comes to intravenous unit (IVU) monitoring IoT platforms can monitor fluid levels and trigger alerts as soon as they are crossed. Such systems not only would make a great difference to patient safety but also streamline workflow and decrease cognitive burden on the care providers during rounds. Hand in hand with the advent of IoT and embedded electronics, polymer science has been a driving force behind the modern medical devices. Polymers are widely used in the healthcare sector due to their low density, flexibility, mechanical strength, chemical inertness and biocompatibility. Medical polymers such as polyethylene, polypropylene, polycarbonate, polyurethane and polyvinyl chloride are used in a range of IV containers, tubing, catheters sensor housings and protective enclosures.

The formability of polymers, ease of sterilization, and cost-effective form factors make them a natural contender for scalable medical applications. In the field of IV medical infusion systems, plastic containers have replaced traditional glass bottles as such break-resistant alternatives are less liable to become contaminated and safer for patients. In addition to the storage of fluid, polymers are also being used to insulate sensors and electronic devices from water, chemicals and physical abuse in a clinical environment. The polymer encapsulation provides not only electrical insulation but also the life extension of the device, which is important for in-situ monitoring application in a hospital.

However, the increasing studies on IoT-based IV monitoring systems have mainly focused on sensing methods and communication protocols by ignoring the importance of material selection/design as well as integration. Not enough attention has been given to how polymer materials have improved system safety, duration of deployment, biocompatibility and sterilizability. In addition, a number of such known systems use complex op-tical or ultrasonic sensors which add to system cost and reduce ruggedness in an actual hospital environment.

Weight-based monitoring with polymer-coated structural design offers a reliable and cost-effective option for IV fluid monitoring. By measuring changes in the weight of a polymer IV bag as it is being delivered, one can non-invasively and accurately determine the volume of residual liquid without directly contacting the liquid. This approach minimizes the risk of contamination and synergize well with polymer-based medical system, which is widely equipped in hospital. The aim of the present study is to fill in these gaps by introducing an automated system for the IoT and polymer integration for high efficacy in monitoring and informing about IV fluid levels. This system employs weight-based measurements polymer-encased electronic modules for acquisition and wireless communication to update healthcare providers in real-time.

Polymer materials customer integration guarantees biocompatibility, mechanical strength, and usage in clinic, the IoT framework provides for off-side monitoring and timely intervention. The novel contributions and features highlighted in this paper are as follows: (i) the system developed for IV fluid monitoring utilizes polymers through a weight-based sensing technique and is introduced in this proposed model (ii) IoT-supported wireless notifications for real-time alerting are integrated in our work, (iii) Leveraging the importance of polymers in increasing safety, stability and product handling. (iv) An experimental validation of prototype system by taking standard polymer IV bottles is provided. Exhibiting how the propaganda of polymer materials and IoT technology, this paper is consistent with the objectives of Polymers and demonstrates that functional polymers play a huge role in smart healthcare devices in the future.

## LITERATURE REVIEW

Different research works have also explored electronic and IoT based intravenous (IV) monitoring systems using ultrasonic, optical, capacitive and weight-based sensing principles. Yet, many of the types of systems presented cannot be used in a real patient due to omitting important aspects e.g. material compatibility, sterilization and robustness over longer times at north clinics. However, the safety and user comfort of such devices improve significantly with Sensor enclosures which use flexible substrate materials. However, literature lacks on the direct integration of polymeric materials with an IoT-enabled IV monitoring systems. This paper is an attempt to connect these isolated islands of research by emphasizing the importance of polymer integration with system design, and validation. The integration of intelligent sensing, IoT concepts, and polymer materials greatly promotes the development of modern healthcare monitoring systems. This section includes an overview of relevant studies related to intravenous (IV) fluids monitoring, IoT-enabled medical devices and the role of polymers in biomedical sensing and device manufacturing.

In the field of Electronic IV Fluid Monitoring Systems, IV fluid spying was dominated by manual “eyeball” inspections done by nurses. This is a simple approach but not accurate and does not meet the demands at high patient loads. Multiple electronic monitoring systems have been developed to overcome this challenge. Early automation techniques were to be developed for optical sensors, infrared drop counters and float-based mechanical switches in efforts to improve monitoring accuracy [1,2]. Despite the added precision of such means, these are increasingly plagued with alignment problems and sensitivity to ambient light or risk of contamination from direct contact with bodily fluids. Following research pursued capacitive and ultrasonic systems to sense liquid levels in IV-bottles [3,4]. Capacitive sensors enabled contact-free measurement, but required complex calibration and were sensitive to changes in the container geometry and dielectric properties. On the other hand, ultrasonic methods become more complex and expensive system-wise despite their precision, which limits the possibility of applying them in a healthcare environment with economic constraints.

Weight-based IV monitoring techniques are more and more appreciated for their simplicity, robustness, independence from the liquid characteristics. Then with the use of load-cell based methods these systems estimate the remaining volume of fluid by measuring changes in container weight during infusion [5,6]. They obviate direct contact with the liquid and hence reduce risk of contamination. Although some researchers have reported high accuracy of force sensors made by applying a strain-gauge load cell bonded to a microcontroller, the majority of designs have limited robustness and long-term performance stability for use in practical clinical environments.

### Integration of IoT-Enabled Smart Healthcare Systems

The Internet of things (IoT) is also envisaged as a disruptive technology in healthcare for continuous monitoring, remote diagnostic and instant data transmission. Multiple patient monitoring systems through IoT had been designed for monitoring physiological parameters such as blood pressure, temperature and oxygen saturation, as well as infusion status [7–9]. Methods such as GSM, Wi-Fi and cloud platforms are commonly used for forwarding the alerts and patient information to clinicians. In the domain of intravenous (IV) therapy, IoT-based monitoring solutions have become increasingly important by providing automatic alert notification if fluid remains close to an extreme limit threshold, which would otherwise lead to negative side effects [10]. In spite of these advances, many systems currently in use are largely focused on communication and data analysis, without addressing considerations such as material compatibility, device safety and requirements for sterilization.

## Significance of Polymers in Biomedical Applications

The polymers are also important for the development of biomedical engineering because of their mechanical, thermal, and chemical versatility. Medical-grade polymers, such as polyethylene (PE), polypropylene (PP), polycarbonate (PC), polyurethane (PU), and polyvinyl chloride (PVC) are widely used for the production of IV bottles, tubing systems, catheters or protective housings [11–13]. Advantages of this class of polymers include light weight, transparency to visible light, flexibility, resistance to chemicals and availability in a variety of forms which sterilize easily.

New research focuses on the use of polymer encapsulation to protect electronic sensors and circuits in medical devices against moisture, biofluids, and mechanical strain [14, 15]. Polymer coatings accomplish much, including electrical insulation and patient safety, while at the same time extending the life of the devices. In addition, the development of functional polymers (e.g., conductive and flexible polymers) has enabled wearable/implantable medical sensors to be developed [16, 17].

## Polymer–IoT Integration in Advanced Medical Devices

The blend of IoT based electronics with polymer materials has opened up new prospective for health care application. Polymer housings and substrates provide mechanical strength to the device and biocompatibility of the components, IoT frameworks enable data-driven clinical decision-making [18]. It has been shown that organically made IoT devices integrated with polymers have increased reliability, portability and expandability compared to their rigid counterparts [19, 20].

More recent publications illustrate the capability of IoT systems to automate IV fluid monitoring. Jindal et al. [21] and Chauhan et al. [22] described smart IV drip monitoring systems which generates real-time alarm through sensors and wireless communication technology to replace manual supervision result and human factor. Though these methods largely resolve automation and communication issues, they are cantered around system structure as well as alert systems, paying limited attention to material selection and long-term device stability. Concurrently, the development of smart biomedical sensing systems is supported by the progress of polymer science. Abdulsada et al. [23] demonstrated the role of polymer-integrated sensing structures to enhance sensitivity and bio immunity durability for biosensing sensor systems. [24] also highlighted the benefits of polymeric biomaterials regarding biocompatibility, their lightweight, and adaptable structure for healthcare devices. Nevertheless, the use of IoT IVU essence monitoring technology has not fully combined with polymer-based material.

Over the years, various polymer compositions have been extensively employed to address optimization problems. Karuppiah et al. [25] have done optimization of the fabrication parameters for naturally - Fiber-reinforced polyester matrix composites with dual fillers, including Taguchi design. Several prominent polymer compositions reported in the recent literature demonstrate significant advancements in performance, adaptability and application-specific efficiency [26–30]

## Research Gap and Driving Force

From the literature review, it can be inferred that despite great strides made in IV monitoring and IoT-based healthcare systems, the importance of polymers still remains minimised. There is a lack of integrated systems supporting weight-based sensing, IoT connectivity, and polymer integration for enhanced safety, strength and clinical relevance. This paper presents an IoT based IV fluid monitoring and alert system with smart polymers. Leveraging the polymeric characteristics along with robust weight-based sensing and wireless communication, the inventive system advances smart infusion monitoring and corresponds to the polymer-associated trend of the present age toward biomedical engineering.

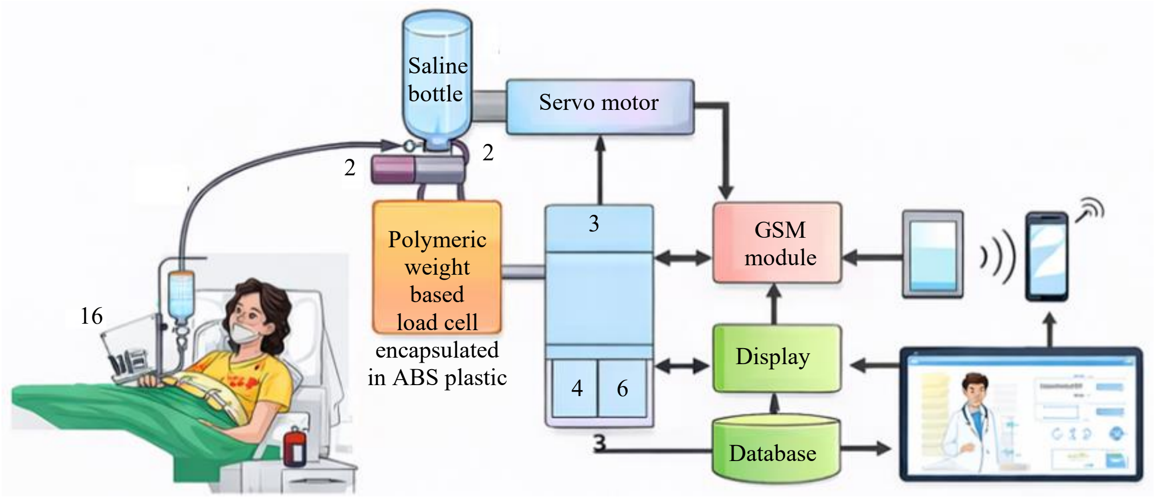

**Figure 1.** System architecture of the IoT-based liquid level monitoring and notification system with polymer encapsulation.

This study is an extension of previous IoT-based IV monitoring research, which uses polymeric materials to improve the security, robustness and clinical application of the system.

## COMPREHENSIVE DESIGN OF THE SYSTEM AND INTEGRATION OF POLYMERS

The general architecture of the IoT-based intravenous (IV) fluid monitoring system with the polymer integration is based on the functional modules and operational sequence described in the system. The device is designed as a modular, scalable and practical solution for clinical implementation and capable to monitor the residual liquid volume inside an IV polymer container continuously, send real-time notifications to medical staff via local or remote interface.

Figure 1 represented the polymer-integrated IoT-based intravenous fluid monitoring system showing the interaction between polymer IV bottle, load-cell sensor, signal conditioning unit, processing module, display, and GSM-based remote notification unit. The need for seamless integration between IoT electronics and polymer-based structural elements. Such a design philosophy improves the patient safety and the device reliability, and follows the current trend of polymer-based biomedical engineering.

At a high level, the architecture of the system follows 4-tier architecture including:
(a). Sensing Tier
(b). Signal conditioning and processing layer
(c). Communication and alerting tier
(d). Visualization and data management layer.

Each tier is actually and functionally reinforced by polymer-centric mechanisms to augment safety, longevity, and arrangement with clinical necessities.

### Sensing Tier

The sensing layer includes a weight sensor (load cell) which is mechanically connected to the IV liquid container. The container IT is made of, for example, polyethylene or polypropylene based on medicinal materials to achieve a good compromise between lightness and resistance to breakage. The load cell is installed in a polymer housing that ensures electric insulation, mechanical durability as well as protection against humidity and aggressive chemicals. As fluid is being infused to the patient, the loss of liquid from the container causes a loss in weight and therefore to strain on one or more load cells, which measures this resistance change and transform into analog voltage output.

### Signal Conditioning and Processing Layer

The low amplitude incoming load cell signal is passed to a signal amplification means for processing. In the designed setup gain and A/D steps are shown as separate blocks or being integrated into a dedicated ADC module (e.g. HX711). These electronic components are contained in a polymer cover: for example, such as Acrylonitrile Butadiene Styrene (ABS) or polycarbonate, which allows thermal insulation, electrical safety and prevents easy sterilization. The digitized signal is processed by a microcontroller and compares the measured weight to predetermined thresholds, for liquid levels stored in memory.

### Signal Communication and Notification Layer

The refined data is transmitted to a communication layer at a point of registration of the liquid level. A GSM-based IoT communication module is also used for transmitting alerts wirelessly to a remote healthcare provider using messages over SMS, voice calls, or internet-based alerts. It also has a communication module that is protected in a polymer case, providing both electromagnetic isolation and robustness. Threshold alert logic (firmware-based) used to yield graduated alerts, including critical alerts as the fluid level approaches a preventing safe minimum.

### Visualization and Data Management Layer

For local monitoring, a display is connected to the processing module for displaying real-time information on reaming fluid level in a bottle and patient ID that is being used. The control and display interfaces are embedded in a polymer front panel to minimize unintended electrical contact and meet medical device safety requirements. The system architecture also supports cloud and database interfacing options which allow historical infusion data to be stored and obtained through web enabled dashboards for clinical trends analysis, audit ability etc.

Figure 2, depict the layered system architecture of the proposed system highlighting polymer integration at the sensing, processing, communication, and visualization levels and polymer components are not merely passive containers but integral enablers of safety, reliability, and clinical usability in the proposed IoT-based IV monitoring system.

## PROPOSED SYSTEM DESIGN AND IMPLEMENTATION

### Hardware Implementation

The proposed polymer-integrated IoT-based intravenous (IV) fluid monitoring system combines precision sensing hardware, embedded signal processing, and wireless communication to ensure reliable and continuous monitoring in clinical environments. Figure 3 illustrates the block diagram of system. The specifications of Arduino microcontroller used are described in Table 1.

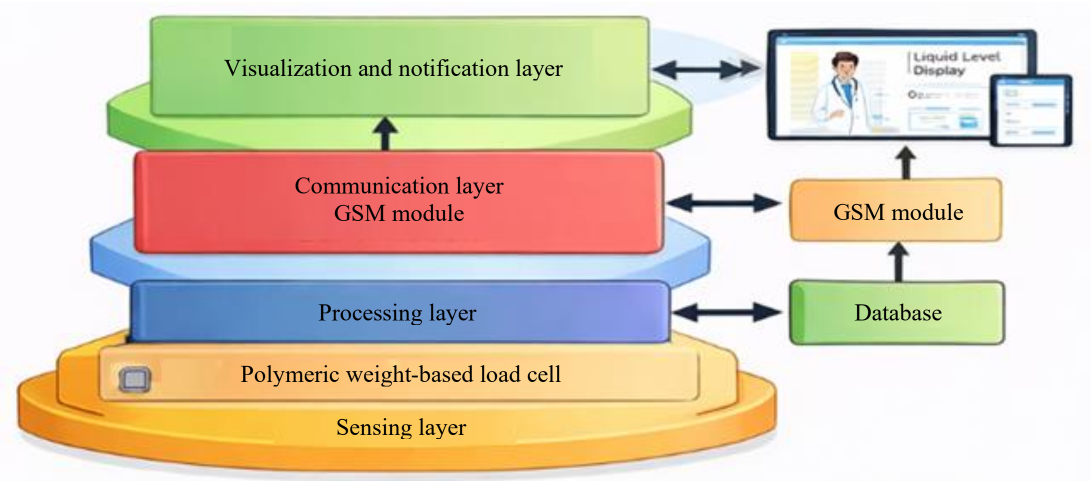

**Figure 2.** Layered system architecture of the IoT-based automatic IV monitoring system.

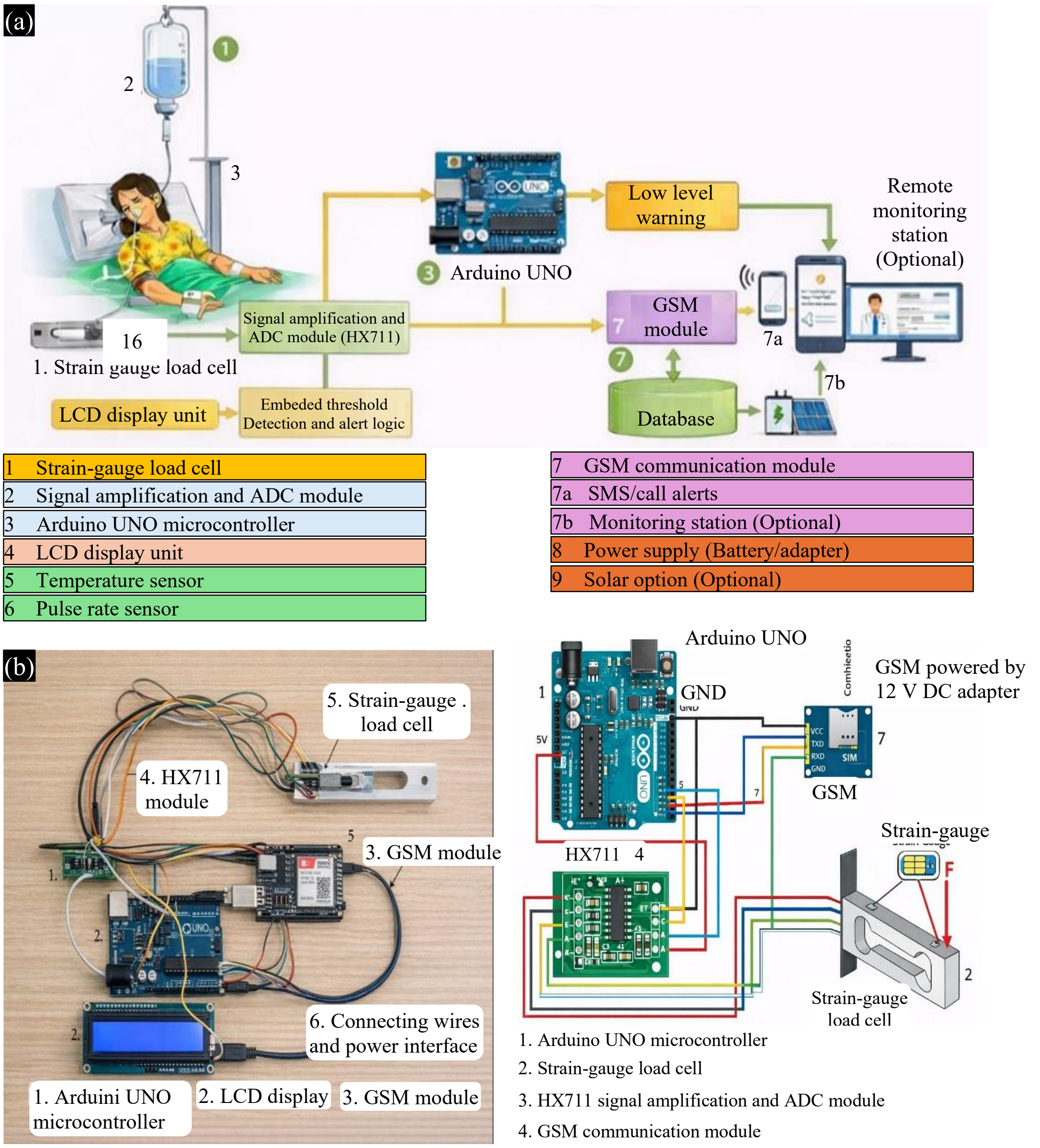

**Figure 3.** (a) Polymeric IOT-based IV fluid monitoring system (b) Detailed hardware description with interconnection of components.

**Table 1.** Specifications of arduino microcontroller.

| S.N. | Parameter | Specification |
|---|---|---|
| 1 | Operating Voltage | 5 V |
| 2 | Input Voltage (Recommended) | 7–12 V |
| 3 | Digital I/O Pins | 14 (6 support PWM output) |
| 4 | Analog Input Pins | 6 |
| 5 | PWM Pins | 6 (Pins 3, 5, 6, 9, 10, 11) |
| 6 | Clock Speed | 16 MHz |
| 7 | Flash Memory | 32 KB (0.5 KB used by bootloader) |
| 8 | SRAM | 2 KB |
| 9 | EEPROM | 1 KB |

The hardware implementation of the proposed polymeric IoT-based IV fluid monitoring system shown in Figure 3 (a) and (b) is centred around the Arduino UNO microcontroller, which functions as the main processing and control unit. The Arduino UNO receives digitized sensor data from the HX711 signal amplification and analog-to-digital conversion module and processes this data using embedded algorithms to compute the real-time IV fluid level. When the parameters are in normal, warning or critical range, indicated with the help of predefined thresholds stored into memory, by means of microcontroller. It is responsible for the control of the LCD display module, serving as an insulation and sterilization-compatible polymer casing to locally visualize the IV fluid state, warning messages or critical alerts in proximity of the patient for medical staff. Simultaneously, the Arduino communicates with the GSM module to send SMS and make calls to off-site healthcare staffs when fluid level drops below critical levels ensuring patient safety and minimizing human monitoring.

The HX711 signal amplifier and Analog to Digital (ADC) module is designed to condition the low-level analog voltage produced by the strain-gauge load cell, which is used as a force-sensing. The load cell is mechanically linked to a polymer IV bag, made of medical grade polymers (e.g., polyethylene or polypropylene). These polymeric materials are advantageous as they can be made of low weight, have chemical resistance, and shatter differently therefore clinically safer. The decrease in the weight of the bottle, in response to the delivery of IV fluid, causes tension on the load cell corresponding in amount to the weight removed that is read as an electrical signal.

The HX711 amplifies the resulting electrical signal and converts it to a high-resolution 24-bit digital output, which can be used to make very accurate measurements with minimal noise interference. Both sensing and electronic components are housed in polymer (typically ABS or polycarbonate) enclosures wrapping around the body of the watch, providing a moisture-proof mechanical protective shield from contact and collision as well as compliance with medical electrical safety standards. The load cell to HX711 module, HX711 module to Arduino and other interfaces (LCD screen and GSM Module) have the cable shared and coded in through insulated wire in regulated power connections. Polymer based structural and encapsulation materials have been combined for long term in-situ monitoring within a real time health care setting to improve system robustness, biocompatibility and in-place deploy ability.

Collectively, these components create an integrated sensing and communications system capable of ongoing monitoring of levels of IV fluid, local real-time data presentation, and remote alerts. Maintenance and expansion are facilitated so that the system can be operated reliably in clinical environments.

### Software Implementation

The software implementation of the proposed polymeric IoT-based IV fluid monitoring system is designed to ensure accurate sensing, reliable decision-making, and timely alert generation with minimal power consumption. The embedded software is developed and executed on the Arduino UNO microcontroller and follows a structured, modular architecture comprising initialization, data acquisition, signal processing, threshold evaluation, and communication routines. The polymeric IoT-based IV Fluid monitoring system is realized through efficient sensing, reliable decision making and intuitive alerting with low power consumption. Its signal processing chain is implemented in an Arduino microcontroller and its programme structure is neatly elaborated under a modular approach including initialization, data acquisition and threshold decision as filtering stage; it adds to that the co-ordination sequences.

The software functions when the device is switched on, initialize all used peripherals load cell interface HX711 ADC LCD display GSM module step-by-step. Calibrations are carried out to obtain a zero-load setting for the strain gauge load cell and to establish scaling of digital sensor readings to predetermined volumes of fluid. This calibration is needed in order to compensate for sensor offsets and mechanical tolerances associated, for example, with polymer IV bags and holing brackets. Software reads digitized weight data from the HX711 module at intervals dictated a priori by the interval the uncalibrated digital values are, for smoothing and noise from patient movements or the environment, filtered and averaged. The processed data is then translated into a measurement of an IV fluid volume using stored calibration constants. The estimated fluid level is afterward translated to pre-defined limits of normal, alert and critical in the software.

A decision module compares the fluid level to these thresholds. Close to the warning level, its software sets off a nice alarm and updates the LCD. When the fluid level is lower than the critical minimum, such systems will go into a high priority alert procedure. It calls up localized images for visual alerts and interface with GSM module to make a call or SMS the health care provider for early clinical intervention.

The software also controls user interface operations to update the LCD for real time fluid volume, system status display and alert output. For reliability and energy efficiency, the program optimizes polling intervals and communication conditionals to facilitate wireless transmissions only when needed. This prevents power waste and “useless” network usages. In summary, the software appliance encompasses sensing, processing, determination of actions and communication seamlessly. Together with polymer-based hardware encapsulation and weight-based sensing, the software delivers a cost-effective, reliable and clinically accurate IV fluid monitoring solution for real-time healthcare. Flowchart and pseudocode of the embedded software are depicted in Figure 4.

## RESULTS AND DISCUSSION

The polymeric IoT-based IV fluid monitoring system concept developed was tested in the form of a working prototype and demonstrated to have a reliable real-time fluid level detection and alerting capability. The experimental validation was performed in a lab-controlled environment using standard polymer IV bottles containing saline solution placed onto a strain-gauge load cell. These reference weights were used to calibrate the system, and the calibration data was stored in memory to provide a relationship between actual weight measured and remaining fluid level.

Through the experimental process, weight of IV bottle was monitored in real-time by a system while dropping its own fluid till simulated infusion. It was able to accurately process the recorded sensor data to interpret fluid levels and display them on an LCD instantaneously, proving the embedded software to be functional. The experimental trials results show a good performance of both fluid level changes detection and mapping to clinically meaningful messages. The resulting findings that match with the result of the uploaded file are referred to Table 2.

The system effectively produced informative alarm messages at moderate liquid-containing levels and provided shouting warnings that the level of liquid was reaching a minimum critical level. These alarms were generated locally at the LCD and transmitted also simultaneously to medical staff using GSM communication module as SMS or call. No noticeable delay in delivering alerts was present and the system performed real-time communication with reliability. The experimental results demonstrate that with polymer IV bottles the weight-based sensing approach enables to a reliable and repeatable measurements.

**Table 2.** Display and alert messages corresponding to IV bottle weight.

| S.N. | Measured weight / fluid level | Displayed message / system response |
|---|---|---|
| 1 | 500 ml | The bottle is full |
| 2 | 250 ml | The bottle is reduced to 50% |
| 3 | 50 ml | The bottle is reduced to 10% |
| 4 | 10 ml | Critical Alert – The bottle is reduced to 4% – Immediate action is necessary |

```
INITIALIZE libraries
- Load Cell library
- LCD Display library
- Software Serial for GSM unit
DEFINE Global Variables:
- Flags to track different weight thresholds and message sending states
- Load Cell sensor object
- LCD Display object
FUNCTION setup():
 Initialize serial communication
 Initialize software serial for GSM unit
 Initialize LCD display
Initialize Load Cell sensor
 Calibrate Load Cell
 Enable LCD backlight
FUNCTION loop():
Update Load Cell data
Get current weight reading
Display weight on LCD screen
Check weight threshold:

IF weight > 50 grams:
- Set flag for first threshold
IF weight drops below 55 grams:
- Send SMS alert
- Display "threshold reached 50" on LCD
- Reset threshold flag
IF weight > 21 grams:
- Set flag for second threshold
IF weight drops below 20 grams:
- Send SMS alert
- Display "threshold reached 20" on LCD - Reset threshold flag
IF weight > 10 grams:
- Set flag for third threshold
IF weight drops below 10 grams:
- Send SMS alert
- Display "threshold reached 10" on LCD
- Include room number in message
-Repeat loop
- Reset threshold flag
```

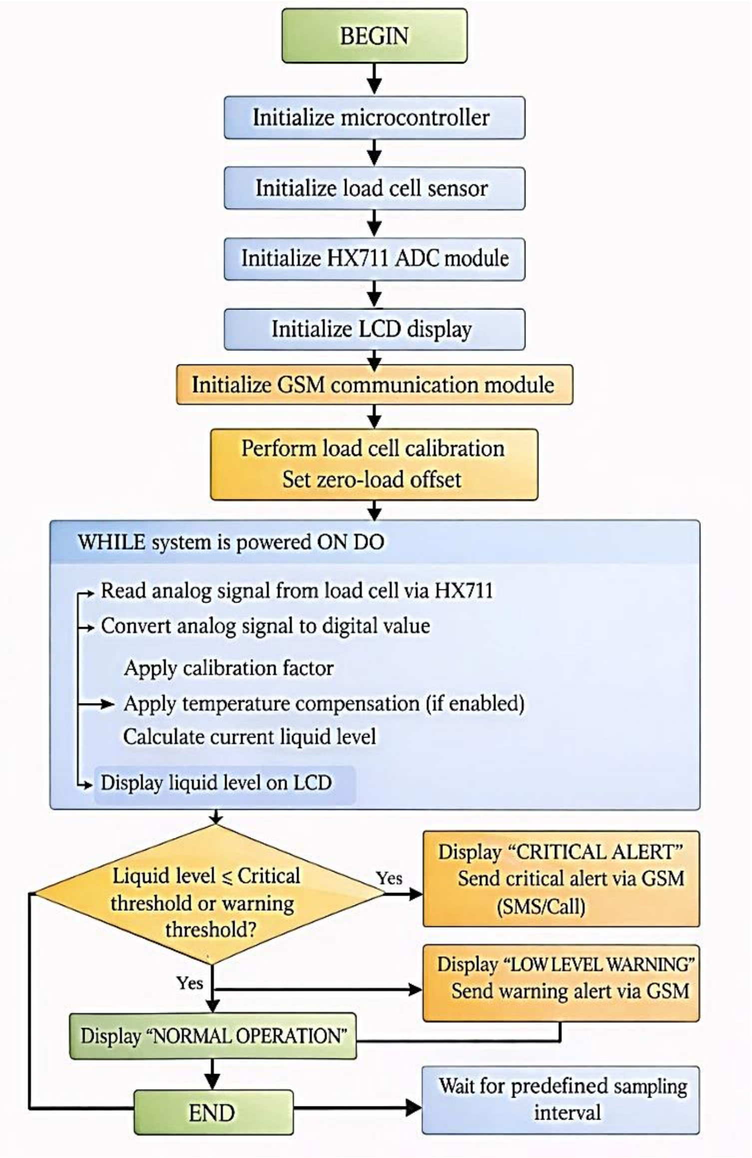

**Figure 4.** Pseudocode and flowchart of the proposed system.

Polymer bottles being lightweight and unbreakable enhance safety and consistency in sensing. In addition, the optics can be encased in the polymer containers to prevent moisture ingress and mechanical damage or unsafe patient contact while increasing the robustness and clinical appropriateness.

**Table 3.** Comparison of IV fluid monitoring techniques.

| Monitoring Technique | Measurement Accuracy | System Cost | Polymer Integration | Real-Time Alerts | Clinical Reliability |
|---|---|---|---|---|---|
| Manual Monitoring | Low | Low | None | No | Moderate |
| Optical-Based System | Medium | High | Partial | Yes | Moderate |
| Ultrasonic-Based System | High | High | Partial | Yes | Moderate |
| Proposed Polymer-IoT System | High | Low | Extensive | Yes | High |

The overall findings confirm that the designed polymeric IoT-based IV fluid monitoring system works reliably, precisely and efficiently, providing an implementation-ready solution for the automated IV fluid supervision needed to increase patient safety in healthcare.

A comparative study was performed to compare the performance of the proposed system with other IV fluid monitoring schemes like visual observation, optical sensing and ultrasonic based systems. The analysis centres around accuracy, expense, polymer inclusion, real-time alerting functionality and clinical utility. Table 3, is a compilation of the relative performances obtained by various monitoring methodologies.

## CONCLUSION

The comparison clearly demonstrates that the proposed system offers a balanced combination of high accuracy and low cost, while providing extensive polymer integration. Unlike optical and ultrasonic approaches, the weight-based sensing mechanism is insensitive to fluid transparency, lighting conditions, and container geometry. The experimental results, and comparative evaluation confirm that the proposed polymer-integrated IoT-based IV fluid monitoring system achieves reliable, accurate, and real-time monitoring performance. The combination of weight-based sensing, embedded signal processing, GSM-based alerts, and polymer-assisted design provides a cost-effective and clinically viable solution for improving patient safety and reducing healthcare workload.

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