

Integration and Automation Systems in Surgical Control Panels

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Abstract - An in-depth examination of how fragmentation and inefficient operations impact surgical operating rooms (ORs) has been conducted in this study through the design and exploration of a Centralized Surgical Control Panel (SCP). The majority of current ORs utilize multiple disparate and non-communicating systems for critical operational functions (e.g. medical gas delivery, patient monitoring, surgical lighting, environmental management). This fragmented model has resulted in an increased risk of human error, multiple specialized points of control (which is more difficult for medical personnel to use) and negatively impacted response times during critical events. The primary goal of this research study was to develop a methodology to integrate these disparate systems into one comprehensive system capable of supporting advanced automation and closed-loop controls. The SCP will serve as the coordinating and data synchronization hub of the OR by receiving continuous data feedback from high precision medical grade sensors including gas pressure monitoring, differential pressure maintenance, and temperature/humidity control, all of which have dedicated sensors built into them. The SCP will enable proactive automated safety management as opposed to traditionally reactive safety management through consolidated data collection, thereby significantly decreasing setup time between surgical procedures, increasing operational efficiency, and eliminating the unacceptably high risk associated with fragmented critical system oversight within operating rooms. This paper details the technical rationale, design methodology, and Material selection and designs is essential to creating a robust, compliant, and safer integrated

surgical suite solution.

Keywords—Surgical Control Panel, Operating Room Automation, Closed-loop Control, Medical Gas System, Integrated Systems, Patient Safety, HEPA Filtration, Sensor Fusion.

I. INTRODUCTION

A successful outcome of an operation in a surgical operating room (OR) is dependent upon all of the critical systems functioning together in an integrated, efficient manner. Historically, the OR infrastructure has been viewed as a multi-faceted set of independent control systems that coordinate the lighting, anesthesia delivery system, medical gas supply and environmental controls. This fragmentation / decentralization of ORs is the source of operational inefficiency, and increases the likelihood of procedural errors, both of which are clear calls for a robust, integrated engineering solution to this challenge.

A. Project Description

This project addresses a critical gap in the surgical operating room industry; it establishes a centralized surgical control panel (SCP) as the foundation for advanced ORs. The primary objective is to facilitate the integration and automation of the key subsystems into a single cohesive interface, to facilitate improved workflow, enhance patient safety through proactive monitoring, and ensure compliance with strict medical hygiene

standards. The automation architecture of the SCP will be driven by a network of high-precision, medical-grade sensors that will provide three main functions:

- Pressure Monitoring: Continuous, real-time assessment of medical gas supply lines and immediate leakage detection.
- Differential Pressure Control: Maintenance of the necessary positive air pressure differential for strict infection control.
- Environmental Regulation: Temperature and relative humidity (RH) monitoring to optimize surgical conditions and minimize microbial risk.

B. Core Objectives

The design of the SCP utilizes state-of-the-art feedback systems for critical functions, including measured and regulated medical gas pressure and flow rates, as well as measured and regulated air changes per hour (ACH) and controlled temperatures within the surgical operating room (OR). This documentation also provides a comprehensive technical justification for selecting medical-grade materials such as high-purity touch glass and corrosion-resistant metals to ensure that the design will meet clinical environments' requirements for durability and sterilizability.

II. LITERATURE REVIEW

Research by Hosseini et al. [1] highlights the dangers of gas leaks during surgeries and emphasises the importance of automated valve control systems to ensure consistent delivery of gases at all times in an OR. Today's operating room (OR) uses central gas management systems with real-time monitoring to prevent fluctuations in pressure and accidental mixing of gases.

Research on clinical hygiene indicates that when HEPA filtration is used in combination with adequate ACH rates, airborne contaminants can be significantly minimised [5]. According to Bartley (2006) and the World Health Organisation (2006)'s infection control guidelines [3], air quality contributes significantly to preventing surgical infections. Modern ORs now have integrated filtration/air cycling systems programmed into the central controller to help regulate temperature, relative humidity and particulate matter.

Surgical suites have been subject to many automated

advancements in the last few decades, making the centralized control of the surgical environment key to mitigating human error, streamlining workflow, and providing synchronization of surgical instrumentation. Furthermore, published research supports the operational advantages of using centralized platforms to facilitate faster set-up times and enhanced intra-system communications / operational workflow.

Multiple clinical studies show the critical need for immediate response times to any deviation in the vital signs of the patient. Integration of cardiac monitoring, anesthesia monitoring, and emergency call systems to all provide immediate alerts in the event of a critical incident to the surgical environment. Research has also shown that integrating the alarm systems of the various monitors available to the central control systems within the suite resulted in better patient outcomes.

Gas leak detection systems are the subject of numerous studies regarding their role in the prevention of hypoxia, explosion and, / or, toxic exposure. In supporting research related to gas pipeline safety, the literature supports the development of multi-layer alarm systems and automatic shut-off mechanisms, which are consistent with the systems described in this report.

III. PROBLEM DEFINITION

A. Need for the Project

In modern surgical operating rooms, there are many critical systems that operate at the same time (i.e. Medical Gas Delivery, Patient Monitoring, Environmental Control, Surgical Lighting). Unfortunately, many hospitals and other health care facilities rely on multiple independent control systems (i.e. Fragmented Control Architecture) to operate these systems. The decentralization of these systems means that there are multiple points of control, requiring extensive training and creating a large amount of inefficiency in both the surgical set-up and the execution of the surgery.

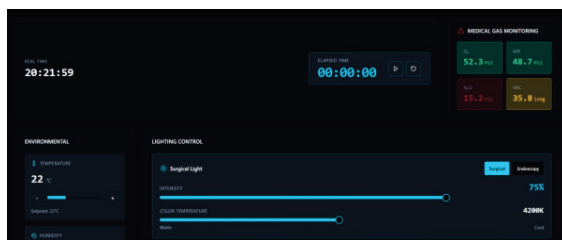
More importantly, the fragmentation of these systems creates a significant risk to patient safety due to the time it takes to synthesize data, the difficulty in quickly finding corresponding alerts, and the opportunities for human error due to manual management of complex dependencies. The problem that this project addresses is the lack of a central, intelligent control and data synchronization platform that can manage the various subsystems that make up the OR. In these situations, the current operating state is controlled reactively, instead of proactively.

IV. INTEGRATED CONTROL PANEL SYSTEM LAYOUT

A. Surgical Control Panel (Central Control Unit)

The Central Control Unit (SCP) acts as a central point of integration for all modalities that input data into the operating room (gaseous, thermal, filtration, monitoring). It provides command signals to all subsystems and alerts to multiple occupants. The SCP is connected directly to seven major subsystems:

- surgical lights
- cardiac monitoring
- anesthesia machine
- gas leak detection
- emergency contact system
- air filtration/ACH system
- temperature monitoring.



The prototype dashboard in figure 1 shows how the entire integrated system operates through the front-end. The upper left panel of the dashboard consists of a clock, showing a real-time clock; there is also an elapsed surgery timer. The upper right panel consists of real-time medical gas pressure readings for O2 (52.3 PSI, N2O (15.2 PSI) and vacuum (35.8 inHg). The lower left panel is used for environmental monitoring, while the lower right panel is used for surgical lighting control with variable intensity and colour temperature; 48.7 PSI (15.2 PSI N2O) and 35.8 inHg vacuum.

B. Real time clock and surgery time monitoring tab

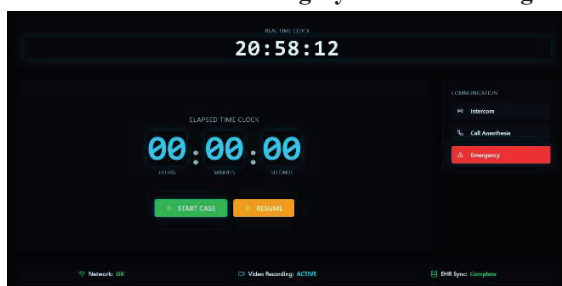


Fig 2 shows the current time as per (GMT +5:30) mode. In the centre, the surgery timer is displayed. On the right side, Emergency and contact options are situated.

C. Advanced Video Integration Tab

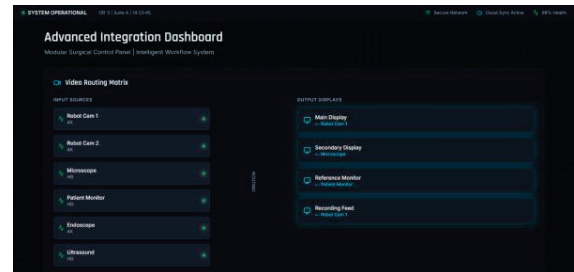
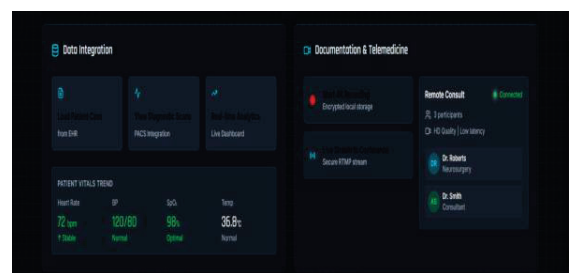


Fig 3 shows the Video Routing Matrix (VRM) on the left side, the number of robotic surgical arms that are operated and their camera functions. It ultimately displays the video recording at robotic arms. It consists of ROBOCam, Microscope, Endoscope and various cameras like dashcams.

D. Patient Previous Medical Data



On the left side (Data Integration panel):

It provides options to manage and access patient-related data, including:

- Loading a patient case from an Electronic Health Record (EHR) system
 - Viewing diagnostic scans through PACS integration
 - Monitoring real-time analytics via a live dashboard
 - Below this, a **Patient Vitals Trend** section displays key health indicators:
 - **Heart Rate:** 72 bpm (stable)
 - **Blood Pressure:** 120/80 (normal)
 - **SpO₂ (oxygen saturation):** 98% (optimal)
 - **Temperature:** 36.8°C (normal)
- These values indicate that the patient is currently in a stable and healthy condition.

On the right side (Documentation & Telemedicine panel):

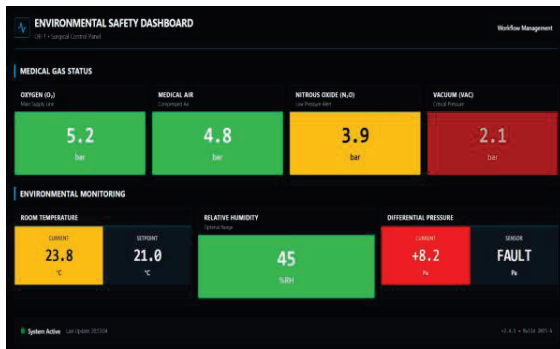
It includes controls for:

- Starting **4K recording** with encrypted local storage

- **Live streaming** the procedure securely to a conference
- A **Remote Consult** section shows an active telemedicine session:
- Status: **Connected** with 3 participants
- High-definition video with low latency
- Displays participating Surgeon

- Displays last update timestamp and software version details

E. Environmental Safety Dashboard



1. Top Section – Medical Gas Status

This section displays the pressure levels of essential gases used during surgical procedures:

- **Oxygen (O₂):** 5.2 bar – within safe range (green indicator)
- **Medical Air:** 4.8 bar – normal (green)
- **Nitrous Oxide (N₂O):** 3.9 bar – low pressure warning (yellow)
- **Vacuum (VAC):** 2.1 bar – critical pressure (red alert)

Color coding (green, yellow, red) quickly indicates system health and urgency of attention.

2. Middle Section – Environmental Monitoring

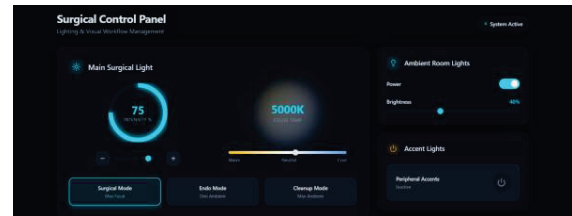
This area tracks operating room conditions:

- **Room Temperature:**
 - Current: 23.8°C
 - Setpoint: 21.0°C (slightly above desired level, highlighted in yellow)
- **Relative Humidity:** 45% RH – within optimal range (green)
- **Differential Pressure:**
 - Current: +8.2 Pa (critical, red)
 - Sensor Status: **FAULT** (indicating a possible sensor malfunction or unreliable reading)

3. Bottom Status Bar

- Shows system status as **Active**

E. Environmental Safety Dashboard



1. Main Section – Surgical Lighting Control

Displays controls for the **Main Surgical Light**:

- **Intensity:** 75% (adjustable via slider and +/- controls)
- **Color Temperature:** 5000K (neutral white light), adjustable along a warm-cool spectrum
- Includes preset lighting modes for different surgical needs:
- **Surgical Mode:** Maximum focused lighting for procedures
- **Endo Mode:** Reduced ambient lighting for endoscopic work
- **Cleanup Mode:** Maximum ambient lighting for post-operation tasks

2. Right Section – Room Lighting

Ambient Room Lights:

- Power is turned ON
- Brightness set to 40%, adjustable via slider

Accent Lights:

- Peripheral accent lighting system is currently **inactive**, with a power control option available

V. MATERIAL SELECTION AND TECHNICAL JUSTIFICATIONS

A. Protective Screen / Glass

Material Characteristics: Toughened safety glass compliant with EN 12150 or high-quality acrylic touch glass. The surface must be smooth, non-porous, scratch-resistant, and compatible with hospital-approved disinfectants.

B. Touch Technology

Projected Capacitive Touch Film allows for highly sensitive input regardless of whether the user is wearing surgical gloves. The enclosure beneath the glass reduces the risk of contamination from microbes.

VI. KEY CONTROL & SAFETY COMPONENTS

System / Sensor	Model	Key Specifications
Medical Gas Pressure	WIKA S-20 Piezoresistive	Range: 0–16 bar; Accuracy: 0.25%–0.5%; Output: 4–20 mA; Material: SS316
HVAC Differential Pressure	SETRA / TSI PresSura	Range: 0– ± 100 Pa; Accuracy: < ± 1%; Flush-mount or duct installation
HVAC Temperature	WIKA TR-10 RTD	Sensing: Platinum RTD; Accuracy: ± 1.5°C at 0°C; 3- or 4-wire

VIII. FUTURE SCOPE

The next generation of surgical control panels will transition from a static control interface to a proactive, cognitive assistant. Key future directions include:

1)AI and Predictive Analytics Intraoperative workflow automation using computer vision to recognize surgical stages and automatically adjust system parameters; predictive alarms based on historical gas consumption patterns.

System / Sensor	Model	Key Specifications
		configuration
HVAC Humidity	Honeywell HIH / IST P14-W	Principle: Capacitive polymer film; Accuracy: ± 2%–3% RH; Maintains 30–60% RH

VII. CONCLUSION

The Centralised Surgical Control Panel (SCP) design and analysis achieved its intended purpose and is a direct response to the fragmentation that is common to today's ORs. This project has validated the necessity of having an integrated OR with an intelligent platform that integrates the ASSEST GAS systems, patient monitors, and environment measurements.

The engineering analysis has confirmed that the use of modern automation methods and closed-loop control is both essential and feasible for improving OR safety. The foundation for these systems is the procurement of highly precise continuous readings from high-precision sensors used to measure gas supply pressure and differential pressure for proactive safety management rather than reactive methods and consistency as they ensure the uninterrupted delivery of life-sustaining gases to patients in a sterile environment through controlled differential air pressures around the patient.

A comprehensive rationale for selecting materials for the system's components has been established to ensure that they are durable enough to meet clinical standards and resistant to the hazardous chemicals and fluids common to the surgical environment. To summarize, the designed integrated SCP will:

- Reduce the risk of human error associated with OR management.
- Significantly improve the efficiency of the surgical workflow.

2)Touchless and Advanced Interaction: Voice control integration for hands-free command, and gesture control using ceiling-mounted depth sensors to eliminate physical touch within the sterile field.

3)Augmented Reality (AR) Integration: Real-time overlay of patient vitals and pre-operative imaging (CT/MRI) onto the surgical video feed for enhanced navigation and precision.

4)Digital Twin and IoT-based Inventory Management: Automated case logging, RFID-based real-time consumable

tracking, and integrated billing through IoT sensors on instrument trays.

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