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Article

Design and Implementation of an Arduino-Powered CPR Feedback Device

Safa Taleb Hamad Obaid[1], **Fatima Salih Hasan Nahabih**[2], **Sajad Kadhim Hussein Harish**[3], **Mohammed Shihab Ahmed Sulayman**[4]

1,2,3. Department of Medical Devices Engineering Technology, Al-Hilla University College, Iraq
4. Department of Medical Devices Engineering Technology, Al-Kitab University, College of Engineering Technology, Iraq
Correspondence: [1]Safataleb999@gmail.com, [2]fs393598@gmail.com, [3]sajadkadhim684@gmail.com, [4]noorxxp464@gmail.com

Abstract: This research examines Cardiopulmonary Resuscitation (CPR), a critical life-saving technique that can greatly enhance an individual's likelihood of survival after experiencing a cardiac arrest. The success of CPR procedures is largely contingent upon the proficiency of the person administering aid. Delivering chest compressions at the correct depth and rate, while ensuring complete chest recoil and minimizing interruptions, is essential for improving survival rates during a cardiac arrest. The absence of effective CPR training models in developing nations significantly affects the training and development of CPR skills. Consequently, this paper seeks to enhance CPR training by creating a high-fidelity CPR training manikin. This model features a feedback mechanism that monitors CPR performance, facilitating effective practice and rehearsal until the requisite CPR skills are mastered. A comprehensive review of current training systems was performed to guarantee the appropriate design of the proposed system. The testing outcomes indicate that the developed manikin prototype evaluates the quality of CPR performance and offers suitable feedback to the trainee. This model can be employed to instruct medical students and other healthcare professionals in the proper execution of CPR.

Keywords: Cardiopulmonary Resuscitation (CPR), Chest Compressions, CPR Training, Feedback Mechanism, High-Fidelity Manikin

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1. Introduction

Cardiac arrest ranks among the foremost causes of mortality globally. The worldwide occurrence of out-of-hospital cardiac arrests varies between 49 and 83 per 100,000 individuals annually. In-hospital arrests occur at a rate of 1 to 5 per 1,000 patients, with annual estimates of sudden cardiac deaths in the United States ranging from 180,000 to over 450,000. The survival rates for witnessed out-of-hospital arrests where cardiopulmonary resuscitation (CPR) is performed by a bystander range from 2% to 7%, while for in-hospital arrests with CPR administered by trained professionals, the rates range from 15% to 20%.

Cardiac arrest transpires when the heart's electrical system malfunctions, leading to a quivering heart instead of a normal beat. This malfunction results in the heart's inability to pump blood throughout the body. Beyond the significant risk of death, other critical concerns include the impact of extended oxygen deprivation on the brain and other essential organs, as well as the potential damage that can occur within minutes of the heart ceasing to function. The brain can incur damage after merely four minutes without blood flow, and irreversible harm can manifest after just seven minutes. Other vital organs at risk include the lungs, liver, and kidneys. Except for those experiencing hypothermia, which can endure for up to 45 minutes, death typically occurs if blood flow is interrupted for more than 20 minutes. Consequently, emergency assistance is generally effective only if provided within seven minutes of blood flow cessation.

Individuals who may experience cardiac arrest include those with heart disease, those who have overdosed on medication, trauma victims, individuals suffering from excessive bleeding, choking, poisoning, or drowning. Cardiopulmonary resuscitation (CPR) is the method employed to offer immediate aid to an individual experiencing cardiac arrest. This procedure integrates chest compressions with, in certain instances, artificial ventilation, aiming to manually reinstate spontaneous blood circulation and breathing in a person who has suffered cardiac arrest.

The effectiveness of chest compressions, which should be administered at the correct depth and rate while allowing complete chest recoil and minimizing interruptions, is vital for enhancing survival rates in cardiac arrest cases. If the depth of compression exceeds optimal limits, it can hinder blood flow by reducing the volume within the cardiac chambers; this can also lead to rib fractures, which frequently occur in individuals who have undergone CPR. Conversely, shallow compressions have been associated with a decreased likelihood of achieving return of spontaneous circulation (ROSC) and a diminished chance of survival. Likewise, surpassing the ideal compression rate can impair the heart chambers' ability to pump blood effectively. Failure to allow complete recoil (greater than 90%) prevents blood from returning to the heart, thereby compromising cardiac output.

Research conducted both outside and within hospital settings regarding the quality of CPR indicates that maintaining an adequate rate and depth of chest compressions poses significant challenges. Furthermore, studies have shown that utilizing real-time feedback devices during CPR has enhanced the quality of resuscitation efforts by both laypersons and trained professionals in both simulated environments and actual situations. Given the direct impact of chest compressions on the heart's electrical activity and overall circulation, along with the potential for rib fractures, lung injury, and damage to other organs during CPR, it is unlawful to administer CPR to someone who does not require it. This underscores the necessity for high-quality training models for the procedure, which will equip medical personnel and the general public with the skills needed to perform effective CPR. For effective CPR procedures, it is essential to utilize models that replicate the sensation of a real human chest and incorporate a feedback system. These models enable learners to make errors and understand their consequences, as well as learn how to avoid them prior to working with actual patients. Consequently, this paper presents a high-quality, high-fidelity, and cost-effective CPR training model designed to facilitate quality simulation-based procedural training and improve CPR performance. The training model aims to make simulation-based CPR training more accessible and provide superior equipment for the medical field. This initiative will tackle the challenge of limited availability of high-fidelity training models with performance feedback due to high costs, while simultaneously enhancing the quality of CPR performance.

The proposed CPR training model includes a feedback mechanism to monitor the status of CPR performance. It simulates scenarios and events that occur during a genuine CPR procedure, which is contingent upon the quality of the individual's performance. This feature will enable practice and modifications until proficient CPR skills are developed.

Literature Review

According to the literature review, numerous researchers have explored the topic of CPR and associated devices. Sivaramakrishnan et al. created a CPR feedback device utilizing Arduino technology, which delivers feedback via a display, audio output, and

LED count. This device is specifically tailored for neonatal resuscitation.Gupta et al. examined the application of smartphones to improve CPR delivery, including the measurement of blood oxygen saturation. Kwangha Lee concentrated on elements such as chest compression, expedited defibrillation, advanced support, and integrated post-cardiac arrest healthcare. There is also a focus on physiological monitoring to enhance CPR quality and identify Return of Spontaneous Circulation (ROSC). Sofia Ruiz de Gauna et al. integrated a photoelectric sensor to enhance the quality of CPR. They developed various alternatives, including linear filtering, velocity analysis, and spectral analysis of acceleration, in conjunction with the photoelectric sensor. Chiwon Ahn and Jucheol Lee created a smartwatch equipped with a built-in accelerometer to ensure high-quality chest compressions during CPR. Habibian et al. introduced an Automatic CPR To-Go (ACT) device, which administers anterior-posterior compression to patients experiencing sudden cardiac arrest, thereby ensuring high-quality CPR.H. Latif et al. developed a CPR training tool known as the LA-VIE game, which has demonstrated effectiveness.

Kelly J. Tucker et al. designed an active compression-decompression device in accordance with AHA standards, recommending a compression rate of 80 compressions per minute, a depth of 1.5 to 2 inches, and a duty cycle of 50%.

Song, J., Oh, T. Lim, and Y. Chee introduced an innovative approach that involves utilizing a vinyl cover to encase a patient's mattress, referred to as the mattress compression cover. This cover is deflated using a vacuum pump immediately prior to CPR, which minimizes mattress compression depth (MCD) and offers precise information regarding chest compression depth.

A. Bronicki et al. discussed the significance of having adequate staffing during cardiac emergencies, taking into account regional variations in personnel needs and ensuring proper conduct across different continents.

N. Varghees and Ramachandran, K. I. concentrated on the acquisition and analysis of heart sounds to investigate various facets of cardiac health.

Background and Theoretical Principles

1.1 Overview

Over the past 25 years, several alternatives to conventional manual cardiopulmonary resuscitation (CPR) have been developed to improve perfusion during cardiac arrest and enhance survival rates. While many of these approaches—such as mechanical devices and advanced techniques—have demonstrated promising results in specific contexts, no method has consistently proven superior to conventional CPR in out-of-hospital basic life support. The American Heart Association (AHA) continues to update CPR guidelines, most notably with the adoption of compression-only CPR, aimed at increasing bystander participation and reducing delays in chest compressions. Nevertheless, regular retraining and careful monitoring remain essential for ensuring both safety and effectiveness.

1.2 Cardiopulmonary Resuscitation (CPR)

CPR remains a fundamental life-saving intervention. Its primary goal is to maintain blood flow and oxygen delivery to vital organs until advanced medical care is available. Over time, CPR protocols have evolved from the ABC (Airway, Breathing, Circulation) model to the more recent CAB (Circulation, Airway, Breathing) sequence, emphasizing early initiation of chest compressions.

The Adult Chain of Survival identified by the AHA highlights five essential links:

- Immediate recognition of cardiac arrest and activation of the emergency system.
- Early CPR with emphasis on chest compressions.
- Rapid defibrillation.
- Effective advanced life support.
- Integrated post-cardiac arrest care.

Several CPR variations have been explored, including high-frequency chest compressions, open-chest CPR, interposed abdominal compression, prone CPR, and cough-induced CPR. While these techniques may offer situational benefits, conventional external compressions remain the gold standard in most settings.

1.3 Pressure Sensors

Pressure sensors are critical in biomedical and engineering applications, enabling accurate monitoring of physical parameters such as airflow, fluid levels, and vascular pressures. These devices convert pressure variations into electrical signals that can be processed and analyzed.

Common types include:

- Piezoelectric sensors – generating electric charge in response to applied force.
- Strain gauge sensors – detecting deformation in elastic elements.
- Bourdon tubes, manometers, and barometers – for mechanical pressure measurement.
- Vacuum and sealed sensors – for specialized environments such as submersibles.

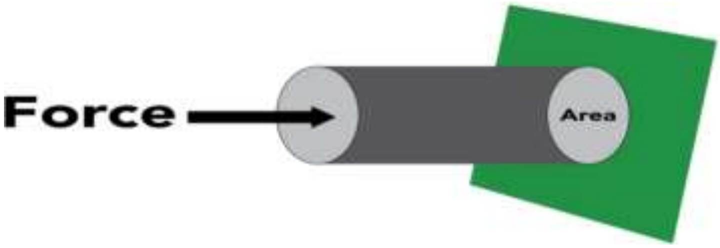

Figure 1. Pressure Sensors

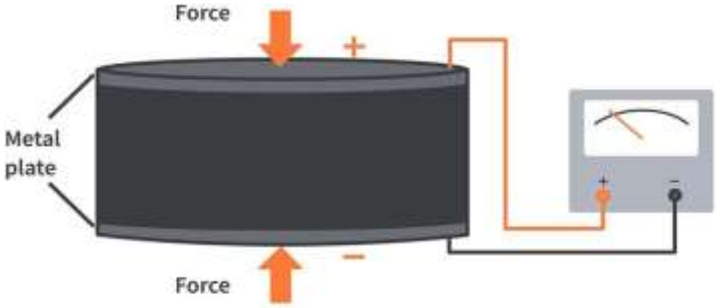

Figure 2. Pressure Sensors as a Force

1.3.1 Pressure Sensors Work

Pressure sensors function based on the same essential principle of identifying physical alterations in pressure. When a pressure sensor identifies a change in pressure, it transforms this information into an electrical signal that can be utilized to extract significant data. This electrical signal can be presented to the user in an understandable format, enabling them to interpret the pressure information. No matter the specific kind of pressure sensor employed, the fundamental working principle stays consistent

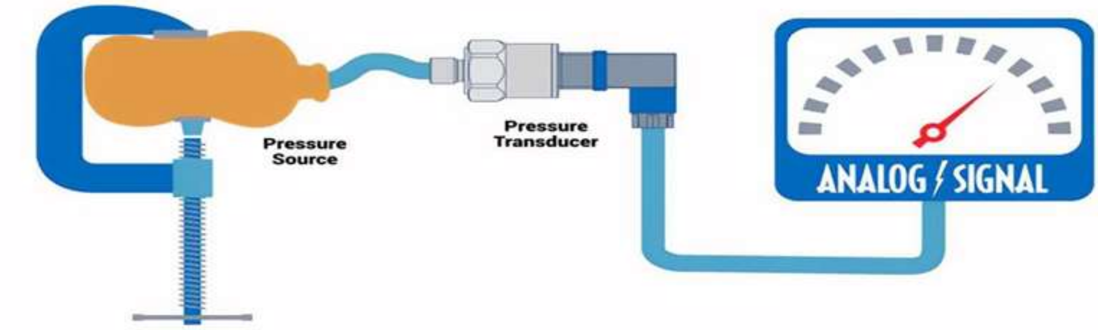

Figure 3. Basic Principle of Pressure Sensor

1.4 Vital Signs (Pulse Rate and Blood Oxygen Saturation)

Vital signs are essential indicators of health and disease progression. Pulse rate and blood oxygen saturation (SpO_2) are particularly important in cardiopulmonary monitoring:

- Pulse Rate reflects cardiac output and vascular health, typically measured at radial or femoral arteries.
- Blood Oxygen Saturation indicates the efficiency of oxygen transport and is routinely measured using pulse oximetry.

Normal SpO_2 levels range from 95–98%, while values below 92% suggest hypoxia. Accuracy may be affected by external factors such as temperature, pigmentation, or smoking. Techniques to improve oximetry accuracy include vasodilator application, warming the skin, adjusting probe location, or using alternative sensors.

1.5 Control Systems and Arduino Integration

Effective control systems are central to the design of biomedical monitoring devices. Control mechanisms are broadly divided into:

- Open-loop systems – operating solely on input without feedback.
- Closed-loop systems – adjusting output dynamically based on feedback.

Arduino-based microcontrollers have gained prominence in biomedical research due to their affordability, programmability, and versatility. They facilitate integration of multiple sensors (e.g., pressure, SpO_2, pulse) with feedback systems, enabling the development of portable, low-cost medical devices.

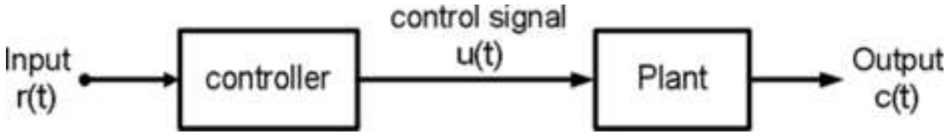

Figure 4. An open-loop system

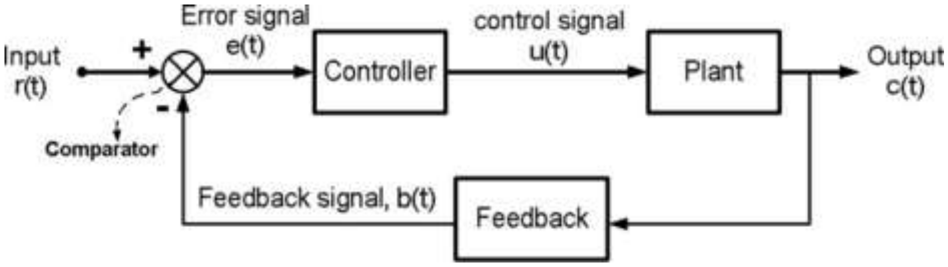

Figure 5. A closed-loop system

2. Materials and Methods

2.1 Arduino Uno

Arduino acts as the core processing unit of the Battery Management System (BMS). It is an open-source platform for computer hardware and software that includes a community of users, various projects, and a company dedicated to the design and production of single-board microcontrollers and kits aimed at creating interactive objects and digital devices that can sense and control the physical environment. Arduino operates as a microcontroller board that can be used either independently or in combination with other electronic components to receive input signals from sensors and to send and receive commands for interaction with the surrounding environment through a variety of actuators. These actuators can include simple components like LEDs, as well as more complex devices such as motors, sensors, Ethernet modules, and other electronic components. Arduino hardware comes in various formats and designs, each providing unique capabilities.

The wiring of the hardware serves as the basis for the software functionality. The Arduino Integrated Development Environment (IDE) is compatible with several operating systems, enabling users to program Arduino boards either independently, in conjunction with computers, or alongside other electrical devices.

Figure 6. Arduino UNO

2.2 LCD (Liquid Crystal Display) I2C-LCD16x2

The I2C LCD module is a user-friendly display module that streamlines the process of showcasing information.

By employing this module, the challenges associated with creating displays are minimized, enabling makers to focus on the essential elements of their projects. Our team has crafted an Arduino library tailored for the I2C LCD, allowing users to implement intricate graphic and text display functionalities with merely a few lines of code. This LCD module, which features a 2x16 character display and a blue backlight, interfaces with the host microcontroller via an I2C connection.

It represents a cost-effective option for projects that necessitate the display of various forms of text, data, or ASCII characters. To set it up, simply connect it to the power source (Vcc), ground (Gnd), serial data line (SDA), and serial clock line (SCL).

Figure 7. I2C- LDC

2.3 Li-Batteries

Lithium-ion batteries are currently the most commonly utilized rechargeable battery technology. These batteries are essential for powering our daily devices, including mobile phones and electric vehicles.

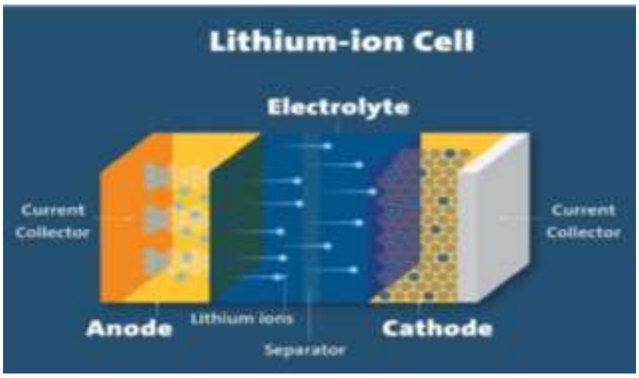

Figure 8. Lithium-ion cell

2.4 MAX30100 Module

The MAX30100 pulse oximeter and heart rate sensor is a biometric device crafted for straightforward integration and functionality via the I2C interface. It boasts low power usage and is suitable for a diverse group of users, such as students, hobbyists, engineers, manufacturers, as well as game and mobile developers. This sensor facilitates the integration of real-time heart rate information into numerous projects and applications.

Figure 9. MAX30100 Module

The MAX30100, in conjunction with other optical pulse oximeters and heart-rate sensors, consists of two high-intensity LEDs (RED and IR) that emit light at distinct wavelengths, along with a photodetector. More specifically, the RED LED emits light at a wavelength of 660nm, whereas the IR LED emits light at a wavelength of 880nm.

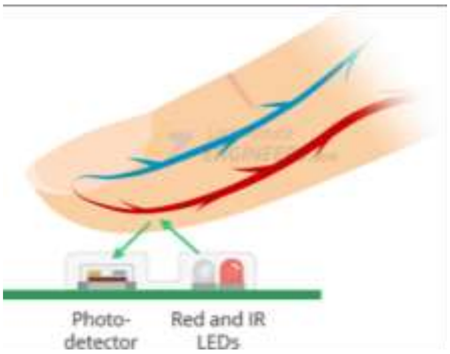

Figure 10. Pulse Oximeter Using MAX30100

The MAX30100 operates by emitting red and infrared light onto regions of relatively thin skin, such as the finger or earlobe, which enables the light to penetrate the tissue. A photodetector subsequently measures the quantity of reflected light. This method, referred to as photoplethysmogram, is employed for pulse detection through the use of light.

2.5 Force Sensitive Resistor

Force-Sensing Resistors (FSRs) are specialized sensors intended for the detection of physical pressure, squeezing, and weight. They provide a straightforward and economical means of measuring and monitoring fluctuations in pressure. The Interlink 402 model represents a particular variant of FSR, and in the accompanying image, the sensitive element is recognized as the circular section with a diameter of 1/2 inch. FSRs are extensively utilized because of their user-friendliness and cost-effectiveness across a range of applications.

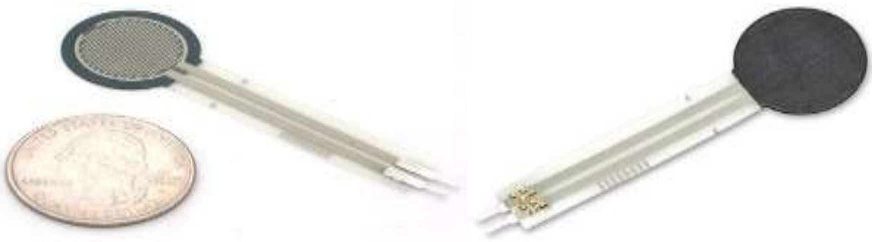

Figure 11. Force Sensitive Resistor

2.6 The Design of the Project

The project design will be demonstrated according to the figure underneath:

The proposed circuit design illustrates the integration of an Arduino Uno microcontroller with essential components for a CPR feedback system.

A force-sensitive resistor (FSR) is connected to detect chest compression depth during CPR practice.

The sensor outputs are transmitted to the Arduino, which processes the data in real time.

An LCD 16x2 display is used to show compression count, rate, and performance feedback to the trainee.

Two LEDs (green and red) are included to provide visual indicators for correct and incorrect compressions.

A buzzer is integrated into the circuit to generate auditory alerts during the training process. The breadboard serves as the prototyping platform, enabling component connections and power distribution.

Power is supplied through the Arduino's USB interface, with regulated voltage distributed across the modules.

This design ensures a cost-effective, real-time feedback mechanism for improving CPR training quality.

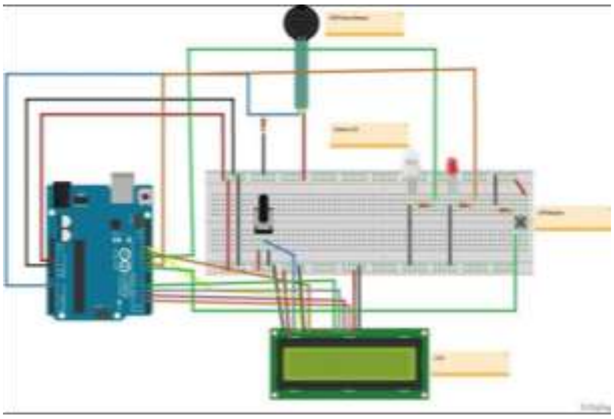

Figure 12. Design Circuit

2.6.1 Software Implementation

The control algorithm was developed using the Arduino IDE in C++ language. The program was designed to continuously acquire sensor signals, calculate compression depth and rate, and provide feedback in real time. Logical conditions were implemented to activate LEDs and a buzzer for visual and auditory alerts, while the LCD displayed cycle count, elapsed time, and compression frequency. The software followed American Heart Association (AHA) guidelines, ensuring compliance with the recommended range of 100–120 compressions per minute and correct chest recoil detection.

3. Results and Discussion

The implemented CPR feedback prototype demonstrated reliable performance in detecting chest compression depth and rate. The force-sensitive resistor successfully distinguished between adequate and inadequate compressions, while the Arduino microcontroller processed the data in real time without delays. The LCD displayed the compression count, rate, and total time, enabling trainees to monitor their performance continuously. The use of LEDs and a buzzer provided clear visual and auditory feedback, which enhanced the learning experience.

The results indicated that the system maintained compression rate measurement within the American Heart Association (AHA) recommended range of 100–120 compressions per minute. This confirms the accuracy of the feedback mechanism for training purposes. Additionally, the cycle counter ensured adherence to the 30:2 compression-to-ventilation ratio, further improving realism in practice sessions.

Comparing this prototype to existing commercial manikins, the system offers a low-cost and portable alternative while still achieving effective performance evaluation. The integration of the MAX30100 sensor allowed preliminary testing of vital signs monitoring, though its accuracy could be affected by external conditions such as skin temperature and motion artifacts.

4. Conclusion

The evaluation of the prototype's operation, in comparison to the expected and simulated results, can be summarized as follows:

- The sensor connected to the manikin effectively detects the compression depth during each compression, and the accumulated depth values over a 13- second interval trigger subsequent feedback from the alert, display, and blood volume indication units.
- The counting unit attached to the manikin accurately captures the compression counts, and the control unit increments these counts and provides the compression rate along with appropriate feedback every 30 seconds, enabling analysis of the count within a minute.
- The control unit efficiently analyzes the inputs from the sensing unit and counting unit, ensuring accurate and timely output.
- The alert unit generates sound notifications every 30 counts, indicating a ventilation break, and produces a distinct sound alarm in case of errors.
- The blood volume indication unit, implemented using neopixel lights, emits a red glow every 13 seconds based on the performance within that time frame. Adequate depth results in all neopixels illuminating, while inadequate depth illuminates only half of the strip.
- The blood speed indication units, also utilizing neopixel lights, exhibit high- speed strip illumination for adequate compression rate and a quarter strip illumination for a slow rate.
- The display unit integrated into the prototype case effectively presents the performance evaluation without any delays.

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