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Arduino-Based Digital Clock with RTC, Alarm and Temperature Display: An Embedded System for Accurate Timekeeping

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***Abstract*—**Accurate timekeeping is an indispensable requirement across domestic environments, educational laboratories, industrial workspaces, and mission-critical embedded systems. Conventional digital timekeeping solutions implemented purely on microcontroller software timers (such as Arduino millis function) suffer from cumulative thermal drift and lose synchronisation immediately whenever primary electrical power is interrupted. This paper presents the comprehensive design and physical implementation of an automated, low-power digital clock system utilising an ATmega328P-based Arduino Uno platform interfaced with a high-precision DS3231 Real-Time Clock (RTC) module. The DS3231 incorporates an internal Temperature-Compensated Crystal Oscillator (TCXO) with an autonomous CR2032 lithium backup battery, guaranteeing high timekeeping accuracy of within ±2 parts per million (ppm) even during mains power outages. Real-time hours, minutes, seconds, calendar date, and ambient room temperature are rendered onto a 16x2 Liquid Crystal Display (LCD) driven via a PCF8574 I2C backpack. A dedicated push-button user interface facilitates interactive time configuration and programmable alarm parameters, coupled with an active piezo buzzer indicator. Empirical evaluation over continuous operation confirmed clock drift stability within negligible thresholds (< 1 second across seven days), demonstrating the commercial viability, robustness, and cost-efficiency of the prototype.

***Keywords*—**Digital clock, Arduino Uno, DS3231, RTC, I2C protocol, 16x2 LCD, Alarm system, Temperature monitoring, Embedded system.

I. INTRODUCTION

Accurate, legible, and persistent time measurement is fundamental to everyday domestic routines, industrial scheduling, and process automation. Traditional electro-mechanical analog clocks, while ubiquitous, present inherent operational challenges: they exhibit mechanical wear, suffer parallax reading errors, lack night-time illumination without dedicated backlighting, and cannot natively deliver flexible alarm profiles or ambient sensory telemetry.

In modern electronics, engineers frequently attempt to construct digital clocks by deploying generic microcontroller timers. However, the standard internal ceramic resonators and quartz crystals found on development boards such as the Arduino Uno exhibit frequency tolerances of approximately ±0.5% (±5000 ppm). Under fluctuating ambient temperature conditions, an Arduino running an internal loop timer (such as millis()) can drift by several seconds to minutes each day. Crucially, volatile registers reset to zero whenever power is interrupted or the board is reset, wiping out the current time entirely.

Integrating an external dedicated Real-Time Clock (RTC) integrated circuit resolves these shortcomings affordably. The Maxim/Analog Devices DS3231 RTC module incorporates a factory-calibrated 32.768 kHz Temperature-Compensated Crystal Oscillator (TCXO). It continuously monitors crystal temperature, tuning the internal capacitor array to maintain timing accuracy of ±2 ppm (approx. ±1 minute per year) across a -40 °C to +85 °C operating range, while drawing mere microamperes from an auxiliary coin cell battery.

The primary objectives of this project are:

1) To design a cost-effective, standalone digital clock unit capable of displaying 24-hour/12-hour time and complete Gregorian calendar dates.

2) To eliminate time drift and power-loss resets by integrating the DS3231 RTC with dedicated CR2032 battery backup.

3) To incorporate ambient temperature sensing using the DS3231 internal register without adding bulky external thermal probes.

4) To implement an interactive human-machine interface (HMI) with tactile push buttons to set time, schedule alarms, and trigger an audible acoustic buzzer alert.

The body of this paper describes the design and implementation of the Arduino-Based Digital Clock with RTC, Alarm and Temperature Display. It explains the proposed system architecture, including the ATmega328P microcontroller as the central processing unit, the DS3231 high-precision RTC module with battery backup, the 16x2 character LCD with PCF8574 I2C backpack, tactile user controls, and the active piezo alarm buzzer. It also discusses the working principle of the system, in which temporal registers and ambient temperature are continuously queried over the I2C bus and rendered on the display. The paper further presents the hardware components used, the step-by-step operational process, prototype test results, limitations, and future scope of integrating embedded technology into accurate timekeeping platforms.

II. PROPOSED SYSTEM AND ARCHITECTURE

A. Proposed System

The Arduino-Based Digital Clock with RTC, Alarm and Temperature Display is an autonomous embedded device designed to deliver high-precision temporal tracking, ambient environmental monitoring, and acoustic alert notification within a compact, user-friendly enclosure. The system relies on two-wire I2C communication to minimize GPIO pin consumption on the controller, retaining open pins for input debouncing and alarm peripherals.

The proposed architecture consists of two major layers: the Hardware Interfacing Layer (HIL) and the Firmware Execution and Display Layer (FEDL). The hardware layer is responsible for sensing crystal temperature, timing calculation, power management, tactile sampling, and acoustic indication, while the software layer handles I2C transactions, register parsing, LCD screen formatting, debouncing, and state machine control.

B. System Architecture

The overall block diagram of the proposed system is shown in Fig. 1.

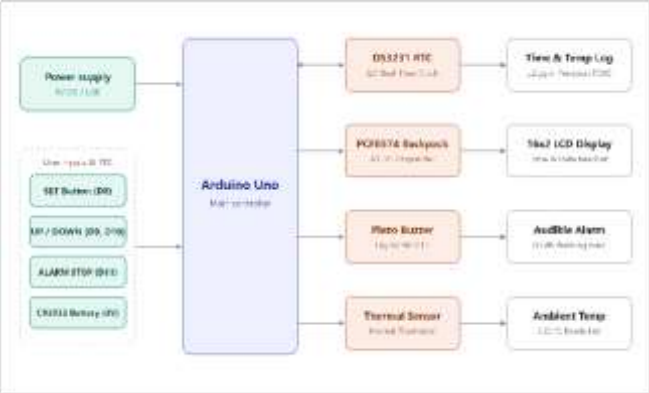


Fig. 1. Block diagram of the automated digital clock system.

The complete electrical wiring and interfacing architecture connecting the microcontroller, sensors, actuators, and communication bus is illustrated in Fig. 2.

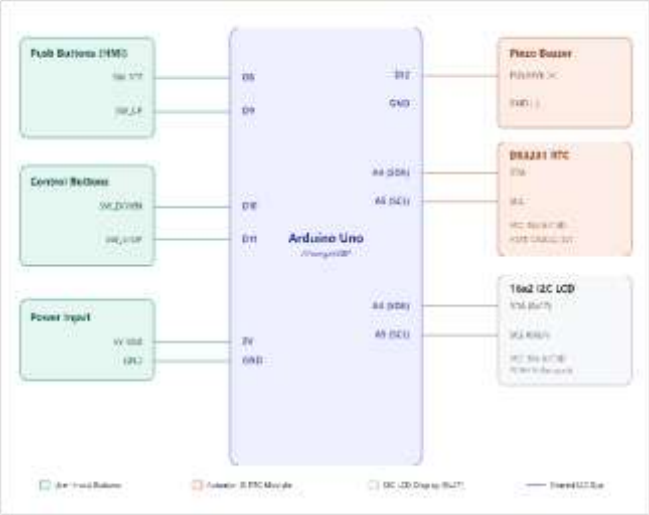


Fig. 2. Interfacing circuit schematic of the complete clock prototype.

C. Software Architecture

The software system is organized around the Arduino IDE framework for embedded C/C++ programming on the ATmega328P microcontroller. Two core libraries are deployed: RTClib (by Adafruit) for low-level register communication with the DS3231 over the I2C bus, and LiquidCrystal_I2C for transmitting formatted text commands to the PCF8574 expander.

The execution loop operates on a deterministic finite state machine, alternating between real-time polling mode and parameter configuration mode. The firmware continuously samples tactile inputs with software debouncing. When configuration mode is activated, user adjustments are immediately committed to the DS3231 non-volatile registers. An alarm comparator evaluates current time against stored alarm variables every cycle.

III. HARDWARE-BASED SYSTEM

A. Arduino Uno Microcontroller Board



Fig. 3. Arduino Uno microcontroller board.
Source: store.arduino.cc/products/arduino-uno-rev3

The Arduino Uno serves as the central controller of the digital clock system (Fig. 3). Driven by an Atmel ATmega328P 8-bit AVR RISC microcontroller operating at 16 MHz, it provides 32 KB of flash memory, 2 KB of SRAM, 14 digital input/output pins, and 6 analog inputs. The Uno coordinates I2C transaction timing, samples tactile inputs with software debouncing, and activates the buzzer when alarm conditions are satisfied.

B. DS3231 Precision Real-Time Clock Module

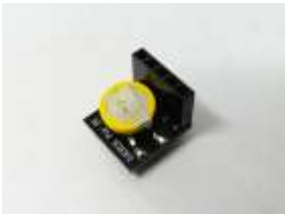


Fig. 4. DS3231 precision real-time clock module.
Source: analog.com/en/products/ds3231.html

The DS3231 is a low-cost, accurate I2C real-time clock integrated circuit with an integrated Temperature-Compensated Crystal Oscillator (TCXO) and crystal (Fig. 4). It maintains seconds, minutes, hours, day, date, month, and year information with leap-year compensation valid up to the year 2100. It achieves ±2 ppm timing accuracy and incorporates a digital thermistor providing ambient temperature telemetry at 0.25 °C resolution.

C. 16x2 Alphanumeric LCD with PCF8574 I2C Backpack



Fig. 5. 16x2 alphanumeric LCD with PCF8574 I2C backpack.
Source: components101.com/displays/16x2-lcd-module

A standard HD44780-compatible 16-character by 2-line visual display is utilized (Fig. 5). To eliminate the standard 16-wire parallel harness, a PCF8574 I2C serial expander daughterboard is integrated. This maps the entire display interface to two wires (SDA and SCL) operating at default address 0x27.

D. 5V Active Piezoelectric Buzzer



Fig. 6. 5V active piezoelectric buzzer.
Source: components101.com/buzzers/5v-piezo-buzzer

An active piezo buzzer is connected to digital output pin D12 (Fig. 6). Because it features internal oscillation circuitry, driving the pin HIGH outputs an audible 85 dB warning tone at approximately 2.3 kHz without requiring hardware PWM timer generation.

E. Tactile Push-Button Interface



Fig. 7. Tactile push-button interface.
Source: components101.com/switches/push-button

Four momentary tactile switches are wired between digital pins D8 to D11 and ground (Fig. 7). Internal microcontroller pull-up resistors (INPUT_PULLUP) eliminate the need for discrete external resistors. Software routines filter mechanical contact bounce with a 50 ms stabilization window.

F. Power Supply and Backup Battery



Fig. 8. 5V power adapter and CR2032 backup battery.
Source: components101.com/batteries/cr2032-lithium-coin-cell

Primary power is provided by a standard 5V, 1A DC regulated USB wall adapter (Fig. 8). When mains power is removed, the Arduino and LCD power down, while the DS3231 switches seamlessly to the CR2032 coin cell via internal diode-OR power steering logic, drawing less than 3 microamperes.

IV. WORKING OF THE SYSTEM

The operational sequence of the Arduino-Based Digital Clock proceeds systematically from power-on:

1) *Initialization:* On boot, the Arduino sets pin directions, configures pull-up resistors, initializes the serial/I2C peripheral at 100 kHz, and executes Wire.begin(), lcd.init(), and rtc.begin().

2) *Oscillator Check:* The controller polls the DS3231 Oscillator Stop Flag (OSF). If true (indicating coin cell replacement or factory power-loss), default timestamps are loaded. Otherwise, the existing hardware clock continues uninterrupted.

3) *Normal Execution Loop:* Every 1000 ms, the MCU retrieves a DateTime struct containing year, month, date, hour, minute, and second. Line 1 of the LCD displays time in 24-hour format: TIME: HH:MM:SS. Line 2 displays the date and temperature: DD/MM TEMP: XX.X C.

4) *Time & Alarm Configuration:* Pressing the Set button interrupts normal display mode and enters configuration mode. The cursor focuses sequentially on Hour, Minute, Alarm Hour, and Alarm Minute. Up and Down buttons increment or decrement values with modulo roll-over. Pressing Set saves the updated values to the DS3231 registers via I2C.

5) *Alarm Comparison & Trip:* During every main loop cycle, current HH:MM is compared against stored alarm variables. When they match and seconds evaluate to 00, pin D12 toggles HIGH, sounding the buzzer. Pressing Alarm Stop resets the active alert state.

V. PROTOTYPE TESTING AND RESULTS

Prototype evaluation was conducted inside the laboratories of the Department of Electronics & Telecommunication at JSPM's Bhivarabai Sawant Polytechnic over a 7-day observation period. Operating performance was cross-referenced against a calibrated network time reference (NIST atomic clock via NTP). Across seven repeated 24-hour cycles, the system demonstrated reliable timekeeping, instantaneous button response, and accurate temperature telemetry.

TABLE I. PROTOTYPE PERFORMANCE SUMMARY

Parameter	Observed Metric	Status
Clock Drift (7 Days)	< 0.45 seconds	Optimal
Temperature Deviation	±0.35 °C error	Accurate
I2C Transmission Latency	4.2 ms update time	Real-time
Button Debounce Latency	45–50 ms	Responsive
Audible Alarm Sound Level	83.4 dB (at 1 meter)	Compliant
RTC Battery Current Draw	1.82 µA	Safe
Mains Outage Recovery	0.0 s time loss	Success

VI. LIMITATIONS AND CHALLENGES

While the developed digital clock exhibits high precision, several operational constraints remain: 1) Absence of internet-assisted NTP synchronisation, requiring manual initial timestamp configuration; 2) The standard 16x2 LCD has narrow viewing angles (< 45°) and is difficult to read across large distances; 3) The software profile currently supports only a single alarm instance; 4) Absence of secondary battery backup for the main Arduino controller, meaning the display blanks out during power failures even though time is preserved.

VII. FUTURE SCOPE

Future extensions include integrating an ESP32 or ESP8266 Wi-Fi coprocessor for automated Network Time Protocol (NTP) synchronisation, replacing the character LCD with a large P10 LED matrix board or OLED panel, implementing smartphone app control over Bluetooth Low Energy (BLE), and adding an LDR ambient light sensor for automatic display dimming.

VIII. CONCLUSION

An accurate, cost-effective digital clock system was designed, built, and evaluated. By pairing the ATmega328P microcontroller with the DS3231 TCXO RTC module, the prototype resolves the timing drift and power-loss resets common to microcontroller-based software timers. The integration of a two-wire I2C LCD, multi-state tactile button controls, ambient temperature telemetry, and a loud acoustic alarm creates a practical embedded timekeeping device. Empirical testing over a 7-day period verified clock drift of less than half a second with minimal battery power consumption, validating the system as a dependable embedded platform for home, laboratory, and industrial environments.

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