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Real-Time Weather Forecasting Using BME280 and STM32 Microcontroller

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***Abstract* - Weather has a significant impact on human activities and important decisions, such as planning a trip, landing an airplane, and planting crops. These decisions are greatly aided by precise weather prediction and monitoring. This study presents the design and construction of a low-cost, mobile weather monitoring and forecasting system capable of gathering, reporting, and storing various meteorological parameters. The system was initially designed using Proteus software and implemented with a BME280 sensor, which measures environmental variables including altitude, wind speed, precipitation, temperature, pressure, humidity, and heat index. This sensor was integrated with an STM32-bit microcontroller that processes the weather parameters. A storage module was embedded to store data, while real-time weather conditions are displayed on an LCD screen. The system processes the weather information and displays the current weather conditions on the LCD. The corresponding data, stored in the embedded storage system, is collected and presented in this study. The results demonstrate the system's ability to accurately present real-time weather conditions based on sensor data. The constructed system is portable, cost-effective, and accurate in providing weather information across different locations.**
***Keywords*: Weather Monitoring, Forecasting System, BME280 Sensor, STM32 Microcontroller, Real-Time Data**

I. INTRODUCTION

Many daily human activities are influenced by atmospheric conditions, which vary over time and can be affected by numerous factors. This has led to the development of weather science, which aims to provide prior knowledge of atmospheric conditions to enable informed planning and the adoption of precautionary measures that improve quality of life [1]. Weather forecasting involves predicting weather patterns by applying physical principles, supplemented by statistical and empirical techniques, and may be carried out for specific locations over defined periods [2].

In this research, we design a weather system that enables users to monitor, collect, store, and forecast weather conditions using a standalone hardware setup without requiring additional installations. The system utilizes sensors capable of measuring humidity, temperature, pressure, precipitation, wind speed, altitude, and heat index. These measurements can be used to program actions for electrical devices within a network based on environmental data. The hardware setup consists of a portable electronic device interfacing with a microcontroller. It monitors real-time conditions through the sensors, allowing users to determine the current state of the weather [3]. Most existing advanced weather forecasting systems require extensive infrastructure and high operational capacity. This underscores the complexity of weather prediction, which relies on efficient observation, data analysis by computers and meteorologists, and rapid communication systems. Weather forecasting has existed for a long time and has evolved through various approaches, including traditional and professional methods. Earlier weather prediction methods were based on personal experience without experimental validation [4]. Given that several critical decisions, such as those related to agriculture [5], [6], depend on accurate forecasting, achieving high precision is essential.

Kedia [7] developed a localized weather monitoring system that used sensors such as the DHT11 and BMP180 to measure variables like temperature, humidity, pressure, wind speed, and precipitation. However, the system exhibited an average error margin of approximately 10%, making it less reliable in predicting accurate weather conditions.

Ukhurebo [8] proposed a machine learning-based weather monitoring system using an affordable Arduino-based setup. This design included an Arduino Mega 2560 microcontroller, multiple weather sensors, a real-time data logger, and an LCD display. The system measured parameters such as temperature, humidity, pressure, light intensity, dew point, and altitude. Its readings were consistent with those from standard weather systems.

Kapoor [2] implemented a weather station using the Internet of Things (IoT) to enhance the accuracy of weather prediction. The system measured climate parameters such as temperature, humidity, wind velocity, and precipitation. Additionally, it featured cloud data storage via Wi-Fi using a Raspberry Pi Zero board, enabling users to access weather information remotely through cloud computing. Gaurav *et al.,* [9] developed a real-time weather prediction system that integrated IoT and machine learning technologies. The system, applicable in environments such as stadiums, agricultural fields, schools, and industries, used key weather parameters-temperature and humidity (measured by DHT11), and light intensity (measured by an LDR). Sensor data was transmitted to the ThingSpeak cloud server via the NodeMCU and ESP8266-01 Wi-Fi module [10], and displayed on a customized HTML webpage. The system used previously recorded data to train a machine learning model, which was deployed using a Jupyter notebook in a Python environment. Real-time sensor readings were used to validate the model, with LED indicators flashing to display predicted values. In [11], a low-cost, user-friendly neighborhood weather station was introduced. This station employs inexpensive sensors to improve the accessibility and usability of environmental monitoring. It effectively measures various environmental parameters such as temperature, air pressure, relative humidity, CO_2 levels, and particulate matter (PM1, PM2.5, PM10), which can be remotely monitored. This work aims to design a portable, low-cost system capable of accurately monitoring, collecting, storing, and forecasting real-time weather conditions. The microcontroller autonomously controls devices based on data received from the sensor module.

A. STM32F401 32-BIT Microcontroller

The STM32F401 32-bit microcontroller, commonly referred to as the "Blue Pill," serves as the core of the system, providing intelligence through software execution [12]. It was selected due to its substantial FLASH memory (256 KB), RAM (64 KB), and wide range of peripheral interfaces. Another key factor was the requirement to develop code in C/C++, which necessitates a microcontroller capable of meeting resource demands-particularly because object-oriented programming languages require a significant amount of RAM. Additionally, the need for precise mathematical computations influenced the choice, as only 32-bit systems can accurately handle 64-bit numerical calculations without introducing errors. In the proposed design, 32-bit computations and variables were utilized to enhance the system's throughput without compromising the accuracy of the computed parameters.

B. BME280 Sensor

The BME280 is a sensor used to detect atmospheric weather conditions. It is capable of measuring three primary weather parameters-temperature, humidity, and pressure-as well as additional environmental phenomena such as cloudiness, precipitation, and sunlight. In essence, the BME280 is essential for extracting environmental weather parameters and serves as a transducer capable of sensing and converting the parameters of interest.

The BME280 was selected to fulfill the objectives of this research work. Its compact size and low power consumption make it well-suited for mobile applications, which are key design constraints. This integrated environmental sensor combines high-linearity temperature, humidity, and pressure sensing capabilities in a single device. Developed by Bosch, the BME280 represents the next generation of digital environmental sensors and serves as a successor to the BMP180, BMP085, and BMP183 sensors.

C. LM2576 DC-DC (Step-down Switching Regulator)

An LM2576 voltage regulator was used in the design. The system was powered by a DC source; however, an AC source could also be used, provided it is rectified before interfacing with the board. The input DC voltage was regulated down to 5 V, as required by the system components. A high-efficiency DC-DC converter was employed for this purpose. Regulation was achieved using a switched-mode power supply (SMPS), which offers significantly higher efficiency compared to a linear regulator. The power losses associated with a switching regulator are considerably lower than those of a linear regulator, thereby ensuring prolonged system operation depending on the battery's capacity and the power consumed. If a linear regulator had been used, a significant portion of the power drawn from the battery would have been lost as heat, reducing overall system efficiency

D. 4-Row 20-Column Alphanumeric Liquid Crystal Display

One of the most commonly used components for alphanumeric output in processor-based circuits is the liquid crystal display (LCD). LCDs are favored for their low cost, compact size, and ease of integration directly onto circuit boards. Based on connectivity, LCDs are classified as either parallel or serial. While serial LCDs require fewer input/output resources, they are generally more expensive and operate at slower speeds compared to parallel types. This project utilized a parallel-driven LCD based on the Hitachi HD44780 character-based controller, which is the most widely adopted controller for microcontroller-based LCD applications.

Displaying computed results to the user is often necessary, and an LCD provides a suitable solution. Although various types of LCDs are available, this study employed a basic alphanumeric LCD capable of displaying four lines of 20 characters each [12].

The LCD was selected based on the following criteria:

1. Portability of the system
2. Ease of compatibility with the microcontroller (i.e., low port requirement and plug-and-play capability)
3. Clear and effective display of information

The 20×4 alphanumeric LCD module was chosen for its compact form factor and support for 4-bit communication mode, which helps conserve the microcontroller's I/O pins. In 4-bit interface mode, only the upper four data lines (D4 to D7) are used for data transmission. Data is sent as two 4-bit nibbles, reducing the number of required data lines and improving I/O efficiency.

II. MATERIAL AND METHOD

A.Hardware Design

To achieve the intended outcome of this research, the system requirements, design criteria, and installation methods were carefully considered during the design and development of the device. Prior to assembling the various units, the device architecture was divided into subunits or modules, each of which was individually planned and evaluated. Fig.1 illustrates the different functional blocks of the system.

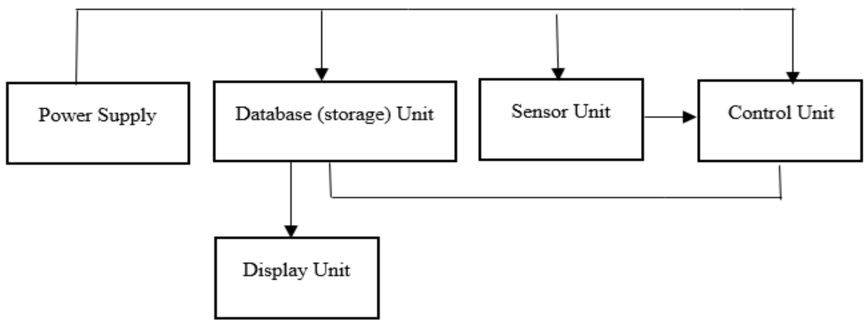

Fig.1 Block Diagram of Weather System Design

B. Power Supply Unit

This unit comprises a 12 V power cable (AC adapter), an LM2576 DC-DC step-down switching regulator, push buttons, a yellow LED, and a 100-ohm resistor, as shown in Fig. 2. The LM2576 is a voltage regulator that steps down the input DC voltage to 5 V, as required by the system components. The four push buttons serve various functions: powering the system on and off, selecting menu options, and powering the LCD display. The yellow light-emitting diode (LED) acts as an indicator, showing whether the system is powered on or off. The 100-ohm resistor serves as a current-limiting resistor, reducing the current flowing through the LED to prevent damage.

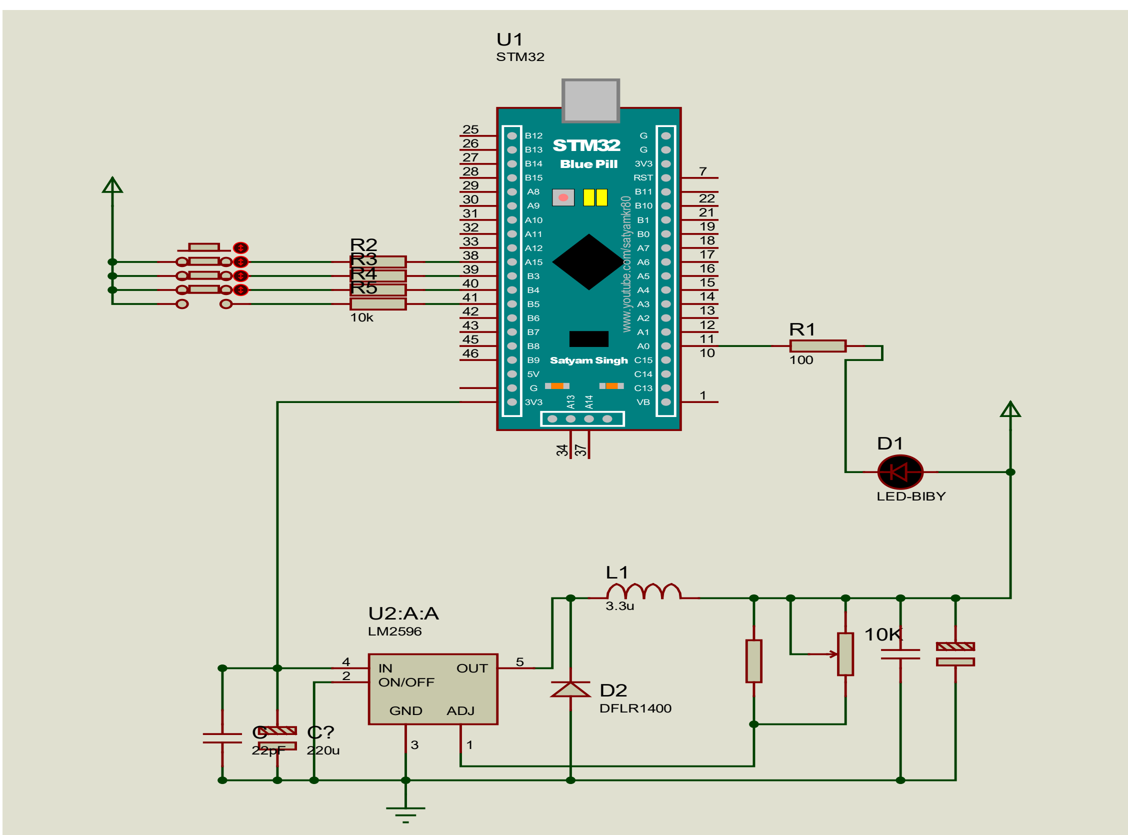

Fig. 2 Power Unit Circuit

In this unit, the four push buttons are individually connected in series with 10-ohm resistors. The positive terminals of the push buttons are connected to the active power input (VCC), while the other terminals are connected in series with resistors R2, R3, R4, and R5. These resistors are connected to pins 38, 39, 40, and 41 of the STM32 microcontroller, respectively. The power supply unit also includes the LED indicator. The LED has two terminals: the positive terminal is connected to the input power (VCC), and the negative terminal is connected in series with resistor R1 and to pin 10 of the micro controllers. This configuration provides a visual power-on indication. The third key component is the LM2576 DC-DC step-down switching regulator, which features five external pins: IN (Pin 4), OUT (Pin 5), ON/OFF (Pin 2), ADJUST (Pin 1), and GND (Pin 3). Pin 4 (IN) is the positive input and is connected in parallel with 220 µF and 100 µF capacitors to the unregulated DC input of the STM32 microcontroller. Pins 2 and 3 are grounded, as they are negatively charged. Pin 5 (OUT) is connected in series with an inductor and in parallel with a diode to produce the regulated 5 V output. To protect the input section of the regulator from reverse polarity damage, a 1N4001 diode was used, followed by a 1000 µF, 25 V capacitor for voltage stabilization. For high-frequency rectification, a 1N5818 Schottky diode was used instead of the datasheet-recommended 1N5822 due to its availability and suitability for the design requirements. The 5 V regulated output was further stabilized by a 2200 µF capacitor to prevent voltage sags during operation. Such voltage fluctuations could shift the resonant frequency of the LC oscillator, potentially causing spurious false metal detection alerts.

C. Database unit

The database unit serves as the storage component of the system and comprises a Multimedia Card (MMC) and a Secure Digital (SD) card. Both are flash memory-based storage devices and are physically similar. These flash memory cards are used to store the weather data collected by the system. In the display unit circuit, the SD card features seven primary pins, which are connected to Port B (pins PB12 to PB15) of the STM32 microcontroller-specifically, pins 25, 26, 27, and 28. The pin configuration of the SD card, as illustrated in Fig. 3, is as follows:

1. GND - Ground terminal
2. VCC - Voltage input
3. CS - Chip Select
4. DO - Data Out
5. DI - Data In
6. CLK - Clock

Pins 25 to 28 of the microcontroller are specialized pins on Port B configured for SPI2 (Serial Peripheral Interface 2). SPI is a synchronous serial communication protocol that enables data exchange between two devices, designated as master and slave, one bit at a time. It operates in full-duplex mode, meaning data can be transmitted and received simultaneously.

The STM32 microcontroller pins are configured as follows:

1. Pin 25 (PB12) - Slave Select (SS): This control line is used by the SPI bus to select one or more slave devices connected to a single master.
2. Pin 26 (PB13) - Serial Clock (SCK): This pin generates the clock pulses used to synchronize data transfer between devices.
3. Pin 27 (PB14) - Master in Slave Out (MISO): This pin receives data from the slave device to the master.
4. Pin 28 (PB15) - Master Out Slave In (MOSI): This pin sends data from the master to the slave device.

D. Interfacing of the STM32 with the SD card connection

1. The CS pin of the SD card is connected to the **SS** pin (Pin 25) of the STM32 microcontroller.
2. The DO pin of the SD card is connected to Pin 27 of the microcontroller.
3. The DI pin of the SD card is connected to Pin 26 of the STM32 microcontroller.
4. The CLK pin of the SD card is connected to Pin 28 of the STM32 microcontroller.
5. The VCC pin of the MicroSD card module can be connected to either 3.3 V or 5 V, depending on the module specifications.

E. Sensor Unit

The sensor unit consists of a BME280 sensor, as shown in Fig. 4. This sensor is capable of detecting more than three weather parameters-unlike many conventional sensors-including temperature, atmospheric pressure, humidity, precipitation, sunshine, and cloudiness. The BME280 operates within a temperature range of -40°C to 85°C, pressure range of 300 to 1100 hPa, and relative humidity accuracy of ±3%. The BME280 sensor includes multiple pins: GND, VCC (3.3 V), SDI/SDA, and SCL. The following outlines the pin connections for interfacing the BME280 with the STM32 microcontroller:

1. GND - This is the ground pin of the BME280, connected to the ground terminal of the STM32 microcontroller.
2. VCC - This is the power input pin, connected to the 3.3 V output of the microcontroller.
3. SDI/SDA - This pin serves as the serial data line for I^2C communication and as a bidirectional data line for SPI communication. The SDA/SDI pin of the sensor is connected to Pin 43 (PB7/SDA) of the STM32 microcontroller. This connection enables bidirectional data transmission, allowing the system to read and write weather data from the sensor.
4. SCL - This is the serial clock line for I^2C communication. It is an output pin that receives clock pulses from the controller. These pulses synchronize the data transmission between the sensor and the microcontroller.

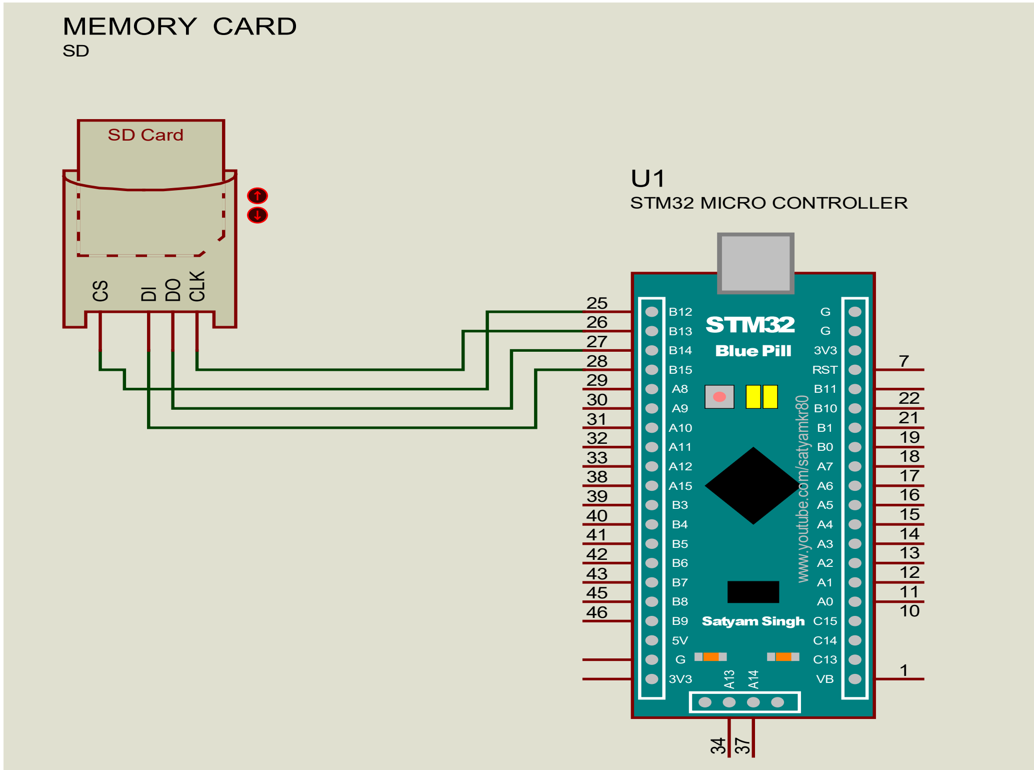

Fig.3 Database Unit Circuit

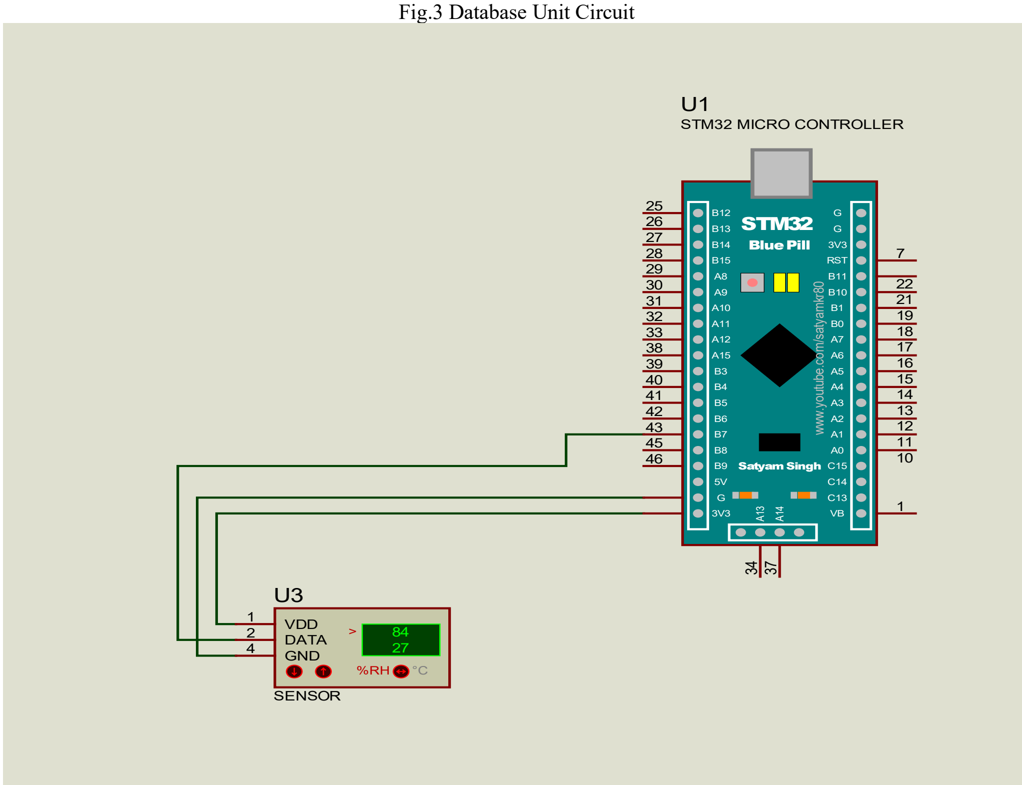

Fig. 4 Sensor Unit Circuit

F. Control Unit

The control unit consists of a 32-bit microcontroller, the STM32F401, as shown in Fig. 5. The microcontroller interfaces with both the sensor and the SD card. It was programmed using the C++ programming language. The implemented algorithm continuously acquires readings from the sensor unit and display unit, and transmits the collected data to the database unit. The control unit circuit comprises the SD card and BME280 sensor interfaced with the microcontroller.

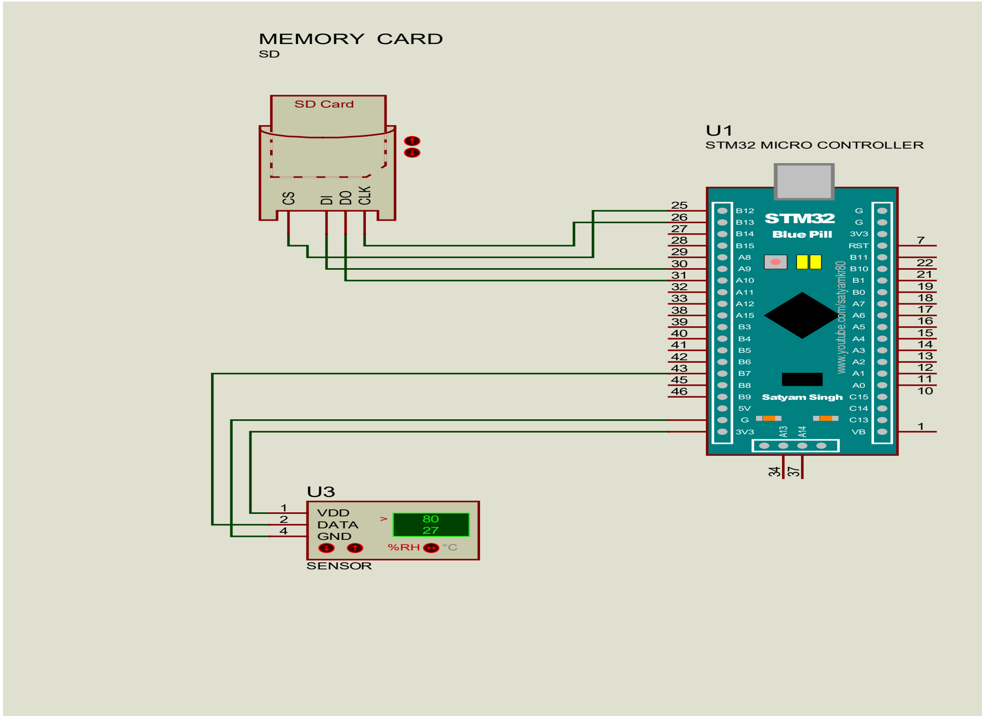

Fig.5 Control Unit Circuit

G. Display Unit

This unit includes a component called a Liquid Crystal Display (LCD), as shown in Fig. 6. In this unit, the date and weather menu are displayed on the screen. The LCD used is a 20×4 alphanumeric display, capable of showing four rows with twenty characters per row.

The display unit presents the output data stored in the database unit-that is, the data acquired from the sensor unit. The display unit circuit is responsible for showing the weather information detected by the sensor. It functions in coordination with both the sensor unit and the database unit.

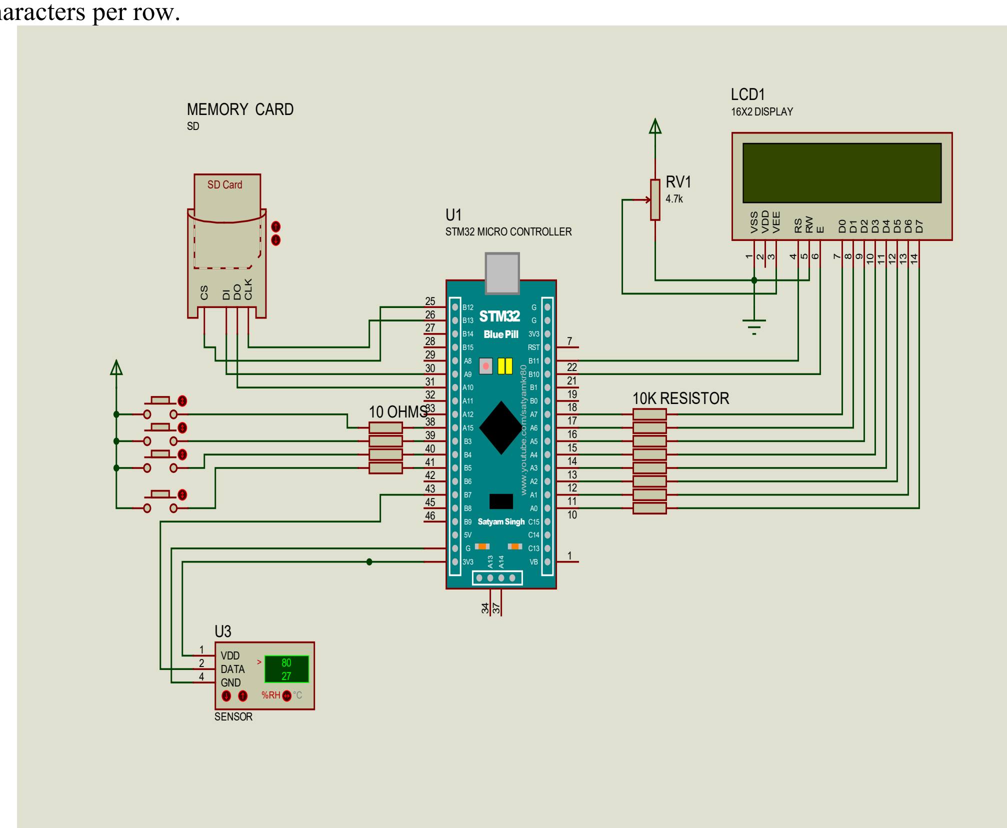

Fig.6 Display Unit Circuit

The complete circuit of the weather forecast station, which consists of the power, database, sensor, control, and display units, is shown in Fig. 7. The figure clearly illustrates how the electronic components are labeled and neatly assembled.

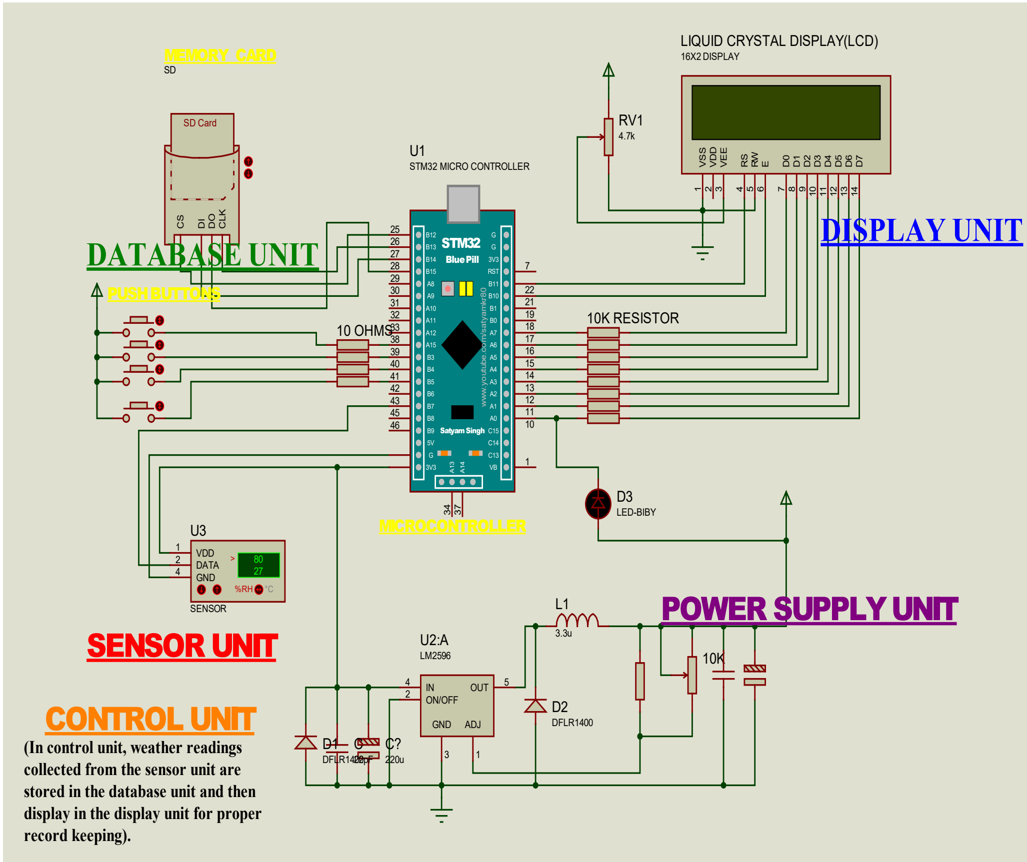

Fig.7 Integrated Circuit of Weather System Design

III. EXPERIMENTAL RESULT

The designed weather forecast system was constructed, as shown in Fig. 8, and deployed at the Nigerian Air Force Base in Kaduna, Nigeria, where a mini airport is located. The system successfully monitored real-time weather conditions and collected meteorological parameters using a sensing device called the BME280. It continuously stored up-to-date weather information-including temperature, pressure, wind speed, humidity, altitude, and precipitation-on a memory card.

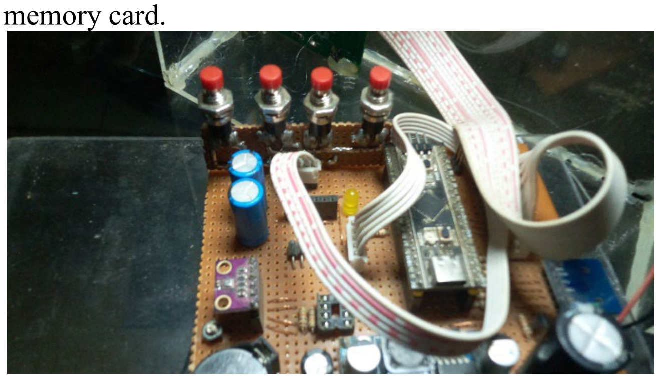

Fig.8 Portable Weather Forecasting System

The completed circuit was set up at the Nigerian Air Force (NAF) Base in Kaduna State. The system was configured to generate data samples at a rate of one sample per second. It was allowed to operate continuously for seven days, with each day's data extracted and recorded separately. The data obtained were stored in CSV format. The weather system recorded three distinct stages of weather conditions: acquiring, stable, and unstable.

A. Acquiring Stage

At the initial stage of powering up the weather monitoring system, the term “weather condition acquiring data” refers to the process of collecting real-time atmospheric data. This data includes key meteorological parameters such as precipitation, pressure, wind speed, temperature, and humidity. The system utilizes the collected data to establish a reference point for the current weather conditions, which is essential for initializing forecasting models. By integrating this real-time information, the system enables the forecasting models to effectively simulate weather patterns and predict upcoming conditions. This initial data acquisition phase forms the foundation for generating reliable weather forecasts. Fig. 9. Sample of meteorological data obtained during the initial (acquiring) stage by the weather forecasting system.

1	DATE	TIME	PRESSURE	ALTITUDE(	TEMPERATURE(	WEATHER CONDITION	HEAT_INDEX	WIND SPEED	HUMIDITY	PRECIPITATION	DELTa_PRESSURE(KPa)
2	18 09 2023	17:39:52	93.93187	718.705	27.57	*acquiring*	28.243	14.155	53.285	17.218	0
3	18 09 2023	17:40:13	93.92983	718.752	27.5	*acquiring*	28.188	14.177	53.569	17.24	0
4	18 09 2023	17:40:33	93.93009	718.52	27.41	*acquiring*	28.081	14.079	53.458	17.126	0
5	18 09 2023	17:40:54	93.93041	718.26	27.31	*acquiring*	27.953	13.938	53.211	16.961	0
6	18 09 2023	17:41:15	93.93021	718.019	27.2	*acquiring*	27.809	13.772	52.906	16.766	0
7	18 09 2023	17:41:36	93.9297	717.789	27.08	*acquiring*	27.662	13.595	52.572	16.557	0
8	18 09 2023	17:41:56	93.93042	717.418	26.96	*acquiring*	27.512	13.417	52.25	16.343	0
9	18 09 2023	17:42:17	93.93216	716.951	26.83	*acquiring*	27.369	13.233	51.891	16.12	0
10	18 09 2023	17:42:38	93.93089	716.77	26.7	*acquiring*	27.229	13.054	51.553	15.9	0

Fig. 9 Initial Stage of Data Acquisition

B. *Stable Stage*

During the stable stage of the weather forecasting system- following the initial data collection - “stable weather condition data” refers to the consistent and reliable set of atmospheric information accumulated and verified over time. This data typically reflects steady weather patterns with minimal fluctuations in key variables such as temperature, pressure, wind speed, and humidity. At this stage, the system has processed the initial real-time data and adjusted its models to account for short-term variations, enabling it to produce more accurate and stable forecasts. The system’s output during this phase provides clearer and more predictable weather forecasts. This stage ensures that the forecasting system operates with a higher degree of certainty and precision. Fig. 10. Sample of meteorological data obtained during the stable stage by the weather forecasting system.

36	DATE	TIME	PRESSURE	ALTITUDE(	TEMPERATURE(	WEATHER CONDITION	HEAT_INDEX	WIND SPEED	HUMIDITY	PRECIPITATION	DELTa_PRESSURE(KPa)
37	18 09 2023	17:51:57	93.93152	710.5	24.12	stable weather	23.875	10.808	49.348	12.848	0.002
38	18 09 2023	17:52:18	93.93259	710.235	24.05	stable weather	23.798	10.757	49.308	12.772	0.002
39	18 09 2023	17:52:39	93.93152	710.167	23.98	stable weather	23.719	10.706	49.275	12.696	0.002
40	18 09 2023	17:52:59	93.93131	710.018	23.91	stable weather	23.641	10.655	49.237	12.62	0.002
41	18 09 2023	17:53:20	93.93238	709.761	23.84	stable weather	23.57	10.61	49.207	12.552	0.002
42	18 09 2023	17:53:41	93.93138	709.701	23.78	stable weather	23.498	10.566	49.181	12.485	0.002
43	18 09 2023	17:54:02	93.9307	709.62	23.72	stable weather	23.43	10.523	49.154	12.421	0.002
44	18 09 2023	17:54:22	93.9301	709.52	23.65	stable weather	23.357	10.479	49.131	12.353	0.002
45	18 09 2023	17:54:43	93.92934	709.441	23.59	stable weather	23.29	10.438	49.109	12.291	0.002
46	18 09 2023	17:55:04	93.93057	709.182	23.53	stable weather	23.222	10.396	49.083	12.227	0.002
47	18 09 2023	17:55:24	93.93107	708.993	23.47	stable weather	23.157	10.357	49.058	12.166	0.002
48	18 09 2023	17:55:45	93.93122	708.84	23.42	stable weather	23.093	10.315	49.021	12.102	0.002
49	18 09 2023	17:56:06	93.93192	708.639	23.36	stable weather	23.029	10.275	48.994	12.04	0.002
50	18 09 2023	17:56:27	93.9309	708.593	23.3	stable weather	22.963	10.238	48.982	11.982	0.002

Fig.10 Stable Weather Acquired Data

A. Unstable Stage

The term “unstable stage” of weather conditions refers to a period during which atmospheric parameters are subject to abrupt changes-particularly when there is a significant difference in temperature or pressure between the ground and the upper atmosphere. During this stage, warm air near the surface rises, potentially creating turbulent conditions that may lead to the formation of clouds, thunderstorms, and other severe weather events. Such instability is often associated with an increased likelihood of sudden weather changes, including heavy rainfall, strong winds, intense sunshine, or severe storms. The output of the designed weather forecasting system during this stage captured four distinct weather conditions: sunny, windy, cloudy, and rainy. Fig. 11. Sample of meteorological data indicating the unstable weather stage and the detected weather condition (rainy).

1107	DATE	TIME	PRESSURE	ALTITUDE(	TEMPERA	WEATHER	HEAT_IND	WIND SPE	HUMIDITY	PRECIPITATION	DELTa_PRESSURE(KPa)	Weather Output
1108	19 09 2023	0:01:30	94.24641	671.1	19.84	Unstable	19.281	9.185	53.676	10.171	0.002	Rainy
1109	19 09 2023	0:01:51	94.24824	670.931	19.84	Unstable	19.281	9.185	53.677	10.172	0.002	Rainy
1110	19 09 2023	0:02:12	94.24698	671.048	19.84	Unstable	19.281	9.185	53.678	10.172	0.002	Rainy
1111	19 09 2023	0:02:32	94.24783	670.977	19.85	Unstable	19.288	9.189	53.68	10.178	0.002	Rainy
1112	19 09 2023	0:02:53	94.2474	671.024	19.85	Unstable	19.287	9.188	53.679	10.177	0.002	Rainy
1113	19 09 2023	0:03:14	94.24738	671.029	19.85	Unstable	19.292	9.191	53.68	10.182	0.002	Rainy
1114	19 09 2023	0:03:34	94.24749	671.023	19.85	Unstable	19.292	9.191	53.678	10.181	0.002	Rainy
1115	19 09 2023	0:03:55	94.24706	671.063	19.85	Unstable	19.292	9.191	53.68	10.182	0.002	Rainy
1116	19 09 2023	0:04:16	94.2471	671.059	19.85	Unstable	19.292	9.191	53.681	10.182	0.002	Rainy
1117	19 09 2023	0:04:37	94.2482	670.955	19.85	Unstable	19.292	9.191	53.68	10.182	-0.001	Rainy
1118	19 09 2023	0:04:57	94.24722	671.049	19.85	Unstable	19.296	9.193	53.681	10.185	-0.001	Rainy
1119	19 09 2023	0:05:18	94.24633	671.151	19.86	Unstable	19.303	9.197	53.681	10.191	-0.001	Rainy
1120	19 09 2023	0:05:39	94.24646	671.14	19.86	Unstable	19.303	9.196	53.68	10.191	-0.001	Rainy

Fig. 11 Data Acquired for Rainy Weather (unstable)

Fig. 12 Sample of meteorological data indicating the unstable weather stage and the detected weather condition (windy).

47009	DATE	TIME	PRESSURE	ALTITUDE(	TEMPERATURE(	WEATHER CONDITION	HEAT_INDEX	WIND SPEED	HUMIDITY	PRECIPITATION	DELTa_PRESSURE(KPa)	WEATHER OUTPUT
47010	30 09 2023	0:12:53	94.16747	677.098	19.28	unstable weather	18.767	9.536	57.593	10.706	-0.027	Windy
47011	30 09 2023	0:13:14	94.16661	677.174	19.28	unstable weather	18.768	9.541	57.62	10.713	-0.027	Windy
47012	30 09 2023	0:13:35	94.16732	677.109	19.28	unstable weather	18.769	9.545	57.648	10.72	-0.027	Windy
47013	30 09 2023	0:13:55	94.16696	677.14	19.28	unstable weather	18.767	9.549	57.677	10.725	-0.027	Windy
47014	30 09 2023	0:14:16	94.16762	677.073	19.27	unstable weather	18.764	9.551	57.705	10.73	-0.027	Windy
47015	30 09 2023	0:14:37	94.16811	677.03	19.27	unstable weather	18.765	9.556	57.73	10.737	-0.027	Windy
47016	30 09 2023	0:14:57	94.16807	677.029	19.27	unstable weather	18.766	9.56	57.756	10.743	-0.027	Windy
47017	30 09 2023	0:15:18	94.16679	677.154	19.28	unstable weather	18.769	9.565	57.78	10.752	-0.027	Windy
47018	30 09 2023	0:15:39	94.16637	677.183	19.28	unstable weather	18.769	9.568	57.798	10.756	-0.027	Windy
47019	30 09 2023	0:16:00	94.16748	677.077	19.27	unstable weather	18.767	9.57	57.815	10.758	-0.027	Windy
47020	30 09 2023	0:16:20	94.16765	677.079	19.28	unstable weather	18.774	9.576	57.831	10.768	-0.027	Windy

Fig.12 Windy Weather Data

Fig. 13 Sample of meteorological data indicating the unstable weather stage and the detected weather condition (cloudy).

5339	DATE	TIME	PRESSURE	ALTITUDE(	TEMPERA	WEATHER	HEAT_IND	WIND SPE	HUMIDITY	PRECIPITATION	DELTa_PRESSURE(KPa)	WEATHER OUTPUT
5340	20 09 2023	0:22:53	94.13962	680.896	19.81	Unstable	19.201	8.862	51.879	9.635	0	Cloudy
5341	20 09 2023	0:23:14	94.13916	680.939	19.81	Unstable	19.203	8.864	51.888	9.639	0	Cloudy
5342	20 09 2023	0:23:35	94.13925	680.954	19.82	Unstable	19.212	8.869	51.893	9.648	0	Cloudy
5343	20 09 2023	0:23:55	94.13919	680.96	19.82	Unstable	19.213	8.871	51.9	9.65	-0.002	Cloudy
5344	20 09 2023	0:24:16	94.14121	680.773	19.82	Unstable	19.213	8.871	51.903	9.651	-0.002	Cloudy
5345	20 09 2023	0:24:37	94.14185	680.714	19.82	Unstable	19.213	8.872	51.906	9.652	-0.002	Cloudy
5346	20 09 2023	0:24:58	94.14291	680.63	19.83	Unstable	19.221	8.876	51.908	9.659	-0.002	Cloudy
5347	20 09 2023	0:25:18	94.14255	680.661	19.83	Unstable	19.22	8.876	51.914	9.66	-0.002	Cloudy
5348	20 09 2023	0:25:39	94.14297	680.635	19.83	Unstable	19.224	8.879	51.918	9.665	-0.002	Cloudy
5349	20 09 2023	0:26:00	94.14291	680.638	19.83	Unstable	19.224	8.88	51.924	9.666	-0.002	Cloudy
5350	20 09 2023	0:26:20	94.14327	680.606	19.83	Unstable	19.225	8.881	51.931	9.668	-0.002	Cloudy

Fig.13 Cloudy Weather Information

Fig. 14 Sample of meteorological data indicating the unstable weather stage and the detected weather condition (sunny).

7587	DATE	TIME	PRESSURE	ALTITUDE(	TEMPERATURE(	WEATHER CONDITION	HEAT_INDEX	WIND SPEED	HUMIDITY	PRECIPITATION	DELTa_PRESSURE(KPa)	WEATHER OUTPUT
7588	20 09 2023	13:11:44	94.10954	708.474	30.44	unstable	32.835	17.385	55.942	20.661	-0.016	Sunny
7589	20 09 2023	13:12:05	94.10806	708.66	30.46	unstable	32.87	17.406	55.954	20.682	-0.016	Sunny
7590	20 09 2023	13:12:26	94.10691	708.824	30.48	unstable	32.913	17.43	55.963	20.705	-0.016	Sunny
7591	20 09 2023	13:12:46	94.10465	709.086	30.5	unstable	32.948	17.448	55.963	20.723	-0.016	Sunny
7592	20 09 2023	13:13:07	94.10375	709.217	30.52	unstable	32.987	17.47	55.972	20.745	-0.016	Sunny
7593	20 09 2023	13:13:28	94.10462	709.185	30.54	unstable	33.028	17.493	55.98	20.767	-0.016	Sunny
7594	20 09 2023	13:13:49	94.10125	709.549	30.56	unstable	33.061	17.51	55.979	20.784	-0.016	Sunny
7595	20 09 2023	13:14:09	94.1018	709.541	30.58	unstable	33.096	17.53	55.988	20.803	-0.016	Sunny
7596	20 09 2023	13:14:30	94.10101	709.668	30.6	unstable	33.14	17.554	55.996	20.827	-0.016	Sunny
7597	20 09 2023	13:14:51	94.10234	709.585	30.62	unstable	33.175	17.573	56.001	20.846	-0.016	Sunny
7598	20 09 2023	13:15:11	94.10166	709.693	30.64	unstable	33.211	17.591	56.001	20.863	-0.016	Sunny
7599	20 09 2023	13:15:32	94.10429	709.484	30.66	unstable	33.245	17.61	56.005	20.881	-0.016	Sunny
7600	20 09 2023	13:15:53	94.10397	709.565	30.68	unstable	33.282	17.629	56.008	20.9	-0.016	Sunny

Fig.14 Sunny Weather Information

IV. CONCLUSION

In this paper, a weather monitoring system was successfully designed and implemented to detect and record essential meteorological parameters such as altitude, precipitation, wind speed, temperature, humidity, pressure, and heat index. By utilizing the BME280 sensor for precise environmental measurements and interfacing it with an STM32 microcontroller, the system effectively captures and processes real-time weather data. The integration of an LCD display allows users to view current conditions instantly, while a memory card provides reliable long-term data storage for further analysis. Additionally, the system incorporates a robust condition-detection algorithm that accurately classifies environmental data into four distinct weather conditions: windy, sunny, cloudy, and rainy. This feature enhances the system's ability to provide meaningful insights into local weather patterns. With potential applications in agriculture, environmental research, aviation, and outdoor activity planning, the system presents a reliable, compact, and cost-effective solution for continuous weather monitoring. Future enhancements may include the addition of more sensors, wireless communication for remote access, and real-time data analytics to improve forecasting accuracy and support decision-making processes.

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Use of Artificial Intelligence (AI)-Assisted Technology for Manuscript Preparation
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