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Smart Flow Computer: Leveraging IoT for Accurate and Efficient Gas Flow Measurement in The Oil and Gas Industry

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Abstract

Accurate measurement of gas flow is essential in the oil and gas sector, typically obtained using orifice sensors and based on AGA report 3 standards. Therefore, this research aimed to obtain Flow Computer configuration to meet the increasing need for accurate and efficient remote meter readings. The experiment was carried out by integrating IoT technology for real-time monitoring through complicated calculations based on AGA report 3 namely Smart Flow Computer. Smart Flow Computer was also assessed which used an ESP32 microcontroller and a current-to-voltage converter, against the Kelton Flocalc software. The results showed that verification, differential pressure, and temperature outputs had relative deviation ranging from 0 % to 0.23 %. The inaccuracies were attributed to signal impurity, measurement uncertainty, and equipment resolution. The ESP32's 12-bit ADC with 4096 levels had a deviation of less than 1%. This was different from the 14-bit ADC found in conventional Flow Computer, with 16,384 levels. This research showed that the ESP32-based Smart Flow Computer had high accuracy with minimal deviation, meeting the standards set by the metrology directorate. The method showed potential to revolutionize remote gas flow monitoring in the oil and gas industry. By integrating IoT technology and advanced microcontrollers, this innovative solution offered real-time data acquisition and reliable calculations, significantly improving operational efficiency and precision.

1. Introduction

Metering systems are essential in the oil and gas industry [1] because of the need for accurate and effective flow measurement to manage the production process or transactions [2] [3] . In this context, Flow Computer is the primary component of the metering system [4]. Flow Computer is a specialized device or computer developed primarily to calculate and quantify flow of fluid [5], particularly gas. Typically, the operation of Flow Computer is based on the American Gas Association (AGA) standard [6]. Fig.1 shows the fundamental configuration of Flow Computer, where the device processes actual measurement from the pressure transmitter (PT), differential pressure transmitter (DPT), and temperature transmitter (TT) to convert the readings into standard volume values. These computations are based on the pressure and temperature conditions mutually agreed upon by the seller and buyer, typically standardized at 1 atmosphere of pressure and 60 degrees Fahrenheit [7].

The orifice sensor method is used to measure flow of gas. In this method, a sensor is placed within the pipe to create a difference in pressure, which can be converted into a value representing the rate of flow [8]. By using the formula stated in AGA Standard Report 3, the conversion process is carried out [9]. This formula, namely AGA 3 standard, ensures accurate estimations of gas flow rate [10], showing that production and transactions adhere to defined norms [11].

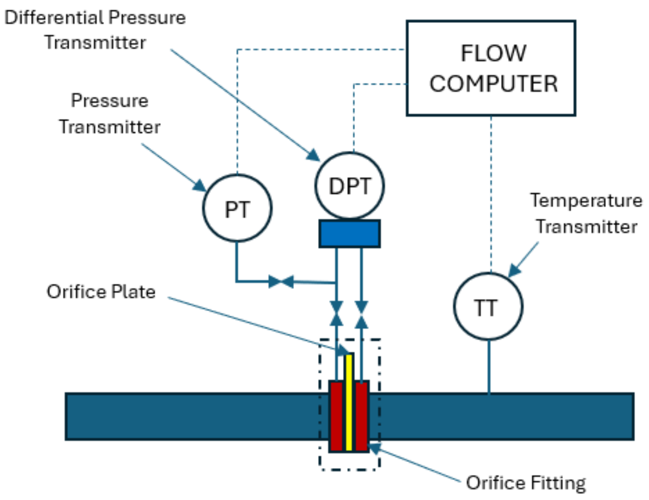


Fig. 1 *Flow measurement configuration*

Contemporary industries are rapidly implementing IoT (Internet of Things)-based systems to improve data collection, real-time monitoring, and control [12]. This shows the need to develop a "Smart Flow Computer" in flow measurement systems [13]. By combining state-of-the-art sensor technology with IoT connectivity, Smart Flow Computer allows for more intelligent as well as efficient monitoring, measurement, and control of gas flow rates. Furthermore, Smart Flow Computer revolutionizes gas flow monitoring by providing customers with instant access to real-time data through computer, regardless of their location, including remote areas [14]. Extensive data from this computer facilitates in-depth analysis, enabling organizations to promptly detect any faults or anomalies in gas flow. The technology reduces the occurrence of mistakes made by humans in the process of measuring flow, improves precision, and results in substantial savings in both time and expenses. Therefore, this research introduced an innovative method of setting up Flow Computers to meet the increasing need for precise and effective remote meter reading. Smart Flow Computer was proposed, leveraging IoT technology for real-time monitoring and incorporating complex calculations based on AGA 3 reports. The system establishes a new benchmark for flow measurement systems.

The experiment was carried out using the ESP32 [15]microcontroller and a current-to-voltage module as a configuration for processing measurement signals. The ESP32 enables remote real-time monitoring through complicated calculations based on AGA 3 and IoT technology. This system configuration achieves a high level of accuracy, meeting the rigorous standards imposed by the metrology directorate for conducting gas transaction activities. The implementation of Smart Flow Computer design on an IoT-based metering system using an orifice plate sensor would have a significant positive effect on industrial flow measurement. The results were expected to improve flow measurement systems' efficiency, reliability, and affordability, thereby supporting the growth and sustainability of industry.

2. Material and Method

2.1 Material

This research used an orifice sensor method, which was considered appropriate compared to ultrasonic, turbine, and positive displacement flowmeter. The selection was based on several factors, including accuracy, reliability, and suitability for the specific gas measurement conditions. The orifice sensor method showed superior performance in high-pressure environments, providing consistent and precise measurement that was essential for the standard volume calculations [16]. However, ultrasonic flowmeters offered non-invasive measurement, and turbine was considered suitable for a wide range of flow rates. Both methods could be adversely affected by flow profile disturbances and require more complex calibration [17]. Although the positive displacement flowmeter showed accuracy in low-flow conditions [18], it was less appropriate for high-flow scenarios and varying pressure conditions. This showed that orifice sensor method with superior performance could be used in this research due to the track record in industrial applications.

The proposed design in this research used the ESP32 microcontroller, which was equipped with built-in Wi-Fi and Bluetooth capabilities essential for IoT applications [19]. This adaptable microcontroller was specifically engineered for a wide range of uses, including mobile devices, electronic gadgets, and IoT systems [20]. Furthermore, the chip possessed the capacity to function with minimal power consumption and used a low-duty cycle. These properties contributed to reduced energy usage, making ESP32 microcontroller an ideal selection for sustainable and efficient technological solutions [21].

Measurement in the oil and gas industry often depends on transmitters that generate a standard direct current (DC) signal ranging from 4 to 20 milliamperes (mA). In this context, microcontroller functions using voltage systems, which are converted into digital form through an analog-to-digital converter (ADC) [22]. This shows the need for a current-to-voltage converter module, which is an essential electrical component converting electric current signals into corresponding voltage signals. The signals are used in numerous applications such as pressure, differential pressure, flow, and temperature measurement. To ensure smooth integration and accurate signal processing, converter module is essential in systems where the signal source is an electric current, but the operational need is voltage.

Ohm's law (V = I * R) is generally used in the current-to-voltage converter module, where V, I, and R represent voltage, current, and resistance, respectively. The module can use a voltage-divider resistor or semiconductor devices such as operational amplifiers to carry out the conversion process [23]. Furthermore, the current-to-voltage converter module is essential for quantifying electric current by producing a voltage that is directly proportional to the current passing through the sensor. An operational amplifier boosts the converted voltage, producing an output voltage with low impedance [24]. This helps reduce the burden on the next signal-processing steps. Moreover, current-to-voltage converters are integrated with signal filters to reduce noise in the signal transmission system, guaranteeing precise and dependable readings [25].

2.2 Standard Gas Flow Measurement

In the oil and gas industry, an orifice sensor is commonly used for quantifying the rate of gas flow in a pipeline. AGA establishes guidelines for converting the pressure difference generated by sensor into gas flow rate. AGA Report No. 3, titled "Orifice Metering of Natural Gas and Other Associated Hydrocarbon Fluids " [26] and AGA Report No. 8 [27], titled "Compressibility Factor of Natural Gas " offers detailed and extensive guidelines. AGA Report No. 3 provides comprehensive guidance on how to use orifice meters to accurately measure flow rates of natural gas and associated hydrocarbon liquids. This report includes full information on design parameters, measurement procedures, and essential calculations required to achieve accurate and dependable outcomes. The basic equation for calculating flow rates using orifice meters follows the guidelines contained in AGA 3, which can be expressed as follows

$$Q = C'.\sqrt{P_f\,\Delta P} \tag{1}$$

$$C' = F_b\,F_r F_Y F_{pb} F_{tb} F_{tf} F_g F_{pv} F_m F_a F_I \tag{2}$$

where Q represents the volume in standard units, specifically standard cubic feet per hour (SCFH). C' is a constant, P_f refers to static pressure, and ΔP represents differential pressure. F_b refers to the base factor that is determined by the size of bore orifice and the diameter of the pipe. The term F_r refers to the Reynolds number factor, which is determined by the streamline of flow. F_Y refers to the expansion factor that depends on the expansion of the orifice, which affects the pressure upstream and downstream. F_{pb} stands for pressure-base factor. In this case, the pressure base is set at 1 atma, or 14.7 psia, F_{tb} refers to the temperature base factor, which is based on a temperature of 60^o F. F_{tf} is an abbreviation for gas temperature flowing factor. The symbol F_g represents the density factor of a real gas. F_{pv} stands for the super compressibility factor. In this situation, the term $F_m$refers to the manometer factor. Since a manometer is not used, the value of this factor is set to 1. F_a stands for the orifice thermal expansion factor. The abbreviation F_l is used to denote the position of a manometer. The factor values are calculated using the formula contained in AGA report 3.

2.3 Propose Method

Fig. 2 shows the components of the proposed Smart Flow Computer, which includes two power supplies, three current-to-voltage converter modules, and one ESP32. The positive transmitter cable is connected to the positive

24V power supply and the negative transmitter cable is connected to the positive input converter module. Subsequently, the converter module is connected to a 12 V power supply, which serves as its power source. The converter module's output is connected to the analog input pin of the ESP32.

Fig. 3 represents the configuration system for smart flow metering. This system includes the ESP32 device transmitting or storing parameters such as pressure, temperature, differential pressure, and gas flow rates that are calculated using the AGA-3 standard. The parameters are sent to the EMQX broker, which serves as a cloud platform for storing transitory data [27]. Furthermore, the parameters from the EMQX broker are published to the web server page, which acts as a subscriber by receiving data from the EMQX broker. The web server page shows the pressure, temperature, differential pressure, and gas flow rate qualities that have been computed using the AGA 3.

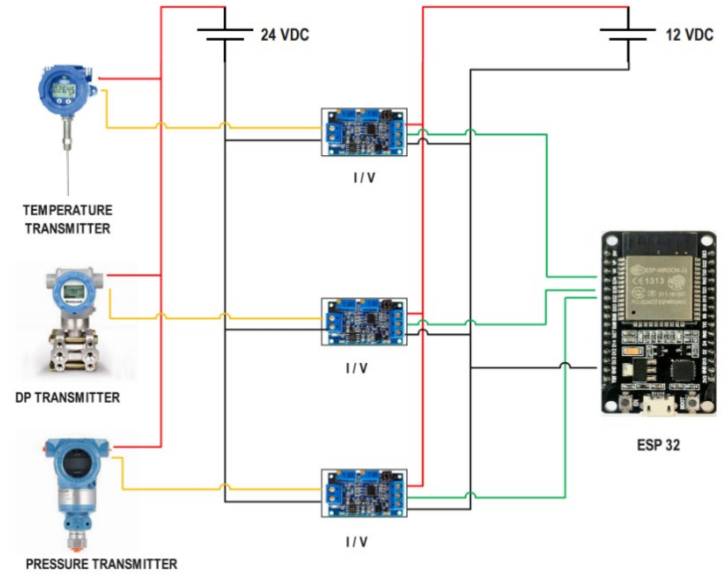


Fig. 2 *Propose wiring configuration*

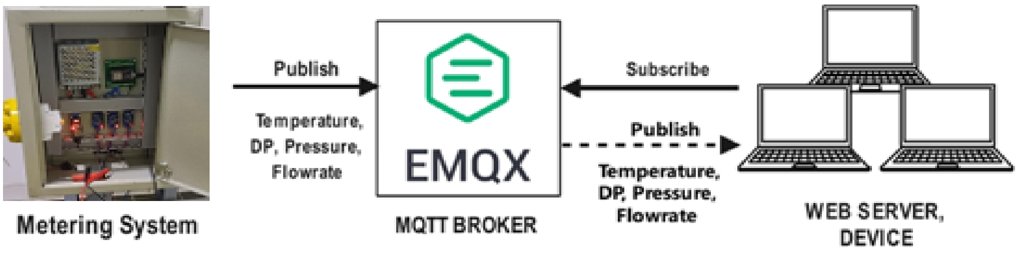


Fig. 3 *Propose system configuration*

2.4 Performance Evaluation

The evaluation of Smart Flow Computers includes a thorough investigation of multiple crucial performance indicators to guarantee their effectiveness and reliability in industrial settings. The key performance metrics include accuracy, response time, dependability, repeatability, drift, power consumption, environmental tolerance, simplicity of integration, user interface, and maintenance requirements [28] [29]. This research evaluates performance based on accuracy and response time, which are fundamental indicators of equipment compliance with regulations. To assess accuracy, measurement of Smart Flow Computer is compared with the Kelton Flocalc software [30] and discrepancies are recorded. Gas flow rate is calculated using the values shown in Table 1. These variables are the condition parameters of the metering skid that are used for apparatus testing.

Response time is determined by creating flow variations and recording the time taken for measurement results to be presented on Smart Flow Computer. The difference between the time shown and recorded by the browser or server is calculated as the delay time

Table 1 *Parameter base to calculate flowrate as AGA Report 3 on evaluation performance*

Symbol	Parameter	Value	Unit
D	Pipe Diameter	2	inch
d	Bore Orifice	1	inch
T_b	Temperature Base	60	°F
P_b	Pressure Base	14.7	Psia
R	Gas Constant	8.341	$m^3 \cdot Pa \cdot K^{-1} \cdot mol^{-1}$
μ	Viscosity	1.11×10^5	$Kg.m^{-1}.s^{-1}$
ρ	Density	0.045	$lb. Ft^{-3}$

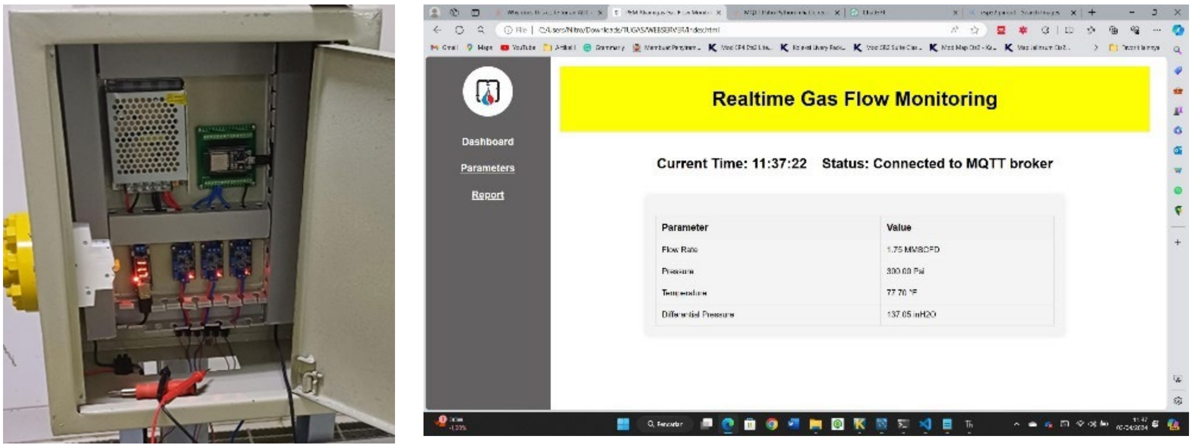
Before determining the overall accuracy, each module conducts testing to identify the level of associated error due to inaccurate measurement results and calculations. To quantify the errors introduced by the current-to-voltage converter, a standardized signal is injected through the signal injector in the form of a current ranging from 4 to 20 mA. This current is expected to accurately match the transmitter signal derived from static pressure, differential pressure, or temperature. Subsequently, the conversion results are read through the serial monitor of the ESP32 microcontroller

3. Result and Discussion

3.1 Result

This research successfully designed the hardware of Smart Flow Computer with three input capabilities and a local display, all contained within a solid enclosure. This advanced system allowed for accurate and effective flow measurement using several input channels, such as pressure, differential pressure, and temperature transmitters. Furthermore, the design allowed for real-time monitoring and communication with humans through the local display. The use of IoT technology enabled the transmission of data, ensuring simple integration with modern digital infrastructure. This also allowed the capacity to monitor and control from a distance, ensuring the best possible performance and quick analysis of data, thereby enhancing the overall efficiency and reliability of industrial processes.

Several procedures are included in the deployment of software on Smart Flow Computer system. Gas flow rate calculation formula, which follows the AGA 3 is implemented using the micro Python language. The AGA based on Equations 1 and 2, calculates the standard gas volume by accounting for gas compressibility factor. Moreover, this factor is significantly influenced by several variables, including the expansion of the bore orifice, the properties of gas fluid, and the characteristics of the pipe material. The comprehensive consideration ensures that the AGA 3 formula provides a precise and reliable standard gas volume measurement, accommodating the complex interactions and potential fluctuations inherent in real-world gas flow scenarios. Apart from its use in computing, the software also facilitates communication between ESP32 and MQTT (Message Queuing Telemetry Transport), enabling a connection with the MQTT broker located at "broker.emqx.io" on port 1883 [31]. The software presents information in a web browser.



Realtime Gas Flow Monitoring

Current Time: 11:37:22 Status: Connected to MQTT broker

Parameter	Value
Flow Rate	1.75 MMSCFD
Pressure	300.00 Psi
Temperature	77.70 °F
Differential Pressure	137.05 inH2O

(a) **(b)**

Fig. 4 *(a) The hardware of Smart Flow Computer; (b) Display of measurement on web browser*

After the hardware and software system have been properly configured, the equipment performs a function test to evaluate functionality. System testing, an essential phase in prototype development, evaluates the device's performance using established criteria. In the context of Smart Flow Computer system, it is essential to use highly precise measuring instruments to ensure that total volume computations accurately represent the actual conditions. The testing method also attempts to verify the optimal functionality and seamless integration of all system components, such as flow sensors, temperature sensors, and pressure sensors. Therefore, the test results provide assurance that the system can function reliably in actual situations and deliver accurate information for subsequent measurement and analysis procedures.

A total of three modules will be verified during the current-to-voltage converter output testing. The three modules function as signal converters, transforming 4–20 mA signals into 0-3.3 V signals for pressure, differential pressure, and temperature measurement. This verification is conducted by comparing the real value with the measured value at the output. The verification steps are conducted sequentially, starting at 0% and increasing by 25% until 100%

Table 2 *Current to voltage converter verification*

%	Input (mA)	Covert Value (Volt)	Output (Volt)	Deviation (%)
0	4.0	0.00	0.00	0.0
25	8.0	0.82	0.81	1.2
50	12.0	1.65	1.62	1.8
75	16.0	2.48	2.46	0.8
100	20.0	3.30	3.30	0.0

The relative error of the current-to-voltage converter shows variability across several inputs, including pressure, differential pressure, and temperature, with a mean deviation of 0.76 %. This shows that there is uncertainty in the resulting value of the converter.

Table 3 *Pressure transmitter on ESP32 verification*

%	Signal (mA)	Pressure Transmitter (Psig)	Pressure on ESP32 (Psig)	Deviation (%)
0	4.0	0.0	0.00	0.00
10	5.6	30.0	29.96	0.13
20	7.2	60.0	59.71	0.48
30	8.8	90.0	90.04	0.04
40	10.4	120.0	119.56	0.37
50	12.0	150.0	150.33	0.22
60	13.6	180.0	180.00	0.00
70	15.2	210.0	209.96	0.02
80	16.8	240.0	240.07	0.03
90	18.4	270.0	269.96	0.01
100	20.0	300.0	300.00	0.00

Table 4 *Differential pressure transmitter on ESP32 verification*

%	Signal (mA)	Diff. Press. Transmitter (inH2O)	Diff.Pres.on ESP32 (inH2O)	Deviation (%)
0	4.0	0.00	0.00	0.00
10	5.6	20.00	20.12	0.60
20	7.2	40.00	40.00	0.00
30	8.8	60.00	60.27	0.45
40	10.4	80.00	79.46	0.68
50	12.0	100.00	99.63	0.37
60	13.6	120.00	119.71	0.24
70	15.2	140.00	140.02	0.01
80	16.8	160.00	160.15	0.09
90	18.4	180.00	180.12	0.07
100	20.0	200.00	200.00	0.00

The ESP32 microcontroller output is evaluated to ensure the accuracy consists of pressure, differential pressure, and temperature. This verification is conducted by comparing the actual value with the measured value at the output. Subsequently, transmitter is validated for measurement range of 0–300 psig for pressure transmitter, 0 – 200 in H_2O for the differential pressure transmitter, and 0 – 200°F for temperature transmitter, producing a signal output ranging from 4 to 20 mA. The ESP32 microcontroller acquires and interprets the output of the pressure, differential pressure, and temperature transmitters through a current-to-voltage converter. Tables 3, 4, and 5 show the output of the transmitter validation as detected by the ESP32. The result shows a mean deviation of 0.12% for pressure transmitters, as well as 0.23% for both differential pressure and temperature transmitters.

Table 6 shows comparative verification data obtained by performing calculations using Smart Flow Computer and Kelton Flocalc software. The calculations include varying the differential pressure signal from 0 inH2O to 200 inH2O while keeping the actual static pressure and temperature constant. The data from Table 1 was used for these calculations, showing that there was no significant difference in the comparison.

Table 5 *Temperature transmitter on ESP32 verification*

%	Signal (mA)	Temp. Transmitter (°F)	Temp. on ESP32 (°F)	Deviation (%)
0	4.0	0.00	0.00	0.00
10	5.6	20.00	20.12	0.60
20	7.2	40.00	40.00	0.00
30	8.8	60.00	60.27	0.45
40	10.4	80.00	79.46	0.68
50	12.0	100.00	99.63	0.37
60	13.6	120.00	119.71	0.24
70	15.2	140.00	140.02	0.01
80	16.8	160.00	160.15	0.09
90	18.4	180.00	180.12	0.07
100	20.0	200.00	200.00	0.00

Table 6 *Temperature transmitter on ESP32 verification*

Diff. Pressure (inH2O)	Static Pressure (Psia)	Temperature (°F)	Smart Flow Computer (MMSCFD)	Kelton Flocalc (MMSCFD)	Deviation (%)
0.00	300.00	77.17	0.00	0.00	0.00
20.12	300.00	77.56	0.68	0.67	1.47
40.12	300.00	77.02	0.95	0.95	0.00
60.17	300.00	77.56	1.16	1.16	0.00
80.00	300.00	77.16	1.34	1.34	0.00
100.17	300.00	77.52	1.50	1.50	0.00
119.80	300.00	77.40	1.64	1.63	0.61
139.88	300.00	77.45	1.77	1.76	0.56
160.15	300.00	77.36	1.89	1.89	0.00
179.68	300.00	77.31	2.00	2.00	0.00
200.00	300.00	77.32	2.11	2.10	0.47

MMSCFD: Million Standard Cubic Feet Per Day)

Table 7 *Delay time of transmission data*

Local Time (Smart Flow Computer)	Server Time	Delay Time (s)
13:20:00	13:20:01	1
13:30:00	13:30:01	1
13:40:00	13:40:01	1
13:50:00	13:50:01	1
14:00:00	14:00:01	1

The time taken to respond can be determined by measuring the delay time, which refers to the duration to transport data from the local equipment to the server. The delay time can be determined by comparing the local and server timestamps. Table 7 shows the local and server time stamps associated with the transferred data. According to M. Suznjevic [32], a maximum delay of 200 ms is required to be declared as real-time in communications with a web server or personal computer (PC). The delay time needed for more investigation to be stated when transferred data is declared as real-time.

3.2 Discussion

Smart Flow Computer designed around the ESP32 microcontroller showed a novel method for gas volume calculation by combining affordability with high computational capability. The application of AGA 3 standard allows Smart Flow Computer to perform complex gas volume calculations with precision using dual-core processor and ample memory in the ESP32. The ability to execute sophisticated algorithms on a cost-effective microcontroller significantly lowers the barrier to entry for advanced gas measurement technologies. This innovation creates opportunities for various applications, from small-scale operations to larger systems that previously found advanced gas metering financially prohibitive.

The integrated Wi-Fi capabilities of ESP32 microcontroller allow Smart Flow Computer to communicate wirelessly through a web server, enhancing the ease of data access and management. Through standard web browsers without the need for specialized software, this wireless functionality facilitates real-time data reading, monitoring, and analysis from remote locations. Furthermore, the seamless connectivity simplifies the operational workflow and enables the integration of Flow Computer into broader IoT networks for advanced monitoring and control. The combination of robust computational power and wireless communication in an affordable package makes the ESP32-based Smart Flow Computer a groundbreaking solution in the field of gas metering, offering enhanced efficiency and accessibility.

Despite the numerous benefits, deviations in the voltage-to-current converter significantly impact the accuracy of Smart Flow Computers, which are essential in various industrial applications. These inaccuracies are caused by signal impurities, equipment tolerance, and resolution limitations of both the multimeter and the converter. Signal impurities such as electromagnetic interference (EMI) and radio frequency interference (RFI) introduce noise and distortions, affecting the conversion accuracy [33]. In converter and multimeter, the quality and tolerance of components also play a significant role. Moreover, the higher-quality components tend to show lower tolerance variations, leading to more accurate measurement.

The resolution of devices is an essential factor, as multimeter with limited resolution can lead to rounding errors. Meanwhile, converter with low-resolution ADC fail to capture fine details in the signal, causing degradation in measurement precision. Changes in the signal injector's input, such as amplitude and frequency, and interactions between parts that are connected, like impedance mismatches and thermal effects, can cause even more errors.

Several innovative solutions are proposed to mitigate errors and enhance measurement accuracy. The implementation of advanced signal filtering methods, such as EMI/RFI shielding and digital signal processing (DSP) algorithms, can significantly reduce noise and distortions. The use of high-precision, low-tolerance components and regular calibration with high-precision standards can also minimize variations and ensure consistent measurement. Furthermore, rounding errors and improved precision can be reduced using high-resolution multimeters and converters with higher bit-depth ADCs.

The application of stable, high-precision signal injectors, and temperature compensation methods is capable of mitigating the effects of signal variability and thermal influences. Comprehensively addressing these factors can substantially improve the accuracy and reliability of Smart Flow Computers, ensuring precise and consistent measurement in industrial applications. However, the current-to-voltage converter's inaccuracies continuously produce significant errors in measurement of pressure, differential pressure, and temperature, as shown by the verification data provided in Tables 3, 4, and 5. These inaccuracies are due to the limitations of the Analog to-Digital-Converter (ADC) on the ESP32 microcontroller, which has a resolution of only 12 bits. The input signal range of 0–3.3 volts corresponds to a resolution of 3.3/4095, which is approximately 0.806 millivolts. The resolution level is significantly lower compared to higher-resolution technology, such as Programmable Logic Controllers (PLCs) or Omni Flow Computer, which typically use 14-bit ADCs with a resolution of 3.3/16,384, approximately equal to 0.2014 mV. The higher resolution of 14-bit ADCs enables more accurate detection of minute voltage fluctuations, minimizing measurement inaccuracies. The poor resolution of the ESP32's ADC has a significant influence on applications that need high precision. This shows that to improve measurement precision, there is a need to upgrade to ADCs with better resolution and apply essential calibration and signal conditioning, as well as error compensation algorithms to alleviate the impact of ADC resolution constraints.

Table 6 shows that there is no significant difference between flow rate calculations obtained from Smart Flow Computer and the Kelton Flocalc software. This confirms the precision and correctness of Smart Flow Computer. When the same settings are used for both devices, the comparison shows that Smart Flow Computer consistently matches flow rate numbers generated by Kelton Flocalc, which is a widely recognized accuracy in manual gas flow rate computations. This comparison shows that the calculation method used by Kelton Flocalc closely matches Smart Flow Computer, specifically depending on AGA report 3. The accuracy of Smart Flow Computer is primarily dependent on the accuracy of the current-to-voltage converter and ADC embedded into the ESP32.

The use of modern calibration methods and sophisticated algorithms in Smart Flow Computer to improve the accuracy of measurements. The application of real-time data analysis and machine learning allows the device to adjust dynamically to varying situations, thereby ensuring consistent high precision. By using superior components and implementing strong error-correcting methods, any little differences will be minimized, causing constant and dependable performance. These advancements will enhance the capacity of Smart Flow Computer, ensuring precise and reliable flow rate assessments in industrial environments.

After analyzing the errors in measurements of differential pressure, static pressure, and flowing temperature, the highest observed deviation value is 0.23%. The primary cause of this divergence can be traced to the component of the current to voltage module and the ESP32 microcontroller, while the inaccuracy of the computation process is insignificant. Therefore, the overall error rate remains below 1%, which falls within the acceptable range set by the metrology directorate for transactional reasons. This suggests the overall precision of measurement system is satisfactory for real-world applications, although there are some differences from the expected values.

4. Conclusion

In conclusion, this research designed and implemented Flow Computer System for a metering system based on the AGA 3 standard using the ESP32 microcontroller. The system performance was evaluated by comparing real-time flow rate values with calculations from Kelton Flocalc software, ensuring compliance with regulatory standards. Smart Flow Computer Design System was successfully implemented for the Metering System using the ESP32 as leveraging IoT technology for accuracy and efficiency, based on the AGA 3 standard. Furthermore, testing was carried out through real-time comparison of flow rate values with calculations from Kelton Flocalc software, showing deviations under 1%. The results showed that the system met the regulatory standards for accuracy in flow rate measurement.

The use of high-quality devices, advanced signal filtering methods, and high-resolution ADCs were recommended to further enhance measurement accuracy. Regular calibration and robust error correction mechanisms would help achieve more consistent and accurate results. By addressing these factors comprehensively, the reliability and precision of the ESP32-based Flow Computer System could be significantly improved, ensuring effectiveness in industrial applications that require accurate flow rate measurement.

The implementation of the Smart Flow Computer system has shown significant improvements in various operational parameters across test environments. Key performance indicators such as measurement accuracy, data transmission latency, system response time, and energy consumption were closely monitored. Measurement accuracy increased by maximum of 1.47%, ensuring compliance with AGA standards for custody transfer operations. Additionally, data latency was reduced from 10 seconds to less than 1 seconds, if we compare it with the use of conventional flow computers that use SMS gateway 2G technology. System response time to parameter changes, such as the ability to recalibrate by performing range measurements online without having to visit the transmitter site, can contribute directly to improving process reliability and reducing operational risk.

The system also demonstrated notable energy efficiency, with IoT-enabled smart devices consuming up to 30% less power compared to legacy flow computing systems, due to the use of ESP32 which is known as a microcontroller with IoT capabilities that consumes efficient energy. Moreover, integration with cloud-based analytics platforms allowed for predictive insights based on historical flow trends, significantly reducing unscheduled maintenance events. These variable outcomes clearly indicate that the Smart Flow Computer system is not only accurate but also highly efficient, offering measurable benefits that support safer, more responsive, and cost-effective operations in the oil and gas industry.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: ***research conception and design:*** *Suka Handaja, Astrie K Dewi;* ***data collection:*** *M. Raihan de Lafayete;* ***analysis and interpretation of results:*** *Suka Handaja, Astrie K. Dewi, M. Ramdhan;* ***draft manuscript preparation:*** *Suka Handaja, Astrie K. Dewi. All authors reviewed the results and approved the final version of the manuscript.*

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