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Robust and highly reliable oil leakage detection with optimal performance in faulty and normal conditions

Charles Anayochukwu Nwonye [1, *], Emmanuel Chikwado Eze [2], Ursula Onyinye Okafo [2], Maryann Mmesoma Nwachukwu [2], Davidson Obichukwu Nnorom [2] and Emmanuel Ifebuchechukwu Nwonye [3]

[1] *Nigerian Television Authority, Enugu, Nigeria.*
[2] *Department of Electronic and Computer Engineering, NnamdiAzikiwe University, Awka, Nigeria.*
[3] *Engineering Materials and Development Institute, Akure, Ondo State, Nigeria.*

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Abstract

This paper proposes the design of robust and highly reliable oil leakage detection with optimal performance in faulty and normal conditions. Flow rates and sound are two parameters considered for the design of this project. The purpose of this design is to ensure that faults do not result in malfunctioning and system failure and to achieve the best performance even with minimum number of input and output devices working properly. The fault detection and isolation (FDI) problem is an inherently complex one and for this reason, the immediate aims are to preserve the stability of the process and if it is possible, to control and continue the process in a slightly degraded manner. The role of the FDI algorithms is to ensure that the control equipment must make correct decision. This system has two flow stations that are connected by a pipeline and flow rate difference is used to detect leakage. First flow station has 2 sound alarms and pumps as output devices and 2 flow meters and start button as input devices. Also the second flow station has the same arrangement as the first flow station except that it does not have a pump. Both flow stations use mobile phones as modems to send and receive short message services. The essence of the two flow meters and two sound alarms at each of the flow stations is to ensure optimal performance and robustness even if one or more of the devices failed. Once, the system starts, the first flow station pumps crude oil to the second flow station while the former also sends the flow rate at its end M1 to the later. Then, the second flow station measures its flow rate as M2 and compares it with M1 so as to check whether the difference is still within the allowable threshold. If the difference between M1 and M2 is within the allowable threshold, the system continues working but once the difference is above the recommended threshold, the second flow station sends short message services (sms) to the first flow station and equally alerts its workers using sound alarm. Then the first flow station switches off the pump and equally alerts its worker that leakage has occurred using the sound alarms. The developed system showed that at sensors (input devices) and actuators (output devices) reliabilities of 50% and above, the system efficiency was up to 95%. This system would go a long way to ensure robust oil leakage detection in our oil industries, if implemented.

Keywords: Robustness; Fault tolerant control; Reliability; Flow rate; Sound alarm and Leakage

1. Introduction

The objective of this system is to maintain system availability when fault occurs, to improve the reliability of the control system and to minimize the effects on the system performance and safety.Over the years, a lot of methods have been proposed for the detection of oil leakage in pipelines conveying crude oil from one flow station to another. However, this work is based on flow rate differences. Some works have been done on flow rate difference as a base for oil pipeline leakage detection, but such works were not robust and fault tolerant [1.2.3]. Hence, failure of any of the components

* Corresponding author: Charles Anayochukwu Nwonye

automatically rendered those systems incapacitated. Hence, this system is designed with spare components so that if one component fails, the system reports such failure while the spare is activated to take over until the failed component is repaired. This project is based on the principle of fault tolerant control system (FTCS). Fault tolerant control (FTCS) has been increasing in the last few years because FTC system has the ability to increase complex systems' reliability and performance requirements in faulty conditions. The design of an FTC system requires knowledge of advanced control mechanism. Systems mostly are very complicated. Designing an FTC system could also be very challenging. Different types of faults such as sensors, actuators and system faults can occur. Each type of fault requires different approach. A fault tolerant control system must be able to perform: fault detection, isolation and diagnosis. It should also have the ability to detect and correct faults. FTC can be either active or passive. The former relies on fault detection and isolation (FDI) scheme to detect the occurrence of faults so as to determine the source and severity of the faults. While in the later, potential component faults are known prior to the design and are taken into considerations during the design stage. This paper proposes the design and development of robust and highly reliable oil leakage detection with optimal performance in both faulty and normal conditions [4, 5, 6, 7, 8].

2. Sensor fault tolerant control system

The sensor fault tolerant control was implemented for robust and highly reliable oil leakage detection. The system mainly consists of the microcontroller along with two flow sensors, analog multiplexer, two sound alarms, an LCD and LED for displaying, switches connected on both sides of the sensors, a relay driver board and two electric pumps as shown in figures 1 and 2. The sensors' outputs are connected to an analog multiplexer which is then connected to the analog to digital converter (ADC) of the microcontroller. The microcontroller gets the sensor values and displays them on the LCD display. Then, the control action is taken by the microcontroller to detect which sensor has failed or working properly according to the values taken by the sensors. The LCD display and the relay drive board are connected to the I/O ports of the microcontroller. The pumpsare connected to the relay board [9, 10,11, 12].

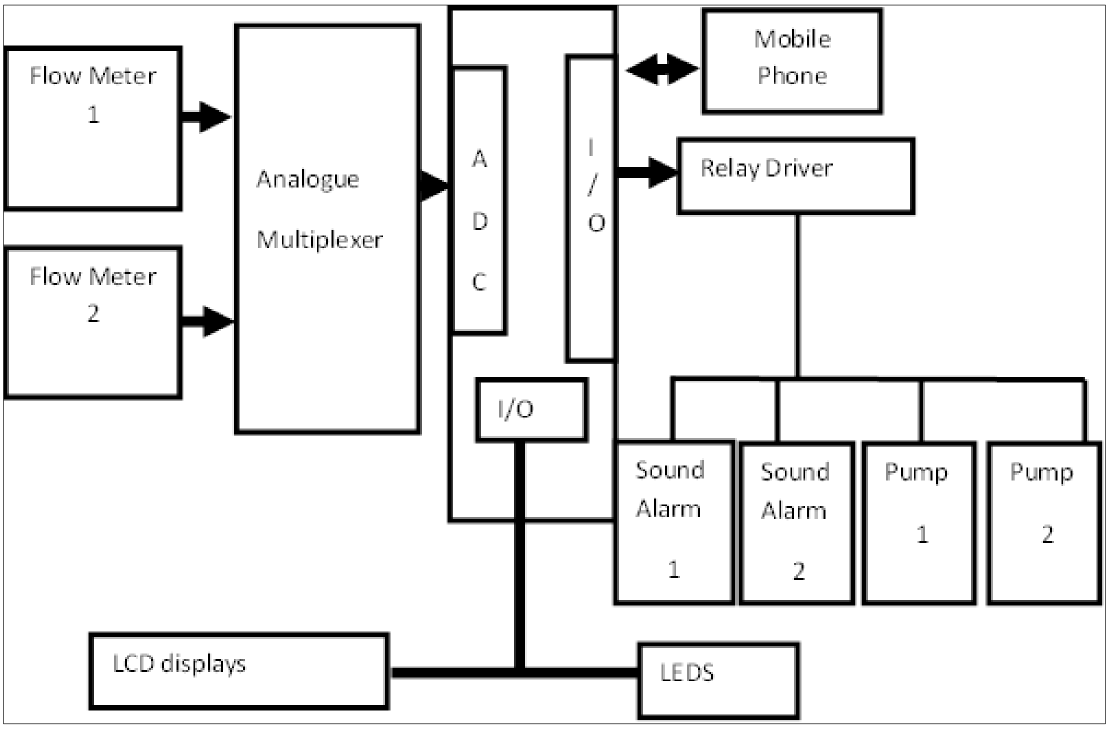

Figure 1 Block diagram of the first flow station

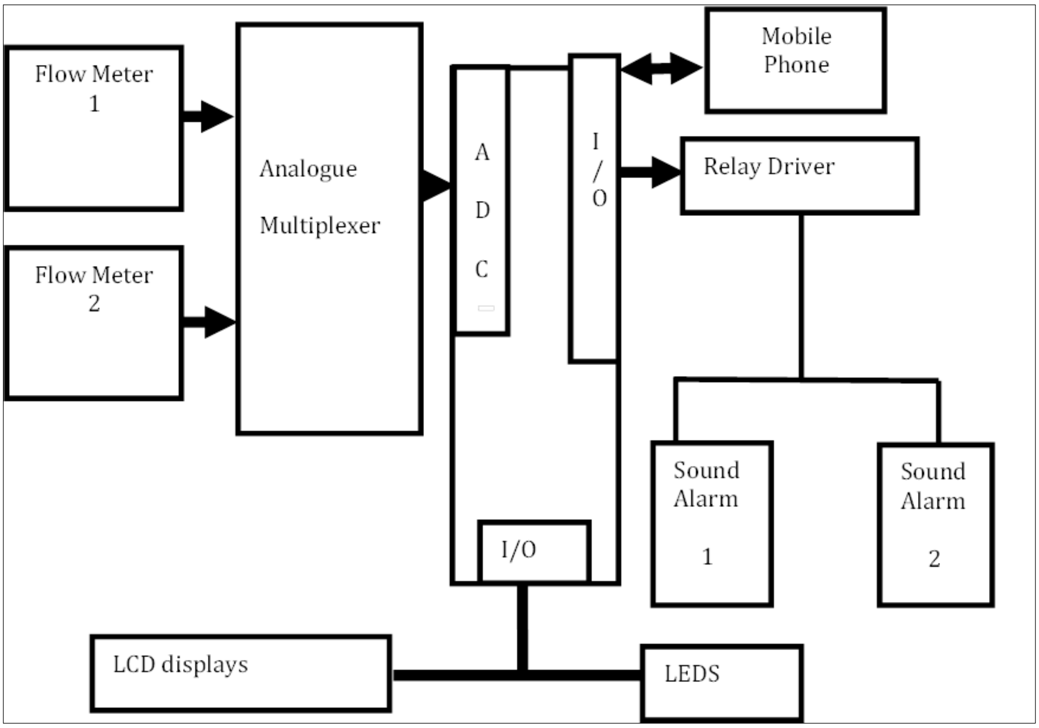

Figure 2 Block diagram of the second flow station

3. System Design and Implementation

3.1. System Design

The model consists two flow stations with the first flow station made up of two flow meters , two sound alarms, power supply circuitry, analog multiplexer, relay driver board, two pumps, LEDs and LCD display. Whereas the second flow station has the same arrangement as the former except that it has no pump. The two flow stations' designs are shown in figures 3 and 4 whereas the physical designed work is shown in figure 6 [13, 14, 15, 16].

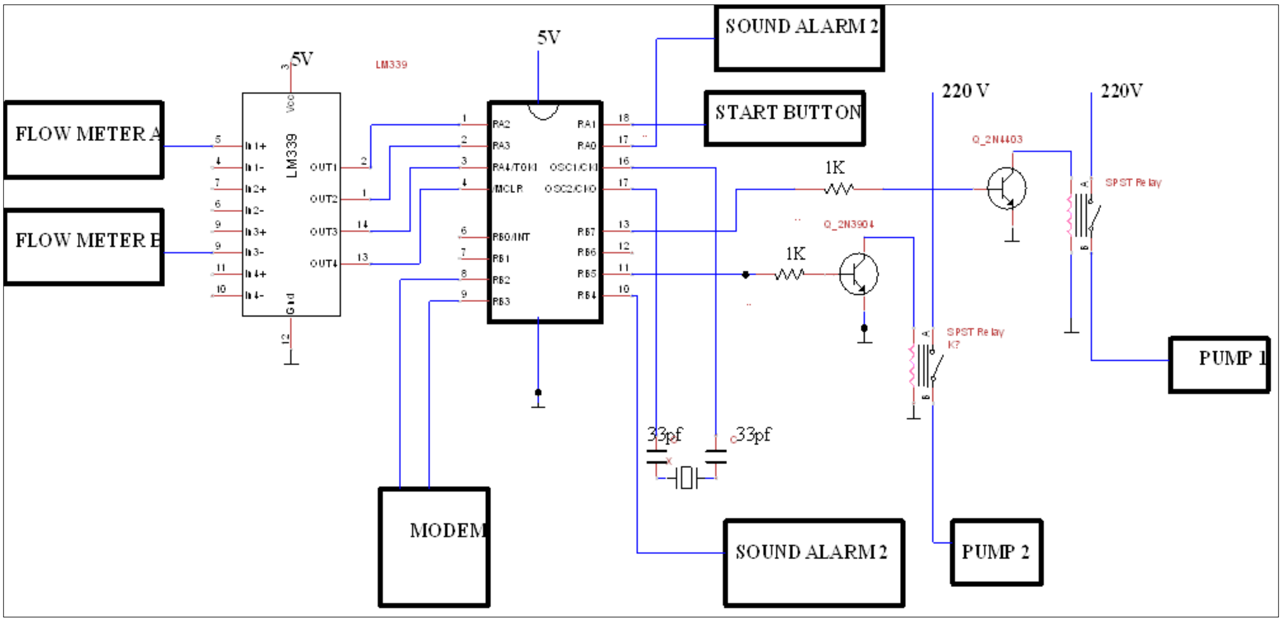

Figure 3 Circuit diagram of the first flow station

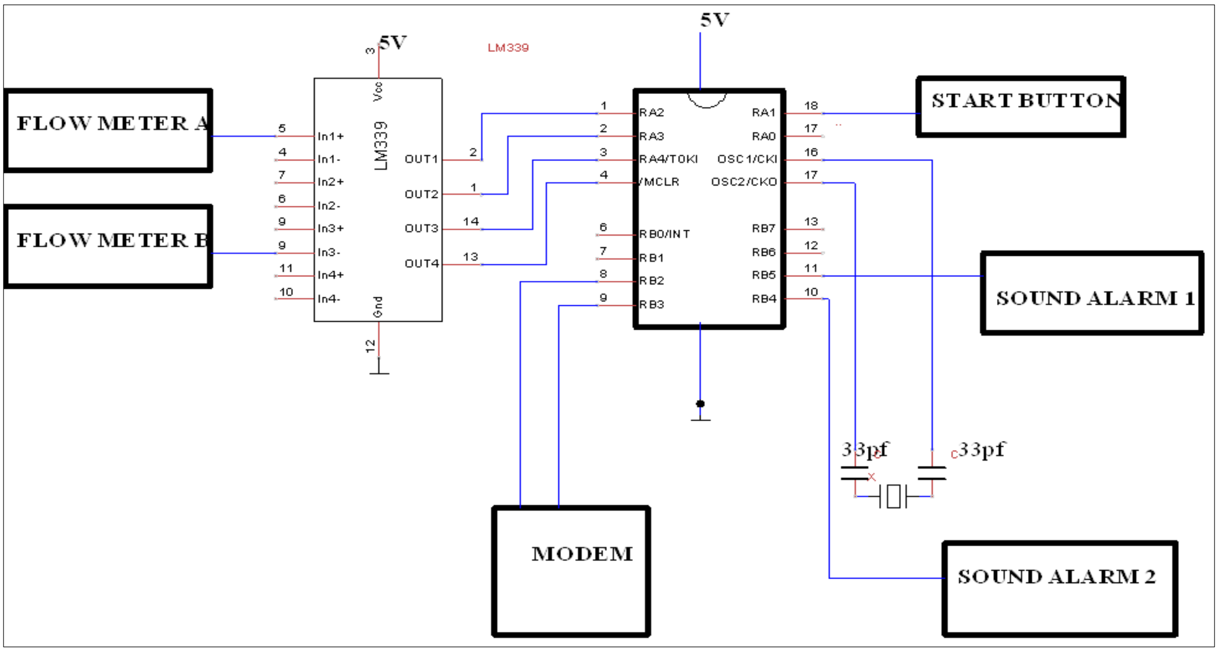

Figure 4 Circuit diagram of second flow station

3.2. System Implementation

After the design and connections of the different components at the flow stations as shown in figures 3 and 4, the required control programmes for the optimal operations of the system were developed using the flow charts in figures 5 and 7 and control programmes of sections 3.3 and 3.4 [17,18.19].

3.3. Control Programmes at Flow station A

The control programme for the operations at flow station A is as follows:

- Step 1: Start
- Step 2: Initialize Modem
- Step 3: Is start button pressed?

No; Go back to Step 2

Yes; Go to Step 4

- Step 4: Start Operations by switching onPump 1 or pump2 and Measure Mass flow rate with MA1
- Step 6: Is pump 1 faulty?

Yes; Go back to Step 4 and activate pump 2

- Step 7: Send Mass flow rate to Flow station B
- Step 8: Is Sms message received from Flow station B?

No; Go back to Step 4

Yes; Goto Step 9

- Step 9: Stop operations and alert workers of leakage using the sound alarm

3.4. Control Programmes at Flow Station B

The control programme for operations in flow station B is as follows:

- Step 1: Start
- Step 2: Initialize Modem
- Step 3: Is start button pressed?

No; Go back to Step 2

Yes; Go to Step 4

- Step 4: Measure the Mass flow rate at flow station B using Mass flow meter 1
- Step 5: Wait for Sms message from Flow station A to know the Mass flow rate at flow station A and compare both
- Step 6: Is mass flow meter 1 faulty?

Yes; GO back to Step 4 and activate Mass flow meter 2

No; Go to Step 7

- Step 7: Is the difference in the Mass flow rates more than the required threshold?

No; Go back to Step 5

Yes; Go to Step 8

- Step 8: Send message to Flow station A that a leakage has occurred and use the sound alarm to alert the workers at the flow station about the leakage.

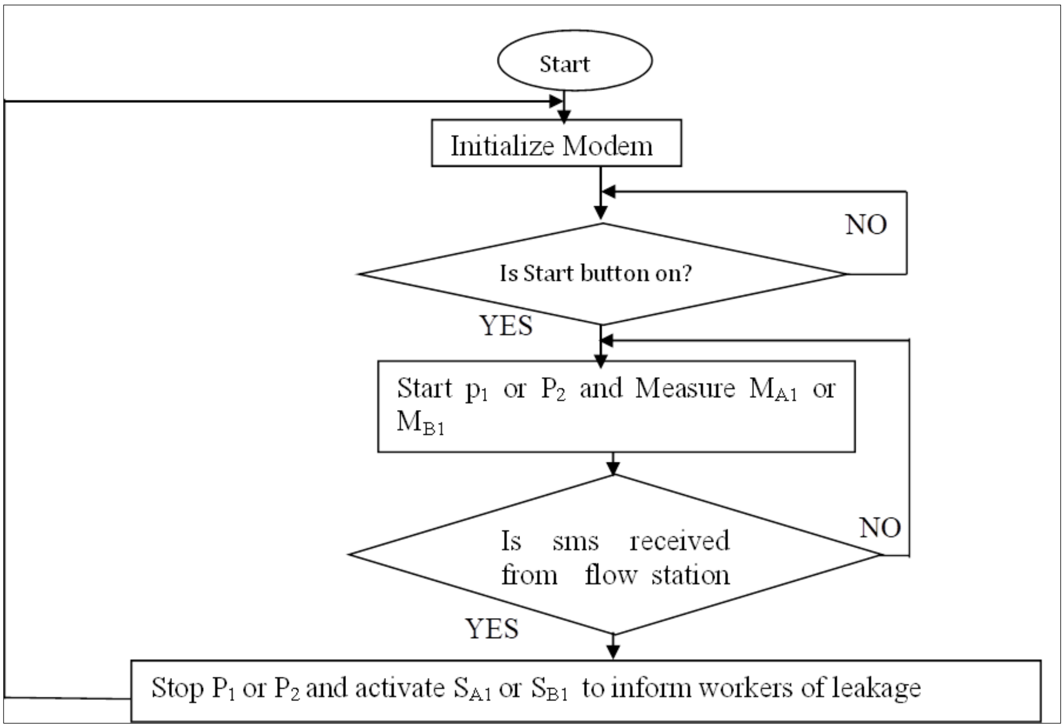

Figure 5 Block diagram of control programme at the 1st flow station

Figure 6 Physical design showing the two flow stations

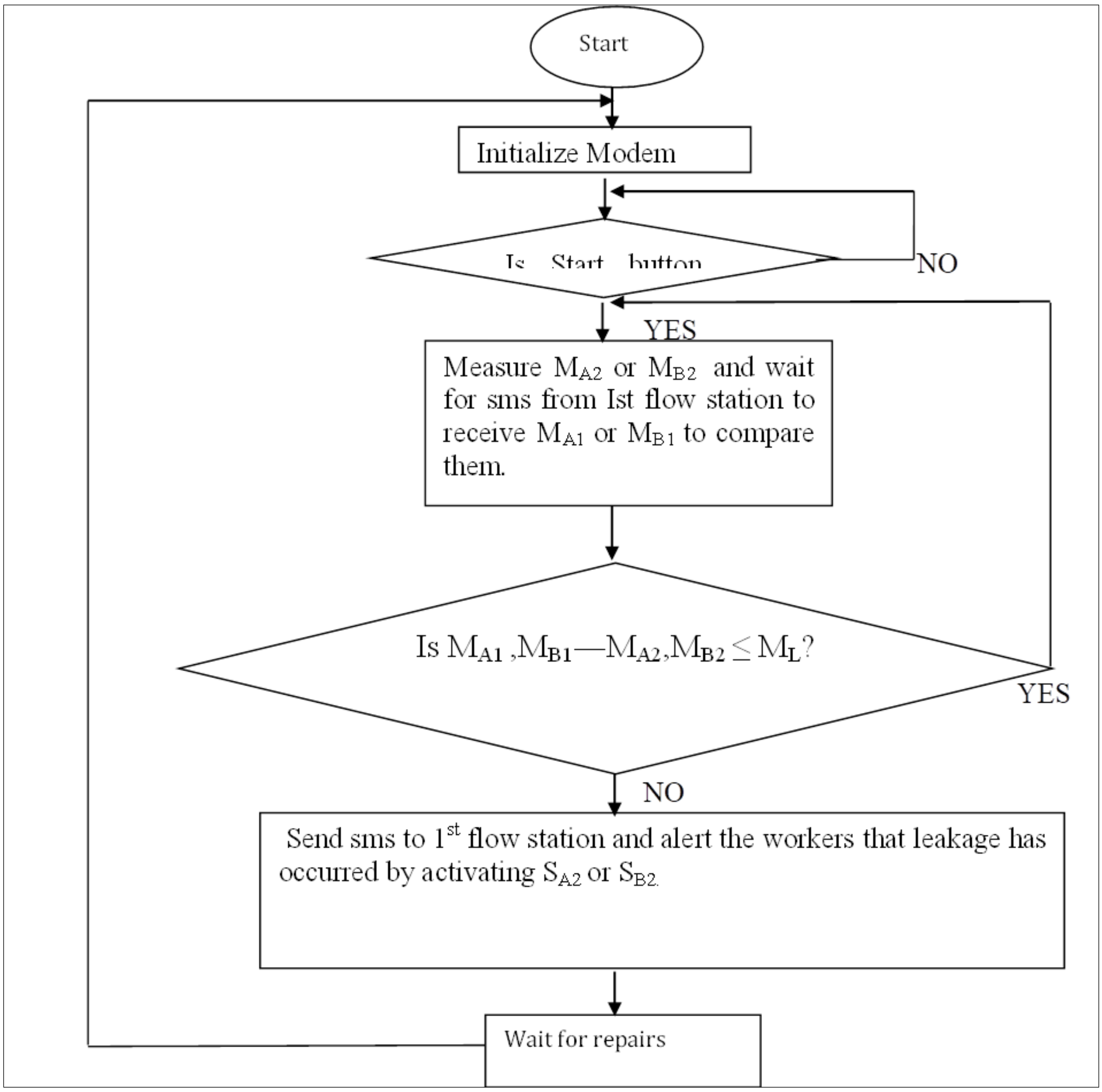

Figure 7 Block diagram of control program of the second flow statio

4. Results

Table 1 Input Fault Tolerant Strategies

M_{1A}	M_{1B}	M_{2A}	M_{2B}	Reliability (%)	Remark
0	0	0	0	0	Failure
0	0	0	1	25	Malfunctioning in faulty condition.
0	0	1	0	25	Malfunctioning in Faulty condition.
0	0	1	1	50	Malfunctioning in Faulty condition.
0	1	0	0	25	Malfunctioning in Faulty condition.
0	1	0	1	50	Working well in faulty condition.
0	1	1	0	50	Working well in faulty condition.
0	1	1	1	75	Working well in faulty condition.
1	0	0	0	25	Malfunctioning in Faulty condition.
1	0	0	1	50	Working well in faulty condition.
1	0	1	0	50	Working well in faulty condition.
1	0	1	1	75	Working well in faulty condition.
1	1	0	0	50	Malfunctioning in Faulty condition.
1	1	0	1	75	Working well in faulty condition.
1	1	1	0	75	Working well in faulty condition.
1	1	1	1	100	Working Well in Normal Condition.

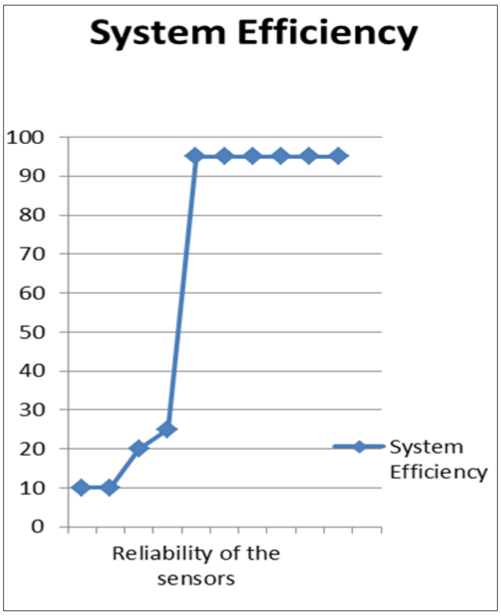

Figure 8 System's operational efficiency at various reliability rates of the sensors

Table 2 Actuating Fault Tolerant Strategies

P_1	P_2	S_1	S_2	Reliability (%)	Remarks
0	0	0	0	0	Failure
0	0	0	1	25	Faulty condition but workers can be alerted of leakage.
0	0	1	0	25	Faulty condition but workers can be alerted of leakage.
0	0	1	1	50	Faulty condition but workers can be alerted of leakage..
0	1	0	0	25	Faulty condition and workers cannot be alerted of leakage when it occurs.
0	1	0	1	50	Working well in this faulty condition.
0	1	1	0	50	Working well in this faulty condition.
0	1	1	1	75	Working well in this faulty condition.
1	0	0	0	25	Faulty condition and workers cannot be alerted of leakage when it occurs.
1	0	0	1	50	Working well in this faulty condition.
1	0	1	0	50	Working well in this faulty condition.
1	0	1	1	75	Working well in this faulty condition.
1	1	0	0	50	Faulty condition and workers cannot be alerted of leakage when it occurs.
1	1	0	1	75	Working well in this faulty condition.
1	1	1	0	75	Working well in this faulty condition.
1	1	1	1	100	Working well in Normal condition.

Nb: M_{A1}= Mass flow rate measured by Flow meter A at the first flow station; M_{B1}= Mass flow rate measured by Flow meter B at the first flow station; M_{A2}= Mass flow rate measured by Flow meter A at the second flow station; M_{B2}= Mass flow rate measured by flow meter B at the second flow station. ; P_1= Pump 1 at the first flow station; P_2= Pump 2 at the first flow station; S_1 and S_2= Sound alarms at both flow stations

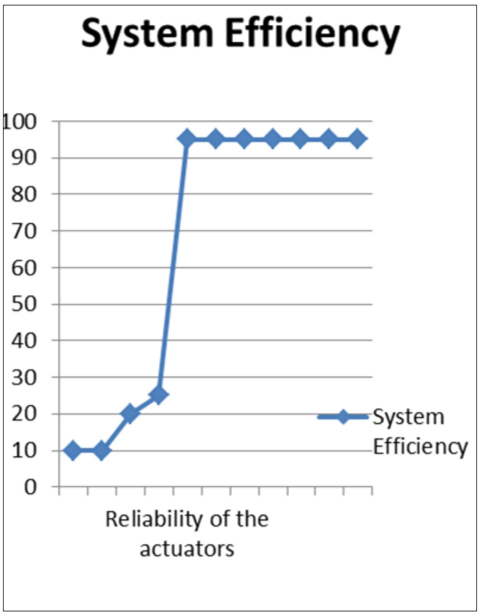

Figure 9 System's operational efficiency at various reliability rates of the actuators

5. Conclusion

This design has shown that robust and highly reliable oil leakage detection with optimal performance in both faulty and normal conditions is achievable. This system used the redundancy technique i.e if one sensor fails; the microcontroller considers the value from the other sensor. The faulty tolerant control system (FTCS) operations represented by the flow chart were then translated into equivalent C language and compiled using MPLAB IDE, the PIC16F877A software development tool. MPLAB IDE then translated the C files into corresponding hex files which were uploaded onto the microcontroller. The microcontroller is embedded with the proposed FTCS for real time implementation. The different input devices' conditions were considered and tested. Also, the different actuators' conditions were equally considered and tested. For each and every condition, the output and input reliabilities were determined as shown in tables 1 and 2. Also, the tables 1 and 2 and figures 8 and 9 showed that with reliability figure of 50% and above, the system operated optimally with high efficiency of above 95% at faulty conditions irrespective of the sensors' or actuators' faults.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Simon B.N, Reddy N.P, Anand K.A theoretical model of an infant incubator dynamics J. BiomechEng; 116; 260 – 6, 2014.

[2] Patton, R.J (2017) Fault – tolerant control. Proceedings of the IFAC SAFE PROCESS, 2, 1033- 1055.

[3] Blanke .M, Stawswiecki. M, Wu.N.E (2021) Concepts and methods in fault tolerant control. Proceedings of the American control conference, 4, 2606- 2620.

[4] Ole Morten Aamo, Jørgen Salvesen, and Bjarne A Foss. Observer design usingboundary injections for pipeline monitoring and leak detection. In Proc. IFACSymp. Adv. Control Chem. Process, pages 2–5. Citeseer, 2016.

[5] L Billmann and Rolf Isermann. Leak detection methods for pipelines. Automatica,23(3):381–385, 1987.

[6] Robert Grover Brown, Patrick YC Hwang, et al. Introduction to random signals and applied Kalman filtering, volume 1. John Wiley & Sons New York, 1992.

[7] Chi-Tsong Chen. Linear system theory and design. Oxford University Press,Inc., 1998.

[8] Andrew F Colombo and Bryan W Karney. Energy and costs of leaky pipes:Toward comprehensive picture. Journal of Water Resources Planning and Management,128(6):441–450, 2018.

[9] Olav Egeland and Jan Tommy Gravdahl. Modeling and simulation for automaticcontrol, volume 76. Marine Cybernetics Trondheim, Norway, 2002.

[10] EngineeringToolBox. Pressure loss in schedule 40 steel pipes.

[11] Ing Gerhard Geiger. Principles of leak detection. Fundamentals of leak detection.KROHNE oil and gas, 2015.

[12] DrissHalhal, Godfrey A Walters, DrissOuazar, and DA Savic. Water networkrehabilitation with structured messy genetic algorithm. Journal of Water Resources Planning and Management, 123(3):137–146, 2007.

[13] Espen Hauge. Advanced leak detection in oil and gas pipelines using a nonlinearobserver and OLGA models. PhD thesis, Norwegian University of Science and Technology, 2007.

[14] Skilling, H. H. , "Electric Transmission Lines", McGraw Hill Book Co. , 1999.

[15] Operation and Maintenance Manual ModelDAS24PT Data Acquisition System, DynamicSystems Electronics Company.

[16] Niger Delta Development Commission (NDDC) publications (2012), "The origin of oil exploration and its achievements so far in Niger delta region".

[17] Akyildiz, I.F.; Stuntebeck, E.P. Wireless underground sensor networks: Research challenges. Ad Hoc Netw. 2016, 4, 669–686.

[18] Walton, R.; Sadeghioon, A.M.; Metje, N.; Chapman, D.; Ward, M. Smart Pipes: The Future for Proactive Asset Management. In Proceedings of the International Conference on Pipelines and Trenchless Technology, Beijing, China, 26–29 October 2011; pp. 1512–1523.

[19] Metje, N.; Chapman, D.N.; Metje, N.; Walton, R.; Sadeghioon, A.M.; Ward, M. Real time condition monitoring of buried water pipes. Tunn. Undergr. Sp. Technol. 2012, 28, 315–320