Faults Detection and Isolation System for Internet-of-Things Device (Autonomous Vehicle)

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ABSTRACT
This study proposed an automated system for faults detection and isolation of internet-of-things (IoT) device with special emphasis to an autonomous vehicle (i.e. self-driven car). Fault detection can be described as the process of identifying faults in physical systems in order to proffer solution to the discovered faults. The developed system was achieved using Structured System Analysis and Design Method (SSADM), Hypertext Pre-processor (PHP) and MySQL. In addition, the developed system was specifically designed to address sudden abnormal faults such as steering and brake stiffness in the autonomous vehicle. The proposed system was developed using Server-alert data synchronization technique which enhances the system to stream the system event log file in order to detect and isolate faults when the system is on motion. The proposed system also provided an emergency backup framework for the stiffed steering and brake faults. The system was tested and evaluated using parameters such as the number of iterations carried out, the number of inputted data for synchronization per iteration, the number of inputted sensor codes per iteration, the number of detected faults of the autonomous vehicle, the time in seconds taken to detect the fault and the system suggestion in addressing the detected faults. A total number of 5 iterations were carried out each for the existing and proposed systems respectively. The proposed system used a speed of 12 seconds to detect and isolate faults of an autonomous vehicle while the existing system used 27 seconds. Furthermore, the system was also tested and evaluated using confusion matrix evaluation technique. Parameters for the adopted confusion matrix evaluation technique encompasses true positive (TP), false positive (FP), true negative (TN) and false negative (FN). The developed system achieved a TP value of 89, an FP value of 5, a TN value of 3 and an FN value of 3. These values were further evaluated using the total number of correct possibilities all over the total number of possibilities made. Hence, a performance accuracy rate of 92% was obtained for the developed faults detection and isolation system.

Keywords
Faults Detection, Isolation, IoT, PHP, MySQL, SSADM

1. INTRODUCTION
The essence of Internet of Things (IoT) does not only encompass the interconnection of physical devices, but also allowing data exchange during applications execution. Data collection in IoT processes is carried out remotely using cloud-based applications. In addition, these devices may belong to activities of data collection in which numerous sensors are joined. This can include temperature, humidity, and light and so on (Sampathraje et al. 2017). This study proposed an automated model for faults detection and isolation of internet-of-things (IoT) device with special emphasis to an autonomous vehicle (i.e. self-driven car). Fault detection can be described as the process of identifying faults in physical systems in order to proffer solution to the discovered faults. Fault Detection and Isolation has attracted numerous interests from industrial systems over the years. This is as a result of the growth and reliability of systems for safety and human use. Fault detection and isolation of automotive systems, physical systems and so on; have become indispensable over the years due to technological growth. Hence, the concept of fault detection and isolation supports the recognition and solution to detected faults (Munya et al. 2022).

The issue of faults such as brake and steering failures in autonomous vehicles has become alarming. Recently, the owner of Tesla autonomous vehicles was sued for fatal accidents caused by his autonomous vehicles due to brake and steering failures. Hence, this necessitated the need to propose faults detection and isolation system for the autonomous vehicle, especially when it's in motion. In other words, the specific problems addressed by this study encompass;

i) Brake failure in autonomous vehicle

ii) Steering failure in autonomous vehicle

Brake failure in autonomous vehicles is usually caused by overheated brake pads, poor data synchronization and damaged rotor disks. Steering failure in autonomous vehicles is usually caused by bad steering rack, damaged sapentine belt and poor data synchronization.

2. RELATED WORKS
Munya et al. (2017), looked at an overview of faults detection and isolation. The aim of the study was to carry out a modified survey on the applications of faults detection and isolation systems. The study discussed fault classification as well as a comprehensive review of fault detection and isolation approaches including model- free methods and model-based methods. Finally, residual generation and residual evaluation were also explained in the study.

Sampathraja et al. (2017), proposed an IoT-based underground cable fault detector. The study detected the location of fault in underground cable lines from the base station in km using a PIC16F877A controller. To locate a fault in the cable, the cable must be tested for faults. The developed system in the study located the exact location of the fault. Furthermore, the prototype was modeled with a set of resistors representing cable length in km and fault creation is made by a set of switches at every known distance to cross check the accuracy of the same.

Abouzar et al. (2023) looked at Fault Detection, Isolation and Restoration Test Platform Based on Smart Grid Architecture Model Using Internet-of-Things Approaches. The aim of the study was to develop an Internet- of-Things-based platform to perform real time co-simulations. Furthermore, physical components of the grid were modeled in Opal-RT real time simulator, an automated Fault Detection, Isolation and

Restoration algorithm was developed using MATLAB and an MQTT communication has been adopted. A 2-feeder MV network with a normally open switch for reconfiguration was modeled to realize the performance of the developed co-simulation platform.

Feng et al. (2013), looked at Sensor-fault Detection and Isolation using Interval Observers. The study proposed an interval observer-based sensor fault detection and isolation (FDI) approach for closed-loop systems. In addition, residuals were defined in such a way that their components were independent of each other at the time instant after fault occurrence, namely kf + 1, where kf denotes the fault occurrence time instant. In this way, it was guaranteed that at kf + 1 the changes in each component of the residuals are only related to the fault in the corresponding sensor. By detecting the threshold violation of the corresponding residual interval components, the proposed method can detect and isolate sensor faults at that time instant.

Mohammad and Javad (2012), looked at Fault Detection and Isolation using unknown input observers with structured residual generation. The study investigated the detection and isolation of faults using structured residuals. Also, actuator and sensor faults were considered. Residuals were generated using a bank of unknown input observers (UIO). Three-tank benchmark system was used as a prototype of much process industries. Furthermore, the simulation of results in the study showed the effectiveness of the studied method.

Mohammadreza et al. (2020), proposed Sensor Fault Detection and Isolation via Networked Estimation: Full-Rank Dynamical Systems. The study considered the problem of simultaneous sensor fault detection, isolation, and networked estimation of linear full-rank dynamical systems. The proposed networked estimation was a variant of single time-scale protocol and is based on (i) consensus on a-priori estimates and (ii) measurement innovation. The necessary connectivity condition on the sensor network and stabilizing block-diagonal gain matrix was derived based on our previous works. Furthermore, considering additive faults in the presence of system and measurement noise, the estimation error at sensors was derived and proper residuals were defined for fault detection. Unlike many works in the literature, no simplifying upper-bound condition on the noise was considered and we assumed Gaussian system/measurement noise.

Hayley et al. (2014), looked at The Role of Healthcare Robots for Older People at Home: A Review. The study aimed at identifying the areas of need that older people have, and the available solutions. In particular, the robotic solutions are explored and critiqued and areas for future development identified. Furthermore, the authors reviewed several literatures for factors that influence admission to nursing home care, and for technological solutions to these factors. The authors did a good job but the study could not be implemented with real-life health robotics.

Pekka et al. (2017), proposed a study on An In-home Advanced Robotic System to manage Elderly Home-Care Patients' Medication. The study examined the safety profile and usability of an integrated advanced robotic device and telecare system to promote medication adherence for elderly home-care patients. The authors did a good job. However, their developed model failed to proffer solution to identified cases of missed doses that were followed up in real-time.

Ayman et al. (2019), presented a study on An Adaptive Intelligent Alarm System for Wireless Sensor Network. The study proposed a basic and adaptable remote arranged for domestic computerization of temperature, moisture, gas, movement and light by executing dependable sensor hubs which can be controlled or observed. The innovation offered energizing and new chance to build the availability of devices inside the home for the home computing. The authors did a good job. However, they had a vague result due to their simulation and non-implementation with a real hardware sensor device.

Debajyoti et al. (2018), analyzed The Elderly Users' Adoption of Smart Home Services. The study proposed and validated a new comprehensive research model called the elderly smart home technology acceptance model by extending the original technology acceptance model that can explain the elderly intention to use the smart-homes. The authors did a good job. However, the analysis of their adopted methodology showed that they only simulated the implementation, and failed to deploy the work to a real smart home area.

3. MATERIALS AND METHODS

3.1 Methodology of the Study

The study adopted Structured System Analysis and Design Method (SSADM). SSADM is a structured analysis modeling language, which uses two types of diagrams: activity models and data models. SSADM has proven to be successful in the development of software systems, specifically in the requirements gathering phase. SSADM notations consist of box-arrow diagrams (blocks), with four arrows on each side defined as: input, output, control and mechanism and one activity in the middle.

3.2 The Proposed System Design

This section presented the adopted method for faults detection and isolation system for autonomous vehicle. The following are sub-headings implemented in this section: system architecture, component design, functional design, network design, interface design and database design.

3.2.1 Requirements for the Proposed System Design

The following are tools for designing the proposed system;

i) Operating system: Linux, windows vista, Microsoft windows 7 and 8

ii) Xampp Local Host Server Application Software Program

iii) JavaScript, Hypertext Preprocessor (PHP) and Hypertext Markup Language (HTML)

iv) Internet Service Provider (ISP) and Chrome Browser

3.2.2 The Proposed System Architecture

The proposed system is a fault detection and isolation model for autonomous vehicles using data synchronization technique. The proposed system was specifically designed to address sudden abnormal faults such as steering and brake stiffness in the autonomous vehicle. The mentioned faults occur as a result of malfunctioning of a sub-system component when the autonomous vehicle is in motion. The proposed system provides an emergency backup framework for the stiffed steering and brake faults. Figure 1 shows the architectural design of the fault detection and isolation model for autonomous vehicles using data synchronization technique.

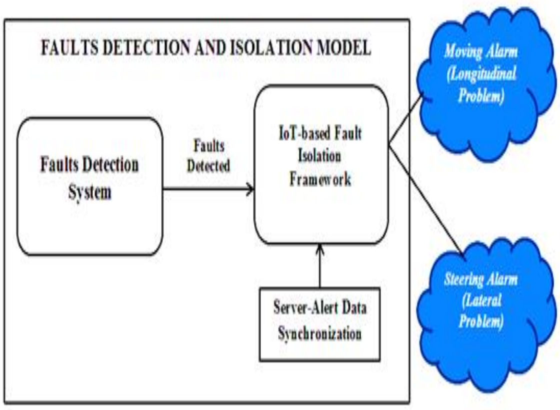

Figure 1: Architecture of the Proposed System

How the Server-Alert Data Synchronization Works in Detecting and Isolating Faults

The role of the server-alert data synchronization system is to detect and isolate faults especially when the autonomous vehicle is in motion. The system tracks the activity of the autonomous vehicle on the server by streaming event logs files, which the server automatically generates. Log files contain information about errors, the vehicle activity and security events that happen on the server. Once the current activity status of the autonomous vehicle is marred by any glitch, it automatically sends an alert to the centralized system and further isolates the detected fault by triggering an emergency system.

4. RESULTS AND DISCUSSION

4.1 System Implementation

The Proposed System was implemented with Hypertext Pre-processor (PHP) and MySQL Relational Database. Hypertext Pre-processor (PHP) is a server-side scripting language for interfacing the frontend and backend of a web application. MySQL is a relational database management system that stores information using pre-defined tuples and attributes. Hypertext Pre-processor (PHP) is an open-source platform which provides cost-effective solutions to issues using a web application. It can function on both desktop and mobile platforms. MySQL provides data security and flexibility to data storage processes. It is an open-source application with on-demand scalability.

Hardware Requirements

The following are hardware requirements for the proposed system implementation;

i) Processor: at least 600-MHZ Pentium III-class processor recommended.

ii) Hard disk: at least 10GB of available space required on system drive, 3.3 GB of available space required on installation drive.

iii) Display super VGA (1024 x 768) or higher resolution display with 256 colors

iv) RAM: Minimum requirement of 4GB for best performance

v) CD-ROM Drive

vi) USB port enabled

vii) Sound card and speakers (optional)

Software Requirements

The following are software requirements for the proposed system implementation;

i) Operating system: Linux, windows vista, Microsoft windows 7 and 8

ii) Xampp Server

iii) Notepad IDE

iv) Web Application Tools (HTML, CSS, PHP and JavaScript)

4.2 Implementation Outputs

The following are interfaces of the implemented faults detection and isolation system;

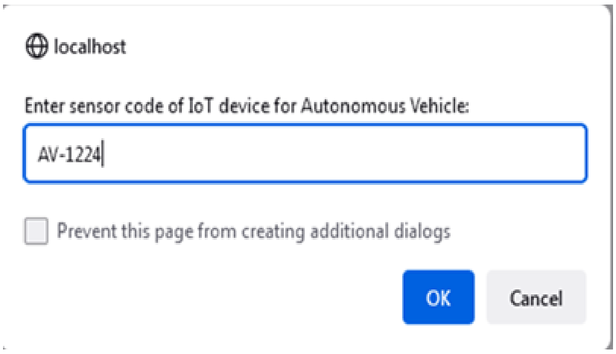

Figure 2: Data Input Page

FAULT ISOLATION MODEL RESULT

EXIT

YEAR	2022
DETECTED FAULT TYPE	Brake stiffness
FATILITY RATE (%)	61%
MODEL SUGGESTION	Isolation mode activated since vehicle is still on motion. However, still consult an expert for maintenance

Table 1: Comparative Analysis of the Existing and Proposed Systems

	Existing System Model		Proposed System Model	
SN.	PARAMETERS	VALUES	VALUES	PARAMETERS
1.	Total No. of Iterations	5	5	Total No. of Iterations
2.	Total No. of Detected Faults	1	2	Total No. of Detected Faults
3.	Total No. of Solutions to detected faults	1	2	Total No. of Solutions to detected faults
4.	Total number of inputted sensor codes per iteration	1	1	Total number of inputted sensor codes per iteration
5	Total time taken in seconds for fault detection	27	12	Total time taken in seconds for fault detection
6	Total number of system suggestion in addressing the detected fault	1	2	Total number of system suggestion in addressing the detected fault

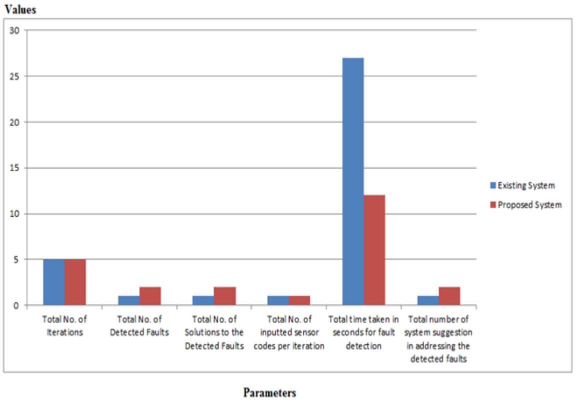

Figure 4: Comparative Analysis Chart of the Existing and Proposed System Models

Performance Evaluation of the Proposed Faults Isolation System

This study adopted confusion matrix evaluation technique for the proposed faults isolation system.

Table 2: Evaluation Table

Positive	TP	FP
Negative	FN	TN

Where TP = True Positive = 89

FP = False Positive = 5

FN = False Negative = 3

TN = True Negative = 3

Table 3: Confusion Matrix Table

	No. of Fault Detection Occurring	No. of Fault Detection Not Occurring	
Occurring	89	3	92
not Occurring	5	3	8
Total Sample	94	6	100

To obtain overall accuracy

$$\text{Accuracy} = \frac{\text{No. of correct possibilities}}{\text{Total number of possibilities made}} \quad (1)$$

$$= \frac{TP + TN}{TP + TN + FP + FN}$$

$$= 89 + 3/89 + 3 + 5 + 3$$

$$= 92/100 \quad = \quad 0.92 \quad = \quad 92\%$$

Misclassification rate (a.k.a. classification error) = (FP+FN) / (TP+TN+FP+FN) (2)

Or 1 – Accuracy of the System = 1 -92% = 0.08 = 8%

Table 4: Performance Evaluation Matrix table

	Accuracy	Classification Error
Eligible Route Occurring	92%	8%
Eligible Route not Occurring		

$$\textbf{Response Time} = \frac{\text{Total Distance of Autonomous Vehicle Covered by the System}}{\text{Total Processing Speed of the System}} \quad (3)$$

$$= \frac{112200}{24}$$

$$= 4675 \text{ Seconds}$$

4.3 Discussion of Results

The proposed system for faults detection and isolation of autonomous vehicles using server alert data synchronization was implemented with Hypertext Pre-processor and MySQL. The system scan enables the system to scan for detected faults of the autonomous vehicle while in motion. Once there is a detected fault, the system isolates the fault and automatically triggers an automatic emergency system to sustain the vehicle's motion until it gets to its destination.

Figure 2 shows the test-set input page for interacting with the system. Figure 3 shows the system scan page that enables the system search for any fault of the autonomous vehicle. The essence of the scan result page is to display results for any detected fault of the autonomous vehicle. The results and performance evaluation of the existing and proposed systems for IoT and data synchronization of autonomous vehicles were illustrated in this study using pre-defined parameters. The results for both models were compiled after executing programs for both systems. The pre-defined parameters for both models encompass the number of iterations carried out, the number of inputted data for synchronization per iteration, the number of inputted sensor codes per iteration, the number of detected faults of the autonomous vehicle, the time in seconds taken to detect the fault and the model suggestion in addressing the detected fault. A total number of 5 iterations were carried out each for the existing and proposed systems models respectively. The existing system model was unable to detect any fault in the autonomous vehicles after the 5 iterations. The proposed system model was able to detect a fault in the autonomous vehicle using server alert synchronization technique, and was able to proffer 2 solutions to the detected faults of the autonomous vehicles in quick response time. In addition, performance evaluation of both systems showed that the proposed system model outperforms the existing system in terms of speed, accuracy and data synchronization. In addition, confusion matrix evaluation technique was adopted for the proposed faults detection and isolation system. Parameters for the adopted confusion matrix evaluation technique encompasses true positive (TP), false positive (FP), true negative (TN) and false negative (FN). The developed image-based detection system achieved a TP value of 89, an FP value of 5, a TN value of 3 and an FN value of 3. These values were further evaluated using the total number of correct possibilities all over the total number of possibilities made. Hence, a performance accuracy rate of 92% was obtained for the developed faults detection and isolation system.

5. CONCLUSION

In this study, faults detection and isolation system was developed and implemented. The system was achieved using Structured System Analysis and Design Methodology (SSADM) ,Hypertext Pre-processor (PHP) and MySQL. The combination of PHP and MySQL produced a unique graphical user interface for the proposed system. Furthermore, the system was also tested and evaluated using confusion matrix evaluation technique. Parameters for the adopted confusion matrix evaluation technique encompasses true positive (TP), false positive (FP), true negative (TN) and false negative (FN). The developed faults detection and isolation system achieved a TP value of 89, an FP value of 5, a TN value of 3 and an FN value of 3. These values were further evaluated using the total number of correct possibilities all over the total number of possibilities made. Hence, a performance accuracy rate of 92% was obtained for the developed faults detection and isolation system.

6. REFERENCES

[1] Abouzar, E., Eduardo, P. and Luca, B. (2023). Fault Detection, Isolation and Restoration Test, Platform Based on Smart Grid Architecture Model, 1 – 5

[2] Ayman S., Osamah K. & Ghaida A. (2019), An adaptive intelligent alarm system for wireless sensor network, Indonesian Journal of Electrical Engineering and Computer Science, 15(1), 142 – 147

[3] Debajyoti, P., Suree, F., Vajirasak, V. & Borworn, P. (2018), Analyzing the elderly users' adoption of smart-home services, IEEE Access, 2018.2869599, doi:10.1109

[4] Feng, X., Puig, V., & Ocampo, C. (2013). Sensor Fault Detection and Isolation using Interval Observers. 2013 Conference on Control and Fault Tolerance Systems (SysTol). NICE, FRANCE: Publisher: IEEE. INSPEC Accession Number: 14004596, DOI: 10.1109/SysTol.2013.6693860

[5] Hayley, R., Bruce M. & Elizabeth B. (2014), The role of healthcare robots for older people at home: A review, International Journal of Social Robotics, 6: 575 – 591

[6] Mohammad, S. and Javad, P. (2012). Fault Detection and Isolation using Unknown Input

[7] Observers with Structured Residual Generation. April 2012, International Journal of

[8] Instrument. April 2012, International Journal of Instrumentation and Control Systems 2(2). DOI:10.5121/ijics.2012.2201

[9] Mohammadreza, D and Nader, M. (2020). Sensor Fault Detection and Isolation via Networked Estimation: Full Rank Dynamical, hed in: IEEE Transaction on Control of Network Systems, 8(2), 1 – 27

[10] Munya, A., Weiam, S., Nasar, S. and Ahmed, J. (2022). Overview of Fault Detection and Isolation. 1st International Conference on Engineering and Applied Natural Sciences, https://www.iceans.org/May 10 - 13, 2022, Konya, Turkey, Turkey.

[11] Pekka, R., Timo, P., Saija, L., Marja, A. & Alan, L. (2017), An in-home advanced robotic system to manage elderly home-care patients' medications: A Pilot Safety and Usability Study Clinical Therapeutics, 39(5).

[12] Sampathraja, L., Ashok, K., Kirubalakshmi, V., Muthumaniyarasi, M., and Vishnu, M. (2017). IoT-based Underground Cable Fault Detector, International Journal of Mechanical Engineering and Technology (IJMET), Volume 8, Issue 8, August 2017, 1299 – 1309, Article Id: IJMET_08_08_132. Available Online at https://iaeme.com/Home/issue/IJMET?Volume=8& Issue 8, Available Online at https://iaeme.com/Home/issue