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IFAC PapersOnLine 58-4 (2024) 246–251

Fault Diagnosis and Identification in AGVs System

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Abstract: This article describes a methodology for the diagnosis of failures in multi-AGV (Automatic Guided Vehicles). Today, AGVs are establishing themselves in the most advanced automatic logistics solutions, providing performance and safety that cannot be achieved with handling solutions with manual forklifts. Furthermore, thanks to the application of Industry 4.0 digital technologies, very advanced tools are available to monitor the performance and diagnose faults of fleets of AGV. In particular, studies on fault diagnosis have mainly focused on (1) the diagnosis of internal components of the automatic truck and (2) the identification of failures in the functionality of the AGV in its interaction with the surrounding environment. This paper shows an approach to fault diagnosis in multi-AGVs system, considering the interaction between each single AGV and the environment, with the scope to help the user increase the system efficiency in an existing layout. The objective of the paper is to introduce and discuss a methodology to study the failure and the available recovery actions of the AGV navigation system. Moreover, the paper presents the real AGV data acquisition and processing architecture actually deployed on the factory shop floor, as well as the result from the experimental study in a real industrial environment.

Keywords: Automatic Guided Vehicle, feet management, AGV navigation system failure and recovery.

1. INTRODUCTION

Automated Guided Vehicles (AGV) are autonomous vehicles programmed to travel on predefined routes to transfer loads in modern manufacturing industries. AGVs are widely used for automated material handling due to their efficiency, productivity and accident-free nature compared to manual forklifts. Consequently, the management and therefore the maintenance of AGV systems have attracted the interest of both the academic and industrial communities (Vis (2006)). In particular, the efficiency and reduction of operating costs of AGV systems have been the subject of scientific research and industrial innovation (Beamon (1998)). The interest of most of the technical and scientific works developed in the first period of diffusion of this technology was focused on optimizing the work of the fleets of AGVs, however, with the continuous growing application of automatic systems in the industrial and productive world, it is considered consolidated the importance of maintaining an AGV. In the literature, there are several contributions for the management of the maintenance of AGV fleets. For example, security requirements and functions are discussed in Trenkle et al. (2013). In this work, three risk situations have been identified: (1) collision with a person, (2) vehicle overturning and (3) load falling. In this regard, the article analysed the speed, the braking distance, and the obstacle detection area for AGVs. Finally, still in the same article, the average time to failures and recovery were analysed and how these affect the safety of the AGVs. In Ebben (2001), a method for the fault management of an AGV case for an underground transport system has been developed. Recently, some authors have proposed to model the reliability of an AGV fleet using cost functions to apply optimization functions on the performance and cost of AGV operation (Tavana et al. (2014)). While there are some studies that focused on the application of Internet of Things (IoT) technologies for the collection of parameters acquired online on AGVs for the predictive identification of faults or critical situations (Chen et al. (2022), Elsisi and Tran (2021)), without considering the AGV's relationship with its surrounding environment. This article provides a contribution in this sense, where an IoT architecture is applied in an AGVs fleet to collect their data and a methodology of fault diagnosis of real-time failures caused by the surrounding environment is applied to a real industrial use case on AGVs fleet. The structure of the paper is as follows: in the next Section the state of the art is discussed, then in section 3 the proposed methodology for implementing a fault diagnosis system is fully described. The use case analysis for implementing the presented methodology is reported in section 4, while the use case setup, the tests carried out in the manufacturing plant and their analysis are described as along as results in section 5. The final remarks are in section 6, Conclusions.

2. STATE OF THE ART

Since the technology of the IoT is nowadays used in all the AGV applications to monitor the single cart as well as the entire fleet, we start the State of the Art (SoA) by introducing scientific background on the IoT. Then

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2024.07.225

the scientific work to diagnose faults in AGVs system is presented, to understand the novelty of the proposed research.

2.1 Internet of Things

With the term IoT we refer to a network of physical objects that are embedded with software, hardware, sensors, etc. that allow connectivity and enable the object to collect data (Madakam et al. (2015)). The scope of IoT is to connect different devices and exchange data through the network. Normally the network is connected via Internet. The possibility to collect all the data allows different kinds of data analysis, including faults analysis. It is not necessary to have the same devices connected, but it is possible to connect different typologies of "things" (Vaidya et al. (2018)). With this architecture, a physical system receives a digital ID, and different kinds of analysis can be implemented; the digital ID is unique in the same network, to allow the recognition of every device connected (Yang et al. (2019)). IoT systems have three main pillars in their application; the first focus is on process optimization; the second target is the optimization of resource consumption; the last scope is the creation of complex and autonomous systems (Pereira and Romero (2017)). IoT technologies allow smaller devices that acquire and send data over the Internet, to have a quick connection between physical and digital spheres, and to consider the distributed nature of modern production lines. To build an IoT application, integration with different technologies, such as Wireless Sensor Networks, Radio Frequency Identification, and Machine-to-Machine (M2M) communication is required (Gupta and Quamara (2020)). When an IoT application is considered in an industrial environment, is normally called Industrial IoT (IIOT). IIoT adoptions in industrial systems provide an increase in efficiency and productivity through the possibility of having smart and remote management of the system (Sissini et al. (2018)).

2.2 Fault diagnosis in AGVs system

An AGV is an autonomous vehicle that is used to transport and sort goods or products in industrial environments. The AGV is made up of a complex system of components, among which we can list: the control software and hardware, the battery with the battery management system (BMS), the electric drives, and the localization system, usually based on laser scanners. AGV moves inside the industrial plant using smart guidance and control tools; there are different technologies to allow the navigation systems, but they can be divided into two main categories (Aguiar et al. (2019)): Trajectory techniques and Autonomous navigation, which can also be merged using hybrid techniques. In the first approach, the AGV trajectories are designed based on the logistical flows that the fleet must support. These trajectories are defined during the design of the layout system and cannot be modified except with an in-depth redesign of the logistics flows. In the second case, the routes of the individual AGVs are autonomously planned by the individual AGV on the basis of the localization method in the plant and autonomous planning of the missions. In particular, this mode is based on so-called SLAM algorithms, which allow you to incrementally build a map of the layout system within which the individual AGV plans its work trajectories. Fault diagnosis refers to the monitoring and identification of faults when they occur. Thanks to the advent of Industry 4.0, and in particular thanks to the development of IoT technologies, there are more available solutions to support the remote fault diagnosis in AGVs system (Yin et al. (2021)). In particular, Chen et al. (2022) proposed a system architecture to allow wireless data acquisition for the AGVs system, understanding that this system can be used to implement a fault diagnosis procedure. The maintenance strategy applied in the AGVs system leverages some aspects, such as the system layout, the maintenance site location (Yan et al. (2018), Yan et al. (2019)), the maintenance schedule (Németh et al. (2019)), etc. In maintenance strategy, the environmental aspects are considered, while in fault diagnosis application in AGVs system, it is more common to find applications where the faults that occur are related to the AGV only. In Wang et al. (2022) a Convolution Neural Network is used to diagnose the fault by analysing an AGV single vibration signal. In Stetter et al. (2018), virtual sensors are used to estimate the forces and the torques acting on an AGV. Mrugalska and Stetter (2019) estimates the Remaining Useful Life of the AGV battery, in order to have a healthy monitoring system for the power system. In Dares et al. (2020) an AGV is developed to simulate fault conditions and implement a fault detection strategy; the importance of considering both internal and external factors is highlighted in the final section. Meanwhile, there are some papers that study the AGV fault diagnosis from the layout perspective. In Witczak et al. (2019), a mathematical model to guarantee the best transportation tasks in an AGVs system is presented, and it uses a model predictive control algorithm and fault-tolerant control. The model optimizes the transportation tasks, but it does not consider the possible fault caused by the interaction of the AGV with the environment and the possible AGV internal fault. In Witczak et al. (2020) a mathematical model to tolerate fault is presented, considering the violation of scheduling constraints as the main effect of the faults. The past research offers valuable insights but the interaction of the AGVs and the surrounding industrial environment is not considered. This paper aims to describe a methodology to understand system faults caused by the interaction of the AGVs with the surroundings. Those systems can be used easily by non-specialist operators to comprehend system faults and allow them to actively participate in troubleshooting, becoming a potential tool to support the operators.

3. METHODOLOGY

The methodology applied in this paper, shown in Fig. 1, can be divided into four steps.

1. Analyse all the possible fault causes. The objective of this step is to precisely identify a set of specific faults to be monitored. In this paper, the fault to be monitored is the loss of the system efficiency.
2. Definition of the fault signature. The objective is to identify the set of specific key events to be monitored in order to detect the faults. The fault to be monitored may be caused by different events, that have to be studied to establish the connection between the event and the faults. Applied in this paper, there are

more events that can cause system loss of efficiency, but three main events are considered in the case study section.

(3) Analysis of the impact of the fault on the industrial system. This step requires a study of how the event impacts the system and for which reason.
(4) Identification of the system variable and the condition that allows the detection of the system fault. At least one variable that satisfies a specific condition is required.

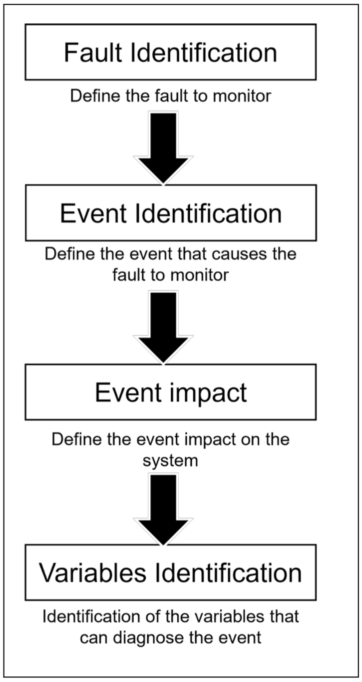

Fig. 1. Methodology.

Implementing this methodology requires good system knowledge and for this reason system expert knowledge is required at the beginning of the analysis. In this specific paper, it is applied to AGVs, but the same analysis can be done with different industrial objects. With this analysis not only the failures of the system components are considered, but also the efficiency losses.

4. CASE STUDY

In this section, the use case is presented. First, the description of the industrial use case is reported with the implementation of data acquisition architecture. Then the presented methodology is applied to a specific fault in this specific environment.

4.1 Case study setup

In order to implement the proposed methodology, data acquisition is required. In this paragraph, the application of an IIoT system in the AGV plant is briefly described. This is an M2M application use case. The AGVs used to validate the presented methodology use localization based on triangulation between laser rays reflected by mirrors in well-known positions. Moreover, the AGVs use a wireless protocol to communicate with their central server where the AGVs commands are set by the user and the vehicle's traffic is monitored and planned. To collect the data from the AGVs in an IIoT infrastructure a general-purpose device such as a Raspberry Pi, mini PC, PC, Banana Pi, etc, is required. In the presented architecture a Raspberry Pi is added. We used a Raspberry Pi to use a small object that does not interfere with the environment and has enough computational power for the required scope. A Raspberry Pi is a single-board computer, and the version used in this project has the possibility to connect the Raspberry Pi to the internet using wireless communication. The AGVs data are read from the Raspberry Pi in the AGV central server via Modbus protocol, which is a standard industrial communication protocol. It is used as the AGV central server because it has a connection with every single AGV inside the plant and because it manages all the AGVs tasks. The Raspberry Pi acquires the data and filters them. The data acquisition architecture is represented in Fig. 2. The software architecture used inside the Raspberry Pi was previously described in Bertoli et al. (2021).

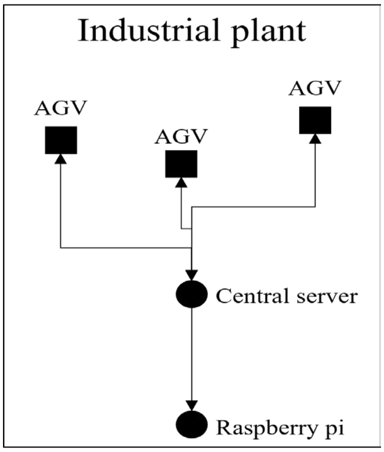

Fig. 2. Data acquisition architecture.

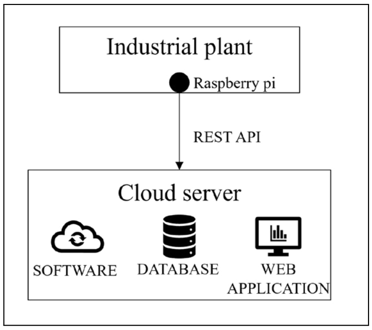

Fig. 3. System architecture.

Then the processed data are sent via rest API in a cloud server where the data can be stored and visualized remotely by the user. To access the data a user interface using a web application is developed. A user-friendly graphical user interface (GUI) is added to support the operator in understanding the data and seeing them graphically, in order to support the decision-making process. Thanks to the cloud server, those data are accessible everywhere, without being physically connected to the AGVs central server in the plant. The system architecture is represented in Fig. 3. In the database the data are stored with the timestamp information, to be able to correlate multiple information at a specific time. For this application, a relational MySQL database is used.

4.2 Methodology application in AGVs system

The fault to be monitored is the AGVs losing efficiency caused by the increase in average mission time because of unnecessary stops or unexpected decreases in speed. This fault can be caused by factors that are related to the environment, with the AGV, and with the relationship with the environment. This event does not occur for just one cause, and it is difficult to understand when it occurs. Thanks to expert knowledge, we studied the system and applied the presented methodology and three different events that cause loss efficiency are identified and evaluated. Those are:

- The number of the reflector. To move inside the industrial plant, the AGV uses the reflectors to collocate itself inside the plant using laser technology. At least three reflectors are required to allow the AGV localization inside the plant.
- Number of times the AGV is in “warning”: The warning state is a critical state for the AGV.
- Difference between the set speed and the real speed. When the AGVs are inserted in a plant, it is set the speed that the AGV can reach in every point. It happens that the real speed is lower than the set one.

The next step for the presented methodology is to understand the impact on the system and its consequences. For the proposed events, they are:

- The number of the reflectors: if the reflectors are not enough, the AGV will stop or it will decrease its speed. When the AGV is not able to see three reflectors, it will stop because it is not able to understand its position inside the plant. When the AGV sees three reflectors but it is not sure of its location inside the plant, it decreases its speed. A possible cause for this event is the interaction with other things or operators that can accidentally cover the reflector when the AGV is moving.
- Number of times the AGV is in “warning”: when the AGV is in “warning” state the speed must decrease, because “warning” is coded as a critical state for the AGV microscan. As in the previous event, the problem is the interaction with other objects in the AGV path.
- Difference between the set speed and the real speed: when this difference is high this means that there is an error in the system setup. The speed in every point is set by the system, if the real speed is lower than the set speed, there is something that affects the AGV system (e.g. there is a human close to the AGV, there is a box close to the AGV path). If this difference is high there is a high loss in efficiency.

The third step is to analyze the system and to identify the variable and the condition to detect the system fault. For the proposed events, they are:

- The number of the reflector: the variable to monitor is the number of visible reflectors for the AGV, and the condition to monitor is when this number is lower than three.
- Number of times the AGV is in “warning”: the variable to monitor is the ”warning” state for the AGV, and the condition to monitor is when the ”warning” state is active.
- Difference between the set speed and the real speed: the variables to monitor are the real speed and the set speed of the AGV at the same point and the condition to monitor is when these two values are not equal.

5. TEST AND RESULTS

Data of interest are collected from the database, all the analyses are made using Python. For this application, a relational database is used. The data are collected in 45 days and refer to the same AGV, inside an industrial plant during normal work days.

5.1 Analysis on the number of reflectors

From the database, all the records when the reflectors are lower or equal to 3 are collected. The data of the reflectors are collected with the specific position of the AGV when this happened inside the plant, in order to be able to know where the AGV was when the fault occurred. To map those data, a heatmap is used. A heatmap is a graphic representation of data. Normally the heatmap is presented as a map or a diagram in which data values are represented as colours. The plant is virtually divided into 400 zones, in order to detect the zone where the major number of errors occurred. Then in every zone is counted how many times the number of the reflectors was lower or equal to three in the period selected. The percentage values are reported in Fig. 4.

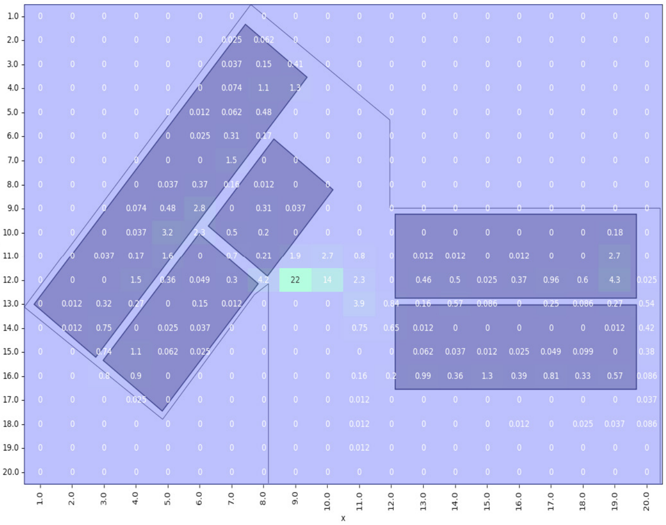

Fig. 4. Reflector analysis.

It is possible to notice that in the background there is the plant map, and the heatmap is directly applied to the map. When the colour is lighter, it means that the percentage value of the number of times that the number of reflectors was minor or equal to 3 is higher. The AGVs move inside the plant following arcs. In this way, the system knows all the possible paths available and it communicates to the

AGVs the route for every job. The route is a set of arches. In every instant, the AGV knows the starting node and the destination node of the arch where it is moving. The starting node is the node where the AGV starts the arch, while the destination node is the node where the AGV is going. The starting node of a new arch is equivalent to the destination node of the previous arch. Another interesting information that can be obtained correlating the previous data is knowing which was the destination node when a critical situation has occurred, such as for example when the number of reflectors is less than or equal to three. In particular, starting from Fig. 5, it is interesting to know which destination node the AGV is reaching when the number of reflectors is lower or equal to three. From the database, all the destination nodes when the AGV's number of reflectors was critical. Studying the result in Fig. 5, is it possible to underline that in particular, two destination nodes are critical, that are number 5 and number 6. Watching the AGV's layout it is possible to note that these two nodes are close to each other, and that highlights a critical zone for the reflector's visibility.

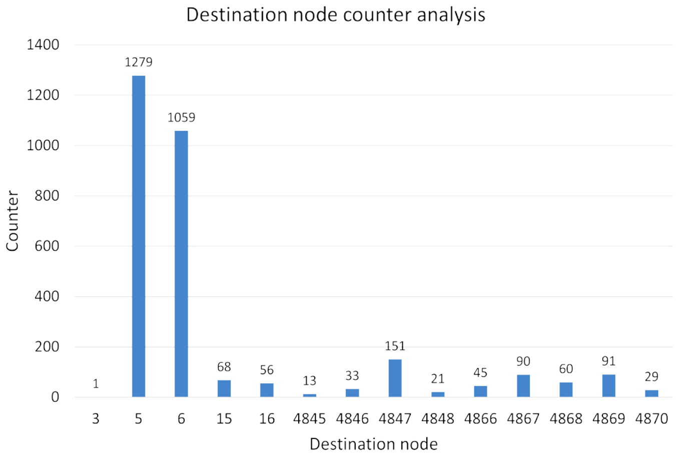

Fig. 5. Destination node analysis.

5.2 Analysis on the AGV "warning" state

For the "warning" state, a new approach is used. When the microscan embedded in the AGV goes into a "warning" state, the AGV decreases its speed automatically. It is possible to set a trigger event that understands when the AGV state becomes "warning" in the Raspberry PI, which sends the trigger and the value that turned on the threshold to the cloud server. The software in the cloud server notifies the user through an email when the microscan goes to a "warning" state and maps where it occurred in the cloud server web application, that can be accessed by the user everywhere. In Fig. 6 is reported the map visible in the web page, where it is possible to see the plant layout and on the map there is a ping that locates where the "warning" state is triggered in the layout. Those data are accessible via the user interface in the cloud server. The advantage of this system is that it allows to receive information about a malfunction in real-time and supports the operator to understand where the warning state is activated and to intervene in the system.

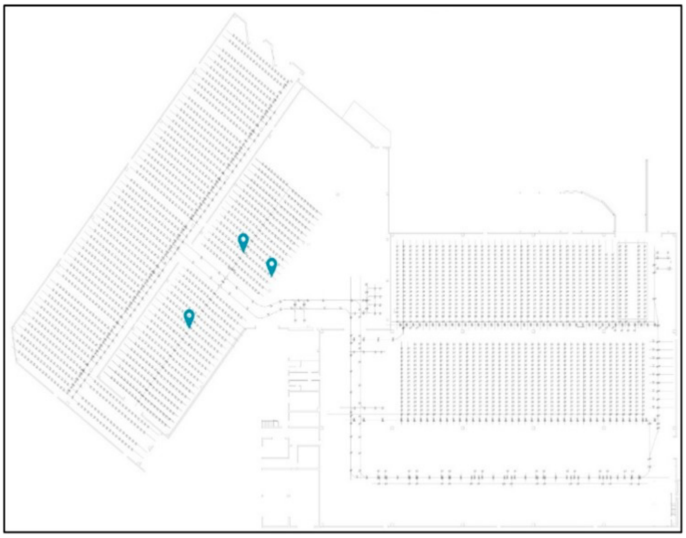

Fig. 6. Warning state analysis.

5.3 Analysis on the speed difference

For the speed difference, the same procedure used for the number of reflectors is used. The implemented system saves in the database the AGV speed, the AGV expected speed, and the AGV position. The objective is to understand when the AGV speed was lower than the expected speed, and in particular when this value is lower than a certain threshold. This is useful information because it helps to organize the layout during the speed-setting procedure. The result is shown in Fig. 7. The layout is divided into 400 areas, and the number of occurrences is counted. As in the previous test, the heatmap is done directly on the plant map. The values in the heatmap are percentage values. As in the previous analysis, it is possible to define some sections in the layout where this difference is more common.

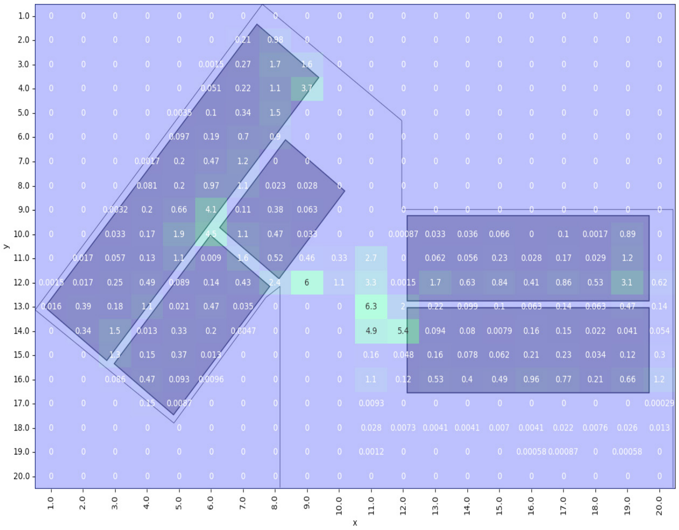

Fig. 7. Speed analysis.

5.4 Mixed analysis

Further information can be obtained by analyzing the collected data. An example is to know how many times the number of reflectors is lower or equal to 3 while the AGV is moving to destination node 5. The destination node 5 is selected because it is the most critical node as shown in Fig. 5. It is possible to discover that it happens 2226 times using the same data of the previous analysis. To increase the useful information for the user, it is interesting to know how many times the number of reflectors is lower or equal to 3 while the AGV is moving to destination node 5, the "warning" state is active and the AGV is inside the green area of Fig. 4. It happens 711 times.

6. CONCLUSIONS AND FUTURE WORKS

The target of this paper is to present a fault diagnosis approach applied in an industrial case. To implement a fault diagnosis system strategy, the collection of the data is a core activity. The presented paper uses the IoT technology to collect the data and a possible system architecture is presented. The analysis done on the collected data allows us to understand if a fault occurred and which one, in order to help the operator understand easily what is happening in the system. In this paper, we propose a methodology to diagnose and analyse a complex fault that is caused by different events. This methodology is applied in an industrial environment, and the study of the AGVs fleet efficiency is considered as a strategic fault. One of the novelty of this paper is the study of the interaction of the AGV with the environment. Starting from the presented implementation the analysis can be extended to the entire plant, to see the AGVs interaction and to search for some correlation between the AGV faults correlated to the plant layout.

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