Faculty of Electrical Engineering

OPTIMIZATION OF MOBILE ROBOT PATH PLANNING IN SEMI-DYNAMIC ENVIRONMENT USING GENETIC ALGORITHM

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OPTIMIZATION OF MOBILE ROBOT PATH PLANNING IN SEMI-DYNAMIC ENVIRONMENT USING GENETIC ALGORITHM

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in Mechatronic Engineering

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2023

DECLARATION

I declare that this report entitled "Optimization of Mobile Robot Path Planning in Semi-Dynamic Environment using Genetic Algorithm" is the result of my own work except for quotes as cited in the references.

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Date : …………13/01/2023…………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechatronic Engineering.

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Date : 13/1/2023

DEDICATION

“Say, ˹O Prophet, that Allah says,˺ “O My servants who have exceeded the limits against their souls! Do not lose hope in Allah’s mercy, for Allah certainly forgives all sins.1 He is indeed the All-Forgiving, Most Merciful”.

(Quran 39, Az-Zumar verse 53)

To my most beloved father and mother

ABSTRACT

In an Industry 4.0 framework, mobile robots are designed to perform tasks autonomously, allowing manufacturers to transform their operations which can be carried out through various integrated applications. Manufacturers could improve their productivity by remotely monitoring mobile robots and controlling their machines' status. Additionally, path planning for a mobile robot is the key role in the automation industry environment area to ensure the profitability achieved. In some cases, the area's environment always fluctuates according to the situation. It may cause the path for the mobile robot to have a different route to reach the goal destination. Hence, a semi-dynamic obstacle with better optimization solutions is crucial to cope with mobile robots in the industry environment. Thus, this thesis aims to develop a mobile robot for industrial applications by leveraging a genetic algorithm (GA). The main objective is to formulate an improved path planning for mobile robots based on GA considering the different obstacle percentage of each environment in the area. The environment design is based on a 2-D coordinated graph with irregular shapes as the semi-dynamic obstacle and by restructuring the genes to plan a robot path. The proposed method is validated in simulations and proven to work effectively in different environments for different obstacle percentages of each investigation conducted to replicate a semi-dynamic obstacle environment. Finally, the simulation was conducted by implementing a random algorithm to verify the proposed GA in terms of the mobile robot's minimum and maximum path lengths. The environment design for mobile robots' path planning based on industry environment shows excellent combinations with the GA method that generate the optimal path for the mobile robot with a semi-dynamic obstacle.

PENGOPTIMUMAN PERANCANGAN LALUAN ROBOT MUDAH ALIH DALAM PERSEKITARAN SEPARA DINAMIK MENGGUNAKAN ALGORITMA GENETIK

ABSTRAK

Dalam rangka kerja Industri 4.0, robot mudah alih direka untuk melaksanakan tugas secara autonomi, membolehkan pengeluar mengubah operasi mereka yang boleh dijalankan melalui pelbagai aplikasi bersepadu. Pengeluar boleh meningkatkan produktiviti mereka dengan memantau robot mudah alih dari jauh dan mengawal status mesin mereka. Selain itu, perancangan laluan untuk robot mudah alih adalah peranan utama dalam kawasan persekitaran industri automasi untuk memastikan keuntungan dicapai. Dalam sesetengah kes, persekitaran kawasan sentiasa berubah-ubah mengikut keadaan. Ia mungkin menyebabkan laluan untuk robot mudah alih mempunyai laluan berbeza untuk sampai ke destinasi utama. Oleh itu, halangan separa dinamik dengan penyelesaian pengoptimuman yang lebih baik adalah penting untuk menghadapi robot mudah alih dalam persekitaran industri. Justeru, tesis ini bertujuan menghasilkan robot mudah alih untuk aplikasi industri dengan memanfaatkan algoritma genetik (GA). Objektif utama adalah untuk merumuskan perancangan laluan yang lebih baik untuk robot mudah alih berdasarkan GA dengan mengambil kira peratusan halangan yang berbeza bagi setiap persekitaran di kawasan tersebut. Reka bentuk persekitaran adalah berdasarkan graf koordinasi 2-D dengan bentuk tidak sekata sebagai halangan separa dinamik dan dengan menstruktur semula gen untuk merancang laluan robot. Kaedah yang dicadangkan disahkan dalam simulasi dan terbukti berfungsi dengan berkesan dalam persekitaran yang berbeza untuk peratusan halangan yang berbeza bagi setiap eksperimen yang dijalankan untuk mereplikasi persekitaran halangan separa dinamik. Akhir sekali, simulasi telah dijalankan dengan melaksanakan algoritma rawak untuk mengesahkan GA yang dicadangkan dari segi panjang laluan robot mudah alih minimum dan maksimum. Reka bentuk persekitaran untuk perancangan laluan robot mudah alih berdasarkan persekitaran industri menunjukkan kombinasi cemerlang dengan kaedah GA yang menjana laluan optimum untuk robot mudah alih dengan halangan separa dinamik.

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LIST OF ABBREVIATIONS

GA	-	Genetic algorithm
PSO	-	Particle Swarm optimization
2-D	-	2-Dimensional
3-D	-	3-Dimensional
ACO	-	Ant Colony optimization
RRT	-	Rapidly -exploring Random Tree
ANN	-	Artificial Neural Network
IIoT	-	Industry Internet of Things
FA	-	Firefly algorithm
CDF	-	cumulative distribution function
5G	-	Fifth-Generations
MBS	-	Main base station
WSN	-	Wireless sensor network
QoS	-	Quality of service
AGV	-	Automated guided vehicle
AMR	-	Autonomous mobile robot
AMS	-	Autonomous mobility system
SA	-	Simulated annealing
HetNet	-	Heterogeneous network
EAPF	-	Evolutionary artificial potential field

VD	-	Visibility graph
IR4.0	-	Industry Revolution 4.0
A4.0	-	Assembly 4.0
IT	-	Information technology

LIST OF SYMBOLS

L	-	Length of grid in meters
S_i	-	Shaded region / obstacle
h	-	Number of cells
O_h	-	Total percentage of obstacle
β	-	Allocation number for divided shaded region
Np	-	Population size
Gn	-	Number of genes
Mg	-	Maximum number of generations
ps	-	Selection rate
pm	-	Mutation rate
pc	-	Crossover rate
G_i	-	Robot pat length before and after optimization
p_i	-	Total of point nodes
x_0, y_0	-	Starting position of robot in x and y axes
x_n, y_n	-	Destination position of robot in x and y axes
F	-	Fitness function
E	-	Destination point
S	-	Starting point

LIST OF PUBLICATIONS

Journal:

Hawari, M.Z.K. and Apandi, N.I.A., 2021. Industry 4.0 with intelligent manufacturing 5G mobile robot based on genetic algorithm. *Indonesian Journal of Electrical Engineering and Computer Science*, 23(3), pp.1376-1384.

Conference Paper:

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2. Ming, W.H., Hawari, M.Z.K. and Apandi, N.I., 2021, July. Mathematical modeling on application of wireless networks for industrial automation-factory automation. In *Journal of Physics: Conference Series* 1988(1), pp. 012024. IOP Publishing.

CHAPTER 1

INTRODUCTION

1.1 Motivation

The last few years indicated fast technological improvement in the mobile robot systems. Mobile robots are designed to perform tasks autonomously, allowing manufacturers to transform their operations which can be carried out through various integrated applications while also benefiting other industries such as medicine, transportation, and communications (Guizzo, 2020). Mobile robots also play an important role in handling certain tasks in industry, to reduce human-to-human interaction and prevent human accidents. A brand-new Industry 4.0 application that makes use of an autonomous system is intelligent manufacturing mobile robots, which requires robots to safely travel through a path and reduce the time taken from one point to another.

Nowadays, the use of automation in Industry 4.0 is continuing to grow and adapt with the intention of achieving smarter and more efficient production. According to an analysis of the trend of patent-innovation applications from Industry 4.0 in 2016, robotic technology is in first place with 26% of the total number of applied patents-innovations (Rojko, 2017). Recent studies shows, by integrating both industrial and mobile robots, Industry 4.0 aims for flexible automation and intelligent manufacturing processes (Karabegović, 2020). These can be seen in some of the most cutting-edge mobile robots in use today such as in distribution centers and warehouses for tasks including security (Krantz et al., n.d.), package displacement (Hao, 2021) and surveillance (Lee and Jeong, 2021). Moreover, future vision for the fourth industrial revolution (IR 4.0), human workers' responsibilities have evolved from execute the actual labor assignment to conduct high-level assessments, while successfully enable the robotic systems to complete the task (Jalinus et al., 2021; Rotatori et al., 2021).

On the other hand, many autonomous mobile robots are expected to operate in a partially known and uncertain environment. The advancement in this mobile robot technology needs to be able to move through its environment without being distracted and must be able to avoid any obstacles that are placed in its path. Path planning is a method used in robotics to localize mobile robots and creates a map of the mobile robot's surroundings. When a priori information about the texture of the environment is used, a method for path planning that minimizes the possibility of becoming lost is taken into consideration for an autonomous mobile robot that uses simultaneous localization and mapping (Valencia et al., 2018). A recent work in Schmid et al. (2020) also suggests a path planner that prioritizes perspective coverage to reconstruct an unfamiliar world without knowing it beforehand.

As path planning requires an algorithm suitable for path planning problems, the genetic algorithm (GA) is introduced as a natural selection-inspired evolutionary strategy. In the early study of the GA concept was proposed by Beckers et al. (1992) and the theory of GA is well explained in Mirjalili et al. (2019) which become a standard tool for solving search and optimization problems in a robot path. Motivated by the work done in Guha et al. (2021). The improved GA with modifications by restructuring the genes results in a better path planning outcomes. Thus, path planning for mobile robots has a substantial impact on the production industries since the advent of mobile robots in Industry 4.0.

1.2 Problem statement

Industry 4.0 plays an essential role in the manufacturing sector, involving the smaller industry to worldwide industry organizations in consumer supply and demand issues. Due to globalization, mobile robots are often utilized in business, healthcare, agriculture, and services sectors and are also effective in risky contexts like homeland security, space detection, and urban security (Wu et al., 2021). Mobile robots now use artificial intelligence technologies to intricate algorithms and carry out more difficult tasks. These recent changes present challenges for industry sector organizations seeking to sustain output and consumer satisfaction (Bader and Rahimifard, 2018). Problems with path planning involve finding a viable path from starting point to the destination point. The challenging part of path planning consists in finding a possible path from the start to the destination. However, it is crucial to measure a possible way from the starting point to the target point in the workspace while avoiding semi-dynamic obstacles with minimum distance.

Research works on tracking control of a wheeled mobile robot have earned attention, where the nonholonomic system suffers from the problem of nonlinearity and uncertainty (Lee et al., 2009; Hassani et al., 2018a). Through this context, GA is known as a sophisticated conventional path planning algorithm and is the most efficient. Studies by Ni et al. (2016) and Jiang et al. (2018) elaborates that the path may differ due to environmental changes. However, there is still a need to be attainable and local minimum destination problems (Rahman et al., 2019). Moreover, the size of the environment, the size of the obstacle, and the quantities of obstacles present should encourage more attention to the system development of mobile robots.

Existing GA works only focus on the robot path with no obstacles. It is crucial to minimize the obstacles that the robot path must overcome before it can reach its destination, where irregular shape obstacles, mazes and narrow environments should be considered. Hence, providing different percentages of obstacles is aligned with the GA proposal by Rahman et al. (2019), which defines the area size because the robot can determine the fastest route to the destination with various settings of the obstacle placements. Consequently, the likelihood of discovering an ideal path is higher, but it adds cost to the timing of the simulations.

1.3 Objectives

The main objectives of this research work are as follows:

a) To formulate a semi-dynamic obstacle with minimum distance for mobile robots in the industry environment.

b) To implement GA for path planning of the mobile robot in semi-dynamic obstacles.

c) To evaluate the proposed GA in terms of the path length of the mobile robot and the time it takes for the mobile robot to reach the destination in the presence of the semi-dynamic obstacle.

1.4 Research scopes

The basic GA programming provides the proposed developed algorithm that includes the GA parameter, which is mutation, crossover, population and fitness value. For the simplicity of model development, we consider the obstacle in irregular shape to be a semi-dynamic condition, and the regular is in a static state. The mobile robot is acts as Agents, and the semi-dynamic obstacle is called an Environment. Agent and Environment are two pillars of Artificial Intelligence, and we aim to build intellectual agents and work in an

Environment. The Agent is the solution and environment are the problems. Another definition of the semi-dynamic Environment in this research is if it does not change with time, while the agent's performance result does.

The parameters will be determined with the best fitness value for each variable, mutation and crossover. The simulation work will be done using the following settings: one robot travelling from one position to one destination. As for the evaluation process, a comparison the performance of manufacturing mobile robots with the multiple experiments conducted with the same parameters and environment with semi-dynamic obstacles.

1.5 Thesis outline

The dissertation of this research paper was divided into five chapters, the chapter and their consecutive topics discussed was briefly explained in this part:

Chapter 1 introduced the research article and provided a summary of the study. This chapter expands on the study's introduction, objectives, problem statement, and motivations.

Chapter 2 discusses the literature reviews conducted on the project's concept and materials. The literature review entailed the examination of a previously published research report. This involves research on industry 4.0, intelligent network mobile robots, path planning, and path planning algorithms.

Chapter 3 discusses the research's methodology and technique. It comprises the design and formulation of a path model for mobile robots, as well as the proposed GA method.

Chapter 4 is the section in which the experiment's results are presented and explained, as well as the research analysis phase of the work is completed. The results were presented in tables and graphs.

Chapter 5 highlights the outcome of the research. It provides the discussion and conclusion for what was considered the essence of every chapter and the project's significant contribution. The recommendations for future work on this topic are also included.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter assesses the literature on the subject of research. First, an introduction to Industry 4.0 is given, followed by a focused study on the path planning of mobile robots in the industry. Finally, a brief explanation types of algorithms that implement for path planning.

2.2 Industry 4.0

As a result of the ongoing merger of technologies that preceded it, the emerging revolutionary phase began in Germany in 2011 and is often referred to as "Industry 4.0." It entails a complete digital transformation of critical company functions, incorporating new technology into every part of the organisation. Industry 4.0 is a model for developing an intelligent, self-regulating, and networked industrial value chain..

Industry 4.0 is envisioned as a smart factory equipped with futuristic machinery and a cutting-edge communication and information infrastructure (Sanders et al., 2016). This revolution will transform the industry into one that is more efficient and successful while still placing a significant focus on communication and interaction between employees (Luque et al., 2017). However, the entire process of integrating and operationalizing industry 4.0 is costly. As was the case with earlier revolutions, it will take time for countries and businesses to adapt to the new one. However, a few nations have already implemented regulations to accelerate the adoption of Industry 4.0 in their manufacturing sectors.

Germany leads the way in terms of implementation, followed by Brazil and Spain (Sander et al., 2016; Luque et al., 2017; Tortorella and Fettermann, 2018). Nowadays, the industrial business is undergoing rapid change. This evolution is being driven by changing client demands and market trends.

Additionally, manufacturing is becoming increasingly individualized. This necessitates rapid adaptation by businesses to these developments (Zhou et al., 2016; Bartodziej, 2017). Industry 4.0 study demonstrates that it is an encouraging answer to these issues. As Industry 4.0 is based on the integration of an organization's manufacturing processes (Sanders et al., 2016; Zhou et al., 2016). It is critical to understand how industry 4.0 is implemented. It is built on the building components of the cyber-physical system (CPS), which are built on a foundation of sophisticated connectivity and decentralised governance. These blocks are capable of communicating in real-time and relaying important information without the need for human interaction. To bring these blocks together on the same platform, however, significant software support is still required. The introduction of these technologies has an effect on an organization's production and efficiency. Due to the fact that they reduce human contact, information is shared not just between machines but also between machines. This has a significant impact on an organization's production time (Jazdi, 2014; Bartodziej, 2017). Industry 4.0 is a novel topic that experts are still debating and researching. Additionally, we are investigating strategies for implementing it in many businesses. Parallel to this, some research suggests that it is premature to talk about implementation and that it will take 10 to 15 years to fully comprehend the phenomenon. As Industry 4.0 is a "smart factory" idea, it will eliminate human contact and entirely automate processes. Whereas many manufacturing businesses demand a variety of diverse procedures.