Task Scheduling Based on Genetic Algorithm for Robotic System in Manufacturing Industry

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Abstract – *With the development of 5G technology, the robotic system has been bought into industrials. Even manufacturers plan the task flow by using project management. An error may occur and make the tasks overlap because they use the traditional scheduling method. It may waste much time between the tasks, and robots will get into standby mode to wait for the next tasks if the scheduling is failed. An algorithm with flexible scheduling is needed to arrange the tasks accordingly with the shortest total completion time. Genetic Algorithm (GA) is applied to task scheduling, and it provides a better solution from previous results or arrangements due to iteration. In this study, an analysis involves multi robots to complete various industrial operations, consisting of multi-tasks. To save time during processing and costs in production, GA may help it have the optimal value about total complete time to avoid any wastage. In short, the manufacturer will have higher productivity and better performance among the robots when applied a suitable Task Scheduling in the industry or workplace.*

Keywords: *Genetic Algorithm, Task Scheduling, 5G, Robotic System, Manufacturing*

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I. Introduction

Task Scheduling is applied to many manufacturing industries, and there are having different types of algorithms to obtain a flexible schedule for all the manufacturing processes. For example, manufacturers use some algorithms: Integer Linear Programming, Shortest Processing Time, Longest Processing Time, and the famous scheduling algorithm, the Genetic Algorithm (GA)[1]. Many industries try to step into Industry Revolution 4.0 (IR4.0), and they have many production lines in the manufacturing sector. To increase their products' productivity or quality, manufacturers will replace human resources with a robotic system. Another reason they are doing this is that the robotic system may reduce the cost of hiring workers and minimize any error in those production lines. At the same time, 5G technology was brought by China, and there started to apply it to industrial areas and home applications. Since 5G technology has a larger bandwidth and higher frequency than 4G, its latency could drop to around 1ms [2]-[3]. Therefore, 5G has a better response on communication systems between devices, machines, or multi-robots. In addition, those industrials are not only used to connect between devices, but also useful for other applications such as Internet of Things (IoT), Quality of Services (QoS), Cognitive System, Big Data Analytics, Cloud Computing, Augmented Reality, and Machine Learning to make the jobs can be accomplished most easily [4]-[5]. With the help of a robotic system and 5G technology, GA may perform well in many industries to obtain the shortest total completion time of all the manufacturing processes.

GA is an optimization tool that calculates the shortest total completion time for the manufacturing processes. In the meanwhile, 5G technology has been introduced into this project. By comparing the 4G-LTE that we have now, everyone hopes to have a better performance, such as lower latency for getting output in a short time. From the development of 5G technology, engineers have limited available spectrum in the microwave band and explain that the existing mobile networks will fail to support the high traffic demand. To improve the 5G architecture, it may use in mobile services like ultra-high-definition

(UHD) video or 3D live program streaming, IoT services, augmented reality, cloud support, etc., in upcoming mobile networks and devices[6].

On the other hand, 5G technology has a larger bandwidth with a higher frequency than 4G. Due to the new technology being used, different applications related to the Internet of Things have been planned to apply by using 5G. They are media, transportation, healthcare, environment, energy conservation, infrastructure and many more. 5G may be applied to different fields because its capability is stronger than 4G-LTE. There is showing the similarity and differences between 4G and 5G based on their specifications in Table I [2]-[3].

TABLE I
COMPARISON BETWEEN 4G AND 5G

Specification	4G	5G
Full-Form	Fourth Generation	Fifth Generation
Start from	2010	2016
	Similarity	
Handover Signal	Horizontal and Vertical	
Technologies	Unified IP, seamless integration of broadband LAN/WAN/PAN and WLAN	
Services	Dynamic information access, wearable devices, HD streaming, and Global roaming	
	DIFFERENCES	
Data Bandwidth	2Mbps to 1Gbps	1Gbps and higher as per need
Frequency Band	2 to 8 GHz	3 to 300 GHz
Data Average Speed	15Mbps to 50Mbps	50Mbps and up
Latency	Around 50ms	Could drop to 1ms
Core Network	All IP network	Flatter IP network, 5G network interfacing(5G-NI)

5G has a larger data bandwidth than 4G. The latency is lower in 5G than 4G and may be applied in more and more applications. On the other hand, industrials are trying to apply this GA with 5G technology together because GA may optimize the IoT coverage and node redundancy. From the best performance, GA can implement the preferential selection of non-critical nodes to maximize the length of the configurations sequence of working nodes. Therefore, there will be giving an outperforms on small IoTs in terms of coverage, the number of nodes, computing time, and the IoT lifespan[7].

The mobile robot is a new development of Industrial Revolution 4.0, and it is helped to deploy the unmanned system for having better performance in production lines or any process chains [8]. Before implementing a robotic system inside an industry, there should make sure that mobile robots or machines may communicate with each other very well for preventing errors and accidents from occurring in the workplace. 5G technology is bought to obtain such strong connection between them and become one of the important elements due to the need for high-performance and long-term data storage, which is 4G network cannot handle that kind of demand. Therefore, the Wi-Fi network from 5G technology plays an important role in ensuring the connection's stability between multi-robots due to lower latency and larger bandwidth from 4G.

Nowadays, manufacturing industries tend to move towards automated and complex manufacturing systems due to increased customer demand for more sophisticated products. If any industrials are going assembly process, they properly involve a highly interrelated level of planning and scheduling problems [9]. Mostly they would like to maximize the net profit by reducing the cost and shortening the processing time of production, a parallel process is required, and only this will have the better output in short. GA has its advantage because it is applied well in the parallel process by both operators on task scheduling to obtain the shortest total completion time. However, the industrials still need an exact figure on how the process is going before using GA to ensure the desired output, such as how many tasks are included in a complete operation.

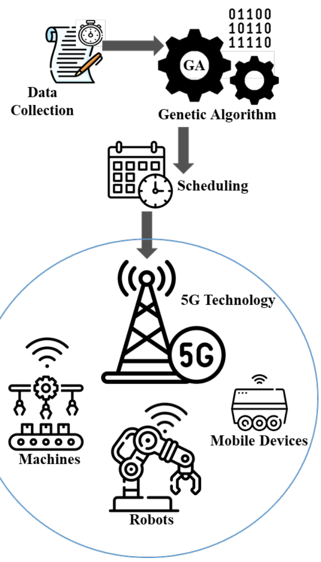

Fig. 1. Application of Task Scheduling in Robotic System based on GA

Besides, better technology is needed to run the algorithm and require a complete robotic system in manufacturing industries to carry out all the processes in production lines. The robotic system is helping manufacturers to reduce the number of human resources, increase productivity and efficiency in their production lines. Depending on the different types of tasks, they may be completed by different methods. Referring to Fig. 1, the schedule will be transmitted to machines, robots, or mobile devices that work in industries with Wi-Fi networks from 5G technology. Fig. 1 shows that machines can complete the tasks that stay at the same place, while robots and mobile devices may help transfer storage. More and more industries are starting to apply the robotic system, and a study from an international team named as International Federation of Robotics, the installation for the robotic system was showing a consistent increase from the year 2010 to 2018 [10]. For having a better performance in the industrial, mostly those robotics or machines are allocated in the same workshop to complete their tasks because the time taken of movement from one place to another is needed and it may consider as a task in scheduling.

In addition, many algorithms may be used for task scheduling, and one of the algorithms is GA in this study. GA also applied to the DNA system and it is a general-purpose to have a better solution, population-based search algorithm that presents the samples from the original set of all possibilities, whether they are solutions in a problem space, strategies for a game, rules in classifier systems, or arguments for problems in function optimization [11]. However, nowadays, people are using this GA for having better scheduling to complete the tasks in the workplace. DNA system has many chromosomes, and people assume the chromosome as the arrangement of tasks or jobs [12]. Then, the genes inside chromosomes will become the individual task, and people rearrange them in a different sequence to obtain a better arrangement. The process is called Crossover and Mutation in this GA. People repeat the process because the algorithm needs iteration to have a better solution from previous results. Therefore, the GA is used for task scheduling in different sectors, including the industrial. They need it to manage the tasks and complete them with machines or robots in production lines. In this paper, a flexible schedule of minimal completion time for multi-robot to obtain an analysis about the relationship between the rate of crossover or mutation and the performance in task scheduling based on GA.

II. System Model

The system is modeled based on GA utilizing MATLAB software which is represented as pseudocode shown in Table II. The concept of GA is according to the iteration of chromosomes population, and those chromosomes are evaluated using a genetic operator such as crossover and mutation.

TABLE II
PSEUDOCODE FOR GENETIC ALGORITHM

Algorithm: Genetic Algorithm

```
// Initialise generation 0:
k: = 0
P_k: = a population of n randomly-generated individuals;
// Evaluate P_k:
Compute fitness (i) for each i ∈ P_k;
do
{    // Create generation k + 1:
     // 1. Copy:
     Select (1 − y) × x members of P_k and insert into P_{k+1};
     // 2. Crossover:
     Select y × x members of P_k; pair them up; produce offspring; insert
     offspring into P_{k+1};
     // 3. Mutate:
     Select z × n members of P_{k+1}; invert a randomly-selected bit in each;
     // Evaluate P_{k−1}:
     Compute fitness (i) for each i ∈ P_k;
     // Increment:
     k: = k + 1;
}
while the fitness of the fittest individual in P_k is not high enough;
return the fittest individual from P_k;
```

In the beginning, the number of population, α should be set as

$$\alpha > 1. \tag{1}$$

Both processes rate of crossover and mutation denoted by y and z, where $y = 0.1, 0.2, \dots, 1.0$ and $z = 0.1, 0.2, \dots, 1.0$, respectively, should be decided before every single simulation. After that, $k > 1$ the algorithm will start to calculate and stop until the shortest total makespan is found. The most important input variable will be the processing time for each task that arrange in scheduling. Processing time may include the time taken for production, doing maintenance or downtime, reloading sources on machines, and others. These all-processing times will be measured in minutes. Then, those tasks are needed to arrange into 5 operations that study in this study. Each operation is owned by 10 tasks so a total of 50 tasks will be studied based on GA.

A. Forming Chromosomes

One chromosome consists of many genes and there need to arrange ten genes in a single chromosome for this study. In this case, we call the gene a Task, T. That is means, one operation is completed by ten tasks. In this study, 5 operations will be tested. Before forming the parent chromosome, we may declare any genes according to O_{ijk} where $i = 1, 2, \dots, 5$, $j = 1, 2, \dots, 10$, and $k = 1, 2, \dots, 5$ while i, j and k is the total number of tasks, operations, and robots, respectively. Then, the first parent chromosome is formed by simply arranging the robots because the sequence will be rearranged in the following process. The sequence will be depending on the number of operations. Therefore, $O_{i,j,1}$ will represent the task is done by robot 1. For example, the first parent chromosome will be $[O_{1,1,2}, O_{2,3,1}, O_{2,2,3}, \dots, O_{4,7,4}]$ and having 50 genes inside one chromosome. However, there just needs to be noticed only the number of robots is showing in chromosomes during simulation. It should be $[2, 1, 3, \dots, 4]$.

B. Crossover

Crossover is a process that combines two parent chromosomes to produce new offspring chromosomes and it may call as genetic operator. The idea for this process is, the new chromosomes may be better than both of the parents if they take the best characteristics from each of the parents. In this process, at least two chromosomes are needed to do the Crossover. There are given examples with 9 genes in one chromosome which is similar to the situation during simulation [13] and the information is well explained by Debarshi Barat in his study. Then, two parents are obtained and shown below in Fig. 2. In this study, One-Point Crossover is applied to get the offspring from both parent chromosomes. There may do a cut-off between the genes at any place and exchange the genes with each other.

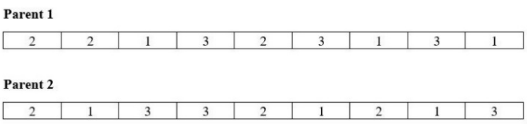

Fig. 2. Parent chromosomes before any process

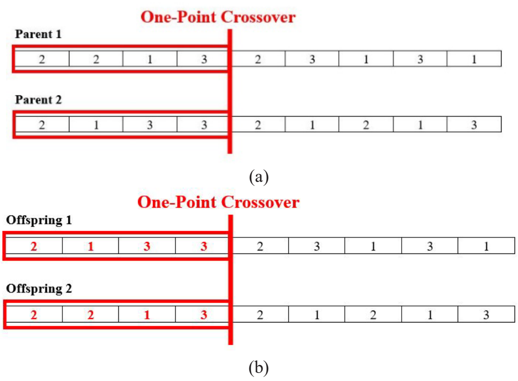

Fig. 3. Chromosomes (a) before and (b) after crossover process

Fig.3 illustrates the difference in the coordination of chromosomes once the crossover process takes place. It is worth noting that the crossover rate is essential to control the capability of the GA in exploiting a located hill to reach a local optimum. Suppose there is a set crossover at a higher rate, the quicker the exploitation proceeds. Therefore, that is not recommended to set the crossover rate too larger, and it would disrupt individuals faster than they could be exploited. Normally, the crossover rate has a value between 0.3 to 0.7.

C. Mutation

Mutation is a genetic operator that alters one or more gene values in a chromosome from its initial state. With the new gene values, this GA may be able to have a better solution than previously possible. Hence, the Mutation process is playing an important part in the GA to prevent the population from stagnating at any local optima. The chromosomes from the previous process need to go for the Mutation process with a method called ‘Boundary’. The boundary is a mutation operator that simply exchanges one gene with another chromosome. The Boundary Mutation process takes place and shows in Fig. 4.

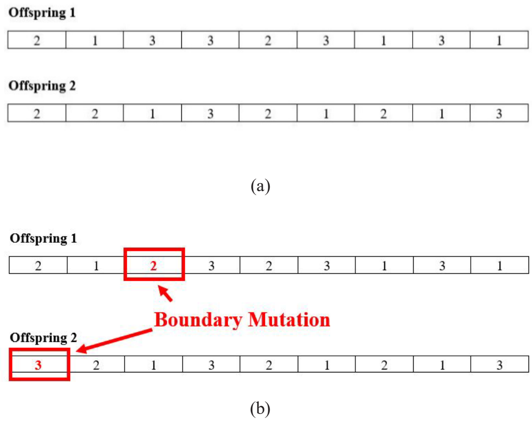

Fig. 4. Chromosomes (a) before and (b) after mutation process

Interestingly, the mutation process may be used to correct those offspring chromosomes that ensure the robots have an average number of jobs to complete. The crossover has a process rate, but the mutation process does. The mutation rate occurs during the evolution according to a user-definable mutation probability. Most of the time, there is recommended to do the mutation with a rate between 0.025 to 0.15.

After completing both crossover and mutation processes, there will be many offspring chromosomes resulting in this GA. Different offspring chromosomes are coming from different parent chromosomes. Therefore, they all have different performances, such as total complete time in task scheduling. The total complete time from each chromosome by substituting the processing time into genes. Following this, the selection of a chromosome is based on the shortest total full time from processing. If the shortest total makespan is not found, the GA will run over again from step-forming chromosomes.

In addition, real-time data is required to run through the simulation using this system model based on GA. The data is recorded from a glove manufacturing industry as the case study. The production lines produce different gloves sizes, such as small, medium, and large, while he recorded the processing time for producing 10 inner boxes of gloves using a stopwatch. Since many machines are running in lines, he tried to standardize the processing time by making an average from those machines. Therefore, that is using 4.5 minutes to produce 10 inner boxes of gloves.

Note that there also need to consider other situations like machine downtime, reloading sources to the machine, and adjusting when the machine is misaligned. These all are recorded as a task when forming chromosomes. Hence, Table III shows the real-time data needed to apply in the simulation and run it using MATLAB.

TABLE III
DATA VARIABLES FOR SIMULATION

Variables	Time Taken
Processing Time for 10 boxes of gloves	4.5 minutes
Doing maintenance or having downtime.	30 – 45 minutes
Reload resources and do adjustment on machines or robots.	10 – 15 minutes

III. Simulation Results

A. Finding The Best Rate of Crossover and Mutation Process

Before simulating in MATLAB, that should ensure the real-time data is the best fit to go through those genetic operators. For example, the production lines produce only a small number of gloves. An individual task should take from 85 minutes to 90 minutes on different machines for producing around 200 inner boxes of gloves. To obtain the best crossover rate from the GA, fixing other system parameters at the beginning and trying different values for having the shortest total makespan is needed. Table IV shows the system parameters settings with various populations and iterations.

TABLE IV
SYSTEM PARAMETERS SETTINGS

	Simulation			
	1	2	3	4
Size of Population, α	100	100	(100, 500)	100
No of Iterations time, k	100	100	100	(100, 500)
Mutation Rate, z	0.5	(0.1, 1.0)	0.5	0.5
Crossover Rate, y	(0.1, 1.0)	0.6	0.5	0.5

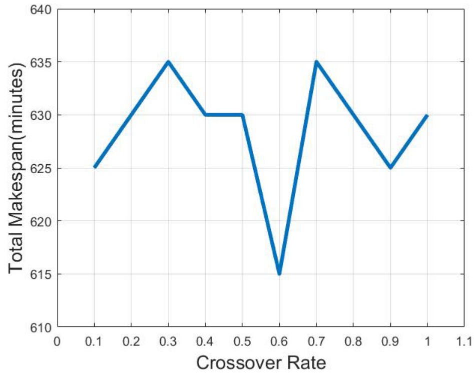

Fig. 5. Total makespan performance with the various rate of crossover

Fig. 5 shows the total makespan is fluctuating from 615 minutes to 635 minutes based on the GA with a crossover rate from 0.1 to 1.0. Next, the simulation time was also around 80 seconds for each crossover rate. In Fig. 5, there may know that the best crossover rate is from 0.5 to 0.7, with having the shortest total makespan at 615 minutes. After studying the crossover rate to apply to the GA, another main system parameter is needed to be studied. The mutation process and its rate will affect the performance as well. According to the results from the crossover process, there is having the shortest total makespan at a rate of 0.6. Therefore, a fixed value for crossover rate and simulation with various mutation rates. Fig. 6 shows the total makespan fluctuates from 610 minutes to 640 minutes based on the GA with a mutation rate from 0.1 to 1.0. In addition, it is seen that the best mutation rate is from 0.4 to 0.5 with having the shortest total makespan at 610 minutes.

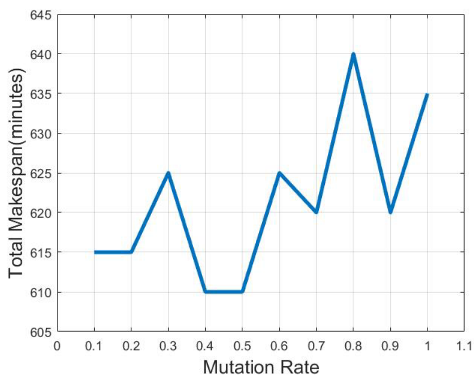

Fig. 6. Total makespan performance with the various rate of mutation

B. Comparison of System Parameters

It is crucial to compare two simulation results obtained from two different system parameters (size of population and number of iterations) to ensure that performance of the GA has not been affected. Fig. 7 shows the total makespan performance that fluctuates between 610 and 625 minutes. That has been not affected so much, but the simulation time is kept increasing from 73.05 seconds to 388.56 seconds.

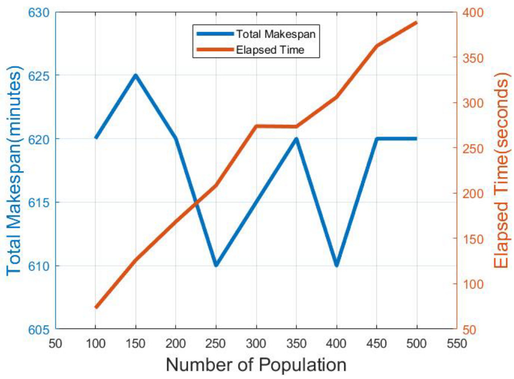

Fig. 7. Total makespan and elapsed time with various number populations

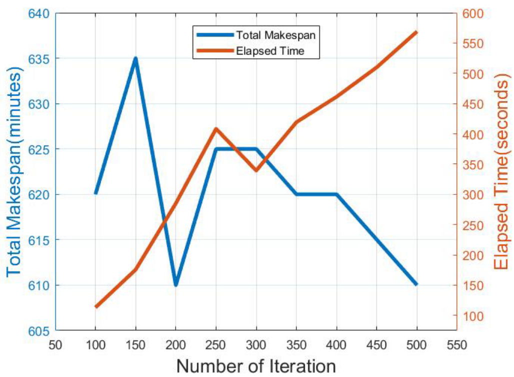

Fig. 8. Total makespan and elapsed time with various number of iterations

Next, another system parameter is needed to study, related to the number of iterations. From Table IV, both crossover and mutation process rates are set at 0.5, while the number of populations is only set at 100. The number of iterations is changed. Fig. 8 shows the total makespan only fluctuating from 610 minutes to 635 minutes. That is the same with the result at the various number of populations. It has not been affected so much, but the simulation time increases from 113.00 seconds to 569.02 seconds. In this study, the best crossover and mutation rates are found after running simulations. Since there may not be a rate directly from simulation, it needs to fix some parameters at the beginning, go through various rate values, and then obtain the range from simulation outputs. The result shows the rate from 0.5 to 0.7 for crossover while 0.1 to 0.3 for mutation. After that, a few simulations were going on to ensure other system parameters like the number of population and iteration will not affect the performance of the GA. There are shows that only simulation time will be affected when the population and iteration increase.

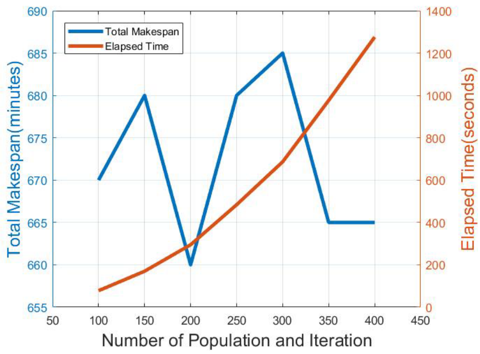

Fig. 9. Total makespan and elapsed time without GA

On the other hand, the results are also affected if the simulation runs without GA. There are means that both genetic operators (crossover and mutation) are set the rate to become 0. Fig. 9 shows the total makespan fluctuates from 660 minutes to 685 minutes while elapsed time keeps increasing from 77.71 seconds to 1275.77 seconds. Compared to the previous simulation, it takes a longer time for completing the tasks, as shown in Fig. 10. Therefore, it becomes not effective enough to do scheduling without GA because elapsed time is up to 21.26 minutes which is equal to a single task like adjusting a machine.

In short, the results are relied on what data inputs are inserted, and there might be differences if the number of robots or tasks are changed. That is needed to collect real-time data from industrials and apply it to GA.

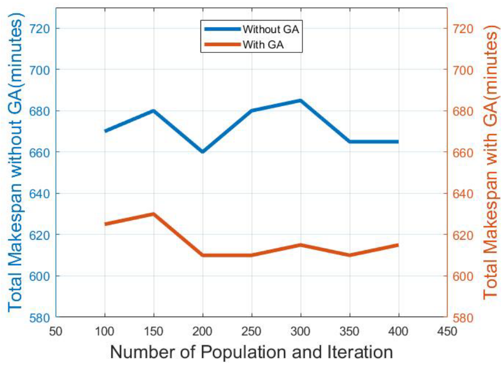

Fig. 10. Total makespan between with GA and without GA

IV. Conclusion

GA is worked to obtain flexible scheduling that gives the shortest total time from processing in production lines. GA helps reduce the cost and save the energy that might be used in extra. The simulation result shows that having the optimal value about the total completion time is between 610 minutes to 635 minutes based on the Crossover and Mutation process. This result revealed that manufacturers might save much time scheduling and applying the GA. The shortest the total complete time from processing, the more savings on hiring workers and using more robots to reach higher productivity.

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