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EFFECT OF CONTOUR INTERVAL ON MINIMIZATION OF TOOL PATH LENGTH IN POCKET MILLING PROCESS

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Abstract

Reduction of machining time in the pocket machining process is important in order to enhance performance and increase productivity. In this paper, the main objective is to decrease the roughing time in pocket milling process by investigating the effect of path interval caused by the uncut area in the pocket milling with sharp corner. Decreasing machining time in process of milling using contour parallel direction as a strategy of machining can be achieved by increasing the value of tool path interval. Though, increasing the tool path interval has caused the existence of an uncut area at the sharp corner. To remove this uncut area, an additional tool path length is generated. So, this paper is carried out to study the consequence of path interval upon the existence of uncut region and the impact to the path length of contour parallel. There were three different values of tool path interval chosen and set to study the consequence of cutting tool path interval on tool path length, which were 5.6 µm, 5.7 µm, and 5.9 µm. Ant colony algorithm was developed to minimise the additional path length. As a result, increasing the path interval has produced larger uncut region at the corner. However, it produced shorter additional tool path length which resulted in lower roughing time.

Keywords: Ant colony optimisation, Contour interval, Milling, Tool path.

1. Introduction

The pocketing machining is one of the crucial processes in mould manufacture. The process is intended to remove all the materials within the specified contour profile. In the pocket milling process, there are two important processes, which are roughing and finishing. Roughing is a process where a certain amount of material needs to be removed and the approximate machining time is about 50% of the entire machining time reliant on shape of the mould [1]. Hence, it is significant crucial to increase the roughing time to enhance the efficiency and productivity of the machining process. Reducing path length in roughing machining is one method to produce shorter roughing time. There are many factors that influence the length of tool path such as, stepover, axial depth of cut, and procedure of machining, that are contour parallel and zig-zag. In term of, the contour parallel method is capable to generate shorter time rather than zig-zag method [1].

El-Midany et al. [2] contrasted the time of machining for various forms of pockets using five different cutting techniques found in the CAM system, such as normal zigzag, contour parallel,smooth zigzag, spiral, and fishtail spiral on different geometric components. They have found that the variety of type of cutting method changes on the component geometry. Xu et al. [3] had also conducted a study to identify the effectiveness of the smooth spiral and the contour parallel method on the rectangular pockets and found that the smooth spiral method can reduce time by 30% compared to contour parallel methods. This is because by using the smooth spiral technique, it can overcome the problem of feed rate reduction on sharp edges of the contour.

However, in contrast to the study conducted by Pavanaskar [4], it was found that contour parallel methods are more effective compared to the spiral method because it can remove more workpieces and produce shorter machining time. Besides, the study conducted by Kim and Choi [1], and Adesta et al. [5] also found that machining time for pocket machining using method of contour parallel can produce quicker machining time contrasted to the zigzag approach.

There are several studies that focused on producing lower machining time in contour parallel by reducing the length of the tool path. For example, Zhao et al. [6] had proven that reducing tool path length can produce shorter machining time. In these research, a mathematical equation has been established to obtain minimum tool path length. Besides, there are several researches that applied the artificial intelligence method to optimise the tool path length. In a previous research by Gupta et al. [7], they optimised the tool path length in pocket machining by minimising non-productive tool path length using Genetic Algorithm (GA).

Oysu and Bingul [8] and Kumar et al. [9] also reduced the non-productivity of tool path length of pocket machining by applying hybrid algorithm which is combination of genetic algorithmand simulated annealing (GA-SA). Besides, Abdullah et al. [10] used Ant Colony Optimisation (ACO) and GA to reduce distance of tool path to minimise machining time.

Meanwhile, Tian and Jiang [11] and Abdullah et al. [12] have use Ant Colony Optimization (ACO) to produce lower machining time by reduce length of tool path in pocket technique by decreasing the sequences of cutting tool. In this study, due to generating contour parallel machining, the model of pocket had to be divided into several parts created by centre of contour to minimise the change of the cutting tool.

In contrast to the research performed by Lin et al. [13], time of the roughing process during contour parallel machining was reduced by optimising path length of contour method. The length of path was decreased by increasing the value of path interval in the roughing process. Consequently, the uncut area appeared at the centre and corner of contour. Mathematical model gets been developed to remove uncut region. Bahloul et al. [14] have developed a mathematical model to determine the optimum tool path interval to avoid existing uncut region. On the other hand, this method is capable to generate lower tool path length. At the same time, this method can prevent the occurrence of uncut region.

Besides, Huang et al [15], has established new spiral method to decrease the length of path. Other than that, they have examined the impact of curvature interval on tool path length. Leroy et al [16] has run several simulations to evaluate the change of tool path approaches on roughing time. This study showed that the tool path length is one of the factors that should be considered to improve efficiency of machining time. Godwin [17] also developed a mathematical model to produce a tool path while considering the radial and axial depth on minimising machining time. Based on the study, 60% to 100% of radial depth range of cutting tool diameter provided a lower machining time.

Meanwhile, Xu et al. [18] investigated the tool path strategies based on traditional contour parallel and optimised contour parallel with the considered existence of the uncut region. In their studies, the larger stepover or tool path interval has generated shorter tool path length, since they had to handle the uncut region problem. However, in the previous study, to generate shorter distance of tool path, the movement and sequences of cutting tool has not been considered. Consequently, it has been generating longer length of the path and increase the period of machining. Consequently, this study shows the extended research by Abdullah et al. [12] to determine the effect of path interval on length of tool path and roughing time influencing by uncut region.

In this present study, ACO has been employed to minimize the length of tool path that using contour parallel strategies by determining the outcome of tool path interval on occurring of the uncut region.

2. Development of Contour Parallel Offset

Contour parallel algorithm was established to produce the path of contour parallel based on the value of tool path interval that has been set. In this study, an algorithm was established based on the technique recommended by Kim et al. [19] and Lee et al. [20]. To produce a complete contour parallel tool path, some steps should be followed, namely defining the coordinate of boundary profile, determining the location and offset point, and generating the offset line. This process will continue until the whole contour parallel method is produced. The detail of this algorithm is explained in the previous study by Abdullah et al. [12]. Figure 1 shows an example of a complete offset of the model that has been used for the simulation process.

Once the tool path contour parallel has been generated, the detection of the uncut area that occurred at the corner of contour was carried out. This was to produce supplementary tool path in order to eliminate the whole uncut regions that existed in each level of contour. Besides, the cutting simulation has been done in MasterCAM to detect the location of the uncut region as shown in Fig. 2.

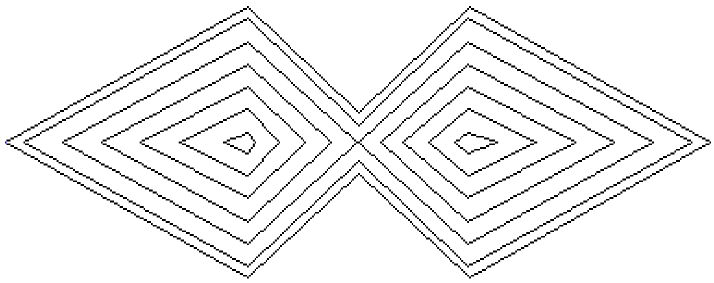


Fig. 1. A complete offset of contour.

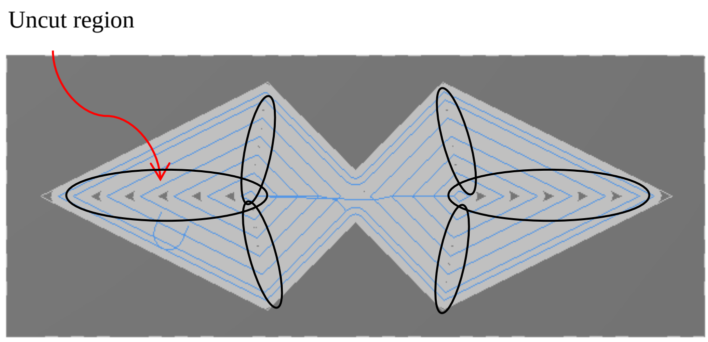


Fig. 2. Uncut region and contour parallel based on MasterCAM.

A clear tool path has been generated to eliminate the whole uncut region that occurred at the corner of contour. Based on Lin et al. [13], the uncut area will occur at the corner of pocketing if the value of tool path interval is greater than 75% of cutting tool diameter and fulfil Eq. 1. The angle, Θ is referring to the larger angle in the corner of the pocket. To ensure the uncut region appeared at the corner, the minimum tool path interval was 5.6 mm. 5.7 mm and 5.9 mm were selected in order to compare the results as explained in Abdullah et al. [12].

$$\omega > r\left(1 + sin\left(\frac{\theta}{2}\right)\right) \tag{1}$$

3. Development of Ant Colony Algorithm

To improve the additional tool path, Ant colony algorithm (ACO) has been applied so that it can produce a lower length of tool path. ACO is one of the artificial intelligence methods implemented from behaviour of ant colonies as established by Dorigo et al. [21]. The pheromones left by ants enable them to be aware of a complex environment in exploring for food which can ensure their return to the nest by a shorter route. In this paper, the movement of the ant to each node represented the cutting tool movement. The ant has been located on the first node of first contour that uncut region exist as shown in Fig. 3.

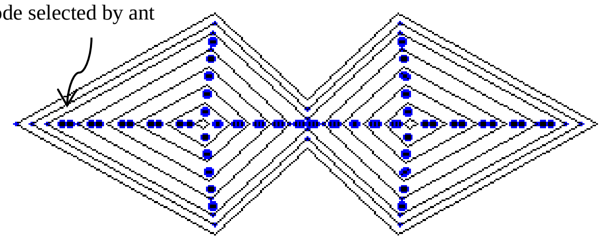


Fig. 3. First node selected by ant.

For the process of the ant choose the next node, probability rule as in Eq. 2 has been applied;

$$P_{i,j}^{k}(t) = \frac{[\tau_{i,j(t)}]^{\alpha}[\eta_{i,j}(t)]^{\beta}}{\sum_{t \epsilon N_i^k}[\tau_{i,j}(t)]^{\alpha}[\eta_{i,j}(t)]^{\beta}} \; j \epsilon N_i^k \qquad (2)$$

where,

N_i^k = Listing of nodes not been troughed by ant k

$\tau_{i,j}(t)$ = Trail intensity at edge (i,j)

σ = effect of pheromone

$\eta_{i,j}(t)$ = $1/d_{ij}$ is called the visibility

β = Weight of the visibility

The route of the ants to the following nodes is influenced by and weight of visibility (β) and weight of pheromone (α). Hence, the determination of α β is one of the important parameters in ACO optimization. The determination of these parameters was explained in the previous paper by Luo et al. [22] and Abdullah et al. [12]. $1/d_{ij}$ is inverse is knows as distance affected by the the movement of ants between two points of uncut region. While d_{ij} is calculated based on the equation as in Eq. 3.

The route of the ants to the following nodes is influenced by and weight of visibility *(β)* and weight of pheromone *(α).* Hence, the determination of α β is one of the important parameters in ACO optimisation. The determination of these parameters was explained in a previous paper by Luo et al. [22] and Abdullah et al. [12]. $1/d_{ij}$ is inversed and known as distance affected by the movement of ants between two points of the uncut region. Meanwhile, d_{ij} was determined by using the Eq. 3.

$$d_{ij} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \qquad (3)$$

At each iteration, the memory has been storing the route of ant to the visited node to ensure the ants will not choose the same node on next movement. The value of tool path length is determined once the whole nodes of uncut regions are visited by the ants. Then, the Eqs. 4 and 5 has been used to revise the level of pheromone on each side.

$$\tau\,(i,j) = (1 - \rho)\,\tau\,(i,\ j) + \sum_{k=1}^{m} \Delta\tau_k\,(i,\ j) \qquad (4)$$

where is:

$$\Delta\tau_k\,(i,j) = \begin{cases} 1/L_{lt} \; if \; (i,j) \in \text{journey by ant } k \\ 0 \qquad\qquad \text{others} \end{cases} \qquad (5)$$

L_{lt} stands distance of clear tool path which is refers to length of eliminating the whole uncut region from the first contour to the last contour. Ant colony optimisation has been used to determine the shortest length of the clear tool path. Besides, L_{lt} also known as the fitness function that must be minimized in the ACO. The ACO simulation has been employed on the different path interval to define the tool path length for each tool path interval. The flow process of ant colony algorithm was applied to minimise the additional tool path as illustrated in Fig. 4.

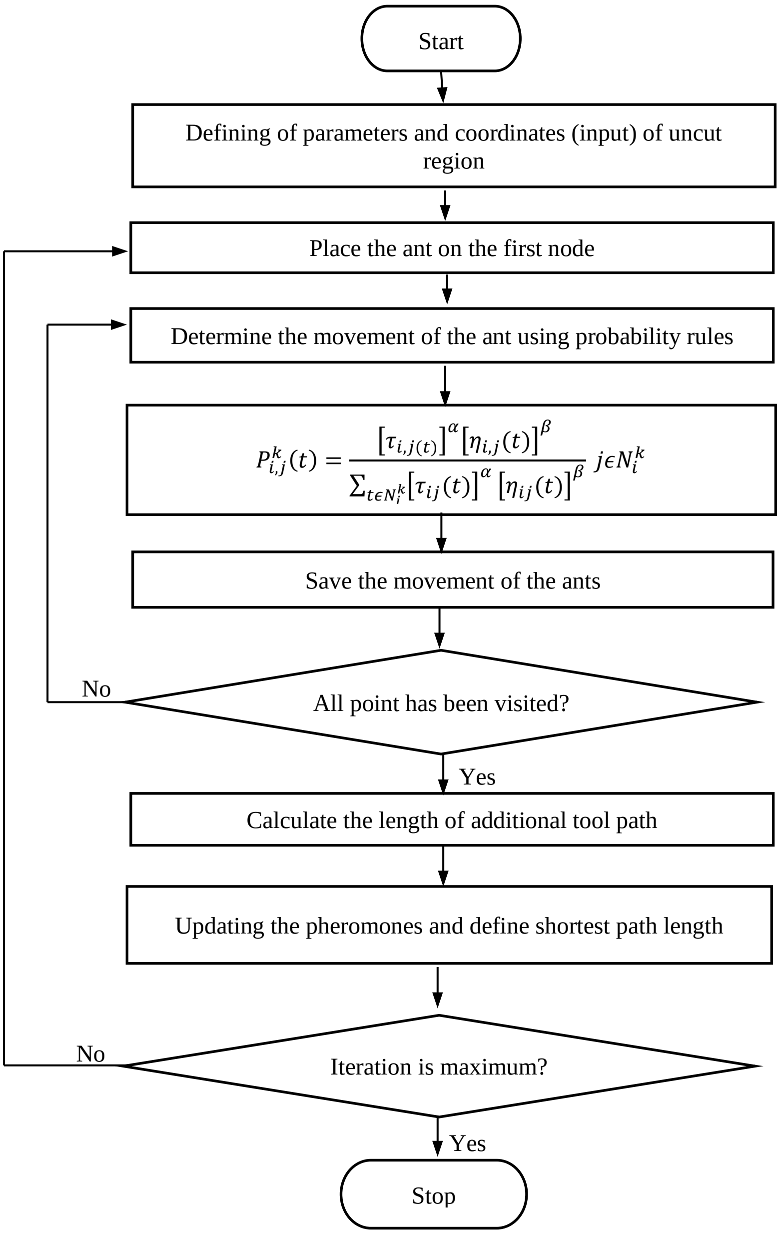
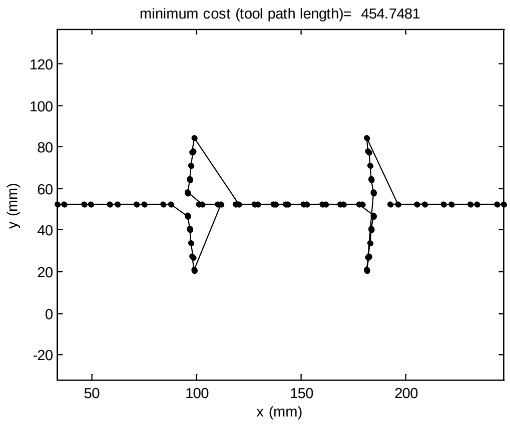


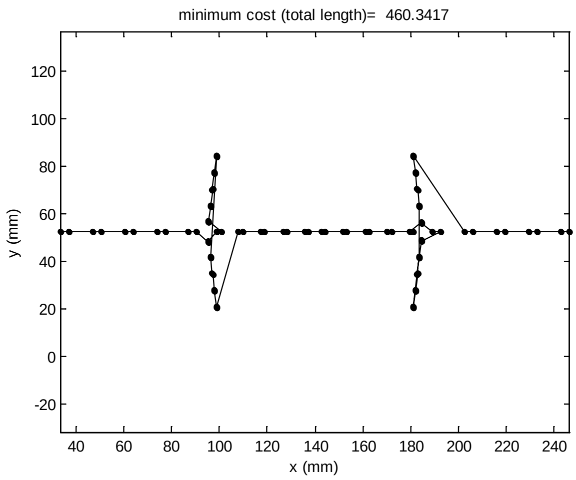
Fig. 4. Flow process of ant colony algorithm.

4. Results and Discussion

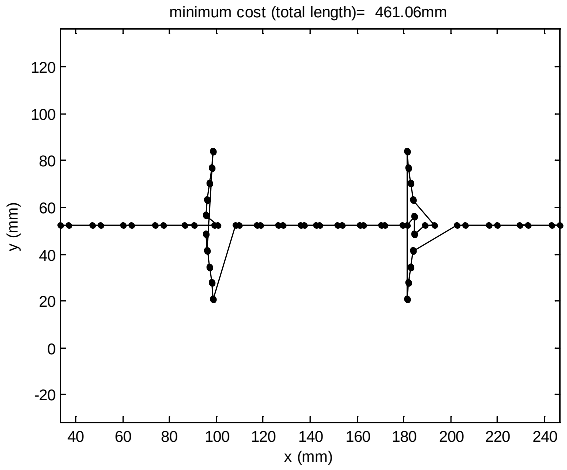
During previous research conducted through Abdullah et al. [12], ACO algorithm was developed to optimise the length of tool path with the uncut region produced using the path interval of 5.7 millimetre (mm). In this present paper, the study has been extended to examine the influence of the value of the path intervals (ω) on the existence of uncut area at the sharp corner on the additional tool path length. There were 3 values of ω used in this study, namely 5.6 mm, 5.7 mm, and 5.9 mm. The determination of ω was based on the minimum value to make certain the existence of uncut region at the corner area. Figure 5(a)-(c), show the outcomes of the minimum tool path length, L_{lt} for three different values of ω based on the ACO optimisation. Based on Fig. 5(a), L_{lt} generated by ω, 5.6 mm was 454.75 mm. Whereas for ω 5.7 mm and 5.9 mm, the values of L_{lt} were 460.34 mm and 461.06 mm, respectively. Figure 6 shows the example of additional tool path based on ω of 5.9 mm on contour parallel technique that was used in the pocket milling process.



(a)



(b)



(c)

Fig. 5. Minimum additional tool path (mm) (a) 5.6 (b) 5.7 (c) 5.9.

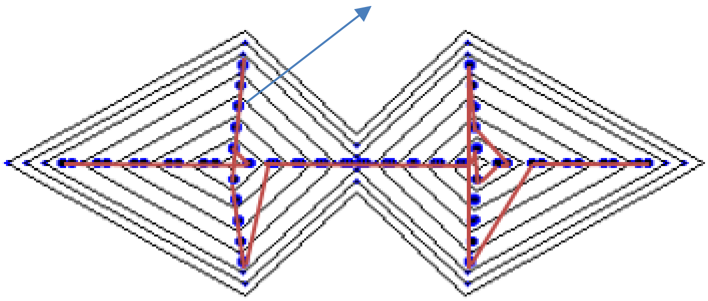
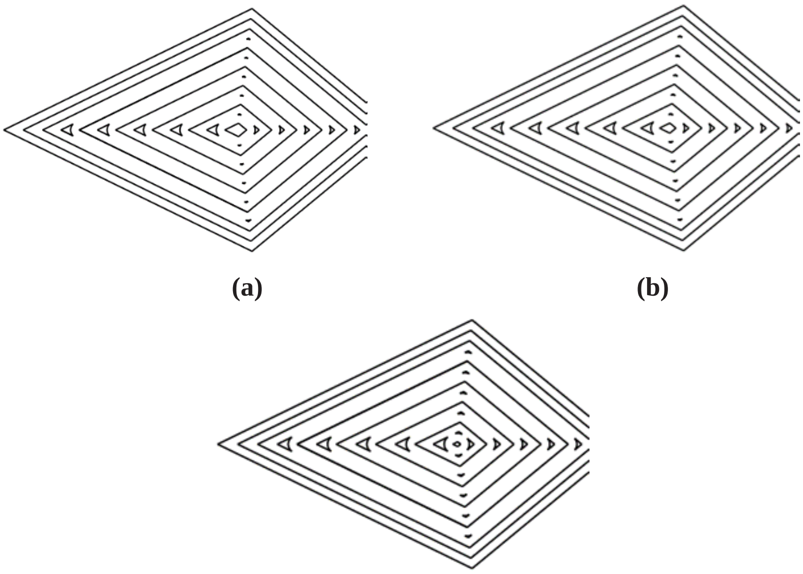


Fig. 6. Additional tool path in contour parallel technique.

By using ACO simulation, it can be assumed that by increasing the value of the path interval, it has produced longer additional tool path length. The value of this length was increased due to the production of larger uncut area as demonstrated in Fig. 7. These findings are similar with the decision adopted by Lin et al. [13] and Bahloul et al. [14]. Based on the previous study by the same authors, if the value of the tool path interval increased, the area of uncut region became larger. For example, based on Fig. 7(a), it is shown that for ω of 5.6 mm, the length of uncut region on the first segment of contour was 4.18 mm. Then when the value of the ω was increased to 5.7 mm, the length of this uncut region has increased to 4.4 mm. Subsequently, this uncut region has increased to 4.94 mm when ω value was increased to 5.9 mm. However, the total tool path length was decreased when the value of ω increased. This is because the length of contour parallel segment was decreased [23].

Table 1 illustrates the total tool path length based on different values of tool path interval. Referred to the table, the length of contour parallel path decreased when the path interval was increased. This value was obtained based on Mastercam simulation with the uncut region. To remove the uncut area, a clear tool path namely additional tool path has been produced. This additional path in influenced by the defined of path interval. The minimum length of contour parallel of each tool path interval are shown in Fig. 4. Even when the value of clear tool path length was increased due to the increasing of uncut region, the roughing machining time still decreased. This simulation results shows that generating of tool path length with larger tool path interval and remove the uncut region using clear tool path method is one of good approach to increase the productivity of machining process. The results in Table 1 shows that decreasing the tool path interval from 5.6(mm) to 5.7(mm) has decreased the length of the tool path about 0.7 %. Then the compared to the 5.9(mm) of tool path interval, tool path length has been reduced about 2.5 %.



(a) **(b)**

(c)

Fig. 7. Uncut region for different tool path interval in mm (a) 5.6 (b) 5.7 (c) 5.9.

Table 1. Summary of tool path length based on different interval.

ω	**5.6**	**5.7**	**5.9**
Contour parallel tool path length (mm)	2295.26	2270.56	2218.94
Clear tool path length (mm)	454.74	460.34	461.06
Total tool path length (mm)	2750	2730.9	2680
Roughing machining time (s)	275	274	268

5. Conclusion

This study was performed to study the consequence of the various path intervals value upon the existence of uncut region and tool path length on tool path length in pocket machining process using contour parallel technique. Based on the simulation results, it is shown that increasing the value of tool path interval has produced longer supplementary tool path length. However, total tool path length is decreased when the value of ω increased. When value of ω is increased from 5.6mm to 5.7mm and 5.9mm, the tool path length has been reduced about 0.7 % and 2.5 % respectively. This is because the length of segment for contour parallel is decreased. As a result, it can be concluded that, larger tool path interval value is more appropriate to produce lower machining time and shorter path length in the pocket machining based on the contour parallel method.

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Nomenclatures

L_k	Total length

Greek Symbols

α	Effect of pheromone
β	Effect of the visibilty
η_{ij}	$1/d_{ij}$ is the visibility
τ_{ij}	Trail intensity on edge (i, j) at time t

Abbreviations

ACO	Ant Colony Algorithm
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
SA	Simulated Annealing

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