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Dynamic Analysis of UAV's Motor Support Bar Length Control System

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Abstract. UAV (Unmanned Aerial Vehicle) can be described as aircraft that do not need any presence of pilots inside it. Basically, UAV is come out in a small aircraft so that the aircraft can be easily controlled by the people from afar[1]. The UAV's motor support bar length control systems are the UAV's control systems that move according to the variable arm length movement and also a constant revolution of the propeller speeds. The purpose of the study is to run the dynamic analysis at the UAV's motor support bar length control systems and also to enhance the UAV's mathematical modelling by using the SOLIDWORKS® software which involved in using both CAD and CAE systems[2]. The detailed design is used SOLIDWORKS® software to conduct the static and dynamic analysis of UAV's motor support bar length control systems. The design is restricted to the arm due to the critical part that has the highest vibration at the UAV's motor support bar length control systems. The results that obtain from the study from the static and dynamic analysis are the displacement of the motor, Von Misses stress of the arm, and also the resonance frequency that will give the modes shape to the systems.

1. Introduction
The quadrotor is widely used of UAV's in the industry or worldwide. Quadrotor's main components are motor (brushless motor) and also the propeller. These two elements will give the quadrotor to hover and manoeuvring around of the area. The propeller from the quadrotor will create a thrust force and in aid the quadrotor to lift. In the meantime, the control system to stabilize and manoeuvre the quadrotor consumes too much battery and also the vibration that occur when the changeable position of the brushless motor. This research is to study the dynamic analysis of UAV's motor support bar length control systems.

2. Background of UAV's motor support bar length control system
UAV is an aircraft that does not need any presence of pilots inside of it due to it is a small aircraft that can be controlled from afar to manoeuvre at the open air. UAV is also involving the environment such as in a significant competition that challenges the people around the world to make the best aircraft in the world. Also, UAV is also helping in the military to spy the outsiders that can be a threat to the country [3]. Most of the UAV are made in quadrotor due to its easy to design, small rotors, and excellent manoeuvrability [4].

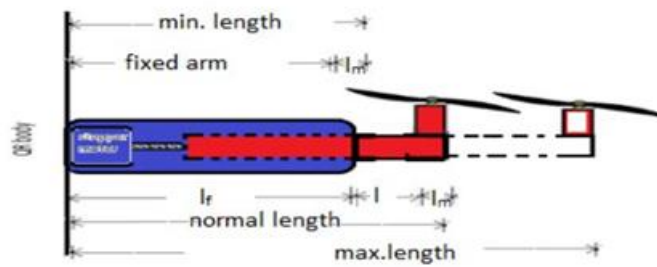*2.1. Control Movement of Variable Arm Length (VAL) quadrotor*

Figure 1. The arm design with respect to the length [3]

The idea of the motor support bar length control systems is come from the idea of the variable arm length system which the system can counteract the energy depletion during the flight time[3]. The problem is because of the motor speed control where the rate of the two motor are increasing, and the other two must be decreased to obtain the yaw movement. In order to cope this situation, the recent research by [3] has shown that when changing the position of the arm's length will counter the energy consumption of quadrotor when implied the theory of increasing and decreasing the motor to generate the required torque in yaw, pitch, and roll attitude as shown in Figure 1 [3].

Based on the above figure [3], we can show that the arm involves of two parts which are fixed and non-fixed part. Furthermore, based on the fixed part contains quadrotor frame at the outer part and stepper motor at the inner parts. In addition, the stepper motor revolves in persistent speed. Moreover, the fixed arm of the quadrotor frame is built in a hollow shape. On the other hand, the threaded shaft is using to connect to the stepper motor and move the sliding arm of the non-fixed part to slide along the fixed hollow arm. The increasing and decreasing of the arm's length from the design cause the formula as follow:

$$\max length = \left(l_f + l_m + L\right) + \Delta d \cdot (l_f + l_m) \qquad (1)$$
$$\min length = \left(l_f + l_m + L\right) - \Delta d \cdot (l_f + l_m) \qquad (2)$$
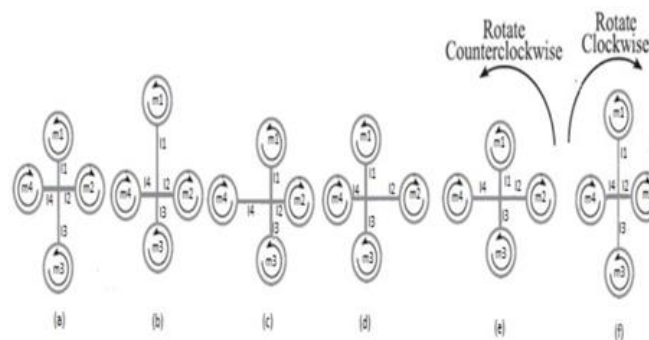

Figure 2. Pitch, Roll, and Yaw attitude with respect arm length [3]

From the above figure [3], the attitude of the quadrotor movement which is determined by pitch angle, θ, roll angle, $\varnothing$, and also the yaw angle, φ. Moreover, the quadrotor attitude based on Figure 2.4(a) and Figure 2.4(b) will cause the quadrotor to pitch backward and pitch forward when there is increase in position of the arm's length of one of the motor with respect of y-axis, respectively. However, the quadrotor attitude that based on Figure 2(c) and Figure 2(d) shows that the roll movement of the quadrotor body when there is increase in position of the arm's length of one of the motor with respect of x-axis position which is in roll leftward and roll rightward, respectively. Meanwhile, the yaw

attitude of quadrotor that rotating counter-clockwise when there is increase in position of each respected motor that is in x-axis in Figure 2(e), while the quadrotor will be rotating clockwise when there is increase in position of each respected motor that is in y-axis in Figure 2(f).

2.2. Vibration during changeable position of the motor
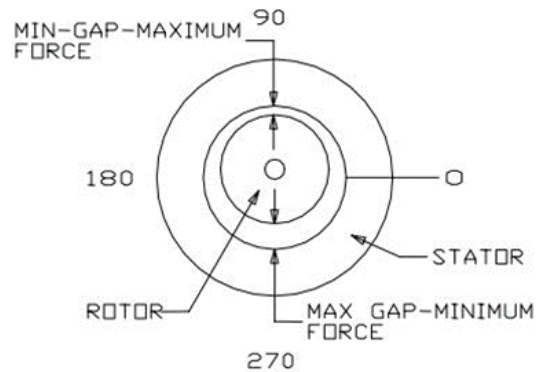
Figure 3. Non-symmetrical air gap around the rotor[5]

Based on the figure above, it shows the source of vibration that occurs from the rotor. The non-symmetrical air gap around the rotor causes some vibration as in our case most likely occur at the brushless motor and also the stepper motor [5]. In addition, the changeable position of the arm of the quadrotor effect on the COG of the quadrotor itself which is the point of support on which the body would stable and balance.
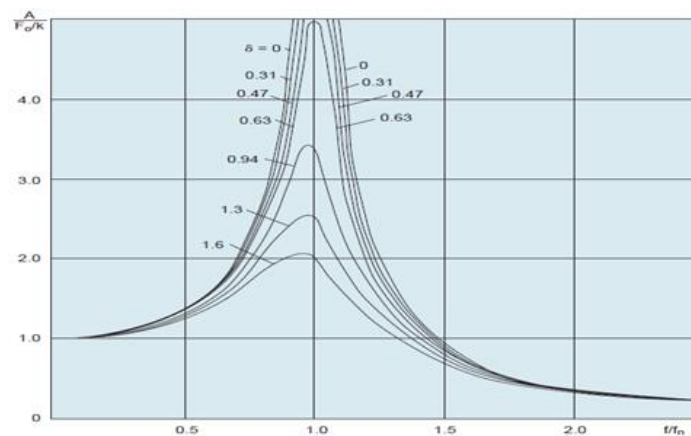

Figure 4. Graph of amplitude-frequency of enormous block motion

The resonance that occurs based on unbalanced mass due to the changeable position of the centre of gravity it is shown based on the above graph above. The forced vibrations that occur that occur to the rotor are due to the external force that applied at the weight of the rotor and shows the harmonic motion of force with respect to the time. On the other hand, the overload COG of an aircraft gives serious vibration for the aircraft and thus occurs fatigue failure to the aircraft. The research has been done by the method of regression analysis and the rain flow tallying strategy was embraced to record the heap cycles on the amplitude and mean value [6]. Besides that, they are also estimated an aircraft vibration using static and dynamic measurements to determine COG position of the main rotor. It shows the main rotor will have the highest uncertainty when compared to other position of COG.

3. Methodology

In the methodology of this study, we have to find the free-body diagram (FBD) of the quadrotor body system. Generally, the FBD is needed when wanting to do the schematic diagram or overview of the whole quadrotor body. Furthermore, the quadrotor body system is necessary to find its dynamic algorithm where the force and torque moment will be the priority of the quadrotor body system.
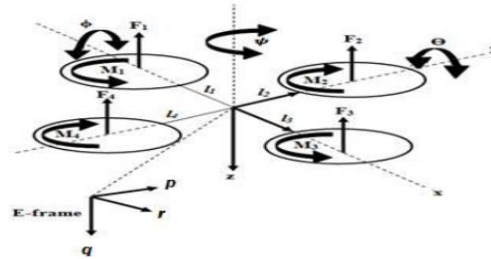

Figure 5. Quadrotor FBD with respect to Center of Gravity (COG)[3]

In addition, the COG of the quadrotor body system will be at the center of the quadrotor body mass system which the COG is needed to be in this state for a steady movement. Next, we will sketch the detail model of the quadrotor in the SOLIDWORKS® since the SOLIDWORKS® provided the CAD system. To determine the COG location of the quadrotor, we will be using the SOLIDWORKS® software, which the SOLIDWORKS® software provided every detail mass properties of the quadrotor by using the evaluate function. Afterward, the static analysis and the vibration analysis is also determined by the SOLIDWORKS® [7]. SOLIDWORKS® has developed its software to the CAE system in which the system can run the various analysis of the design based on the real-time simulation[2]. The design is limited to the arm itself which the vibration mostly occurs on that part. Lastly, we compared the result of both static analysis and vibration analysis of the quadrotor by the variable of the arm length.

3.1. Design development

The development to find the mass properties and also to run the static and vibration analysis on the system, we have to design the model of the structure before proceeding with the analysis. The design is made by using the SOLIDWORKS®   and consists of few parts for model the quadrotor which is the body of the quadrotor with two stands, four fixed arms, four moving arms, four stepper motor, four brushless motors.
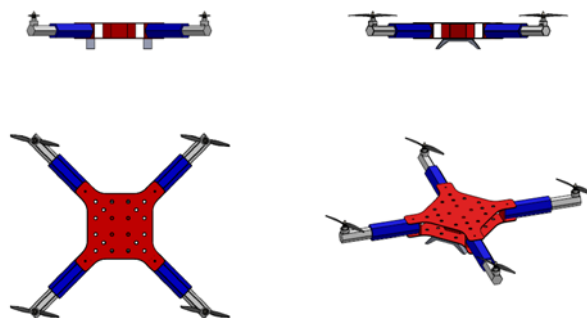
Figure 6. Full model VAL-quadrotor using SOLIDWORKS®.

The assembly of the design is shown based on the above figure where the stepper motor will act as a mechanism to move the moving arm to certain position to give the attitude of quadrotor movement without any change of the rotation of propeller at the brushless motor.

3.2. Mass properties of the quadrotor
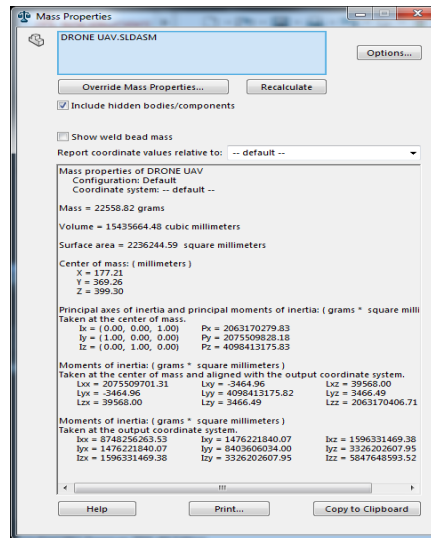
**Figure 7.** Mass properties of quadrotor using SOLIDWORKS®

The mass properties of the quadrotor can be evaluated inside the SOLIDWORKS® software. This function can be done by went to the "Tools" tab then click the "Evaluate" and after that select the mass properties icon of the model. Based on the mass properties, we can find the total mass of the quadrotor, center of mass, principle axes of inertia and also the moment of inertia.

3.3. Static and dynamic analysis using SOLIDWORKS®
The SOLIDWORKS® Simulation will be using to find the static and dynamic analysis of the quadrotor. First, we will run the static analysis due to we suspect there will be a dynamic analysis based on multiple static responses at the model. The static analysis will be run at the most critical part of the design of the model which at the arm of the quadrotor where it is most likely occur the vibration.
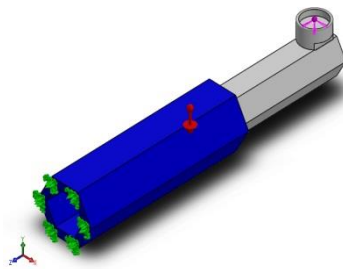
Figure 8. Configuration of the load, fixed geometry and the gravity applied to the arm of the quadrotor using SOLIDWORKS®
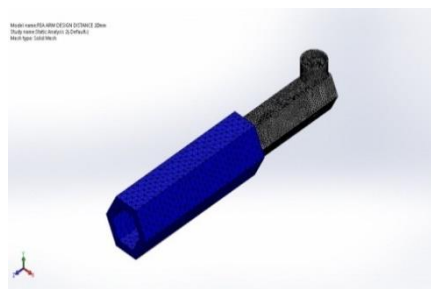
Figure 9. Mesh model of the arm of the quadrotor using SOLIDWORKS®.

The finite element method (FEM) of static analysis must determine the parameter to the arm since we make it as the simplified design of the quadrotor to show the dynamic analysis of the system. The end of the fixed shaft was given a fixed geometry since it is attached to the frame of the quadrotor. Meanwhile, the remote mass was determined at the moving arm which the remote mass that was given is actually the mass of the brushless motor. The gravity acceleration is set at the top plane of the design. This parameter is used only for the static analysis only with respect to the changeable position of the arm. The position of the arm will start from the initial point of the moving arm until 60 mm with the increment of 20mm. After that, we run the mesh analysis before run the simulation for the static analysis. From the static analysis, we can figure out the Von Misses stress and maximum displacement in our cases of study. Meanwhile, the dynamic analysis for SOLIDWORKS® does not need the parameter for gravity acceleration. The steps for setting before run the simulation is almost the same with the static analysis. The result that we get based on the dynamic analysis is the mode shapes along with the resonance frequency.

4. Result and discussion

For the simulation of the study on the static and dynamic analysis, the results more focus on the comparing the effect of changeable position to maximum displacement, Von Misses stress and also the mode shapes with respect of the resonance frequency at the quadrotor arm.

4.1. Static Analysis of quadrotor

The resulting force based results from the simulation as shown from below table:

Table 1. Resultant Force at the quadrotor arm calculated by SOLIDWORKS®

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	1.66893e-006	61.4167	1.14441e-005	61.4167

The resultant force at the quadrotor arm is 61.4167N based on calculation made by SOLIDWORKS® software with applying the parameter to the arm of the quadrotor. The maximum displacement results show that the peak displacement happens at the end of the moving arm which is the remote mass is apply.
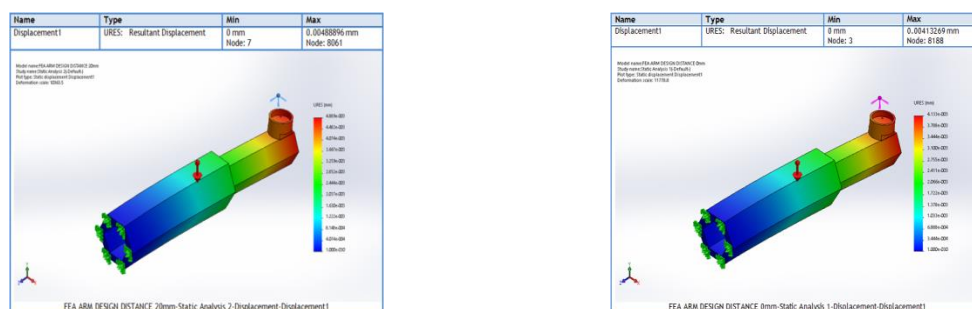
Figure 10. Displacement of 0mm of the arm of the quadrotor (left) and 20mm of the arm of the quadrotor (right) using SOLIDWORKS®.

Figure 11. Displacement of 40mm of the arm of the quadrotor (left) and 60mm of the arm of the quadrotor (right) using SOLIDWORKS®.

The results of the changeable position of the arm with respect of maximum displacement at the arm of the quadrotor can be seen from the graph below:
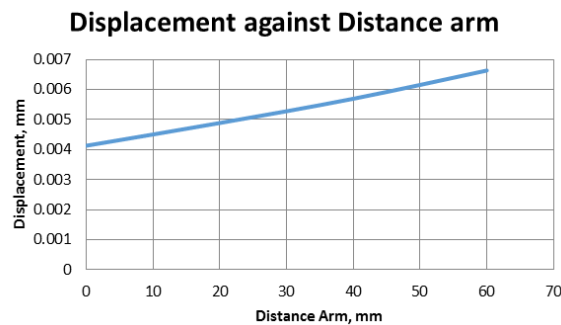

Figure 12. Graph displacement against distance arm.

Based on the above graph, it shows the displacement of the quadrotor movement along Y-axis against the distance arm along X-axis movement. It shows the distance of arm influenced the displacement of arm movement along Y-axis. The displacement of the arm along Y-axis increase steadily against the distance arm. In addition, based on the static analysis of the quadrotor also shows the Von Misses stress at the quadrotor arm design.
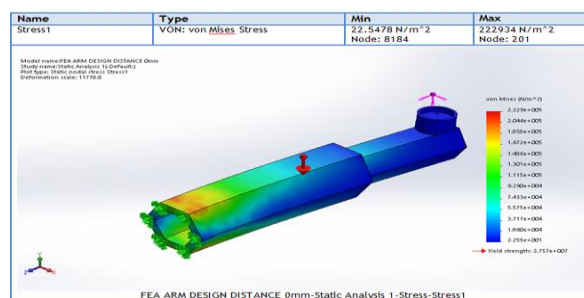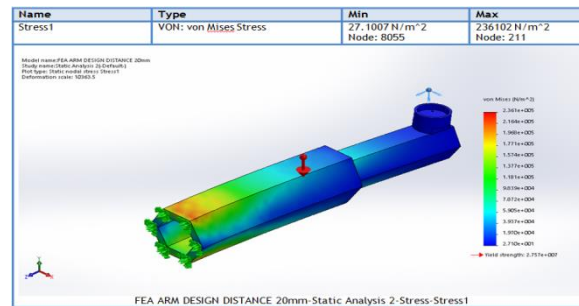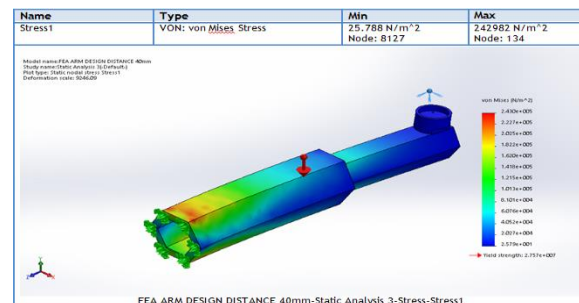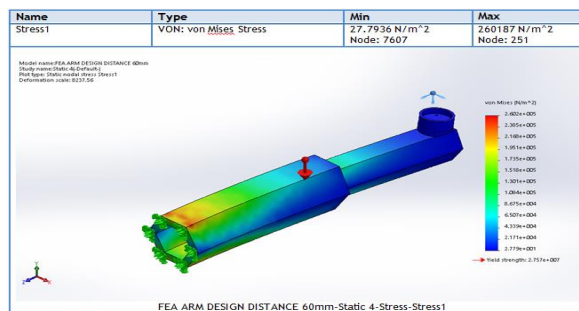

Figure 13. Von Misses stress at 0mm distance of arm using SOLIDWORKS®.

Figure 14. Von Misses stress at 20mm distance of arm using SOLIDWORKS®.

Figure 15. Von Misses stress at 40mm distance of arm using SOLIDWORKS®.

Figure 16. Von Misses stress at 60mm distance of arm using SOLIDWORKS®.

The Von Misses stress results shows that the stress most likely occur at the fixed arm. In addition, the Von Misses stress also increase when there is an increase of the arm length. The red arrow in the figures indicated that the yield stress of the arm is 27.57 MPa due to the material properties we have selected at the arm is 1060 Aluminum alloy. Besides that, the highest amount of stress happen at the arm are 22.29 KPa, 23.61Kpa, 24.30 KPa, and 26.20 KPa at the distance of arm 0mm, 20mm, 40mm, and 60mm respectively. Based on the highest amount of the stress, it is shows that it is still below of the yield strength of the arm of the quadrotor.

4.2. Dynamic Analysis of quadrotor
The dynamic analysis of the quadrotor that we want to find in this study is the resonance frequency of the quadrotor with its mode of shapes.

Table 2: Table of resonance frequency and distance of arm length according to its mode shape.

Modes 1		Modes 2		Modes 3	
Frequency(Hertz)	Arm Length, mm	Frequency(Hertz)	Arm Length, mm	Frequency(Hertz)	Arm Length, mm
318.64	0	318.8	0	1275.3	0
291.77	20	292.24	20	1152.7	20
268.9	40	269.39	40	1055.2	40
248.84	60	249.07	60	975.12	60

According to the table, it shows the modes of resonance frequency against with the distance of moving arm. In the modes 1, it shows the resonance frequency is decreasing when increasing the arm length from 318.64Hz to 248.84Hz. In the meantime, the modes 2 show the same decreasing when increasing the arm length to 60mm which are from 318.8Hz to 249.07Hz. On the other hand, the resonance frequency also decreasing in modes 3 where the resonance frequency drops from 1275.3Hz to 975.12Hz.
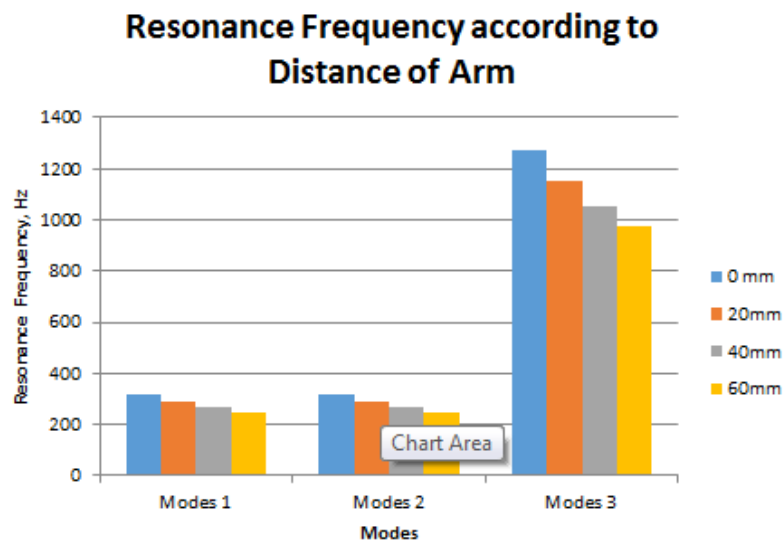
Figure 17. Graph resonance frequency according to distance of arm.

According to the graph shown, it shows the graph of resonance according to its modes shape. From the observation, it shows that modes 1 and modes 2 almost give the identical resonance frequency and shows increasing in the modes 3 for resonance frequency by according to the distance of arm length. In addition, based on its modes shape, it shows that each modes showing a decreased in value of resonance frequency against with the arm length of quadrotor and obviously the modes shape 3 shows the decreasing with drastic.

5. Conclusion

5.1. Summary

Throughout the experiment that we have conduct from the analysis of SOLIDWORKS® Simulation, we have achieved the results the results of the static and dynamic analysis are maximum displacement, Von Misses stress and the modes shape of the resonance frequency. The maximum displacement and the Von Misses stress show increasing trends towards the increment of the position of the arm. Meanwhile, the mode shapes of the resonance frequencies decrease with respect of increasing of the arm position. The analysis shows that the Von Misses stress still in the range of the yield strength which the quadrotor can be controlled in the sky but must be taken care with force frequency which can meet the natural frequency of the quadrotor when the position of the arm is increasing.

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