UDC 62-742

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THE APPLICATION OF MULTILATERATION TECHNOLOGY IN AIR TRAFFIC CONTROL

1. Introduction

The main task of the air traffic control system (ATCS) is to ensure that the air traffic safe and in order and increase the flight time and space utilization of flight routes and airports by managing and controlling the entire process of aircrafts from take-off to landing. The control area of both military and civil aviation aircraft activities can be divided into 3 parts: area control (flight routes), approach control (terminal area) and airport control (airport scene).

Until now, air traffic control two coordinate radar systems are the main technique of military civil aviation surveillance aircraft, whose surveillance range is 250 nautical miles (approximately 450km). However, airport control has to use the way of visual inspection to monitor aircrafts which are taking off, landing or moving in the airport duo to the lack of modern radio means for effective surveillance. It may cause that the pressure on air traffic controllers will be enormous when the aircraft flow is large. Therefore, the world civil aviation industry has began seeking new technological solutions science 10 years ago, such as laying high precision sensors around the airport to report the current location and route of each aircraft. At present, some experimental passive surveillance systems have been tested in several important airports in Europe and the United States. The best performance of them is to allow taking-off with less than 70m of visibility.

Considering the advantage of the multilateration, this paper introduces the multilateration into the ATC application to satisfy the mission requirements of ATC. And the key problems in engineering implementation have been analyzed and solved.

2. Multilateration Technology

Multilateration uses multiple receivers to receive the signal of the target radiation source simultaneously. Because the receiver can not confirm the emission time of the emitter, the method of measuring the time difference of signals arriving at different receivers is adopted. The distance difference is calculated according to the time difference, and the target position is obtained by geometry method. The working principle as shown in Figure 1.

The distance between the radiation source P and the reconnaissance station A and B is RA and RB, respectively. The time from which the electromagnetic wave emitted from the target P arrives at the A and B stations is T_A（$T_A=R_A/c$） and T_B（$T_B=R_B/c$）.If the measured time difference is $T_{AB}=T_B-T_A=(R_B-R_A)/c$, then we can confirm the point P on the hyperbola which focuses on A and B. The distance from one point of the hyperbola to the A station and the B station is equal to R_B-R_A. Similarly, if measure the time difference between the electromagnetic wave of the target emitted at the C station and the A station is $T_{AC}=T_C-T_A=(R_C-R_A)/c$, we can determine another hyperbola. And the intersection point of the two hyperbolas is the estimated value of the P location of the emitter. By using the arrival azimuth information of the radio wave to remove another false mirror point which is symmetrical to the baseline.

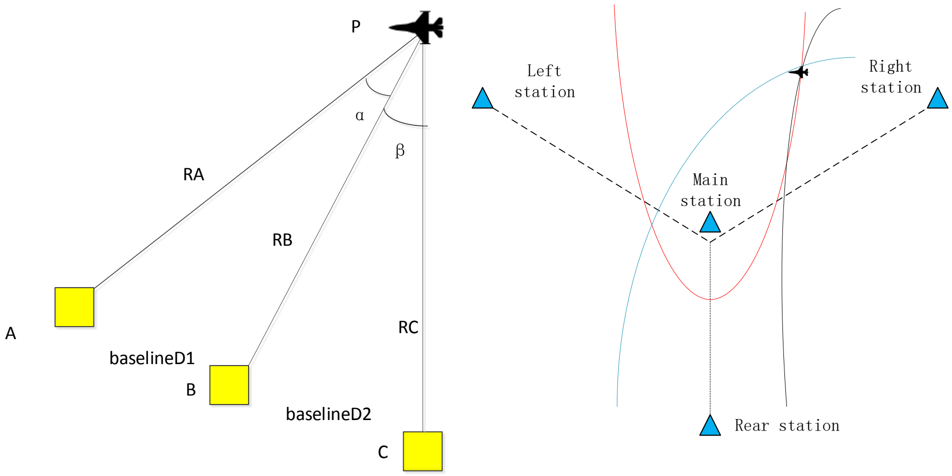

Figure 1. TDOA location principle (Hyperbola fix)

The three station TDOA location will be the position on the positioning plane, and this location can be approximately considered the horizontal position when the target distance is far away. In order to obtain the high value, the 4 station TDOA location should be adopted. The measurement equations are

$$\begin{cases} \sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}-\sqrt{x^2+y^2+z^2}=c\times\delta t_1 \\ \sqrt{(x-x_2)^2+(y-y_2)^2+(z-z_2)^2}-\sqrt{x^2+y^2+z^2}=c\times\delta t_2 \\ \sqrt{(x-x_3)^2+(y-y_3)^2+(z-z_3)^2}-\sqrt{x^2+y^2+z^2}=c\times\delta t_3 \end{cases}$$

By solving the equations, the three-dimensional position solution of the target can be obtained.

3. The features of multilateration technology used in air traffic control surveillance system

Multilateration technology is a new ATC surveillance technology. The position of an aircraft or other moving target is determined by multipoint passive sensor receive mode. Because the system is completely compatible with the SSR radar and ADS-B downlink data transmission link, it can receive and decode the SSR code and S model plane address, which has the target identification capability and high-precision positioning capabilities. The biggest feature of this technology is that it fully utilizes the onboard standard transponder, and does not need to install other airborne navigation equipment to complete the positioning monitoring. It is compatible with ADS-B technology, with high data update rate (1 times per second, two radars at least 4 seconds 1 times), and has lower system cost (compared with the existing SSR radar system, its investment cost is less than 1/3).It has high positioning accuracy, wide area positioning accuracy within 50 meters in the air, the ground positioning accuracy within 10 meters, with the ability to target identification. The interference to other systems is small, and the receiving station antenna is a simple omnidirectional antenna without rotating mechanism, which is characterized by small size, flexible site configuration, and good adaptability of system monitoring coverage. Therefore, this technology has a good application prospect in the air traffic surveillance field.

4. Key Technologies

4.1. The design scheme of the system

System design uses at least 4 low-cost sensors. According to the system characteristics, the system design can be divided into signal forwarding based centralized and time synchronization based distributed schemes, as shown in Figure 2 and 3.

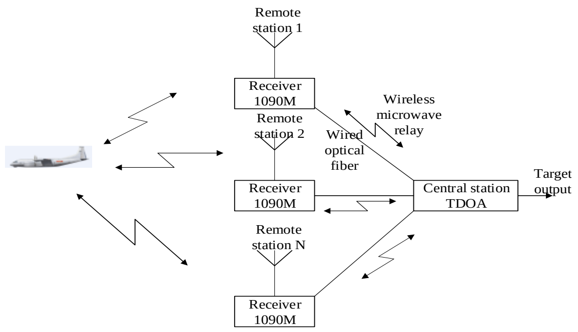

Figure 2. Signal forwarding based centralized schemes

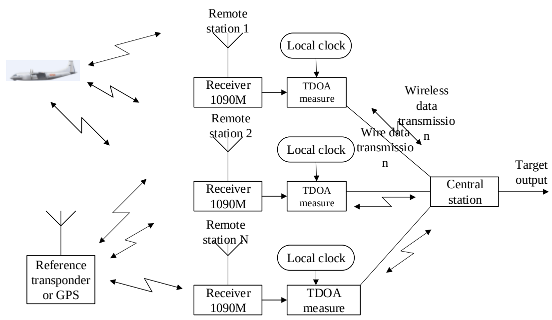

Figure 3. Time synchronization based distributed schemes

According to the system characteristics of the signal forwarding system:

1) Communication between auxiliary station and central station;
2) The center station measures the time difference between the main and secondary stations, and extracts the symbols to complete the identification function;
3) The system design is simple and the cost is low;
4) The time difference measurement needs many pulses, and the measurement accuracy is potentially high.

Shortcomings:

1) The relative relation between auxiliary station and central station is fixed and the interchangeability is poor;
2) The influence of modulation and demodulation on the rising edge of each station should be strictly controlled.

The characteristics of the time synchronization systems:

1) Each station can measure arrival time precisely;
2) Auxiliary stations are interchangeable;
3) Data transmission between station and station is flexible through data exchange, without distance differences. Point to multipoint transmission can be used;

Shortcomings:

1) The number of targets in instantaneous processing is limited by the data rate;

2) The time difference accuracy depends on the time synchronization accuracy.

4.2. Error analysis of distribution station and location

According to the distribution of terrain and buildings in a domestic airport, the detection area is divided, and the location of IFF receiving and processing subsystem is planned, as shown in figure 4.

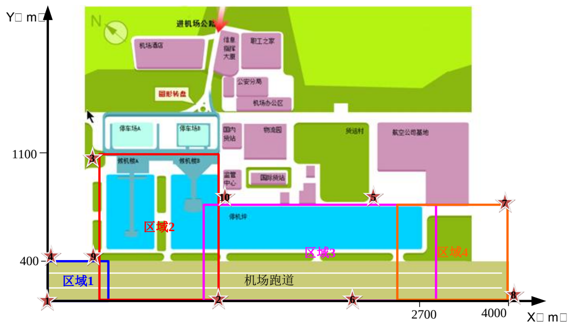

Figure 4 Detection area division

According to the above classification and site distribution, multi point positioning algorithm is applied, according to the N(0, 30) of the Gauss distribution simulation random timing error, repeated operation 30 times, with the mean positioning error as the final positioning error, the simulation results are shown in figure 5.

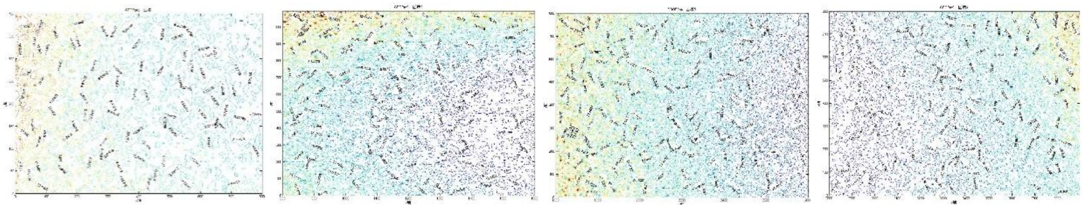

Figure 5 System simulation results

The simulation results are as follows:

Zone 1: positioning error <12 m.

Zone 2: positioning error <15 m.

Zone 3: positioning error <27 m.

Zone 4: positioning error <30 m.

4.3. Anti-multipath interference method

Multipath propagation is due to various objects around the radiation source and receiver, including buildings, vehicles, pedestrians, trees and even the reflection of radio wave refraction and diffraction caused by energy disperse in space, and through multiple paths to the plurality of correlation signals into the receiver. The multipath interference caused by buildings, vehicles and ground surfaces in airport scenes is especially serious. According to the actual measurements of multipath interference at the airport, there are four main features that can be used:

1) Because the path difference caused by the pulse along the stray pulse, will not damage the pulse, due to the IFF response signal pulse interval is smaller, the conventional 1.45us, pulse width 0.45us, S encoding mode interval 1us, pulse width 0.5us. Therefore, the trailing edge of the front pulse has not reached the bottom, and the front edge of the latter pulse has been dashed;

2) The spurious pulse amplitude generated by multipath is not stronger than the main signal, and the signal amplitude will be less than 500mv (the following floating threshold is below the signal top 300mV, which can satisfy the suppression of multipath and obtain better quality TTL pulse);
3) The pulse width of multipath is not fixed pulse width, the pulse width is generally small, and the interval is rather chaotic;

For 1 symbol strings, the effects of multipath on each pulse are approximately the same, including amplitude, width, etc.

According to the characteristics of multipath interference signal, we can consider the following processing methods:

1) Considering the floating threshold mode and pulse width discrimination: floating threshold can ensure the accuracy of measurement of pulse width and multipath inhibited. When unable to suppress multipath trigger pulses, the pulse width of the judgment can restrain some spurious pulse. Waveform and channel anti multi path effect diagram shown in Figure 6, 7;

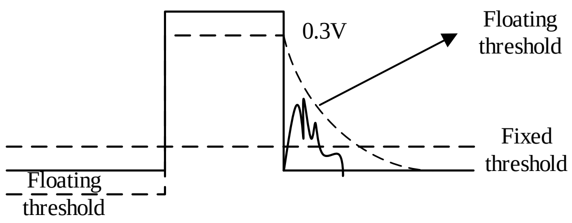

Figure 6. The waveform sketch

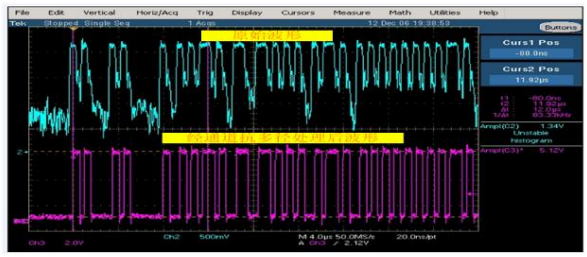

Figure 7. The actual effect of channel anti multipath interference

2) The channel gain is controlled according to the amplitude characteristic of the signal amplitude and multipath, so as to suppress the spurious pulse produced by multipath as much as possible;
3) When there is a low amplitude pulse followed the strong pulse, the influence brought by floating threshold may lead to pulse loss, so the floating threshold discharge delay time should be adjusted according to the actual situation of signal to find a balance point;

4.4. High precision time difference extraction method

According to the analysis of the station and its positioning error, the time difference measurement accuracy must be better than the 10ns index in order to meet the requirements of the positioning accuracy of the air traffic surveillance system.

1) The influence on error of TDOA measurement accuracy

For the measurement of the pulse rising edge arrival time, we have implemented a low speed clock phase shift method. The so-called phase refers to two channels signals with the same frequency, in one of which is a reference signal, the other channel signals moves forward or backward relative to the reference signal to form a phase difference. Digital phase delay method is usually used to delay to determine the length of the phase difference between the two digital signals. As shown in Figure 8:

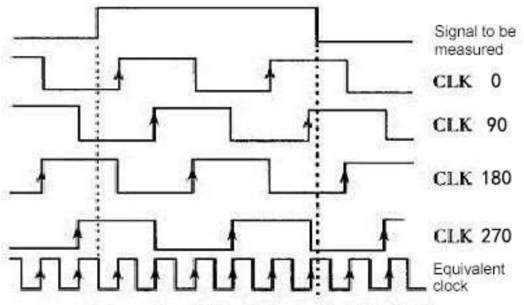

Figure 8. Measurement principle based on digital phase-shifting technology

As we can see, this method is equivalent to the fourfold frequency multiplication of the original actual count of the clock frequency, the clock frequency of 4f the measured signal counting measurement, so as to improve the measurement accuracy to the original 4 times. At the same time, the method ensures the maximum working frequency of the circuit is f, the clock frequency is increased to avoid a series of problems brought.

2) Influence of rising edge stability on error

According to a regional surveillance area is 10 * 10km, we simulate the minimum and maximum power of each point of the plane after reaching the sensor response signal path loss, the simulation results are shown in Figure 9, one of the biggest power difference is 32dB.

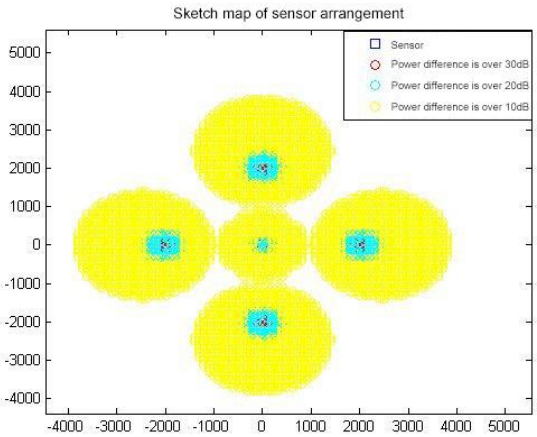

Figure 9. The power difference distribution of the sensor deployment

To verify the influence of the signal power and the rising edge of the video pulse on the stability of the comparison shaping pulse (TTL level), the following tests are carried out.

On the oscilloscope, the pulse modulated by the pulse source is synchronized, test the delay between a wide pulse and a modulating pulse; test the change in the delay time Δt of the rising edge of the video pulse at different power levels. The test block diagram is shown in figure 10:

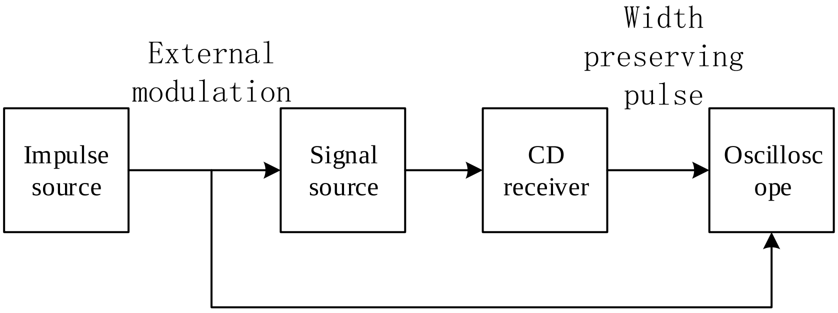

Figure 10. The test block diagram

Test method 1:

Input signal power: -40dBm to 0dBm, 10dB step

By filtering (reducing video bandwidth), the logarithmic video rise time is 100ns to 160ns.

Test results are as follows

Signal power （dBm）	-40	-30	-20	-10	0
Time delay Δt（ns）	156	177	183	185	166

Test method two:

Input signal power: -40dBm to 0dBm, 10dB step

Remove filter capacitor, logarithmic video rise time is 60ns ~ 120ns

Test results are as follows

Signal power （dBm）	-40	-30	-20	-10	0
Time delay Δt（ns）	162	158	154	152	146

According to the above test results, rising edge stability in 40dB dynamic range in the narrowband filter case, the error is 29ns. In the broadband detection, the error is 16ns. Therefore, SDLVA is considered in the design of broadband detection, if the pulse arrival time is not corrected according to the amplitude information, only the rising edge of the stability degree is an error on the TDOA error indicators have exceeded the system, the location error cannot meet the requirements of the system.

5. System test status

At the end of 2012, the system realized monitoring and positioning of the aircraft takeoff and landing, docking, taxiing on the aircrafts ground and bridges parked nearby targets in a domestic airport, the test results are shown in Figure 11.

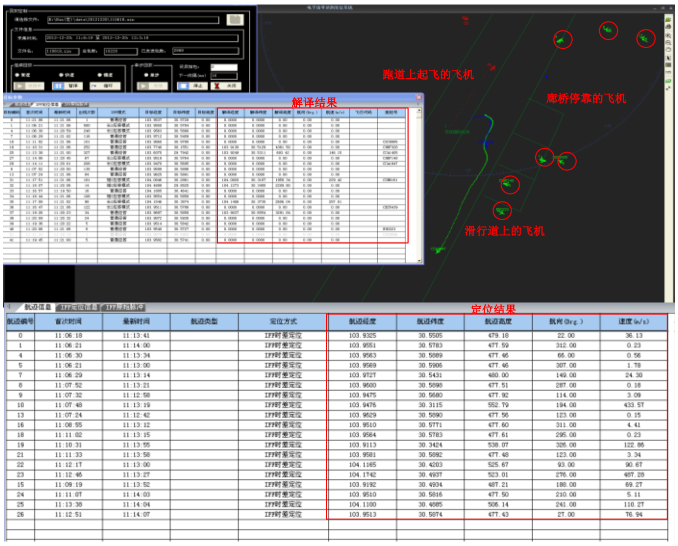

Figure 11. System scene monitoring

It can be seen from the test result that the system can recognize the multi-mode response signals of civil aviation, including conventional A/C mode response signal, long and short S mode response signal and so on. The system uses multilateration technology to give the target latitude and longitude, heading, speed and other information. At the same time, the system also has a certain capacity for identification of civil aviation targets. It can be compatible with the ADS-B downlink data link, and can receive and interpret the S mode response signal.

6. Performance comparison between system and ADS-B device monitoring

In order to detect the monitoring and positioning ability of the system, the real-time monitoring comparison between the system and the ADS-B device is carried out in the test process, as shown in figure 12.

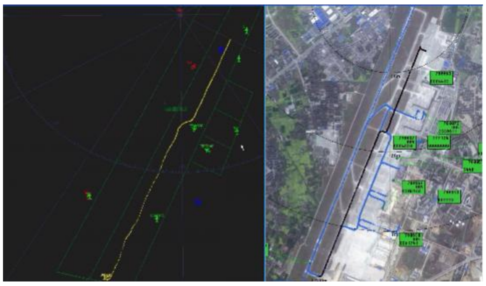

Figure 12. Performance comparison between system and ADS-B monitoring

By comparison, we can see that:

1. The aircraft on the taxiway of the airport, the system has a better ability to target monitoring. Through positioning accuracy analysis, the relative positioning error is less than 1%R, the normal direction which plus or minus 60 degrees in the alignment of the main station is equivalent to ADSB. The distance error is within the range of 20 meters, as the angle increases closer to the baseline position, the error is greater.

The following is the result that the system and the ADSB device take the GPS positioning timestamp as the baseline, and compare the anchor point data at the same time, as shown in figure 13.

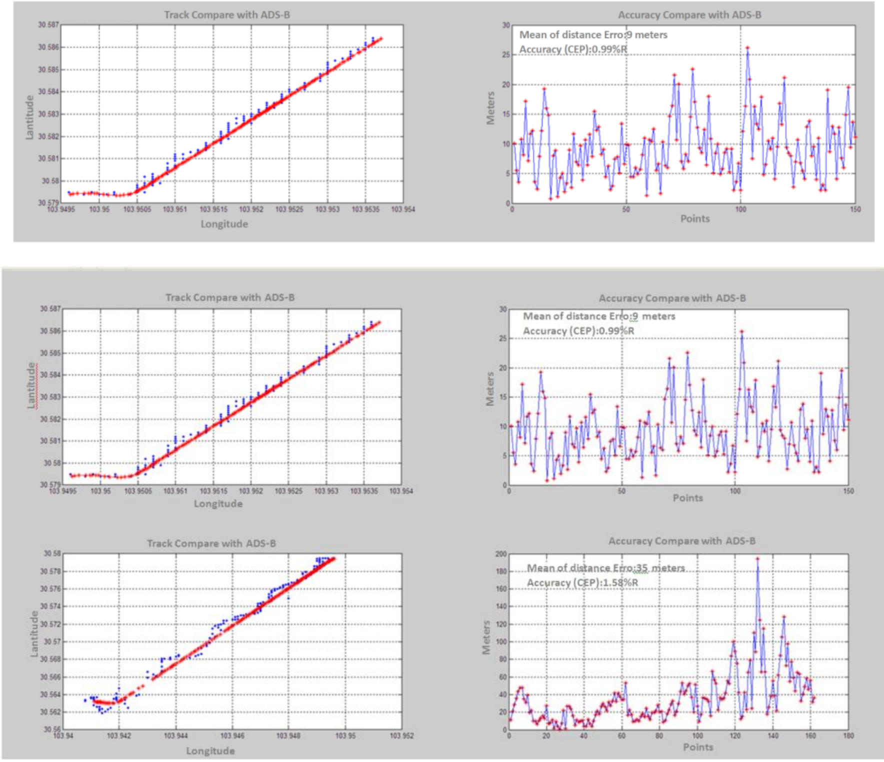

Figure 13. Target accuracy comparison

2. The aircraft taxiing or taking off at the airport ramp and runway, when responding in A/C mode, the system can achieve target tracking and detection, while the ADS-B device can not give the target effective location, as shown in figure 14.

Figure 14. The system only receives the target of answering the A/C mode signal

3. For bridges parked aircraft, when no signal shielding, system can achieve effective positioning. But for the depths of bridges parked aircraft, the signal is blocked by ground object and can not meet the requirement of multi station TDOA location condition, the system can not give the target location, as shown in figure 15.

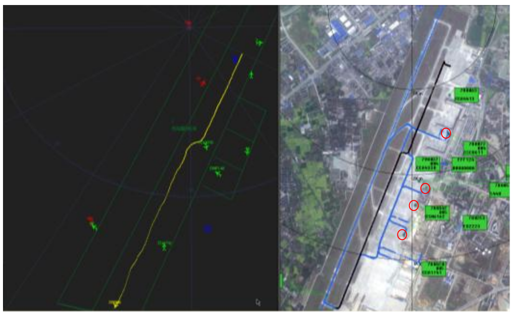

Figure 15. On the scene, the system can not effectively locate the target

7. Conclusion

Although the multilateration technology is mature, it suffers many problems when it is applied to ATC. This paper provides a detailed analysis of key technologies and solutions. Some of them have been verified in the concrete project. Test results show that the proposed method can monitor and locate aircrafts that are taking-off, landing, and gliding and other target near the boarding bridge. And the positioning accuracy and the effective range is equivalent to ADS-B.

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