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A THERMAL EYE ON UNMANNED AIRCRAFT SYSTEM

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Summary

Acronyms

AS- Amorphous Silicon

AVI- Audio Video Interleave

DIEM Dipartimento di Ingegneria delle Costruzioni Meccaniche Nucleari

GAF-Gruppo Aeromodellisti di Forlì

GPS - Global Positioning System

GUI- Graphic User Interface

HTE-High Temperature Events

MDV-Meccanica Del Volo

OEM Original Equipment Manufacturers

PC Personal Computer

TC Thermal Camera

TO- Take Off

UAS - Unmanned Aerial-vehicle System

USB- Universal Serial Bus

UAV - Unmanned Aerial Vehicle

Introduction

Risk management and catastrophic event monitoring represent a traditional use of remote sensing from satellite or aircraft. Concerning volcanic events they both show two relevant limits: long revisiting time (satellites) and high cost and high human risk for monitoring during the eruption (manned aircraft). During the last Eyjafjallajökull volcano eruption, occurred in Iceland during the month of April 2010, the overcoming of these two limits have evidenced the need to look for alternative systems. The massive ash cloud that affected many European countries, pointed out that the ash problem cannot been considered as local administration question affecting restricted area. Unmanned Aircraft Systems (UAS) having autonomous flight and real-time telemetry transmission with no on board personnel, may offer a good solution to these short comings. To explore the operational aspects of such UAS deployments for volcanology [Casadevall, 1994, Dunagan, ,2007, Schneider, 2008, Zehner,2010] INGV in partnership with MavLab department of University of Bologna (Unibo) developed a UAS system named RAVEN-INGV. [Giulietti et al. 2011, Amici et al. 2010].The project, anticipated by a flight test on 2004 [Saggiani et al. 2003, Saggiani et al. 2004, Saggiani et al. 2006, Giulietti et al. 2011] had the aim to realize a UAS able to fly in autonomous mode and to carry different payloads. Actually the platform is done and the INV-MavLab teams efforts are concentrated on two different aspects: planning and realizing an autonomous flight within 2011. selection and integration of different sensors on the RAVEN-INGV.

These two activities were both anticipated by a series of laboratory and flight tests on smaller size UAS platform operated by radio control to overcome the problem of flight permits..

In this technical note we describe some payload related activities . A thermal camera which represents the first payload on INGV UAS systems has been tested. In particular we describe:

1) laboratory set up and integration activities
2) the flight set up
3) results of the first in flight thermal acquisition experiment realized on July 30 2011, in Italy.

1. Payload

A TC (thermal camera) jointly with a pilot view camera is the first payload of the INGV UAS system. The choice of the TC was motivated by the nature of the principal observing targets: volcanoes and HTE (High Temperature Events). Their monitoring may benefit by using a TC; if mounted in nadir configuration a TC may provide surface thermograms and detect thermal anomalies. Further, it may be a support to the fieldwork surveys giving the opportunity to map not easy reachable and wider areas with very high spatial resolution.

This note describes the activities carried on to integrate the TC with the flight electronics and the acquisition system.

1.1 Thermal EYE Camera features

The chosen camera is a thermal EYE 3600AS (TE 3600AS) designed for Original Equipment Manufacturers (OEMs). The TE 3600AS camera uses a proven Amorphous Silicon (AS) microbolometer technology. The 30 micron pitch detectors make possible a lightweight (67g), long-wavelength passive-infrared camera core (spectral response 7-14micron), capable of less than 50 milli-kelvin thermal sensitivity and a saturation temperature of 600°C. The camera has a frame rate of 25 hertz real time and generates a PAL video output [l3 infrared products 2008].

The focal-plane array is sensitive to exposure to particularly high levels of radiant flux as Sun or any other source of radiant flux that the unprotected human eye cannot tolerate [l3 infrared products 2008].

The camera is characterized by an automatic contrast that is decreased when the image is characterized by warm objects (i.e. cars, boats) and is increased when the scene is characterized by low thermal contrast. A color palette may be selected to color the image and the camera can be configured to display the temperature of the object into the frame.

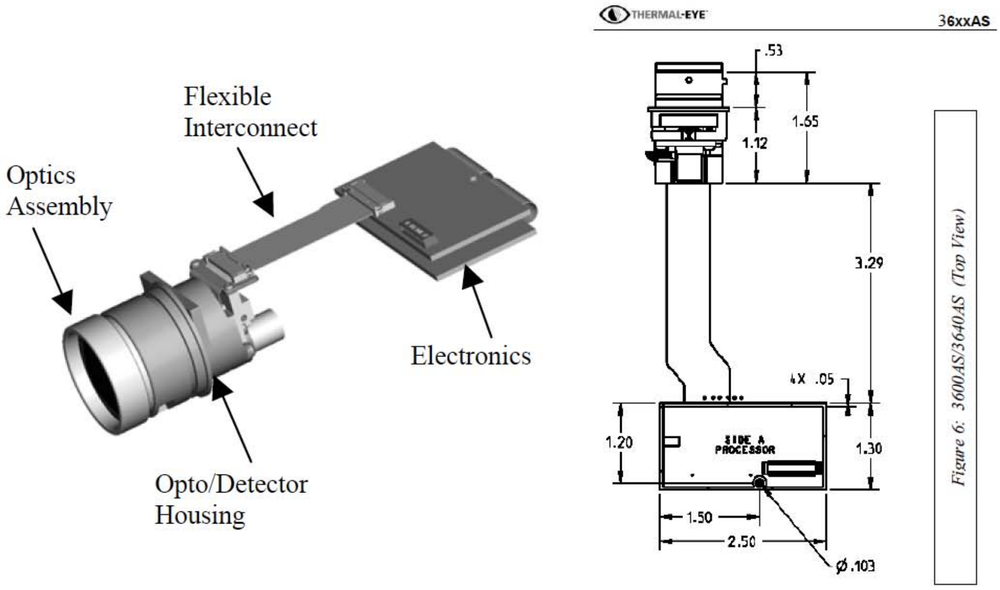

Figure 1. Components of the TE 3600AS core and size (source user manual, www.Thermal-Eye.com).

In addition the cameras can also be customised, using the Developer's kit Graphic User Interface (GUI), to change the appearance and behaviour of the camera.

1.2 Frame design

In order to fix the TE 3600 AS on UAVs systems a specific frame has been designed and realized by MDV. The design of the frame is for low weight unmanned aircraft; the shape, the material (aluminum) and the fixing system are optimized to obtain safe and easy mounting and dismounting operations (Figure 2).

On the frame, two output connectors are available:

- A standard female USB connector allows the GUI communication.
- A DB9 connector reports all camera pins, including analogue video output and power.

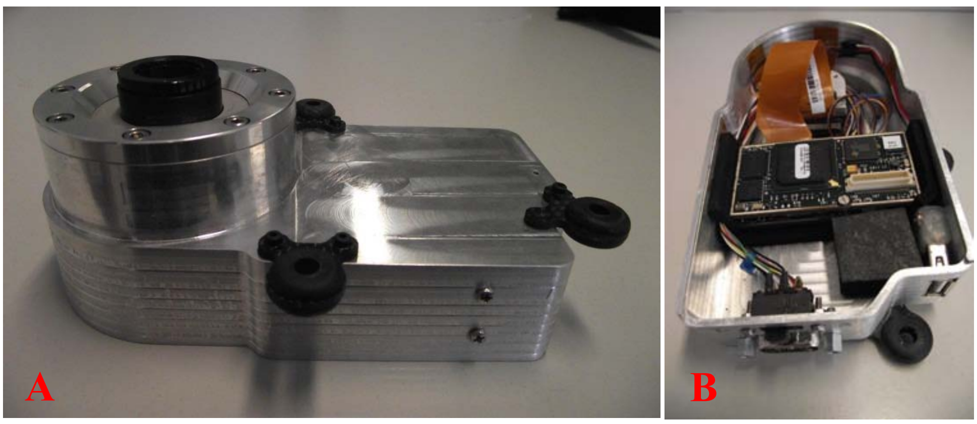

Figure 2. a) TE 3600AS customised frame for UAS installation b) TE 3600 AS electronics and optics configuration in the frame.

2. Set-up

2.1 Laboratory / fieldwork configuration

In order to characterize the behavior of the TE 3600 AS both, indoor and fieldwork, set up have been designed. An USB frame grabber is connected to the TC and both, camera and frame grabber, are connected to a hosting computer (figure 3). In the case of fieldwork set up the PC is replaced with a laptop. Both acquisition and visualization of the data may be done by using native Matlab software . A detailed description of software and procedures is on the following section 2.2.1.

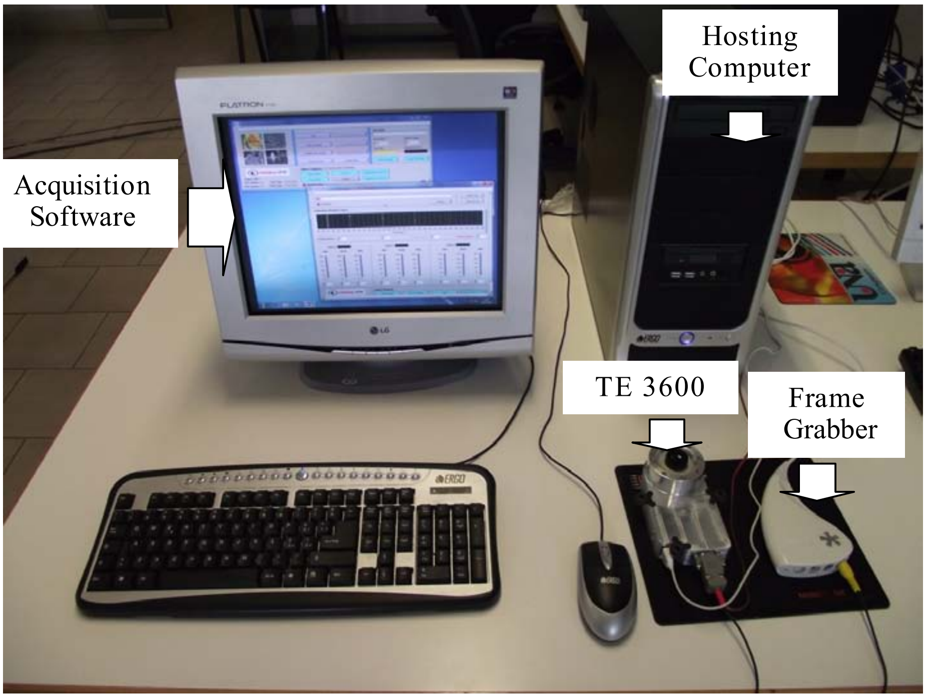

Figure 3. Laboratory set-up for Thermal eye 3600 AS tests.

A qualitative test to characterize the behaviour of the camera in presence of a hot spot was realized. A squared shape electric resistance (10cmx10cm) was located 1m far from the camera. The resistance was warmed up fixing a set point with a power of 5Watt. Figure 4 shows two snapshots taken at different time showing the warming up process of the resistance. This qualitative test was aimed to verify the quality of connections, acquisition and recording system and the quality of the images.

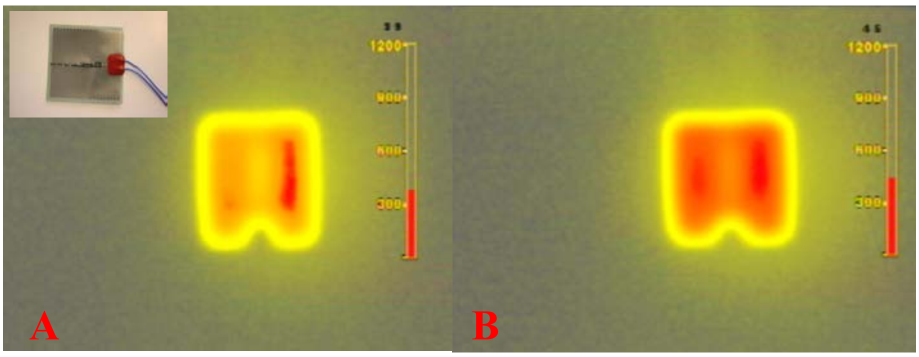

Figure 4. TC images of the resistance show the warming process: a) starting warming up phase (insert visible snapshot) b) thermal image at a fixed set point. In this qualitative experiment high temperature is red in the false colour scale.

2.2 Flight configuration

The flight configuration is quite different from the lab one due to the different requirements:

- Low weight: 615g
- Low size: 2cm * 10 cm * 8cm
- Low power consumption. (12Watt)

2.2.1 Acquisition system

Starting from strict requirement a custom solution for the acquisition system based on commercial components was developed.

The embedded solution is based on four PC-104 compliant stackable modules: Power supply, Frame grabber, PC and Wi-Fi module:

1. **Power supply module:** it is a DC-DC converter offering up to 75 Watt. It can power all stacked modules over PC-104 bus using a low weight (250 g) 3 cells Lithium Polymer battery
2. **Frame grabber module**: it is a real time PAL/NTSC Frame Grabber and live video overlay controller for PC/104+ bus.
3. **PC module**: it consists in a low power consumption embedded pc running Windows XP operating system. It allows to acquire each frame from the video grabber module and to store the resulting video into the 4 GB compact Flash who also hosts the operating system.
4. **Wi-Fi module:** By using this module it's possible to operate the embedded PC in wireless connection. The embedded system is integrated in a compact cubic configuration (12cmx10x8and a weight of 615gr) as showed in figure 5.

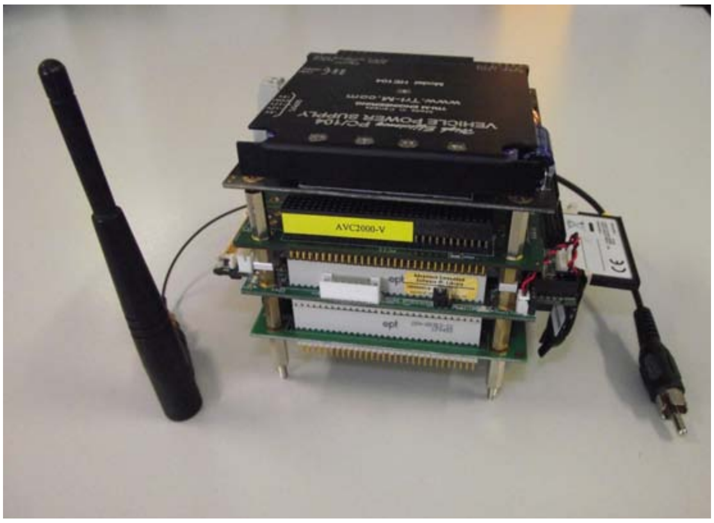

Figure 5. Embedded acquisition system (standard PC104 format).

2.2.2 On board installation

The platform chosen for this test is the Cardinal UAS, a 2,10 m wingspan electrical powered aircraft.

The camera was fixed on the bottom of the fuselage to obtain the nadir view with a minor modification of Cardinal's center of mass. Figure 6 shows the TC as installed on the aircraft.

Figure 6. External view of the Thermal Eye 3600 AS fixed on the Cardinal fuselage.

3. Software

3.1 Matlab toolbox

For the laboratory test we used the Matlab Image Acquisition Toolbox, a tool available for desktop applications. It was chosen since it is easy and affordable to use: the hardware is directly connected to the tool which allows to set acquisition parameters, and to preview and/or to acquire image data. It is possible to log the data to MATLAB in numerous formats, and also to generate an AVI file, just right from the tool (Matlab User manual).

The *Image Acquisition Toolbox* offers the following panels:

- Hardware Browser – – it is used to show the image acquisition devices currently connected to your system.
- Preview window – it is used to preview and acquire image data from the selected device format, and to export data that has been acquired in memory to a MAT-file, the MATLAB Workspace, or to tools provided by the Image Processing Toolbox software
- Acquisition Parameters – It uses tabs to set up general acquisition parameters, such as frames per trigger and color space, device-specific properties, logging options, triggering options, and region of interest. Settings you make on any tab will apply to the currently selected device format in the Hardware Browser (Matlab User manual).
- Information Pane – It displays a summary of information about the selected node in the Hardware Browser.
- Image Acquisition Tool Help –it displays Help for the pane of the desktop that has focus. Click inside a pane for help on that area of the tool. For the Acquisition Parameters pane, click each tab to display information about the settings for that tab.

The matlab image tool is the perfect tool for laboratory test of TC 3600 AS.

3.2 Thermal Eye GUI

It's a basics Graphical User Interfaces, it permits access to the individual panels used to alter the behaviour of the camera. These include:

- Color Panel – used to define the temperature based colorization parameters;

- User Parameters Panel - used to configure the AS camera by defining which functions are enabled or disabled.
- Real Time User Control Panel – used to implement temporary real-time control of the cameras functions
- Symbology Panel – used to load custom symbols, load custom start-up logos, and/or redefine the existing symbols such as the temperature bar and cross-hair.

The communication between Thermal Eye GUI and camera is carried out by means of USB cable.

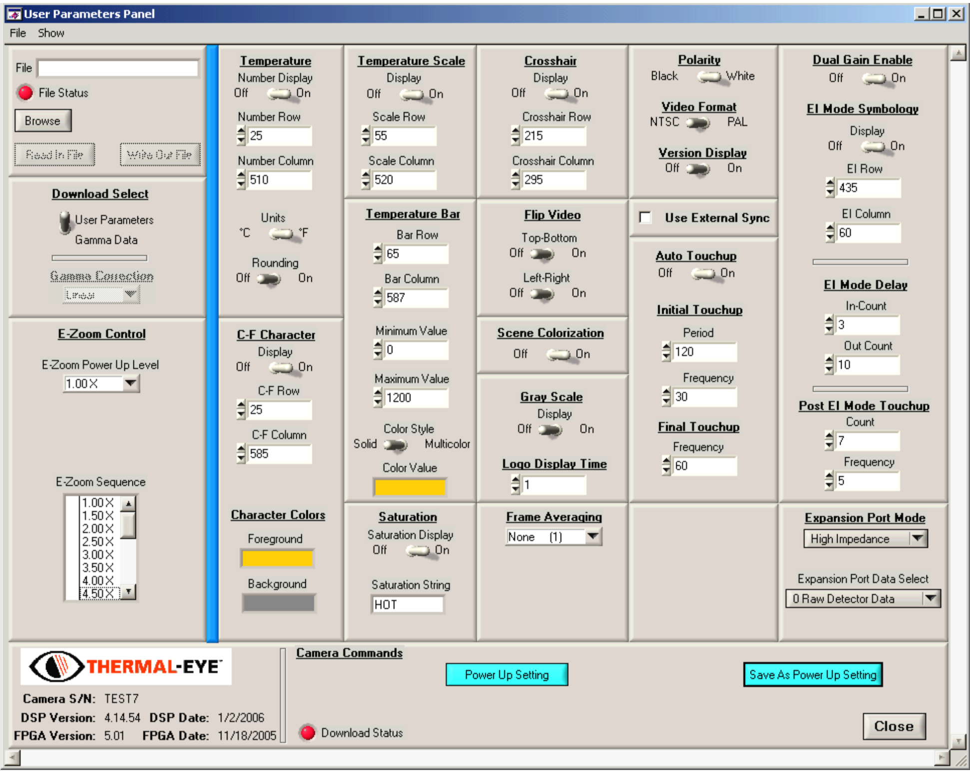

Figure 6. Thermal Eye Graphic user interface.

4. Flight test description

On June 26-30 2011 a series of laboratory and flight tests were performed. The aim of the laboratory test carried on the TC eye 3600 AS acquisition system, was to check the camera in a controlled room (laboratory test as described in section 2.1) .

The flight test was performed to check the integration of both payloads (TC 3600 AS and acquisition system) in real operating conditions

The UAS was lodged in a car and the integration was completed in the flight area. The chosen area is managed by Gruppo Aeromodellisti di Forlì (GAF, http://www.gruppoaeromodellistiforli.it). It consists of a grass strip of about 150m surrounded by land fields, located close Forlì town (Lat 44°18’12.01N, Lon 12°3’27.34’’E). A vineyard and soil-grass lands are located very close to the taking-off and landing area.

The test was realized at sunset on June 30 2011 at 8:00pm GMT. Despite it was been raining for most of the night before and it was cloudy during the day, the weather condition at time of the flight was very good. Moreover not severe wind was present. The pre-installation of the camera on board of the Cardinal was realized by DIEM laboratory. The acquisition system was checked and batteries were charged. The UAS was lodged into a car (Figure 7a) Final assembling, ground control station assessment (Figure 7b), and interface connection checking (Figure 7c) were performed on the GAF flight area, close to the TO strip.

Figure 7 Flight test at Gruppo Aeromodellisti di Forlì strip on June 30 2011: a) Cardinal lodged on the car; b) Final assembly phase; c) Telemetry and acquisition software testing; d) Cardinal Take Off.

The flight was realized in radio controlled mode. The overlooked area, shown on Figure 8 in visual range by Geo-eye Google view, covered different kind of lands types, a main road and a farm house (Figure 8).

Figure 8. Geo-eye view as by Google located on the take of strip, shows the area overlooked by Cardinal.

The file acquired during the flight was very good and not problem were detected. By a visual analysis of the recorded video, saved in AVI format, it has been possible to recognize the different overlooked areas. In particular in Figure 9 shows two frames extracted by the video. The first one, Figure 9a, shows a detail of the farm house acquired during a turn of the UAS and a second one (figure 9b) acquired over the vineyard.

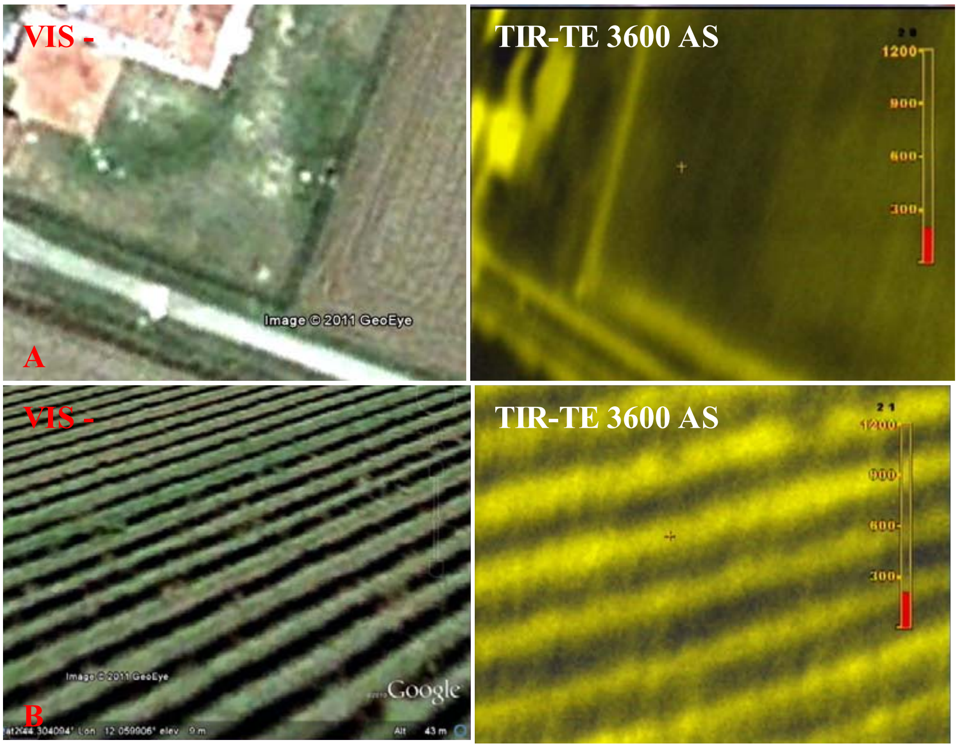

Figure 9. a) Farm house image as shown on Google Earth (left) and TIR image, over the same area is visualized in false colors (right). B) Vineyard details as on Google Earth and TIR image, over the same area is visualized in false colors (right).

Conclusion

We have reported the results of the first thermal camera flight experiment realized by using a UAS with fix wings in Italy. The payload is Thermal Eye 3600 AS thermal camera operating in the range 7-14 micron.

In order to fix the camera on a UAS system a proper frame, compact and light, has been realized; this frame could be also be easily adapted on different kinds of UAS platforms.

An embedded compact acquisition system has been developed taking into account the requirements of performance stability. Laboratory test has been realized to check the acquisition system and to start the characterization of the camera (at moment at qualitative stage).

The integration of the payload on the Cardinal and the acquisition during the flight tests represent the first important result from both a technical point of view and a scientific point of view. Concerning this second point the next steps will consist in a quantitative characterization of the TC acquired data.

This flight test represents a preparatory phase of the RAVEN-INGV flight test.

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