OPTAG - A COMBINED PANORAMIC PHOTOGRAMMETRIC AND RADIO FREQUENCY TAGGING SYSTEM FOR MONITORING PASSENGER MOVEMENTS IN AIRPORTS

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ABSTRACT:

Up to five percent of aircraft departure delays are caused by late passengers or late bags at a gate, and the impact of this in missed slots and subsequent cost will increase as the number of flights increases. This paper describes the development of a combined real time panoramic imaging system, capable of photogrammetric measurement, with a new long range radio frequency tagging system that is directed towards the real time monitoring of passengers within an airport environment. The system is designed to enable the immediate location of checked in passengers who are either missing or late, and thus reduce passenger-induced delays and speed up aircraft turn around.

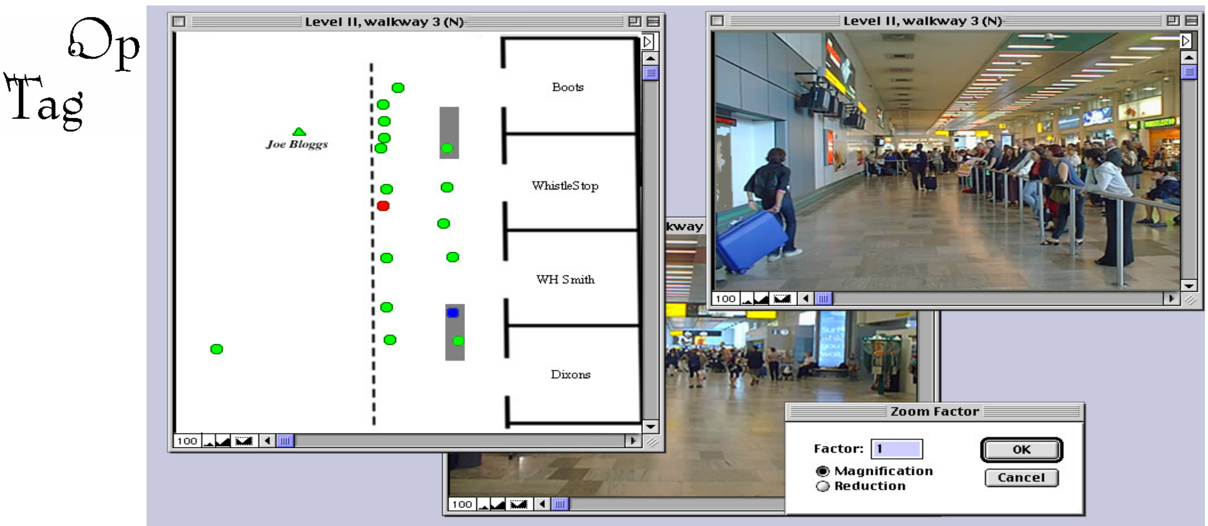
The paper introduces the overall design of the system and reports on the capabilities of a newly developed twelve mega pixel panoramic imaging system that has been designed to deliver calibrated panoramic images and high resolution targeted views at frame rates of up to twelve fps over an Ethernet network. The camera is composed of eight sensors that must be individually calibrated in order that their individual images can be geometrically corrected and stitched together in real time. Detail is given concerning some of the camera calibration processing carried out and the observed consistency in imaging geometry between sensors following their manufacture and subsequent alignment using optical bench techniques.

1. INTRODUCTION

1.1 Background

OpTag is a three year European Union funded research project that aims to develop a network of new high resolution panoramic cameras that exploit real time image processing to deliver geometrically corrected high resolution panoramic images to client workstations located within an airport environment. The imaging system is combined with a new long range radio tagging system that, registered into the same coordinate datum can provide information as to the identification of individuals within the airport (Figure 1). Once complete, the combined system will allow airport staff to determine locate and observe selected individuals.

Whilst the system will have security applications, the economic driving force for the project is to enable the immediate location of checked in passengers who are either missing or late, and thus reduce passenger-induced delays and speed up aircraft turn around.



Separate map, live video and video playback windows
Green - location updated within previous 30 s; Red - location not updated within previous 30 s;
Blue - tag location unchanged for more than 10 minutes.

Figure 1. Schematic example of what the user might see

System design is focussed towards providing a platform for further development with the research effort concentrated towards high quality image delivery and system reliability. Potential users of the system include airports, security authorities, airlines and airport service suppliers for increased security (Passenger tracking, unusual behaviour analysis and secure/restricted area access) and efficiency (monitoring passenger flows, locating late passengers to gate and staff management).

The project has completed the specification stage, developed the panoramic camera hardware and image processing, compression and communications software. At the time of writing, work is on-going with a final refinement / testing stage of the camera system and the integration of the radio frequency tagging system within a common user interface.

2. THE OPTAG SYSTEM

2.1 Overview of the system

A critical part of Optag is the integration of a unique cellular-based far-field RF-ID tag tracking system with a high-resolution panoramic image monitoring network.

The basis of the system is that airport users will carry ”tags” which can be either boarding cards, security tags or personal cards. The radio frequency tagging system uniquely identifies and tracks each individual tag position within a 2D model of the airport environment and these location data are overlaid onto the panoramic images from a high quality camera system.

In a large airport, tens of thousands of passengers may need to be tracked to a good accuracy once per second. In any given cell (of approximately ten m radius) there may be up to one thousand passengers. This is a much more challenging requirement than the simple short-range passive tags used in, for example, transport ticketing.

Benefits include the ability to detect, locate and assist late-running passengers, combined tag / video monitoring of any suspicious persons, location of lost children and video imaging to establish their safety. The tags themselves are planned to be transmit-only, containing a unique ID which can be cross-referenced to the passenger and flight details.

2.2 The OpTag Tag

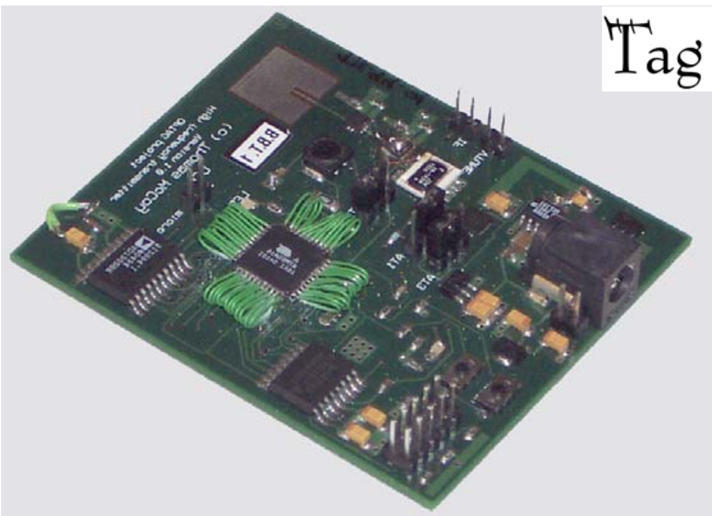
The prototype tag, (Figure 2a), radiates a very low power signal in the 5.8 GHz band and uses a random burst strategy to allow more than one thousand tags to be operating successfully in the same cell. The tag readers, which may be integrated with the camera hardware, contain a sophisticated receiver that is able to detect the very short bursts sent by each tag, perform direction finding on them in order to estimate their bearings, and pass this information on via a network interface. The result is a system that is easy to configure and expand.

Location is determined by means of amplitude-comparison direction finding and triangulation over two or more cells. Error modelling studies have demonstrated sufficient angular accuracy to estimate the position of tags to a target spatial resolution of one metre.

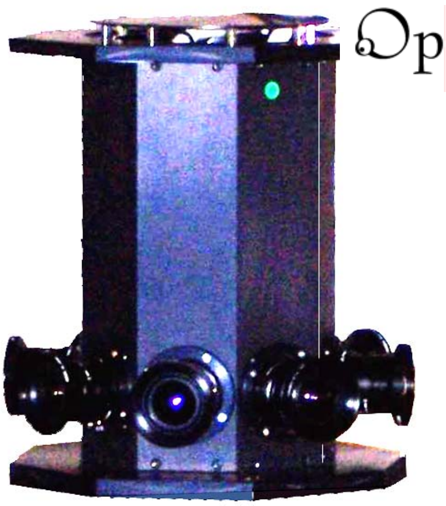
2.3 The OpTag Camera

The Optag Camera (Figure 2b) is designed to continuously deliver full 360 degrees views plus several local targeted views which can be selected by an operator sitting at a remote client workstation. The system supports multiple operators who can each select their own choice of individual zoom views from the panorama, simultaneously, this ability is in direct contrast to a pan tilt and zoom security camera where only one view is available at a given time. Such a capability is very important in an airport environment where there can be as many as eight different users of CCTV information.

Whilst the camera operates internally to deliver synchronised images from all eight sensors at frame rates in excess of twelve fps, images from the camera server are delivered at slower rates. The restriction is due to image processing capabilities of current DSP hardware. Images from each camera server can be supplied at one frame per second for the whole panorama (~10,000 x 1,200 RGB pixels) and at up to twelve frames per second for operator selectable window transmission. Sub sampled panorama are also delivered at the rate of a few frames



a)



b)

Figure 2: (a) prototype radio frequency tag, (b) an OpTag camera unit

per second to allow users to monitor the complete 360 degree view at typical 1280x1024 screen resolutions.

Each OpTag camera unit deploys eight interconnected camera units to simultaneously observe a 360 degree view without recourse to any moving parts. A Digital Signal Processor (DSP) equipped image capture board and an Ethernet capable host computer make up the camera hardware. The individual camera units constituting each panoramic camera have been purpose developed for the project in order to optimise image quality for the airport environment and to ensure the level of opto-mechanical stability required for long term calibration stability.

The optical geometry of each sensor has been mechanically configured such that the principal point is offset in the vertical direction by almost half the image format. This configuration means that each panorama looks only below the horizon line allowing ceiling mounting of the camera unit without loss of image format or converging vertical lines as would have been the case had each sensor been tilted. The DSP has the capability to handle Bayer interpolation, photogrammetrically derived geometric image correction, image stitching into a cylindrical projection and output M-JPEG image compression.

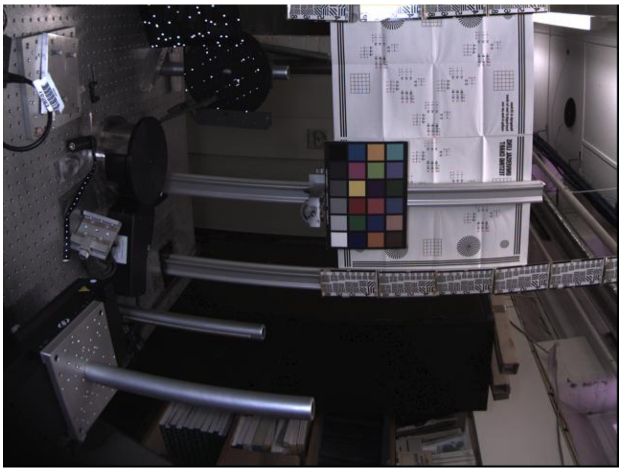


Figure 3: An image of a test array taken with a single camera module under mixed lighting conditions. Note the de-centred radial distortion due to the vertical principal point offset.

Following analysis of test charts, such as those seen in figure 3, the camera is resolving between 80 lines per mm (lmm^{-1}) for vertical lines and 90 lmm^{-1} for horizontal lines. This analysis, based on an optimised Bayer reconstruction algorithm [1] is comparable to the 119 lmm^{-1} Nyquist of the sensor.

The project has also developed a communication protocol to support a low delay real-time video transmission with error correction over a common Ethernet channel with multiple camera (server) and user interface (client) connections. This network is extensible to allow connection between the camera units for distributed object identification.

2.4 The OpTag User Interface

Client software consists of a user interface to provide image display operations from multiple camera units, tag location data collection and a set of operations necessary to integrate information from the different sensor types and present it to the operator.

Further work in support of these processes includes a tracking solution that is designed to follow a moving object in both imagery and on a 2D plan of the airport environment. This solution will allow identification of individuals in multiple image viewpoints and will permit the operator to select a tag location from the display of the 2D plan, or select a person in one camera image and automatically find the same person in the other images and on the 2D plan. This work will be reported in a subsequent paper.

2.5 Cylindrical projection

Use is made of a cylindrical projection geometry similar to that described by Schneider and Maas [2] to display projections of epipolar lines on the cylindrical panoramic images which will allow either the display of a direction of sight of one camera on another camera's image (from the camera to the first wall or floor occlusion) simply by clicking in the first image (Figure 4), or will show the direction of an individual as specified by the radio tagging system in the panoramic image display.

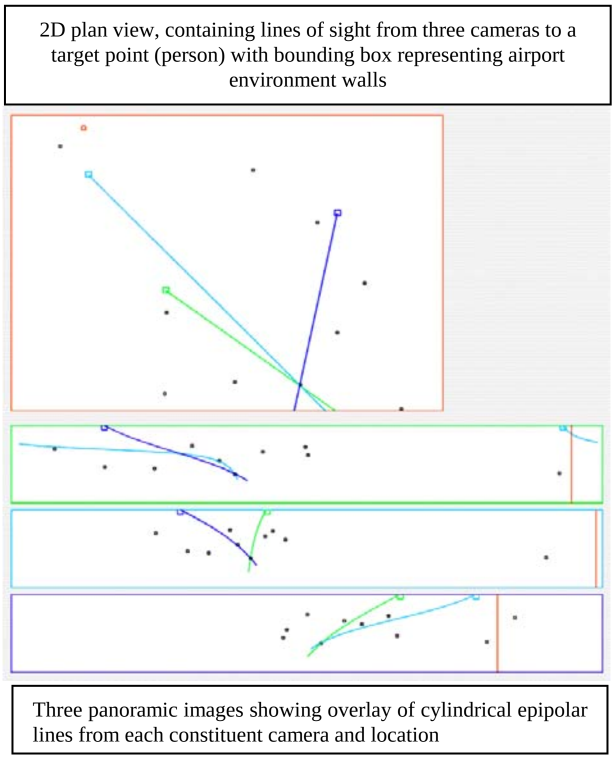


Figure 4: Cylindrical epipolar geometry underlying the user interface. The three lines show lines of sight from three Optag cameras to a target point overlaid onto (top) a simple 2D plan and (bottom) the component panoramic images. The epipolar curves seen in the three bottom views are generated from a cylindrical projection and include occlusions as generated by the bounding box in the plan view

3. CALIBRATION OF THE CAMERA SYSTEM

Recent panoramic photogrammetry conferences and workshops have included several papers on the calibration of panoramic cameras, for example [2-4]. This work will not be repeated here, instead this paper focuses on calibration of individual sensors which constitute the OpTag camera cluster and a minimisation in the physical variability between the individual sensor units with the aim of using a common set of lens distortion parameters for all camera clusters to provide a image correction and stitching solution that is appropriate for deployment at the single pixel image measurement level dictated by the OpTag system specification.

3.1 Sensor calibration

As explained in Section 2.3, eight synchronised sensing units equipped with 1600 x 1200 pixel CMOS sensors output eight bit Bayer images which are stitched together and geometrically transformed to a cylindrical projection to constitute a full 360 degree OpTag camera view. Each of these sensing units is fitted with a 6.5mm C mount lens which have been obtained as a single manufactured batch of lenses.

In order for the direction of any object within the field of view of the camera to be calculated, the imaging geometry of the camera system must be fully understood. Following mechanical mounting of each sensor within the OpTag camera body, each individual sensor is calibrated using a photogrammetric self calibrating bundle adjustment [5,6]. Here a convergent network of images is taken of a calibration wall, consisting of several hundred retro reflective targets, from thirteen viewpoints. A sample set of images, displayed in an overview mode, are shown in figure 5 whilst a diagram of the imaging network used is given in figure 6. In figure 6 each photo location is shown as a green cone and the locations of each physical retro-reflective target is shown as blue and green dots. RMS image residuals resulting from a series of such calibrations demonstrate fit between the sensor model and the real imagery of the order of one quarter of a pixel.

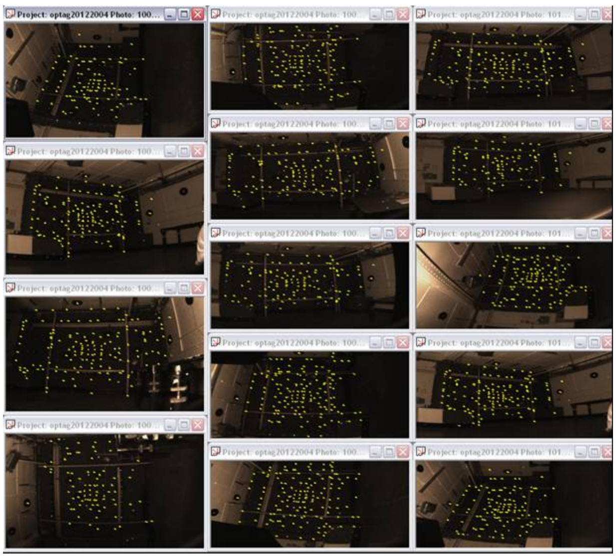


Figure 5: A selection of calibration images with measured image location highlighted, (inset) a typical image of a retro-reflective target

Most significant for camera performance in the Optag project are the consistency of the image magnification between all eight camera sub-units and the geometric stability of the units over time since the system will be moved from one location to another during the demonstration period of the project.

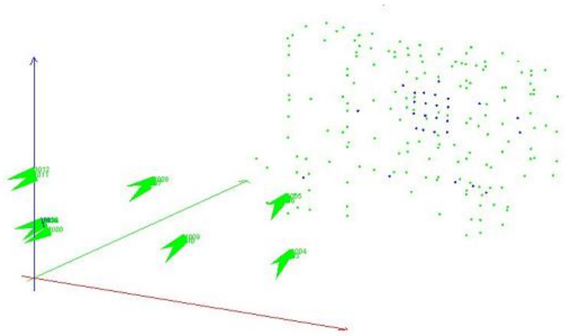


Figure 6: The imaging network used to calibrate the OpTag camera.

Principal distance is the dominant factor in determining consistent magnification and is a function of the variation between individual lens characteristics and individual lens focus settings. Next in importance is the radial lens distortion present in each camera since individual lenses, whilst selected from the same production run, can be expected to exhibit small variations due to manufacturing tolerances. Consistency in the offset of the principal point in the y (vertical direction) is also of importance as this alignment dictates how many common image lines will be available for the panorama.

Parameter	**Mean value (mm)**	**St.dev (pixels)**
Principal point X	0.29mm	6.6
Principal point Y	2.05mm	4.9
Principal distance	6.16mm	1.4

Table 1: Variation in principal point and principal distance for eight sensors

Table 1 demonstrates remarkably consistent principal distance from repeated calibration data collected using sets of eight sensors. The observed consistency is a function of the quality of the lenses used and their mechanical mounting to the sensor. The variation in principal point offset is larger being attributable to the pitch of the small adjustment screws built into each camera unit to facilitate the common alignment of each sensor in the cluster.

Figure 7 shows the variation in radial lens distortion for the same eight sensor units. Again the data is surprisingly homogenous demonstrating excellent agreement of the order of a pixel for all but the very edge of the image format. The larger observed variation in radial distortion at the periphery of the field of view is most likely attributable to the minimal number of targets imaged at the edges of the image format - a typical limitation of network based photogrammetric camera calibration [7].

This observed level of consistency is very significant as it means that the same radial lens distortion correction can be applied to all eight of the sensors in the panoramic camera cluster making the calibration process much simpler and offering the possibility of holding a common distortion correction lookup table in memory for all individual sensors which is then modified by simple shifting based on the principal point variation within each individual sensor.

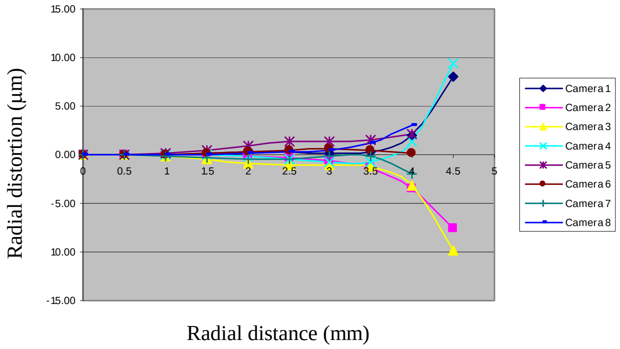


Figure 7: A family of radial lens distortion curves showing discrepancy with respect to a mean curve for eight sensors.

3.2 Validation against known target coordinates

The completed camera has been deployed to image a known array of 3D retro-targets. Results from measurements using image centroiding techniques combined with photogrammetric intersection solutions demonstrate target coordinate precisions of the order of a few millimetres at object distances in the range of five metres (Table 2). Such measurement precision is far in excess of that required for the Optag project, but offers promise for further work in a wide range of photogrammetric measurement tasks.

Object coordination precision			Image measurement precision		Number of images in solution
X (mm)	Y(mm)	Z(mm)	x(µm)	y(µm)	
0.16	0.46	1.90	1.98	1.28	16
1.85	5.36	1.97	3.94	1.21	3

Table 2: Summary of coordinate measurement precision obtained through multi-image intersection.

It is worth noting that the 3D coordination carried out for this validation is restricted by the convergent geometry of the deployed imaging network (similar to that in figure 6). Such a configuration places all targets within a small proportion of the panoramic viewing extents with all targets on one side, rather than within, the cluster of cameras. More optimal deployment of panoramic imaging systems occur when the objects to be measured are imaged over a much greater extent of the panoramic field of view.

A further difference is that when the OpTag system is deployed to locate a person or object within the field of view of the sensing system, the capability to locate objects of interest will be restricted by the ability of the operator to identify and accurately measure common points on any person or object to be coordinated. The key point of the validation is that the geometric understanding and associated mathematical model of the imaging system is fit for purpose.

4. SUMMARY

The OpTag project aims to deliver better, up to the moment, knowledge of the movements of passengers in the air side of a terminal before they enter the aircraft. It is designed to enable airlines and airports to improve the management of checked-in passengers and thus reduce passenger-induced delays as well as to speed up aircraft turn-around. The proposed system utilises a combination of a new real time panoramic camera combined with information from far field radio frequency tags carried by each airport passenger.

The design and calibration of the OpTag camera and its individual component sensors have been optimized to confer a consistent geometrical design that is geometrically stable and commensurate with the needs of the OpTag project.

Laboratory tests to investigate variations in key image geometry parameters (principal distance, principal point offset and radial lens distortion) have, in conjunction with incremental refinements of the camera hardware, produced a system is verifiably able to perform at the pixel level.

Work is continuing to integrate both optical and radio frequency sensing systems and refine a graphical user interface which will be tested at an end of project trial at a European airport

5. REFERENCES

[1] Seager, J. W., Harvey, E. S., Robson, S., Shortis, M. R.- Refining a Bayer Filter to improve photogrammetric measurement quality and reduce image artefacts. Proceedings on CD-ROM, 12th Australasian Remote Sensing and Photogrammetry Conference, Fremantle, Australia, ISBN 0-958136-1-0 (2004)

[2] Schneider D. and Maas H.-G., 2003. Geometric modelling and calibration of a high resolution panoramic camera. In Gruen/Kahmen (Eds.), 6th Conference on Optical 3D Measurement Techniques, Vol. 2, pp. 122-129, Zurich, Switzerland.

[3] Huang,Y.D. & Harley, I.A. 1990. CCD calibration without acontrol field. *International Archives of Photogrammetry and Remote Sensing*, 28(5/2):1028-1034.

[4] Amiri Parian, J. and Gruen, A., 2003. A Sensor Model for Panoramic Cameras. In Gruen/Kahmen (Eds.), 6th Conference on Optical 3D Measurement Techniques, Vol. 2, pp. 130-141, Zurich, Switzerland.

[5] Cooper. M.A.R., and Robson. S. 1996. Chapter 2: Theory of close range photogrammetry. In Close Range Photogrammetry and Machine Vision. Edited by K.B.Atkinson. Whittles, Caithness, Scotland. 371 pages. ISBN 1 870325 46 X pp.9-51.

[6] Fryer, J. G., 1996. Camera Calibration. Close Range Photogrammetry and Machine Vision, K.B. Atkinson Ed., Whittler Publishing, Caithness, pp. 156 - 179.

[7] Luhmann, T., Robson, S., Kyle, S., Harley, I., 2006: Close range photogrammetry. Whittles Publishing, Caithness, UK, to appear in summer 2006.

5.1 Project Partners

Partners in the project are Innovision (UK), UCL (UK), Photonics (France), TSI (Greece), Longdin & Browning (UK), Slot Consulting (Hungary), Debrecen Airport (Hungary), and Europus (UK). The project is supported by the aerospace sector of EU Framework 6.

5.2 Further Information

Further information concerning this project can be obtained from the project coordinator:

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