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SMALL FIXED WING AUTONOMOUS AERIAL VEHICLE FOR FOREST MANAGEMENT APPLICATIONS

ABSTRACT

In this work a forest management infrastructure solution using small autonomous aerial vehicles is proposed. The FALCOS unmanned aerial vehicle developed for remotemonitoring purposes is described. This is a small size UAV with onboard vision processing and autonomous flight capabilities. A set of custom developed navigation sensors was developed for the vehicle. Fire detection is performed through the use of low cost digital cameras and near-infrared sensors. This approach is extended to a radiometric forest inventory and forest fire danger characterization. Test results for navigation and ignition detection in real scenario are presented.

I. INTRODUCTION

Aerial solutions have been used in forest fire detection, [1,2] ranging from human piloted planes (expensive and not efficient) to unmanned aerial vehicles.

The result presented in this article concern the work that is being carried out on forest fire detection, radiometric forest inventory and forest fire danger characterization. Our approach is based on small fixed wing autonomous aerial vehicles with onboard image processing in visible and near infrared spectrum.

Unmanned Aerial Vehicles (UAVs) are used for fire search in most cases to provide aerial imagery for the region of interest. Flight control is usually autonomous and it is achieved through custom design solutions [4] or by the use of commercial autopilots such as PiccoloTM [11] or MicroPilotTM systems.

Sensors onboard range from visible light cameras to infrared thermal imagery systems. In the most simple cases, image feed is sent wirelessly to ground control station from video processing and user control. Thermal imagery through the use of infrared sensors provides good estimates for fire ignitions [2] and can be combined with visible spectrum image processing to discard false positives.

Other approaches to fire detection do not rely in direct fire detection but in smoke plume identification [3].

Different types of UAVs are used, from dirigibles and moving wing systems [1], to fixed wing solutions [4].

Fixed wing UAVs have advantages in autonomy, range of operation and area covered. Several types of systems have been used in fire prevention with different capabilities and available payload. UAV technology has been driven mainly by military interest. One example of a spin off, is the use of Predator UAVs [5] in civilian forest fire prevention in the USA.

Currently there is a crescent interest in the use of light small UAVs flying at low altitude for civilian applications, opposed to the HALE (High Altitude Long Endurance) or MALE (Medium Altitude Long Endurance) more expensive and operationally complex systems.

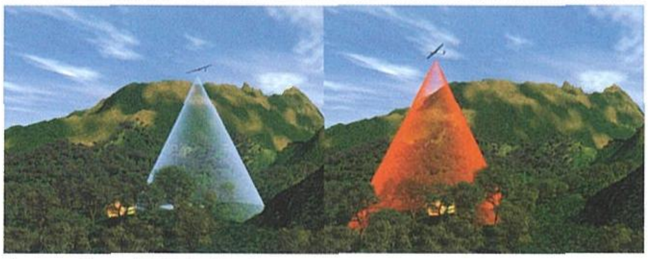

Figure 1 · Light small UAVs fire detection.

The approach presented in this work relies in small fixed wing autonomous aircrafts. These low cost vehicles have high autonomy in terms of mission control with onboard video processing. This allows operation with minimal human intervention and without stringent requirements for image wireless transmission, since only detected possible fire images transmitted to ground for user verification. Reduced cost and space imply a combination of simple visible light image and near IR images to detect possible ignitions.

Complementary work been carried to perform the danger risk charts based in proximity of existence roads, houses and others artificial infrastructures. A complete and uniform continuous cover of land space is required. If the images are captured with an overlapping of more than 60%, ther relative parameters to the forest occupation such as the height of the trees or the density of occupation can be calculated.

System range and autonomy are obtained not by individual vehicle autonomy but by the use of multiple coordinated vehicles.

The remain of the paper is organised as follows: in the next section the FALCOS autonomous aerial vehicle is described followed by control architecture and manoeuvre based fire search. In sequence, the system

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This work has been partly supported by ISEP-IPP under project FALCOS and by Fundação de Ciência e Tecnologia under project BoaVista.

and approach to fire candidate detection is presented. Finally some flight performance and fire detection results obtained in operational test missions are presented followed by some concluding remarks and further work directions.

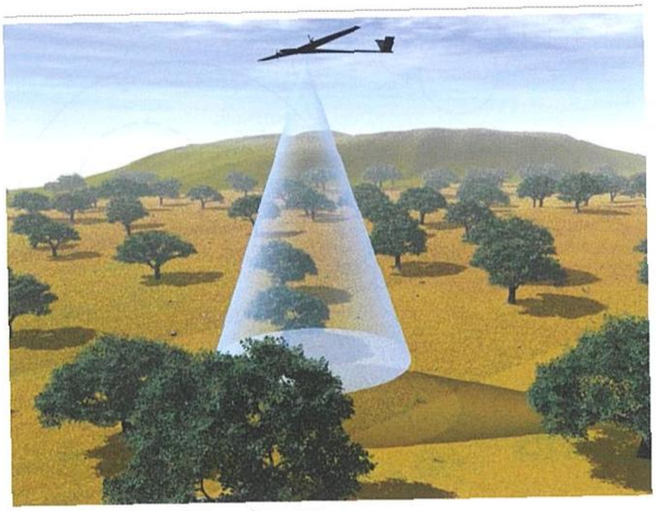

Figure 2 · Forest characterization and inventory.

II. FALCOS AUTONOMOUS AERIAL VEHICLE

The FALCOS (Flight Autonomous Light Cooperative Observation System) autonomous aerial vehicle is used in the fire detection mission experiments. This small, fixed wing, electric AAV has onboard embedded processing for navigation, control and sensing. The vehicle prototype with 2.5m wing span, carries a set of low cost digital cameras and navigation sensors.

Figure 3 · FALCOS Autonomous Aerial Vehicle test prototype.

Electric propulsion was a main consideration in the UAV design. Although with strictly less energy density compared with internal combustion options a set of advantages make this option a favourable one in small light UAVs. Advances in battery and photovoltaic cell technology provide acceptable densities along with the possibility of in-flight recharging.

Power motors are more efficient with the additional use of brushless dc motors. Motor control is easier and safer (no problems with start and stop in the air), motors have lower weight, induced airframe vibrations are reduced and operational use of aircraft in forest surveillance has lower ignition risk in case of failure.

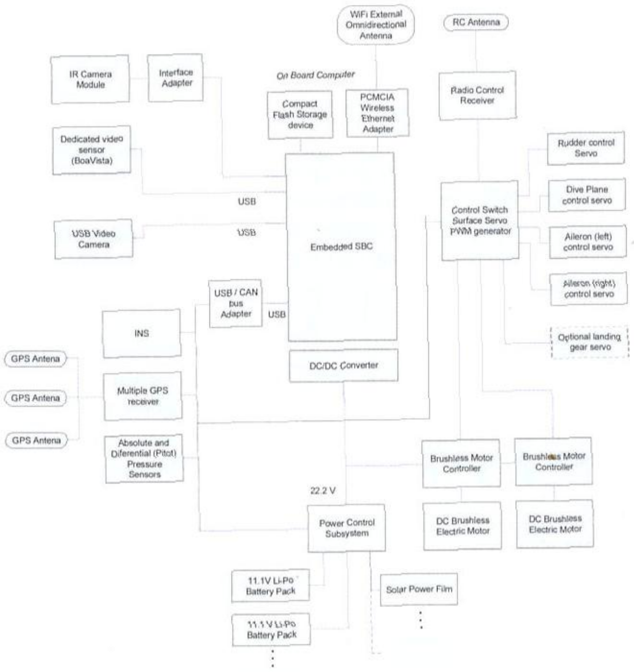

Figure 4 · Overall System architecture.

Vehicle energy in flight conditions has two possible sources: batteries and solar photovoltaic cells. Currently a set of Li-Po battery packs are used as main energy source. This battery technology offers the highest W.h/kg ratio for all current COTS technologies. Currently values up to 240W.h/kg are available.

Vehicle control, navigation and application processing is performed in the onboard computer. This is a low power single board computer running a Linux based operating system with real-time properties. Servo control can be issued either from the CPU in autonomous flight mode or by a standard radio control in remote piloting.

An ethernet wireless modem with external antenna is used for communication with ground station. This link provides telemetry, mission configuration and control and the vision data transmitted on the fire detection events. Relevant events for the hybrid control system, such as ATC (Air Traffic Control) events or others from the ground control or authorities are also transmitted.

A CAN bus is used to connect navigation sensors and power control to the main CPU and vision sensors connect through USB link. A set of navigation sensors with local processing embedded in a hierarchical architecture provides the information necessary for vehicle navigation.

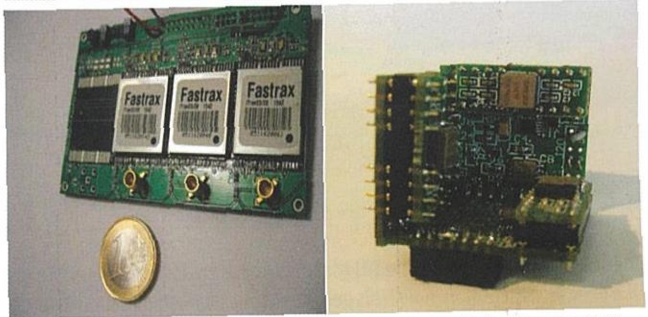

Figure 5 · Custom developed inertial navigation system (right) and multiple GPS receiver (left).

A multi GPS onboard system was designed to determine vehicle attitude accurate estimates along with position. This system uses 3 GPS receivers synchronized with antennas placed at the wing and tail tips. The pseudo-range and carrier phase information providing distances to GPS satellites are used directly in a filter to determine vehicle orientation. Real time kinematics (RTK) filtering allow high degree of accuracy. Absolute and differential pressure sensors provide altitude and airspeed information A low cost small size embedded inertial navigation system (INS) was designed. Aimed at mobile robotics applications this system combines inertial navigation information from triaxial accelerometer and gyroscope sensor configuration.

A low-power real-time vision system (LSAvision) [6] developed for mobile robotics applications is used on the AAV for fire detection and relative position measurements. The implemented vision architecture has low computational cost, low latency, low power, highly modularity, configurability, adaptability, and scalability. Data flows in a pipeline structure with stages allowing hardware (BoaVista system) or software implementation.

Relevant object detection is achieved in real time, with surface vehicle identification by segmented image blob and edge processing. Near infrared sensors are used with a combination of suitable optical filters to obtain a first level of thermal imagery. These sensors constitute a low cost approach and in conjunction with the visible spectrum ones provide a first set of possible ignition detection candidates. The onboard fusion of image sensing data capabilities provides a means to reduce the requirement of full cooled precision IR sensors fire detection.

III. FIRED SEARCH MANOEUVRE

A hierarchic architecture is considered to integrate the vehicle's navigation and control systems and a hybrid systems framework was adopted in order to design control and navigation algorithms.

The global control design relies on the concept of manoeuvre, which is modeled by a hybrid automaton [7, 8] This can be briefly described as a set of discrete states and transitions between them, being a set of controlled continuous flows associated with each one. The manoeuvre implementation involves not only the vehicle hybrid control law, but also the navigation filters. The control and navigation systems are integrated in the manoeuvre design. In addition, more complex manoeuvres can be obtained by the hierarchic composition of simpler manoeuvres.

The next figure depicts the information flow

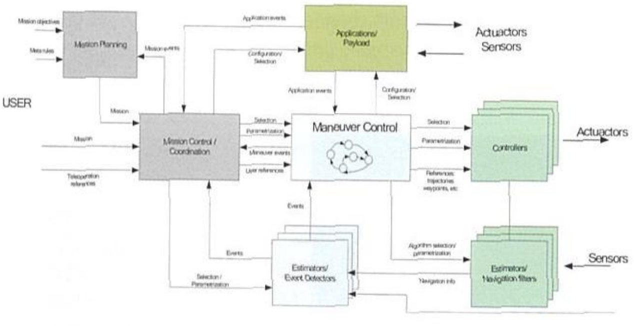

Figure 6 · Control architecture information flow diagram.

The hierarchic control structure [9] assumes at the lower level the existence of a vehicle stabilization layer. This performs basic flight stabilisation controlling roll, pitch and yaw and keeping desired velocities and altitude.

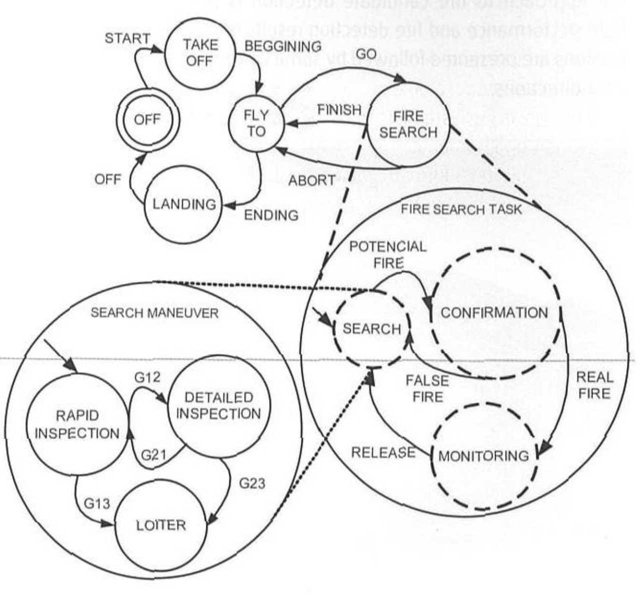

Figure 7 · Hierarchical Mission to manoeuvres organization.

Control manoeuvres are organized on top of this layer providing adequate guidance and with successive degrees of abstraction. The discrete states in the manoeuvre hybrid automata can either be simple continuous control laws or other lower level manoeuvres.

The vehicle is able to perform standard way-point navigation (using Line-of-Sight piloting or Serret-Frenet frames approaches), but also dedicated manoeuvres with direct sensory inputs (such as loitering over an onboard identified target, geographic feature following etc).

On the top level, manoeuvres are organised in a tasks. The task are the elementary component of the mission. The mission can be automatically generated or according to user specifications. The vehicle mission is determined by a graph of hierarchical automata, proving autonomy and adaptability onboard.

IV. FIRE DETECTION AND INVENTORY PROCESS

In order to provide a low cost and easily deployable solution, system operation relies in a semi-automatic approach to fire detection and forest inventory.

Instead of performing expensive thermal imagery or using standard multi-spectral approaches (such as identifying the most spectrum feature of fire, double peak at 4,5 um [10]) our approach extracts from near IR image possible targets, filters reflections and correlates those with the same visible image.

The possibility of high level of onboard information processing reduces requirements in mechanic image stabilizers, since reconstruction can be processed in realtime by software (the vehicle acts as a gimbal system itself).

Along the project technical guiding line, all the on board application sensors are characterized by low cost, small dimensions and weight and low power consumption.

The visual information is provided by low cost vision sensors, namely one in the visible spectrum and one in the near infrared one. Both can be either low cost digital cameras or dedicated hardware vision sensors (like BoaVista system [6]). The near infrared imagery is obtained with uncooled sensors and a combination of optical filters.

The dedicated vision sensors with parallel hardware processing (image segmentation, edge, blob and feature identification)are developed. These imaging sensors use standard optics and achieve resolution in the order of 3-5 Mpixels and frame rates up to 100 fps. At the operating altitude ranges from 500m up to 2000m the vehicle is capable of ground resolution from 1m up to 4m (with standard FOV lens).

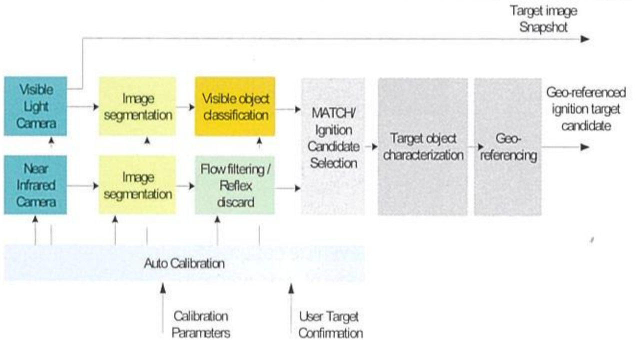

Figure 8 · Fire detection system architecture.

The available resolution can provide 5x5m of fire detection ground resolution, in strips of 1x1km to 4x4km and resolutions from 0.5 m to 2m.

The embedded real-time vision framework LSAvision is used in the on board image processing [6]. onboard realtime processing implies low computational available power and the emphasis on image processing efficiency rather then on absolute performance. Thus an approach based on image segmentation, and with a pipeline structure (easily performed in parallel reconfigurable hardware) avoiding complex computation algorithms.

Colour image segmentation is used on both sensors to provide object candidates. Further flow filtering is used on the near IR image to discard reflections and possible targets are matched with visible image objects for confirmation (colour, feature rejection). Possible ignition targets are then geo-referenced and an alarm is issued. The AAV system operator then can use this information along with a visual snapshot to reject or confirm the target.

The user interaction can also provide feedback for the system auto-calibration in addition with initial parametrisation.

Data gathered by the vehicle vision system can also be used to characterize the forest areas, determine risk charts, by measuring the vegetation type and hydration state, density or colour.

Acceding these characteristics can be done through the register of the reflection of the wave lengths of the red (650 ± 25 nm) and of the next infra-red ray (750 ± 25 nm). Through this information it is possible to calculate the vegetation indexes, that allow to separate the covering of the ground in vegetated surfaces, not vegetated and with water.

On the other hand, by regression analysis, it is possible to use these spectral bands to calculate foliar area indexes (LAI - leaf area index) and canopy closer index (CCI) that they complement the relative information to the type and structure of the vegetal occupation of the ground.

V. RESULTS

Several test missions were performed in simulated environment to test the control architecture (see next figure) and in operational scenario to test the vehicle navigation system, automatic control and fire identification.

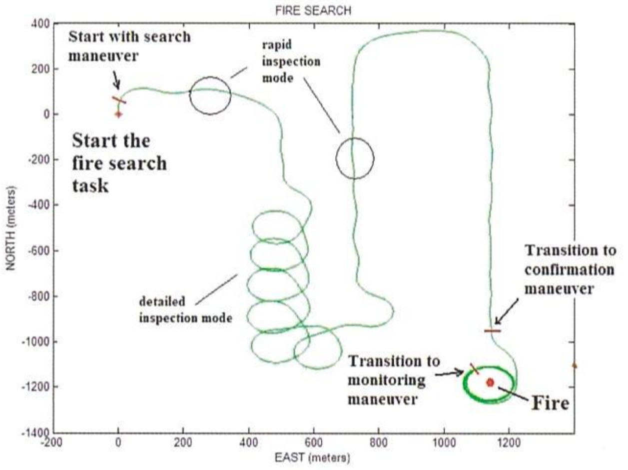

Figure 9 · Fire detection simulation run, with flag in mode transition.

In operational scenario the missions are performed in Portuguese county of Alvaiázere, on a mountain forest area. A small ground area was cleared for the tests and allows vehicle take-off and landing (done at this stage with remote control).

The vehicle performed several flight missions, and a test fire with 1x1m area was set up.

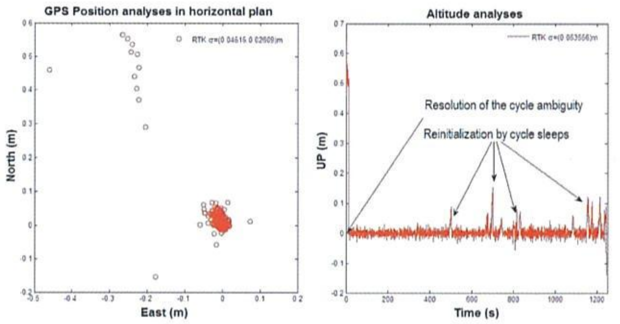

Figure 10 · GPS position analysis in RTK mode.

RTK GPS filter results are presented for a stationary experiment in figure 10. On the left carrier phase cycle ambiguity resolution is marked along with filter restart due to cycle slip detection.

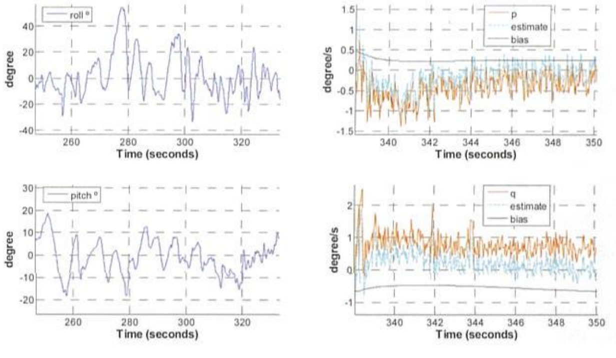

Figure 11 · INS roll and pitch measurements on final landing approach.

INS filtering results for roll and pitch determination are presented in figure 11 for a final landing approach (in this case with direct remote control). Embedded filter correction for gyro bias can be observed on the right. A relatively high degree of pitch and roll variation is due to air turbulence near ground and human control effects.

GPS estimated positions for a fire-circling manoeuvre are presented in figure 12. Wind effects on the aircraft are translated in a drift in SW direction.

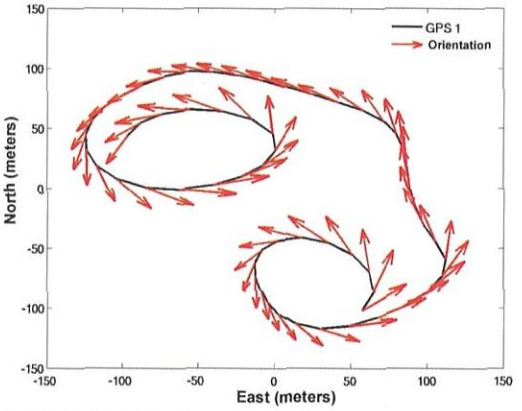

Figure 12 · PS estimated position and horizontal orientation test run.

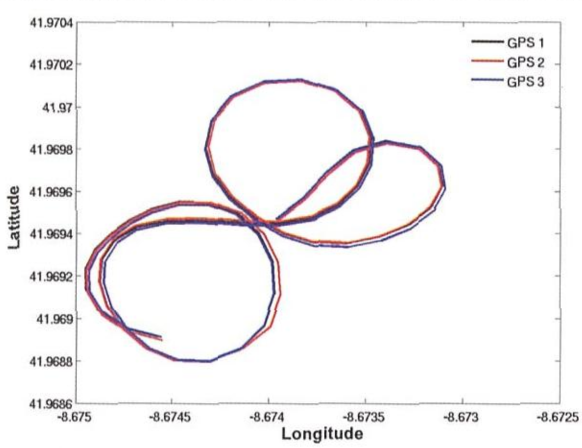

Figure 13 · Multiple GPS position in a loitering manoeuvre.

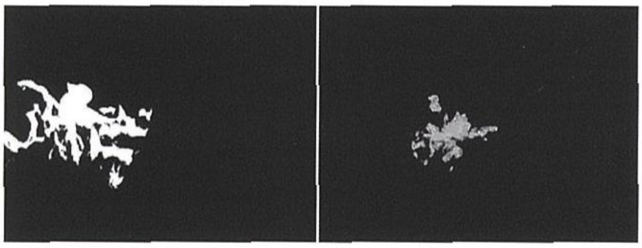

Figure 14 · Fire blob identification example in the near-IR spectrum (left – original image, right - fire blob identification) for 20m distance.

Multiple GPS position results in a loitering manoeuvre are presented in the previous figure.

A set of experiments were performed with the vision system to detect fire. In a static position near-IR images provided fire blob candidates for a test fire of 1m and with VGA resolution, up until 200m.

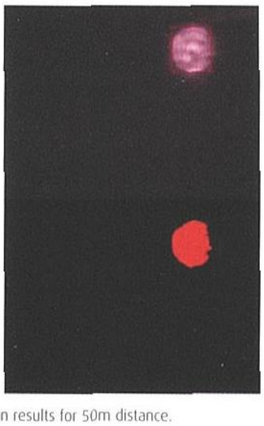

Figure 15 · Fire identification results for 50m distance.

VI. CONCLUSIONS

In this work an autonomous aerial vehicle designed for fire detection in forest environment and forest management was presented. Custom navigation sensors developed for the system were also described and validated through operational field missions.

An ignition detection architecture and system is presented with some preliminary results obtained near-IR image processing.

Further work is to be done in the visible light and near IR information matching in particular in the onboard implementation and performing an extensive set of test missions. Autocalibration issues are also under address. Namely the extension and implementation in the developed hardware vision sensor. This sensor currently has only been tested in image segmentation and run-lengthencoding compression.

ACKNOWLEDGMENTS

The authors would like to acknowledge the important collaboration of Associação de Produtores Florestais do Concelho de Alvaiázere in the mission field tests.

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