3D virtual representation of drones' flights through Cesium.js and Oculus Rift.

M. Di Paolantonio, C. González Fernández, M. José Latorre, A. Roldán París y F. Pedrera García

Elecnor Deimos, Ronda de Poniente, 19, 28760 Tres Cantos, Madrid, felix.pedrera@deimos-space.com.

ABSTRACT

Nowadays, Unmanned Aerial Vehicles (UAV), known as drones, are tools whose use is increasing in the field of earth's surface images capture. Their applications range from precision agriculture, infrastructures monitoring to geological studies, resulting in an inexpensive alternative to the manned aerial vehicles traditionally used in photogrammetry.

UAV systems can be equipped with different instruments: optical cameras, multispectral or infrared ones, that in combination with satellite localization tools with accuracy in the order of centimetres, allow to obtain different products from a single flight, products like: georeferenced mosaics, digital elevation models (DEM), outlines, 3D textures, point clouds, etc.

This work describes the representation of drone's flights in web browsers using 3D globes visualization technology Cesium.js and virtual reality headset Oculus Rift.

Starting from data collected in different flight campaigns, the interactive visualization is performed using telemetry data, digital elevation models, georeferenced images and mosaics. These data are processed by open source software (GDAL) and loaded and served by a geographic data server (GeoServer) through OGC web services (WMS, WFS). This representation allow users to virtually experience the flight and to visualize in an interactive way the images and the flight data captured by the onboard instruments, taking advantage of the immersive visual interface offered by Oculus Rift and the orientation of the point of view through its integrated sensors.

Keywords: *UAV, Cesium, Oculus Rift.*

DATA

Data are the main theme of this work, starting from the initial structure, going through the back-end processing, till reaching their visualization in the front-end. On board instruments of UAVs provide us telemetry data as .dat files containing the fields shown in Table 1. Telemetry formatTable 1.

Table 1. Telemetry format

Value	unit of measurement
Relative time elapsed	[seconds]
Stamp time (creation time)	[seconds]
Stamp time (creation time)	[milliseconds]
Update flag	[dimensionless]
Stamp time (application time)	[milliseconds]
Stamp time (application time)	[milliseconds]
Roll	[SI(degrees)]
Pitch	[SI(degrees)]
Yaw	[SI(degrees)]
Angular Rate X	[SI]
Angular Rate Y	[SI]
Angular Rate Z	[SI]
Ground Speed X	[SI]
Ground Speed Y	[SI]
Ground Speed Z	[SI]
True Bearing	[SI]
BFS Acceleration Y	[SI]
Longitude	[degrees]
Latitude	[degrees]
Altitude	[SI(meters)]
Rate of Climb	[SI]
Calibrated Air Speed	[SI]
Indicated Air Speed	[SI]
Static Pressure	[SI]
Temperature	[SI]

BACK-END

Architecture

The system, as shown in Figure 1Figure 1. Back-end architecture, is composed by two main elements: server and data storage. Since telemetry data could come with associated images the following architecture has been chosen:

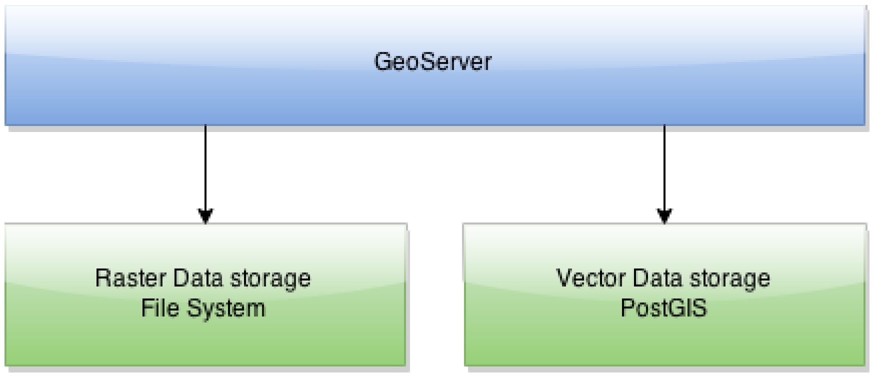


Figure 1. Back-end architecture

Data storage

- *Vector Data storage:* a geospatial database that handles geometry and vector features (telemetries) built with PostGIS, an extender for PostgresSQL object-relational database that comes with support for geographic object.
- *Raster Data storage:* a file system instance images' storage.

Server

Implemented through a GeoServer instance, an open source server for sharing geospatial data that comes with a number of open standards implementations such as Web Feature Service (WFS) and Web Map Service (WMS).

Data distribution

Web Map Service

It is a standard protocol for serving georeferenced map images over the Internet, since images have a high resolution, in order to achieve an efficient delivery the following processing has to be done:

- *Mosaic:* starting from a bunch of georeferenced images relative to an area of interest a new completed and continuous image (mosaic) is generated, overlapping the original rectified images.

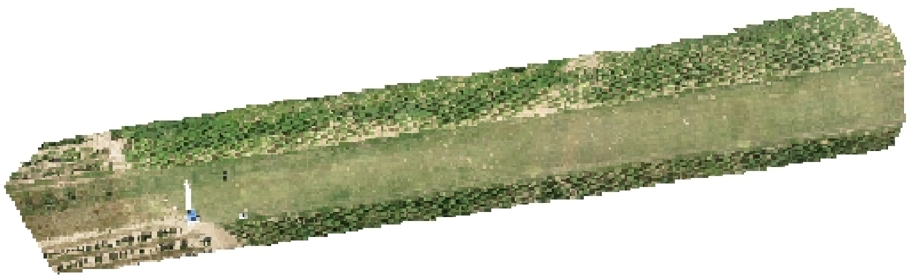


Figure 2. Generic mosaic of UAV's images

- *Pyramid:* collection of multiples mosaics where each mosaic is associated to a different zoom level.

Web Feature Service

It is a standard that provides an interface allowing requests for geographical features across the web using platform-independent calls.

Data processing and loading

Telemetry

The following list represents the first processing steps performed on .dat telemetry files:

- shapefile creation: taking advantage of the software QGIS[1]., an open source Geographic Information System, a new .shp file representing a layer of points is generated from each telemetry.
- PostGIS[2]. database upload: each .shp file is uploaded as a new table to the Vector Data storage by the following command:
  shp2pgsql -W LATIN1 -s 23030 -I ***fileName****.shp* ***name*** | *psql -d* ***databaseName*** *-U postgres.*
  database table processing: the table columns are renamed according to their contents through PostregreSQL[3].[2]. code.
- GeoServer[4].: finally the database is exposed to the server as a new data storage and its layers are published.

FRONT-END

Fundamentals

Cesium.js

Cesium.js is a JavaScript library for creating 3D globes and 2D maps in web browsers. It uses WebGL for hardware-accelerated graphics, and it is tuned for dynamic-data visualization. Its stack is composed of four layers[5].:

- Core: it processes and performs operations like linear algebra, intersection tests, and interpolation.
- Renderer: a thin abstraction over WebGL.
- Scene: globe and map constructs like imagery layers, polylines and cameras.
- Dynamic Scene: Time-dynamic visualization constructs including CZML rendering.

Core

Contains low-level, widely-used functions mostly related to math:

- Matrices, vectors and quaternions.
- Transformations, such as cartographic to Cartesian.
- Map projections, such as Mercator and Equidistant Cylindrical.
- Julian dates.
- Splines for interpolating position and orientation.
- Geometric routines like triangulation, subdivision surfaces, vertex cache optimization, and computing ellipse boundary points.

Renderer

Abstraction over WebGL that includes built-in GLSL uniforms and functions; abstractions for shader programs; textures and cube maps; buffers and vertex arrays; render states; framebuffers.

Scene

It is a representation of all graphical objects and states for canvas and provides relativity high-level map and globe constructs, including:

- 3D globe, 2D map, and 2.5D Columbus view.
- Streaming high-resolution imagery from multiple sources, including Bing Maps, ESRI ArcGIS Map Server, OpenStreetMap, and Web Map Service (WMS).
- Polylines, polygons, billboards, labels, ellipsoids, and sensors.
- Cameras that control the view and respond to input.
- Animations that change properties over time.

Dynamic Scene

It enables data-driven visualization, primarily via the processing of CZML, a JSON based schema for describing a time-dynamic graphical scene.

CZML

It describes lines, points, billboards (markers) and other graphical primitives. It specifies how they change with time and it has a relation with Cesium similar to the relationship between Google Earth and KML[6]..

Oculus Rift

It is a virtual reality head-mounted display developed by Oculus VR[7].. Its characteristics are listed in Table 2.

Table 2. Oculus Rift SDK2

Characteristic	Value
Resolution	960 x 1080 per eye
Refresh Rate	75 Hz, 72 Hz, 60 Hz
Persistence	2 ms, 3 ms, full
Field of view	100° Field of View (nominal)
Video in	HDMI 1.4b
Sensors	Gyroscope, Accelerometer, Magnetometer
Inertial Update Rate	1000 Hz

Architecture

Libraries

- Bootstrap[8].: HTML, CSS, and JS framework for developing web applications.
- JQuery[9].: JS library for traversing and manipulation of HTML documents.
- D3[10].: JS library for manipulating documents based on data, using HTML, SVG, and CSS.
- Cesium[11].[10].: JS library for creating 3D globes and 2D maps in a web browser.
- CesiumSensor[12].: Cesium plugin for visualizing sensor volumes.
- CesiumOculus[13].: Cesium plugin to support VR devices using a VR-enabled browser, for example Mozilla Firefox Nightly.

Modules

As shown in Figure 3, front-end architecture is composed by a Main module that handles the four modules following described:

- User Input module: it processes inputs coming from mouse, keyboard and interface's buttons.
- Profile module: it draws UAV's altitude profile with respect to sea level, taking advantage of D3's capabilities.
- Scene module: it returns to the Main an object scene and a method to renderize it and its 3D elements according to the mode select by the user (Viewer, Oculus). This is achieved through libraries Cesium (creation and Viever mode rendering), CesiumOculus (Oculus mode rendering), CesiumSensor (camera pyramid sensor creation).
- Telemetry module: it requests to GeoServer telemetry data in GeoJSON form, processes them and passes to the Main a new object composed of:
  - data coming from back-end.
  - altitude and time data needed by Profile module.
  - position, orientation and time data in a CMZL structure needed by Scene module (actually by render function).
  - few others structures for quickly accessing data

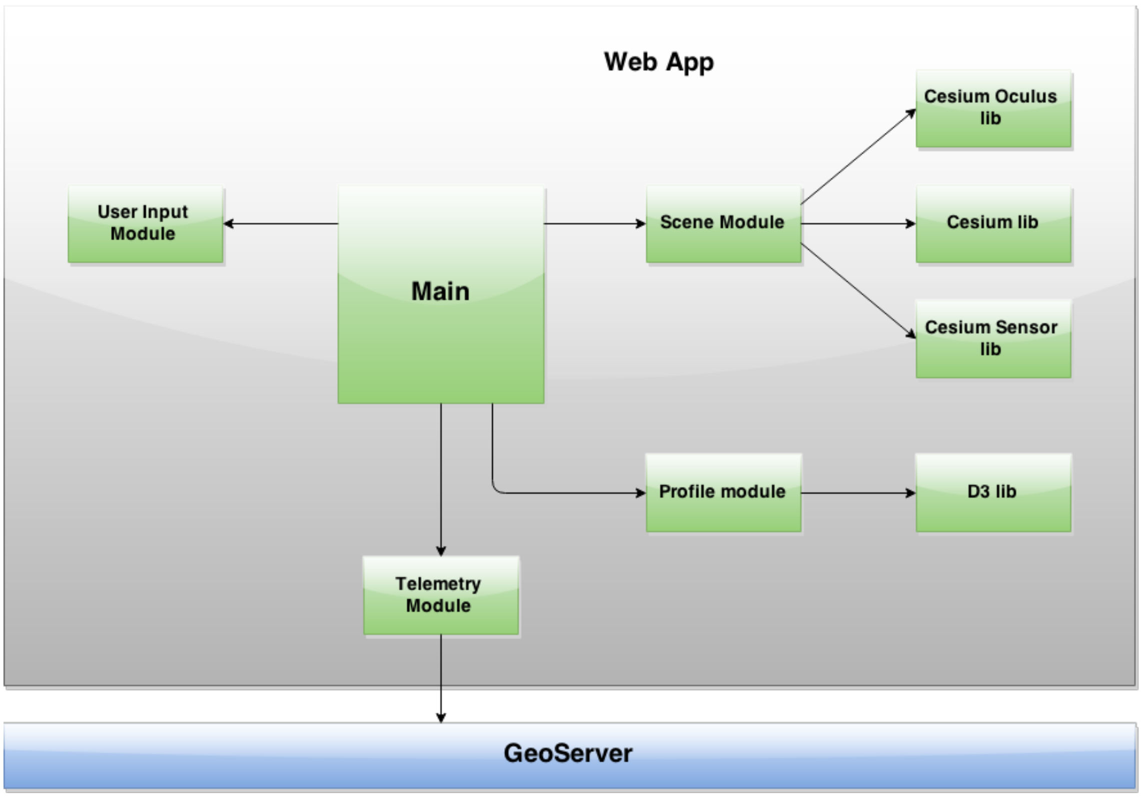


Figure 3. Front-end architecture

Workflow and Data Processing

As described in Figure 4, once the application has been initialized is ready to load the three fundamentals elements (*path, sensor, UAV*) relatives to the current selected scenario and to start a render loop that, according to time, displays these elements in an animated way.

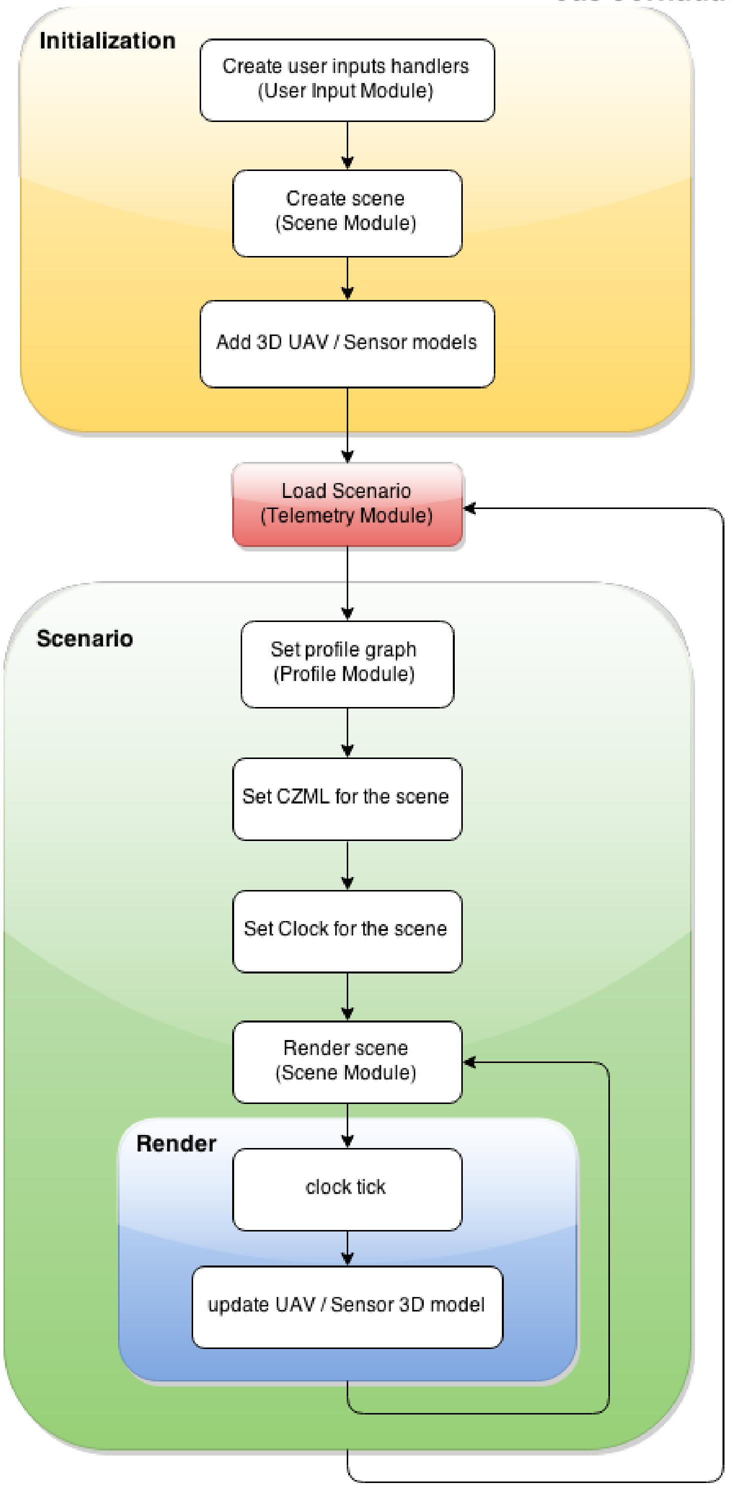

Initialization
Create user inputs handlers (User Input Module)
Create scene (Scene Module)
Add 3D UAV / Sensor models
Load Scenario (Telemetry Module)
Scenario
Set profile graph (Profile Module)
Set CZML for the scene
Set Clock for the scene
Render scene (Scene Module)
Render
clock tick
update UAV / Sensor 3D model

Figure 4. Workflow

Sensor and UAV models

- Taking advantage of the *Cesium Sensor* plugin a pyramidal cone is created with apex centred in the current-time telemetry point and projection angles X of 50 degrees and Y of 70 degrees. This design is based on the Canon Powershot S110 camera which is frequently used for these applications[14]..
- For the UAV model a previous conversion from .dae to .glTF has been done in order to serve it to Cesium scene in its own compatible format.

Scenario Data retrieving

As mentioned before data are served by GeoServer through the OGC standard WFS.

Telemetry

It is received as a GeoJSON object by calling an url with this structure:
"*http://**geoserverInstance**/**workspace**/ows?service=WFS&version=1.0.0&request=GetFeature&typeName=**workspace**:**name**&outputFormat=application/json*"

Mosaic layer (pyramid of mosaics)

Having images and the related mosaic's pyramid stored in GeoServer, the mosaic layer could be directly added to the scene as a new layer, lying over the base map, using the Cesium's feature:

```
Cesium.WebMapServiceImageryProvider({
      url : "http:// geoserverInstance /ows?version=1.1.1&",
      layers : "workspace:name",
      parameters : {
      transparent : true,
            format : "image/png"
      }
})
```

CZML set up

The engine of each scenario is the relative CZML. What follows is a simplified version of the object created by the Telemetry module from the server's GeoJSON response when the load of a new scenario is requested:

```
{
      "path" : { … },
      "position" : {
            … ,
            "cartographicDegrees" : positionsTimeTagged
      },
      "orientation":{
            … ,
            "unitQuaternion": quaternionsTimeTagged,
      },
      "clock" : {
            … ,
            "currentTime" :startTime,
      }
}
```

This object is an entity representing the telemetry as a polyline in the scene, thanks to the property *path*, with its own lifetime cycle defined by the *clock* property and with specific values of *position* and *orientation* for each moment of the lifecycle. In details:

- *position.cartographicDegrees*: an array with the following structure [*Time*, *Longitude*, *Latitude*, *Height*, *Time*, *Longitude*, *Latitude*, *Height*, ...], where *Time* is an ISO 8601 date and time string, *Longitude* and *Latitude* are in degrees and *Height* is in meters (WGS84).
- *orientation.unitQuaternion:* array with the following structure [*Time, q0, q1, q2, q3, Time, q0, q1, q2, q3, ...*], where *Time* is an ISO 8601 date and time string,

and *q0, q1, q2, q3 are* the components of the quaternion Q calculated form roll (ϕ), pitch (ϑ) and yaw (ψ) as follow[15].:

$$Q=\begin{bmatrix} qo \\ q1 \\ q2 \\ q3 \end{bmatrix}=\begin{bmatrix} \cos(\phi/2)\cdot\cos(\vartheta/2)\cdot\cos(\psi/2)+\sin(\phi/2)\cdot\sin(\vartheta/2)\cdot\sin(\psi/2) \\ \sin(\phi/2)\cdot\cos(\vartheta/2)\cdot\cos(\psi/2)+\cos(\phi/2)\cdot\sin(\vartheta/2)\cdot\sin(\psi/2) \\ \cos(\phi/2)\cdot\sin(\vartheta/2)\cdot\cos(\psi/2)+\sin(\phi/2)\cdot\cos(\vartheta/2)\cdot\sin(\psi/2) \\ \cos(\phi/2)\cdot\cos(\vartheta/2)\cdot\sin(\psi/2)+\sin(\phi/2)\cdot\sin(\vartheta/2)\cdot\cos(\psi/2) \end{bmatrix}$$

Equation 1. Euler angles to quaternion

Render loop transformations

Once the CZML is fed to the scene, and its clock is set as scene clock, the interaction between the following Cesium methods ensures the synchronization between frame rendering and time animation:

- *Cesium.requestAnimationFrame(callback)*: a browser-independent function to request a new animation frame.
- *Cesium.Clock.tick()*: it advances the clock from the *currentTime* based on the current configuration options. It should be called at every frame, regardless of whether animation is taking place or not. The configuration options are indeed the ones manipulated by user with animation buttons.

Therefore, during the render loop the CZML entity changes its *position* and *orientation* based on clock's current value. Then, with a simple call to:

property.getValue(clock.currentTime)

current *position* or *orientation* can be obtained. Next step is the update of the model matrix of the UAV and Sensor 3D model each time a new frame is drawn:

- starting from the *position,* with the method *Cesium.Transforms.northEastDownToFixedFrame(origin, ellipsoid),* a 4x4 transformation matrix is computed from a North-East-Down (NED) reference frame centred at the provided position to Earth element ellipsoid's fixed reference frame.
- starting from the *orientation* a 3x3 transformation matrix is computed using again Euler's angles in the following way[15].:

$$M=\begin{bmatrix} q0^2+q1^2-q2^2-q3^2 & 2\cdot(q1\cdot q2-q0\cdot q3) & 2\cdot(q0\cdot q2+q1\cdot q3) \\ 2\cdot(q1\cdot q2+q0\cdot q3) & q0^2-q1^2+q2^2-q3^2 & 2\cdot(q2\cdot q3-q0\cdot q1) \\ 2\cdot(q1\cdot q3-q0\cdot q2) & 2\cdot(q0\cdot q1+q2\cdot q3) & q0^2-q1^2-q2^2+q3^2 \end{bmatrix}$$

Equation 2. Quaternion to Euler's matrix

- The final step is a matrix multiplication to obtain a unique transformation from translation (*position*) and rotation (*orientation*), that can be used as the model matrix for UAV and Sensor elements.

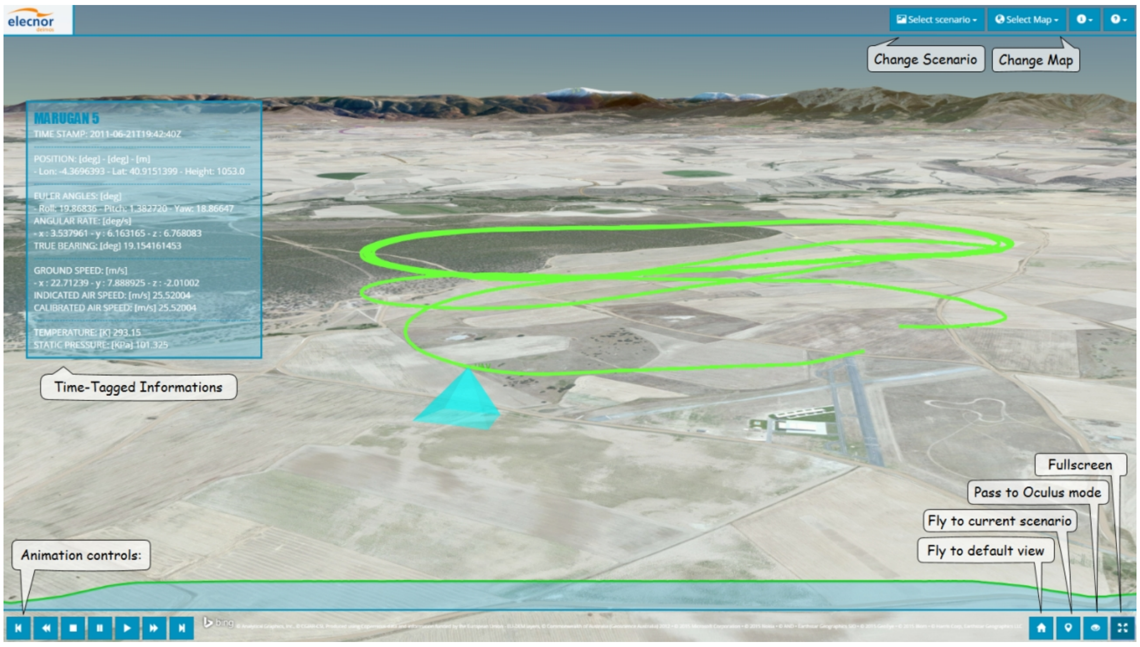
SIMULATOR

As already mentioned the simulator has two visualization modes with different features and functionalities.

Viewer mode

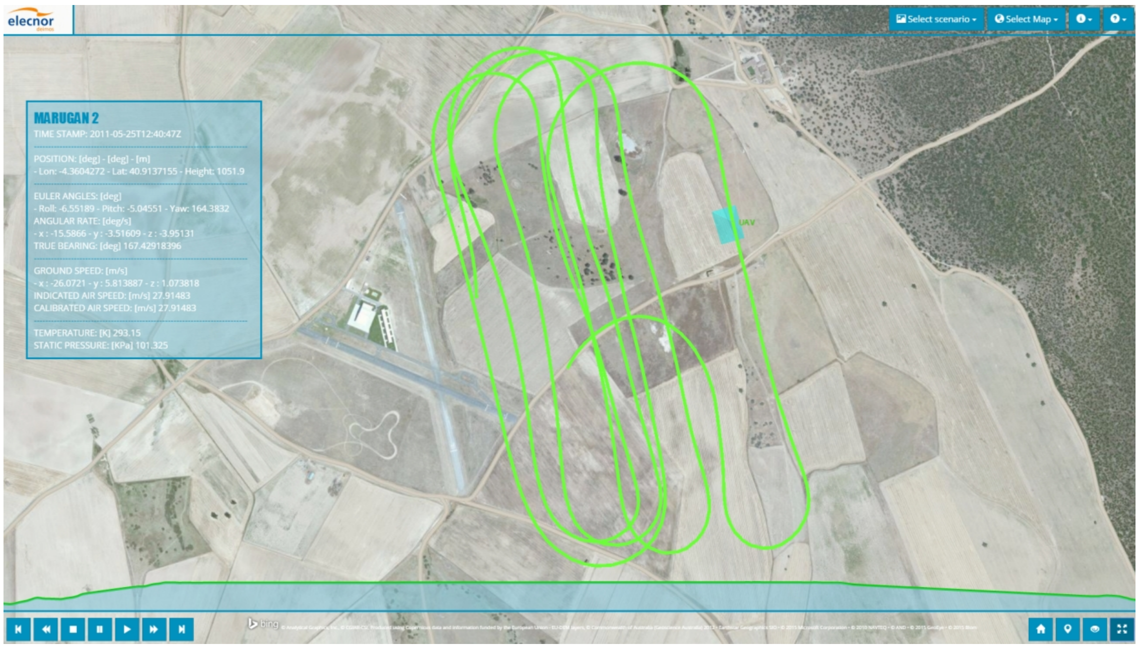
In addition to the buttons displayed in Figure 5, the user can directly interact with the scene (actually the globe) in the following way:

- Pan view: left click + drag.
- Zoom view: Right click + drag, or Mouse wheel scroll
- Rotate view: Middle click + drag, or Left click + drag up/down.



MARUGAN 5
TIME STAMP: 2011-06-21T19:42:40Z
POSITION: [deg] - [deg] - [m]
- Lon: -4.3696393 - Lat: 40.9151399 - Height: 1053.0
EULER ANGLES: [deg]
- Roll: 19.86836 - Pitch: 1.382720 - Yaw: 18.86647
ANGULAR RATE: [deg/s]
- x : 3.537961 - y : 6.163165 - z : 6.768083
TRUE BEARING: [deg] 19.154161453
GROUND SPEED: [m/s]
- x : 22.71239 - y : 7.888925 - z : -2.01002
INDICATED AIR SPEED: [m/s] 25.52004
CALIBRATED AIR SPEED: [m/s] 25.52004
TEMPERATURE: [K] 293.15
STATIC PRESSURE: [KPa] 101.325

Figure 5. Viewer mode - Marugan 5



MARUGAN 2
TIME STAMP: 2011-05-25T12:40:47Z
POSITION: [deg] - [deg] - [m]
- Lon: -4.3604272 - Lat: 40.9137155 - Height: 1051.9
EULER ANGLES: [deg]
- Roll: -6.55189 - Pitch: -5.04551 - Yaw: 164.3832
ANGULAR RATE: [deg/s]
- x : -15.5866 - y : -3.51609 - z : -3.95131
TRUE BEARING: [deg] 167.42918396
GROUND SPEED: [m/s]
- x : -26.0721 - y : 5.813887 - z : 1.073818
INDICATED AIR SPEED: [m/s] 27.91483
CALIBRATED AIR SPEED: [m/s] 27.91483
TEMPERATURE: [K] 293.15
STATIC PRESSURE: [KPa] 101.325

Figure 6. Viewer mode - Marugan 2

Oculus mode

In this kind of visualization the user interaction is handled by keyboard inputs:

- W / S: move camera forward / backward.
- D / A: move camera right / left.
- Q / E: move camera up / down.
- Shift: speed up, duplicate movement's velocity.
- Space Bar: level camera with respect to horizon.
- J: jump in the UAV, keep updating camera position according to the UAV's one, user will be in the place of an hypothetical pilot and have a first person view.

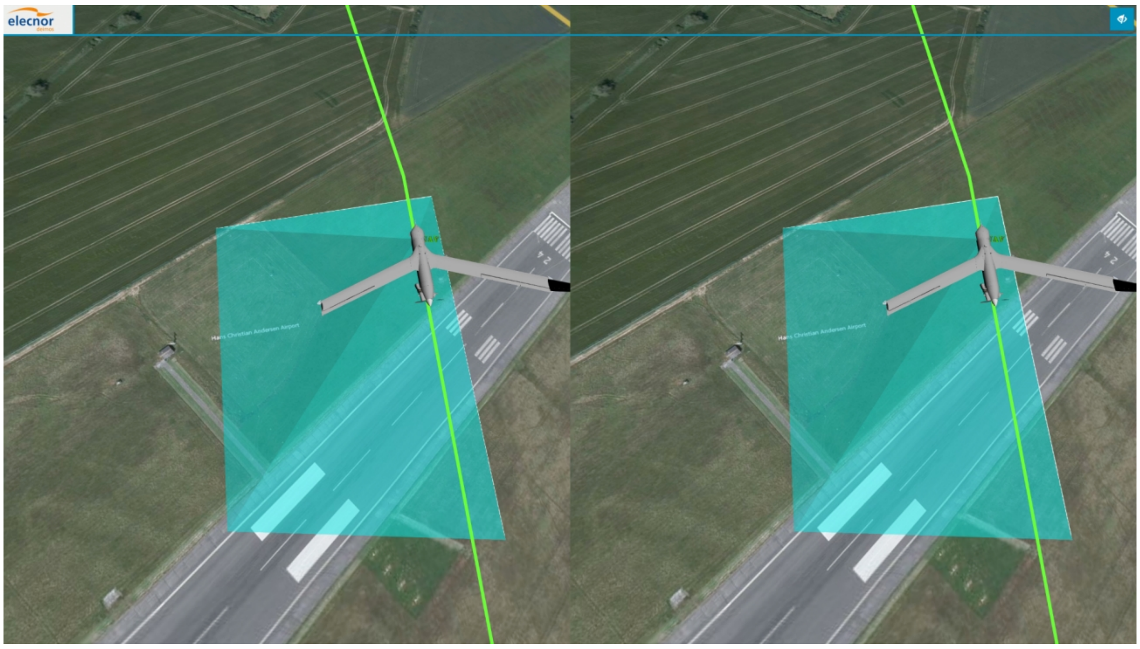


Figure 7. Oculus mode (ScanEagle)

CONCLUSIONS AND FUTURE WORKS

The technology described in this paper represents a realistic and immersive way of UAV's flights representation that can be used by common users to browse catalogues of flights and their data as well as by drone's operator in order to refine their flight technique. From this research it would be noteworthy adding a digital elevation model taking advance of the feature: *Cesium.CesiumTerrainProvider({....})* and passing to the feature heightmap or quantized-mesh tiles directly processed from flights' data[16].. At the same time it could be interesting to investigate the possibility of adding new features like flights planning where the user can create his own flying paths and choose between different models of camera and UAV.

ACKNOWLEDGEMENTS

This work has been partially supported by Spanish Government by the project ADAM with reference IPT-20111026 under program INNPRONTA and Deimos Space S.L.U.

REFERENCES

[1]. http://docs.qgis.org/2.6/es/docs/user_manual/working_with_vector/supported_data.html
[2]. http://postgis.net/docs/using_postgis_dbmanagement.html#shp2pgsql_usage
[3]. http://www.postgresql.org/docs/
[4]. http://geoserver.org/
[5]. Patrick Cozzi. Architecture. https://github.com/AnalyticalGraphicsInc/cesium/wiki/Architecture
[6]. https://github.com/AnalyticalGraphicsInc/cesium/wiki/CZML-Guide
[7]. https://www.oculus.com/
[8]. http://getbootstrap.com/
[9]. http://jquery.com/
[10]. http://d3js.org/
[11]. http://cesiumjs.org/
[12]. https://github.com/AnalyticalGraphicsInc/cesium-sensors
[13]. https://github.com/NICTA/cesium-vr
[14]. Unger, J., Reich, M., & Heipke, C. (2014). UAV-based photogrammetry: monitoring of a building zone. ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-5, 601–606. doi:10.5194/isprsarchives-XL-5-601-2014
[15]. Diebel, J. (2006). Representing attitude: Euler angles, unit quaternions, and rotation vectors. Matrix, 58, 1–35. doi:10.1093/jxb/erm298
[16]. http://blog.thematicmapping.org/2014/10/3d-terrains-with-cesium.html