BIRD MIGRATION STUDY TOOL BASED ON CARTOGRAPHIC DATA AND GNSS TRACKING SYSTEMS

Harbil Arregui, Aitor Moreno, Oihana Otaegui

Vicomtech-IK4, Paseo Mikeletegi 57, 2009 Donostia (Spain)
{harregui, amoreno, ootaegui}@vicomtech.org

Abstract

Bird migration behaviours and patterns offer invaluable information about environmental evolution of regions. Traditional bird ringing techniques are often used for nature monitoring. A web based geographical visualization and analysis tool is presented in this paper, showing how cartographic data of wetland areas, their vegetation and water facilities can be combined with bird tracking systems to enhance the positioning information given by the latter. This tool, designed inside the MONNA project, aims to collect and display migration trajectories for both scientific and general public use, based on a 3D web visualization environment.

This work presents an advanced visual analytics tool for bird monitoring, extensible to other regions as cartography gets available and that can also be linked to meteorological historical data. Challenges for the future include combining cartography with a better resolution and an improvement of the altitude information given by the positioning devices.

INTRODUCTION

The birds are a special kind of animals. One of their most singular characteristics is the ability to fly. The flight skill gives them the possibility to travel far distances (even thousands of kilometres), crossing mountains and oceans in an economic and fast manner. Birds have a well trained orientation sense and great navigation skills. They can remember where they have been so they can return to the very same place in the next year. Thus, due to this inherent mobility and depending on the season, migrating birds live in different places around the globe, separated by thousands of kilometres. This seasonal behaviour is unique to the birds, which is based on the flying capabilities of the birds.

Of course, not all the birds migrate in the same way. In fact, there are non-migrating birds. Generally speaking, the birds migrate from cold zones to warmer zones in autumn. They return back in the next spring. The migration itself depends on the morphology of the birds. Bigger birds can fly higher and longer distances without making stops. Smaller birds fly slower and at lower altitudes.

Bird migration analysis is widely used in studies of many environmental aspects. The population trends and migratory pathways can be of help on understanding climate change effects and staging sites evolution. Bird ringing techniques allow identifying and tracking individuals across different regions in order to follow their movement patterns [1][2][3].

This work presents a web based geographical visualization and analysis tool, showing how cartographic data of wetland areas, their vegetation and water facilities can be combined with bird tracking systems to enhance the positioning information given by the latter. This tool, designed inside the MONNA project [4], collects and displays migration trajectories for both scientific and general public use, based on a 3D web visualization environment.

On one hand, different tracking device types are used to regularly send bird GNSS positions for two use cases: long range using international telephony SIM card, and local range near known wetlands (Urdaibai Biosphere) using a specific antenna system. All this data is collected in the server database and published as web services to be consumed by authorized users and the web interface.

On the other hand, standard SHP and WMS formatted available cartography sources are handled. These data sources, published in the OpenData service of the local government. allow the MONNA system to overlap on the 3D terrain information regarding the delimitations of the Urdaibai wetland and different types of vegetation in the area, among others.

BIRD TRACKING SYSTEMS AND SIMILAR PROJECTS

The main challenge in bird tracking systems is to obtain a reliable long-range signal-transmitting device that can be deployed and carried by a small animal. This device must be able to emit enough energy to be detected, requiring an adequate power supply. Existing positioning alternatives for bird tracking go from GNSS, Doppler effect, to GSM network-based triangulation to solar geolocation. In general, the acquired positions must then be sent somewhere for storage, and the availability of the data in real time will be possible or not depending on the selected technique. The main current bird tracking systems can be classified in four big technology groups according to their data retrieval modes: satellite-based, ground-based receivers, dataloggers and radar.

Regarding data management and analysis platforms, first, Movebank [5] must be mentioned, as one of the most popular systems for collaborative sharing of tracking datasets, in combination with weather data. Under the Avian Knowledge Network [6], two projects have been empowered: eBird (general public-oriented) and LaMNA (for scientists and proffesionals). In addition to these, Ornitho [7] is another widely used platform, were hundreds of amateur users add information of bird observations.

For further reference, a good to review of the current tracking platforms is done in the article by Eli S. Bridge et al. [8].

The MONNA Project

The Urdaibai Bird Center is located at the Biosphere Reserve (Bizkaia, Spain), a strategic point for the birds following the East Atlantic Flyway Migration, and it is set between two big geographic barriers: the Bay of Biscay and the Pyrenees. This becomes Urdaibai an important rest and feeding area for the birds, especially when meteorology is adverse. It is relevant, therefore, that the research projects carried out in such strategic point along this migratory flyway allow working in coordination with other wetlands along the same route.

The MONNA Project aims to contribute in the development of nature monitoring systems that may help adopting efficient public policies for both environmental management and biodiversity protection and conservation. MONNA combines technological developments for bird movement analysis based on new European technologies in areas such as geo-positioning and data emission, with the creation of a reference living lab to promote the new emerging nature monitoring sector.

Therefore, one of the main objectives inside the project was the research and development of a bird tracking platform where collected data can then be offered for scientific research, academic use or divulgation to general public.

BIRD MIGRATION ANALYSIS WEB PLATFORM

After evaluating the needs and requirements, a software platform has been designed and developed as shown in this section, in order to capture the positions of individual birds, store and process tracking information and auxiliary data, and present it all visually in an interactive web interface.

Devices and data acquisition

Two different tracking system types have been used within the project: GSM-GPS and SIGFOX. Each device is attached to a bird and its objective is to periodically collect and send the GNSS positioning to a central server. The hardware details of the devices are beyond the scope of this paper but, when evaluating a good tracking device, a compromise among the following concepts must be considered.

- Battery consumption

- Weight

- Positioning accuracy and acquisition timeout (directly linked to the battery lifetime)

- Data emission cost

- Leak-tightness of the device.

GSM-GPS Devices

The GSM-GPS devices used in MONNA are based on mobile telephony communications to send the positioning data generated by the internal GPS module, through an international SIM card. These cards must be activated and a contract

with a mobile telephony provider must be subscribed. The communication itself is done using the lightweight OpenDMTP protocol [9]. Each GSM-GPS device has an embedded software client that implements this protocol. The MONNA platform runs an OpenGTS server module that supports the OpenDMTP protocol and listens to the incoming requests from the clients.

SIGFOX Devices

The second device types use the SIGFOX technology [10], and they work in a different manner. The GPS module obtains the position of the device periodically, like the GPS-GSM ones, but the data emision is not activated until the device gets inside a SIGFOX antenna coverage. The data is then sent to a SIGFOX proprietary backend. At this moment, the coverage is limited to the territory of France and Urdaibai. The cost of each sent message is much lower than by using the previous system, however, the existence of the specific ground-based anthena is a must.

The SIGFOX backend provides a REST API to access the stored data. In order to extract the positioning information from this backend and use it in the MONNA web platform, a client for this API was developed in C++ and installed on the server. This client reads all the new data from a list of registered devices every hour and stores the information in the MONNA database, after filtering and checking for any errors or inconsistencies.

Generic approach

The MONNA platform allows accepting data coming from other kinds of devices. The architecture is open, so any other dataset can be added to the system if a connector is implemented to insert the data into the database. The most basic mechanism is to create a file containing all the INSERT SQL statements with the appropriate fields and run it from the MySQL management console. The new data would be instantly reflected in the system.

Storage and information management tools

All the information coming from the devices (bird positions) and information of users, wetlands, bird species and devices is stored in a MySQL database on the MONNA server.

Schema description

On one hand, the main database table is *"EventData"* and all the retrieved positions are stored here. Both the OpenGTS server and the SIGFOX REST API client insert the new positions of the devices in this table.

On the other hand, tables *"Bird"*, *"Device"* and *"Wetland"* have auxiliary related tables to handle bird species, bird capture data, device types, and wetland subzones and observatories, among others. Meteorological data can also be stored in the table defined for it. The database also contains other tables regarding users and their roles to manage permissions on data upload and editing, such as adding new birds to the system, or editing ringing information.

Web Services

In order to provide external access to the data (for any possible future use), a set of web services has been defined and implemented using Java Jersey, returning JSON and KML formats. Java Jersey is a technology for developing RESTful web services in Java; it is a standard and portable JAX-RS API. Three sets of web services have been created and classified accordingly:

- *BirdResources*: Methods for bird and ringing information access.

- *WetlandResources*: Wetland information access.

- *PositionResources*: Methods for positioning data access for different parameters.

The access URL for the API looks like: *http://{host:port}/API_Functions/rest/...*

The Table 1summarizes the most useful web services, as some are referenced on later sections of this paper.

Table 1. Summary of the web services for data access.

URL	Description
API_Functions/rest/bird/all	All registered birds
API_Functions/rest/wetland/all/kml	All registered wetlands
API_Functions/rest/position/last	Last position sent by each registered device

API_Functions/rest/position/last/deviceId={deviceID}	Last registered position for the "deviceID" device
API_Functions/rest/position/last/after={timestamp}	All the positions registered after the specified "timestamp" (URL encoded like *222013-05-10%2010:02:00%22*)
API_Functions/rest/position/last/accountID={account }	Last positions sent by each registered device inside de "accountID" account.
API_Functions/rest/position/all/deviceId={deviceID}	All the positions registered for the "deviceID" device.

Cartography layers

Some of the key aspects related to the migrations and behaviour of birds, are the interpretation of the land use, the different vegetation areas existing in the region and conservation policies.

During the last years, public institutions are making an effort providing open access to cartographical datasets of interest. In the case of Euskadi, an important set of cartographic data infrastructure is provided, which contains layers of great interest for the MONNA project, as the environment related ones. The Figure 1 shows a set of example Habitat/Environment layers available at the OpenData Euskadi repository [11], displayed on their online visor.

Figure 1: Example layers provided by the OpenData Euskadi covering the Urdaibai area.

Data are available and ready to download in Shapefile (SHP) format [12], or by using the Web Map Service (WMS) provided. For a deeper analysis of the available layers and their integration in MONNA, the software Quantum GIS [13] has been used. After adding the WMS *getCapabilities* URL in Quantum GIS, a list of all the available layers is obtained along with their name and other feature information and metadata. To make use of the desired layers inside the MONNA web maps, the URL of each individual layer must be extracted.

Inside the MONNA web platform, the selected layers are shown over a Google Earth 3D web virtual environment. To obtain this, the images returned by the WMS server are converted into KML objects by calling the Google Earth API's *addKmlFromString* function from JavaScript. The result is shown in Figure 2.

Wetlands and observatories

Apart from the layers provided by the OpenData Euskadi service, information about the wetlands classified as Importan Bird Areas (IBA) has been included in the MONNA database. The geo-referenced wetlands with their observatories and other interesting data from an ornithological view are served in KML format by the previously presented web services, and displayed over the 3D Google Earth viewer, along with the other layers and the bird positions.

Users with administration access to the web platform are able to directly upload custom KML files that are also displayed over the Google Earth map (see Figure 2).

3D Web environment for trajectory visualization and animation

The 2D visualization of the migration trajectories and the wetlands is very handy: it offers easily understandable visualizations. The use of 2D interactive maps (Google or Bing maps) is quite common nowadays, and Movebank is an example. However, the very nature of the migration data is considered 3D (or 4D, if we include the time). Birds (individual elements or flocks) fly from one place to other, taking a significant amount of time. The travel has frequent stops, where the birds rest and feed. For ornithology researchers, the flight altitude is very important to understand the migration patterns. Depending on the weather, the global winds and other meteorological and atmospheric phenomena, the birds will vary their course, including the altitude.

The visualization of such 3D element using 2D maps is feasible. The utilization of coloured lines is a very common technique to visualize elevation, where a dark colour could represent a lower altitude than a brighter colour.

The apparition of 3D tools like Google Earth has made popular the utilization of maps in 3D. The latest online version of Google Maps includes by default a 3D visualization without plugins (using WebGL as the rendering backend). Nokia maps and Bing maps provide similar technologies in their products.

There are other 3D globe viewers that are more oriented to the development of custom applications, providing an open API to ease the addition of custom layers to the 3D virtual environment. In this regard, Cesium [14] has been selected in MONNA as the base 3D graphical API to visualize the migration paths on the Web.

Cesium is a WebGL powered 3D globe viewer. Its Javascript API has been conceived and designed to help develop custom applications. It offers the ability to choose the terrain and imagery providers (Bing imagery is the default provider, but OpenStreetMap or TMS/WMS servers can be configured). Cesium provides several basic geometric 3D elements which can be added to the scene: lines, polylines, textured polygons, billboards, 3D models… Also, Cesium supports animations which can be defined statically or dynamically. Their parameters and configuration are accessed through a well designed timeline widget on screen.

Figure 2: Habitat and vegetation limits layers (coloured) near Urdaibai in combination with the bird positions.

Cesium

Based on the 3D elements provided by Cesium, the visual migration tracks were defined as coloured polylines (*Cesium.PolylineCollection*). Each polyline is composed of the points acquired from the tracking devices. As each sample is tagged with the acquisition timestamp, the animation of the migration path will be accurate.

The data is stored in the Monna database, so the Web Services are used to retrieve the data transparently. When a device ID is selected, the web service *DeviceID* (*API_Functions/rest/position/last/deviceId={deviceID}*) is invoked through an AJAX request. The answer contains a JSON array with the locations of the given device ID. Each location contains the longitude and latitude, the altitude, the speed and the unix timestamp.

Figure 3: Bird path around the Urdaibai wetland shown in with Cesium

The JSON information is then parsed and Cesium entities are created on the fly to visualize the migration track. First, a polyline (*Cesium.PolylineCollection*) is created with a random colour (see Figure 3). The very long segments may produce visual collisions between the trajectory and the globe (the line goes through the globe which is a bad behaviour following a sphere chord). In order to prevent this artefact, we subdivide the segments into smaller pieces (given a maximum segment size). The timestamps of the added points are interpolated using the segments timestamp and the distances (see Figure 4).

Figure 4: Long segments in bird migrations can cause problems due to the curvature of the Earth.

The second entity is the animation path. In Cesium, this is created using standard entities and loaded as a *Cesium.CzmlDataSource*. The animation is globally defined by the animation span (starting and ending timestamps) and the default clock speed. This configuration is reflected in the animation widget in the user interface. Once the

migration trajectory is loaded (all the locations which compose the track), the user can press "play" to start the animation. The current point of the bird is visualized as a small billboard running over the track (see Figure 5). Using the graphical interface of the timeline widget, the animation can be speed up or down, just by moving the speed dial (2x, 10x, 1000x …) or paused. Additionally, the user can go directly to a specific timestamp by clicking on the desired position on the main timeline track, resuming the animation from that point.
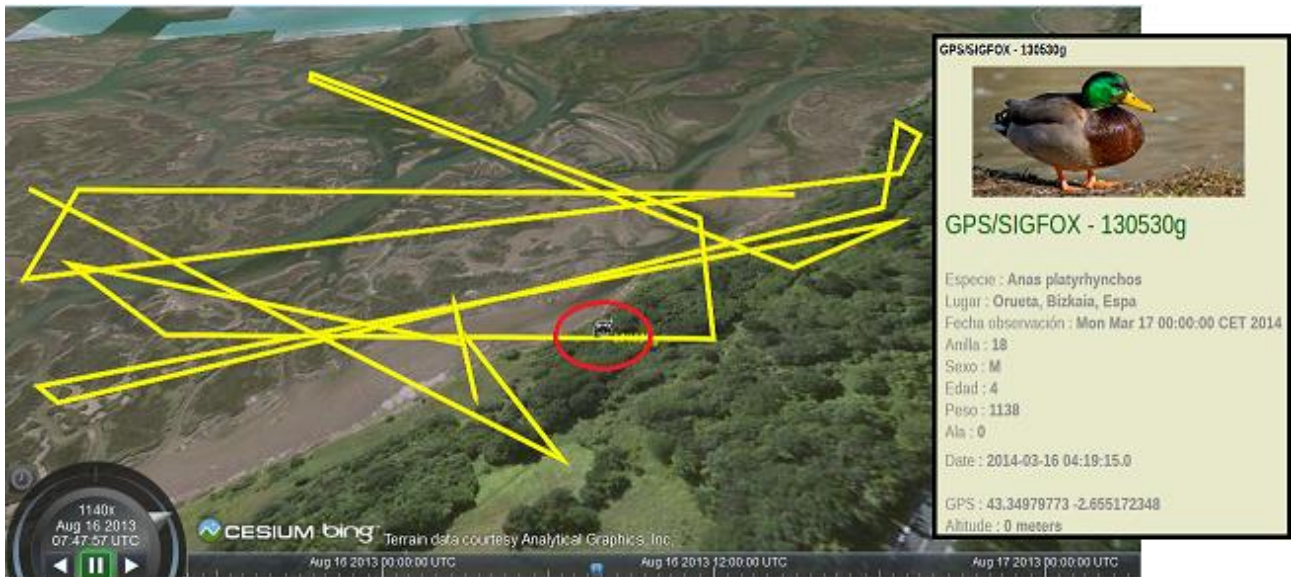

Figure 5: Animation track of a bird during a stop in Urdaibai wetland. The icon in the red circle shows the current position in the animation. The animation timeline is configured to match the bird track duration. The bird metadata is shown in the right side of the figure.

Altitude graph (HTML5 canvas)

The 3D interactive visualization of the migration provides a realistic outlook of the migration tracks. Nevertheless, the Cesium output can be combined and linked with other traditional visualization tools. In order to show these capabilities, a pure HTML5 canvas has been added to the web page. This graph shows an altitude graph of the selected bird trajectory where the X axis measures the distance flight by the bird and the Y axis shows the altitude. This specific graph is useful to understand the flight patterns, including the number of stops that the birds do during the migrations.

This visualization minimizes the area of the graph covered during the stops. While the bird is still or moving around a location, the accumulated distance is not increased very much (see Figure 6). As the X axis measures the travelled distance, the increment is small. If the graph would represent the elapsed time in the X axis, the long stops would cover large areas of the graph.

In that graph the time and the 2D location over the map are not shown. But the positions on the graph (distance, altitude) can be related with the position on the Cesium 3D viewer. While the animation is being played, a vertical line is displayed in the graph to show where the bird is located.

The opposite relationship is also possible. Clicking on the 2D graph selects the closest 3D point in the Cesium widget, moving the current position (in the timeline track) to the timestamp of the selected point. This action can only be done when the animation is paused or stopped.
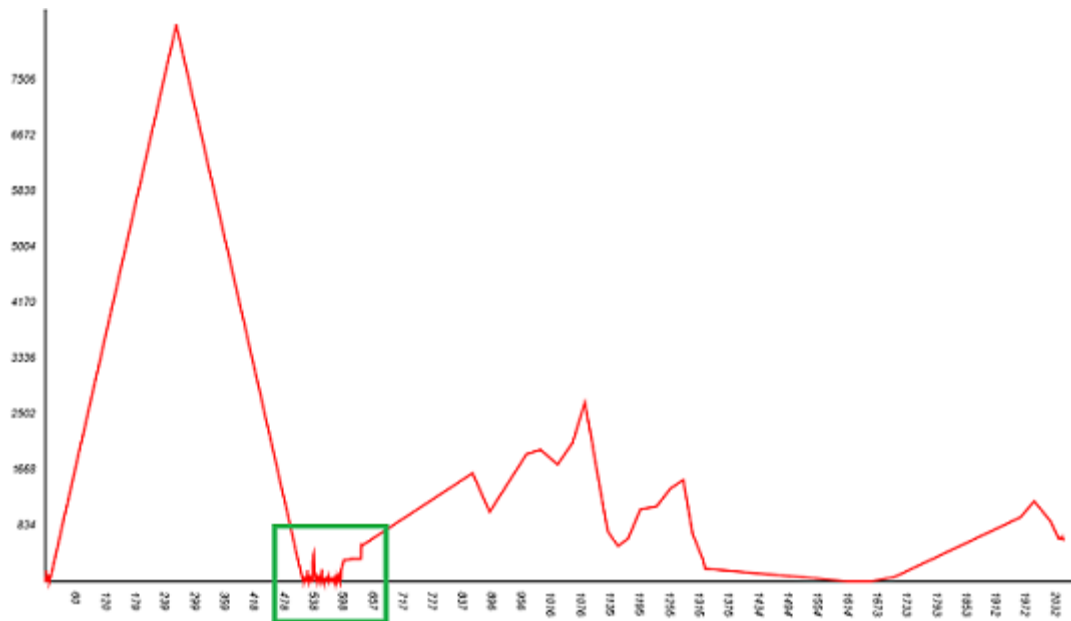
Figure 6: Altitude graph for a bird migration. The span shown in green represents a stop in the bird migration. The bird spent a significant amount of time in that spot, but the accumulated travelled distance is small.

Usability issues

The visualization of the migration tracks is totally dependent of the acquired data and its quality. A preliminary quality assessment is performed in the DB when the data is acquired (checking timestamps consistency). But due to transmission errors, the inserted data can be invalid for visualization purposes. For example, during a flight the GPS signal can fail detecting the position or the altitude. If a bad position is returned, the migration trajectory might be broken (especially if the returned position is (0, 0) or a place in the Antarctic Ocean). If a bad altitude is returned, the flying patterns are altered. This is especially relevant when negative values are returned (below sea level).

In order to filter the spurious locations, we analyze each location, and its previous and next ones. Using the longitude, latitude and timestamps we calculate distances and speed applying thresholds for the maximum horizontal and vertical speed. If the location does not pass the horizontal speed test, we discard the location. If the location passes this one, but does not past the vertical speed test, the location is kept, but an interpolated altitude is set.

Another usability issue comes with the number of locations for a given migration. Even if the Cesium performance is quite good, loading an animation of lot of track points slows down the 3D visualization. Qualitatively speaking, a track with more than 1000 locations starts to degrade the performance. Although a better JS implementation and better hardware can raise this number, this limitation exits. In this work we don't have datasets with so many locations, so we have not taken any action to deal with this situation.

Web interface

The web interface combines all the modules previously described to allow users access the visualization and management tools. It hosts the following main modules:

- Profile management: User registration and login. Users with different roles have been defined according to their access and data management credentials.

- Wetland management module: to see existing layers and upload wetland information in KML format.

- Tracking data loading and visualization. Data loading is transparent for the users and it is automatically done by the extraction modules (SIGFOX client and OpenGTS server). The visualization has two views: Real Time (last positions of each device) and Trajectory Analysis.

- Bird capture and ringing management module: forms to register new birds into the database including device information.

- E-learning module: Slideshows describing different bird tracking techniques and basic introductory information about ornithology concepts for the general public.

CONCLUSIONS AND FUTURE WORK

This work has introduced a web management and visualization of migrating bird data. During the project GSM and SIGFOX devices were used, but the platform is valid for other systems if the suitable data structure is followed. The devices attached to the birds send periodical positions which are stored in a database for further processing and visualization. The Web interface offers the basic functionality to register and identify the birds (ring, photo, weight...). The wetlands are also registered in the system with the associated cartographic information (contour) and other relevant metadata.

This work has also presented an interactive visualization of the data acquired from the devices attached to the birds. The data is retrieved from the database via a set of Web Services. The web application is composed of three interactive elements.

The first component is a Google Earth interactive application where the metadata of the wetlands is shown. The cartographic information about the wetlands is shown by the online creation of a KML file with the information stored in the database.

The second component is a Cesium WebGL powered globe viewer where the 3D migration path is shown. The visualization is composed of a static polyline and an interactive animation track. The user can interact with the animation using the default timeline widget.

The last component is a 2D graph rendered in a HTML5 canvas. This graph shows the altitude along a migration track (travelled distance vs. altitude). This graph is bidirectionally linked with the 3D Cesium component. When the animation is being played, a vertical line is shown to visualize the current position of the bird and its altitude. When the animation is not running, the user can click on the 2D graph to move the animation position to that precise moment.

Therefore, an advanced visual analytics tool for bird monitoring is presented, extensible to other regions as cartography gets available and that can also be linked to meteorological historical data.

As future work, we aim to address the combination of the available cartographic information with a better resolution and an improvement of the elevation information given by the positioning devices, since new better and cheaper sensing techniques can provide environmental data in 3 dimensions.

Additionally, the usability issues of the Cesium component could be addressed by filtering the retrieved information and simplifying or smoothing the bird trajectories using similar techniques to the Level-of-Detail techniques in Computer Graphics.

ACKNOWLEDGEMENTS

REFERENCES

[1] BERTHOLD, Peter. *Bird Migration: A General Survey*. Hans-Günther Bauer and Valerie Westhead(trad.). 2ª ed. UK: Oxford University Press, 2001. 253 p. ISBN-13: 978-0198507871

[2] BALMER, Dawn. COIFFAIT, Liz. CLARK, Jacquie. ROBINSON, Rob. *Bird Ringing: A concise guide*. 1ª ed. UK: British Trust for Ornithology, 2008. 75 p. ISBN-13: 978-1-906204-45-7

[3] KERLINGER, Paul. How Birds Migrate. 2ª ed. USA: Stackpole Books, 2009. 230 p. ISBN-13: 978-0-8117-3230-4

[4] MONNA Project: http://www.monna-project.eu

[5] Movebank: https://www.movebank.org/node/2

[6] Avian Knowledge Network: http://www.avianknowledge.net/index.php?page=about

[7] Ornitho (Catalunya): http://www.ornitho.cat/

[8] BRIDGE, Eli S. Technology on the Move: Recent and Forthcoming Innovations for Tracking Migratory Birds BioScience (2011) 61 (9): 689-698

[9] OpenDMTP Project: http://www.opendmtp.org/

[10] SIGFOX Technology: http://www.sigfox.com/fr/#!/about

[11] OpenData Euskadi: http://opendata.euskadi.net/w79-opendata/es/contenidos/informacion/que_es_opendata/es_que_es/que_es_opendata.html

[12] ESRI Shapefile format: http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf

[13] QGIS Development Team, 2014. QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

[14] CESIUM. http://cesium.agi.com/

BIOGRAPHY OF AUTHORS

Harbil Arregui

Harbil Arregui works at Vicomtech-IK4 since February 2010. She belongs to the area of Intelligent Transport Systems and Engineering as a contributing researcher. She obtained a degree in Telecommunications Engineering at the University of the Basque Country in 2009, specialized in communications and signal processing. She has participated in several local and European projects related to the transport sector and GIS technologies, and published papers in international conferences.

Aitor Moreno, Ph.D.

Aitor Moreno received a Ph.D. degree in Computer Science in 2013 from the University of the Basque Country. His thesis titled "Urban and forest fire propagation and extinguishment in Virtual Reality training scenarios" received the "Cum Laude" designation.

In 2002, he received a degree in Computer Science from the University of the Basque Country.

In October 2002, he joined Vicomtech-IK4 as a full time researcher. He is involved in several regional, national and international projects focusing mainly on Computer Graphics, Virtual Reality and interactive simulations. He has published several papers in international conferences and journals. His main interests are Computer Graphics, Simulation, Virtual Reality and advanced interaction techniques (Human-Computer Interaction).

Oihana Otaegui, Ph.D.

Oihana Otaegui is the Head of Intelligent Transport Systems and Engineering Department. She received her MEng degree in Electronic Engineering and her PhD on Acquisition and Tracking for Satellite Navigation from the University of Navarra, Spain. She has a large experience in satellite navigation and transport fields.Before joining Vicomtech-IK4 in 2007, she worked as a Researcher at CEIT (Spain) and at Fraunhofer IIS (Germany) on, among others, fast acquisition algorithms for Galileo/GPS/EGNOS. In her current role she oversees and is responsible of the department projects related to positioning, transport, user information services and security. She has participated in several FP6 and FP7 projects during her activity in Fraunhofer and Vicomtech.