GIMA

Geographical Information Management and Applications

Applying open GIS solutions in glider competitions

MSc Thesis

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I. Abstract

This research report concerns the real-time tracking of gliders in a competition. The objective of the research was to establish an open data exchange mechanism for real-time glider competition data. The research investigated different solutions including those of other, similar sports which utilize real-time tracking. The methodology consisted of several steps: interviews with developers and simulations using test flights. The results show that currently existing tracking systems are either too expensive to maintain or have too low coverage for gliding competition purposes. Suitable open GIS standards were investigated and several promising standards of the Open Geospatial Consortium (OGC) were found, including well-known standards such as WMS and WFS but also standards that belong to the Aviation Information Management Branch. Lastly, standards of The World Air Sports Federation and the International Gliding Commission (FAI-IGC) were investigated but were not found useful due to compatibility issues with geographic information systems (GIS). The research also investigated the available glider tracking devices including Flarm and ADS-B transponders. The research concludes by envisioning an open data exchange mechanism as a new OGC standard which combines several of the previously mentioned standards. This standard is based on a gossip network architecture and makes use of the GSM network and a Raspberry Pi computer and is compatible with currently in-use devices on gliders.

Keywords: OGC, WFS, WMS, IGC, GML, AIXM, FIXM, WIXM, glider, Flarm, ADS-B, transponder, gossip network, Raspberry Pi, open standards, gliding, real-time sports tracking

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III. Table of content

IV. List of Abbreviations

AIM	Aviation Information Management
AIXM	Aeronautical Information eXchange Model
DBMS	Database Management System
FAA	Federal Aviation Authority
FAI	The World Air Sports Federation (Fédération Aéronautique Internationale)
FAI-IGC	International Gliding Commission, branch of FAI
FIXM	Flight Information eXchange Model
GIS	Geographical information system
GML	Geography Markup Language
GPSS	Gpsseurnata.net
GPS, GNSS	Global Positioning System; Global Navigation Satellite System*
GT	www.glidertracking.com
ICAO	International Civil Aviation Organisation
IGC	International Gliding Commission
OGM	Open Glider Network
O&M	Observation and Measurements Schema
SOS	Sensor Observation Service
SWE	Sensor Web Enablement
UAV	Unmanned Aerial Vehicle
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WXXM	Weather Information eXchange Model

*In this theses the term GPS (Global Positioning System) is used instead of GNSS (Global Navigation satellite system(s)).

1 Introduction

1.1 Background

Competitive gliding belongs to the type of sport which is only interesting for a small group of people. An important reason for this is that without a real-time tracking system in place, the outsider does not know what the competitors are doing after take-off and before landing. Multiple trials have been done (e.g. www.glidertracking.com (GT) or Open Glider Network (OGN)), to engineer a sustainable real-time tracking system; however none of these have been used widespread, due the high equipment or maintenance costs or low aerial coverage. Furthermore, all these systems share one common drawback, namely that they are proprietary. They are engineered as closed systems, having their own way of dissemination and because the real-time data is unavailable to third parties. They are not necessarily closed intentionally; however the developers have focused more on the sensor system development. One good example was initiated voluntarily by three Dutch glider pilots : www.glidertracking.com (GT).

The Dutch National Glider competition was supported by their real-time tracking system for free, which proves that there is supply and demand for open and free real-time tracking solutions for the glider. It has to be emphasised that people have merely demanded the real-time information with certain types of accuracies, but not on one specific sensor system. It is likely that not one sensor system can provide the demanded information, but the combination of multiple systems can.

Different kinds of sensor systems exist, such as satellite based, smart phone-based, Flarm[1] based or transponder based. All these sensor systems have different types of output, accuracy, precision, and time frequency, although they might give the same information (for example: geographical coordinates, time stamp, elevation, sensor or glider id). The information is similar, but the data exchange mechanism between the sensor systems and front end users has not worked out very smoothly. The exchange mechanism is always tailored to one specific sensor system and therefore it is not interoperable with any other one. In other words, a durable solution is lacking because existing solutions are not interoperable. If interoperability is achieved, various existing sensor systems might be combined successfully. Interoperability can be achieved by creating an exchange mechanism between the sensor system and the end users of the information. The exchange mechanism takes into account the input data, the output requirements and uses the available standards.

1.2 Research objectives

In this part of the report, the objective of this research is defined. The objective is followed by the detailed research questions and the last section explains what is beyond the scope.

[1]FLARM® is an affordable, active and cooperative traffic and collision-warning system for general aviation and recreational flying. Flarm shows nearby traffic and, warns visually and acoustically of approaching other aircraft or fixed obstacles. It has typically 4-8km radio range (Flarm.com, 2014)

The objective of this research is to establish an open data exchange mechanism for real-time glider competition data. This exchange mechanism is going to facilitate developers to access this data using open source solutions and open standards.

This objective can be expressed with four main research questions:

1. What are the characteristics of real-time glider competition data?
2. What are the needs of developers?
3. What are the minimum requirements for an open real-time exchange mechanism?
4. What are the relevant available open source solutions and standards and how can they be applied?

The research questions may bring references to the case studies to emphasise the relevant information.

1.3 Understanding gliding

In order to understand GIS aspects of gliding, three case studies are presented. The first case study points out the low popularity of gliding due to the low level of real-time information, in addition, understanding real-time information is not easy. In other sports, it is easy to tell who the winner is during races like Formula 1: the fastest is the best. In case of gliding this is not the case. Regardless of any specific competition rule, generally scores are calculated according to the flown distance, to the flown time, and to the performance of the glider. Due the high differentiation in performance, for each glider a multiplier is assigned: the higher the performance, the lower the multiplier. This gives an extraordinary complexity to real-time in calculating any ranking. A further calculation example with detailed numbers is going to be provided in the research to explain the nature of gliding scoring. This issue poses the question of to what extent should the exchange mechanism provide calculated data or should it not be done at all? This requires a user need analysis.

1.4 Case study 1: Public entertainment

As it was mentioned in the introduction, gliding should be more interesting for an outsider. Therefore it calls for a good way to disseminate information. In this way, not only the cartographic appearance is important, but also the accompanying real-time information. Which information can be calculated about competitors real-time? It encompasses information like current ranking, time difference between two gliders, and optimal speed according to current weather conditions. This information can be definitely calculated; therefore the exchange mechanism must support access to certain numerical data like coordinates and elevation. The dissemination also includes the combination of real-time data with other thematic data like the precipitation map.

To accomplish these conditions, the technical data has to be visible as a map and the data set itself should be in the format of a vector file. Cartographic manipulations like recoloring have to be enabled. The requested data has to be able to overlay with thematic data set. This requires a good spatial reference system. The accuracy of the data is less important, the normal GPS accuracy is satisfactory because the resolution of the map is low and it should cover a large area. The time accuracy is important; it should be lower than 30 sec (this can be understood as the density of the vertices). However, although the delay of data is allowed, the continuous dissemination is crucial. If the entire data restreaming is delayed by 10-20 minutes, the public would still continuously see how the competition is going on, since gliders are far away and no other reference point exists.

1.5 Case study 2: Mobile app for rescue team

During gliding, it is a normal event if a pilot is not able to return home because of the weather and is forced to outland. Outlanding means that a pilot may choose any field which looks the most seamless. It is often not easy to find a safe landing place, especially in mountainous areas. If this happens, the team of the pilots has to go to him by car and unset the glider. It can happen only after the pilot has landed somewhere and made a phone call. That has two limitations: first, in the case of a crash, the pilot might not be able to call requesting help. Second, the team can only begin the rescue journey after the landing has happened and the pilot has phoned back to home. In addition, if the landing is 100-150 km away in air distance, the arrival can take a long time. Although real-time information might be available at the airport, the rescue team is still located there, waiting for a rescue call. A mobile app using this framework would enable the rescue team to speculate the likely location area of the outlanding and they can already be on the way by car to that speculated location. Lastly, the official rescuing authorities can also use such a mobile app in case of emergencies.

The technical requirements for this application are focused on the possible landing location. The possible landing locations should be visible and it often happens that other gliders outland around the same area (within 50-100 km^2). Therefore all the gliders outlanding locations should be visible. If a glider is below a certain altitude from the ground, it must land, therefore the altitude is necessary data. The reference system of the altitude is less important, but it is measured from the ground and not from the ellipsoid, thus the relative altitude is needed and not the absolute. The system must support the ability of an outsider server to retrieve the global surface elevation and calculate the relative elevation. The time frequency is less important, therefore 10-20 minutes is satisfactory. Time frequency does not become important if an accident happened. The decision making could take some time, possibly longer than a few minutes, because it could be possible that there is no service in the vicinity of the landing spot, therefore the pilot cannot make a phone call and he must walk or hitchhike to a suitable location. Therefore, this application is not suitable as an urgent emergency decision-making support system. Lastly, mobile devices are likely to receive their data via mobile internet and often the data traffic is limited. Hence the exchanging mechanism must support a light version of the data streaming.

1.6 Case study 3: Google glass

Google glass is expected to be an innovative invention which can revolutionize the info communication sector. Besides obligatory instruments, there is at least one piece of navigation equipment on board, but they are barely interoperable with the real-time tracking systems. Using Google glass would help the pilots focus more on flying. Google glass are connected to smartphones, thus via smart phones, the exchange system can be reached. The nearby opponents and team mates can be shown on the glass and would facilitate the job of the pilots.

The Google glass displays relatively few information and it works as a location-based service. Hence, only data is needed about nearby gliders, thus the system must support partial data streaming. Mobile phones are using mobile internet to get data, therefore the size requested data cannot be large, thus the system must support a light version of data streaming.

1.7 Research questions

1.7.1 First research question

What are the characteristics of real-time glider competition data?

The first research question discusses the nature of the real-time glider data. Different types of sensors are used to track gliders, and those sensors can measure multiple types of data. An example can help better understand this data. A smartphone can have an accelerometer, compass, and GNSS coordinates, and therefore it can measure the geographical coordinates, elevation, acceleration, roll, pitch and yaw with certain accuracy. The obligatory flight recorder, however, can measure fewer types of data. It is obliged to measure the GNSS coordinates and pressure altitude, the rest of the data is usually calculated depending on the type of the sensor. The fundamental difference between the smart phone and the flight recorder is that the latter is a certificated and closed device.

Figure 1: Roll, pitch and yaw of an aircraft (Wikipedia/Flight dynamics, 2014)

It is also important to define the term “real-time”. Gliding is not the only sport which has multiple participants and demands for real-time tracking. Not only are gliders in the air, but there are other objects like birds or meteorological balloons which can be tracked. This research compares gliding with other sports and with other objects which can fly in the air.

According to the aforementioned issues, the following sub questions are formulated.

- What is the difference between commercial flight data and glider data?

- How does the competition influence the characteristics of the data?
    - What are the characteristics of glider flight data?
    - What real-time flight data is available?
- How does gliding differ from any other multi-participant sport?
    - What influences the fact that gliding happens in the air?
    - What are the limitations of a glider?
- How does the competition circumstance influence the exchange mechanism?
    - Which data should be available for whom?

1.7.2 Second research question

What are the needs of developers?

This section discusses the output requirement of the exchange mechanism. The target user group of the exchange mechanism are software developers and not the pilots, the public or ground control. They are going to access, process and redistribute flight data in multiple manners. The three case studies, which are described in 1.4-1.6, show that the information can be used on different devices. The exchange mechanism allows developers to easily access the information using standards instead of accessing directly to the sensor's raw data. They might want to have direct access to the flight data or via some simple service like Sensor Observation Service (SOS) offered by the Open Geospatial Consortium (OGC) and combine it with third party data, map layers, etc.

Two case studies point out a possible weakness of the mechanism which is the size of the information, or in other words, the data traffic. Developers probably want to limit the request to the relevant data sets and not to all of the information. Therefore, unnecessary data traffic should be avoided.

The following sub questions are formulated from the second research question.

- What kind of data and which data format is to be requested?
- What kind of applications need to be developed on this framework?
- Which kind of services has to be available for developers?
- What is the level of freedom of developers to access the relevant information?

1.7.3 Third research question

What are the minimum requirements for a real-time exchange mechanism?

The first most conspicuous characteristic of this exchange mechanism is that it must support real-time data exchange. Is a 10 or 20 minute update frequency satisfactory? In the case of gliding competition, the three different case studies provide good examples. In the first case, the data can be delayed, but it has a demand for a few seconds of capture time. In the second case, a 10-20 minute update still can save lives. In the last case, a few seconds update is crucial. The real-time need is strongly related to the competition circumstance. Multiple participants compete to win, therefore their real-time locations and accompanying information may challenge the competition regulations. Therefore, the legal aspects have to be taken into account, although that is beyond the scope of the research.

The mechanism links the diverse sensors together, although it must have some minimum requirements to be input data. The official flight recorder's specification given by FAI IGC requires that data may be transferred from the flight recorder in another form (eg. binary code) as long as it can be converted into the IGC format (FAI, 2011). It is wise to follow the FAI's principle, in a sense that forces sensor system suppliers to avoid binary data. Therefore, further generic preconditions about input data has to be established in the frame of this research question.

Legal aspects have to be taken into account because the current competition regulations vary on using electronic devices on board. One example of this could be that using Google glass, which shows the nearby competitors, may not be allowed.

Incorporating the issues above, the following sub questions are formulated:

- How does the real-time demand influence the exchange mechanism?
- What are the minimum requirements for the input data?
- What can be the legal consequences of an open mechanism?
- What are the output requirements concerning the interoperability?

1.7.4 Fourth research question

What are the relevant available open source solutions and standards and how can they be applied?

The first question defined the input, the second determined the output and the third set the minimal requirements of the exchange mechanism. The last research question is the synthesis of these three, which searches the suitable standards and services.

The objective of this research clearly aims that open standards and open source solutions are going to be used. There are pros and cons to using them, therefore this aspect is discussed in the frame of this research question.

Open standards and open source solutions are sought, therefore it is likely the standards of OGC are going to be used and the exchange format is going to be Geographical Mark-up Language (GML). However, the exchange mechanism is more than a file format; it is going to offer some generic services like SOS. The following sub questions are formulated from the third research question.

- What are the available and relevant open source solutions and open standards?
    - What does the Open Geospatial Consortium offer?
    - What are the suitable open standards?
    - What are the suitable open source solutions or services?
    - What are the pros and cons of open standards and solutions?

- How can interoperability be defined for the targeted open data exchange mechanism?

1.8 Beyond the scope

The research avoids the engineering problems related to sensors. It may list the benefits and drawbacks of the different kinds of sensor systems, but it does not attempt to solve them. It is also beyond the scope to establish a direct real-time link between sensors as no third party resources were found available for this research. It will be satisfactory if the log files of the different systems are available and the data can be simulated.

The research takes into account the legal aspects of the real-time data accessibility, although creating an approved usage condition document can be only done if the exchange mechanism is ready to use. Therefore this may be a course of action for a follow-up research.

2 Live tracking, standards and sensors in sports

The exchange mechanism can be looked at as an interoperability issue. Generally speaking, interoperability is the ability of a system, or component of a system, to a provide information portability and inter-application cooperative process control. (Yao & Zou, 2008). In this case, the system interoperability is understood as the interoperability between the sensors. The inter-application cooperative process control is regarded as the sensor data streaming to developers in a standardized manner.

Therefore, this chapter discusses the available GIS standards in aviation and discusses how other sports use (live) tracking systems. In the third section the architecture of Glidertracking.com (GT) is described. The next two sections describe real-time sensors and corresponding interfaces and data formats. The last section gives a brief overview on special internal communication network: gossip network.

2.1 GIS standards in aviation

2.1.1 Aeronautical Information Management (AIM)

Aeronautical Information Management (AIM) covers many different services and databases within the aviation industry, ranging from flight reference data, geographical spatial data, airport databases weather information, pilot briefing data, etc. (Rusu et al., 2012). Merging this information is beyond the scope of this research, although any end user product which uses the exchange mechanism to disseminate glider's location probably will use an aeronautical based map which is derived from the aforementioned aspects of (AIM).

US Federal Aviation Authority (FAA)'s NextGEN and the Single European Sky ATM Research (SESAR) conducted by EUROCONTROL (Rusu et al., 2012) programmes, along with the OGC interoperability programme, have been developing and strengthening multiple OGC standards (WFS, SLD and others), drafting GML profiles and developing domain-specific exchange models such as Aeronautical Information eXchange Model (AIXM) and the Weather Information eXchange Model (WXXM) and Flight Information eXchange Model (FIXM) for aeronautical, weather and flight information respectively. These models have been updated through extensive, scenario-based experimentation, and include a strong temporality model (Brooker, 2013). AIXM is now in its 5th version (AIXM 5.1) and it is being adopted by ICAO (International Civil Aviation Organisation) as the global standard for aeronautical data inter-change (Rusu et al., 2012). AIXM and WXXM are based on GML.

It can be concluded that the highest level authorities (FAA, ICAO and EUROCONTROL) in commercial aviation have been developing open GIS standard which are already part of the largest open GIS organisation, OGC.

2.1.2 IGC and FAI

The responsible international gliding authority is The World Air Sports (FAI, Fédération Aéronautique Internationale). One branch of FAI is the International Gliding Commission (FAI-

IGC). This organization laid down the specification of a digital flight recorder (FR, commonly called logger) and its file format: *.igc.[2]

Each flight recorder must be certified and approved by the IGC in order to ensure the data quality. The IGC file format is a simple ASCII file, which consists two main parts: single instance records and multiple instance records. In both cases the type of the records are marked with a capital letter (A, B, C, D, E, F, G, H, I, J, K or L). An example IGC file is provided in Appendix A.2. A short summary of the content of the records is given in Appendix A.1.

2.2 Live tracking in other sports

This section elaborates how other multi-participant sports using real-time tracking. Those sports were selected, which share similarities in some manner with gliding. The first criteria were, that these sport have many participants and competitors are spatially distributed. The last criteria were limited cargo capacity and limited electricity. As result, orienteering and bicycling was selected. Open and semi-open solutions were sought including commercial solutions which has some open segments. The following relevant solution were found.

2.2.1 BikeSpike

BikeSpike is mentioned here as a solution showing how it is possible to track other vehicles in multiple-participant sports which have limited electricity resources and limited cargo capacity.

BikeSpike is a startup company which designed an anti-theft and safety solution for bicycles consisting of hard- and software (Figure 2). BikeSpike helps to track and recover a bike if it gets stolen, it notifies the owner if someone is tempering with it and sends an alert to key contacts in the event of a traffic collision (BikeSpike.com, 2015).

Figure 2: BikSpike design (Kickstarter, 2015)

BikeSpike advertises its product as having an open API. This API has not been launched yet and its capabilities are as of yet unknown. It is also not explicitly described how it communicates with the server. It probably uses a mobile internet connection because its

[2] In further sections, “IGC” is reference to the file format and not to the committee. If the committee is referenced, FAI-IGC is used.

usage is limited to the USA, Japan and EU only, and some scratches on the website suggest that.

2.2.2 Garmin Connect Web Services

Garmin Connect Web Services API sends GPS Data in several formats via SOAP, XML or REST to Garmin. In turn, GPS and non-GPS data is sent from Garmin in the same format and protocol to a developer's Web Services API.

Like a streamlined racing bike, lightweight REST APIs are optimized for data speed. In turn, analysis of this data is what propels cycling forward; it's what helps riders achieve higher than average speeds, better wattage for stages, day after day on Grand Tours.

The incremental progression for the Garmin Connect model of Open API Management enables races such as Le Tour de France to add an API Management layer, using an API Gatewayto layer management onto the APIs which serve rider data, location, and speed. Interestingly, riders' performance data could even be shared with the World Anti-Doping Agency to weed out doping cheats (ProgrammableWeb (2013). Unfortunately, GARMIN's website says, that it is still under development, however the cited article was published 18 months ago.

2.2.3 Ori-Live

Ori-Live is a distributed and modular computer system, including software and hardware for the tracking and real-time coverage of live sports events, particularly orienteering sports. Ori-Live is situated in an information system which is supported by a modular and distributed architecture consisting of several components and services (Figure 3). The system infrastructure is based on a TCP-IP network on which several nodes are distributed with specific functions. Multiple instances of the same components can be used allowing better and redundant control. To keep track of intermediate times RS-232, GSM and GPRS links are used. In order to real-time track competitors, Ori-Live developed a subsystem: Ori-Point. Ori-Point is a GSM module for remote tracing of control stations and timing systems developed specifically for Ori-Live. Ori-Point is based on a Siemens GSM platform with Java VM. This allowed for the adaptation of the device to the particular needs of orienteering events (Ori-live, 2010).

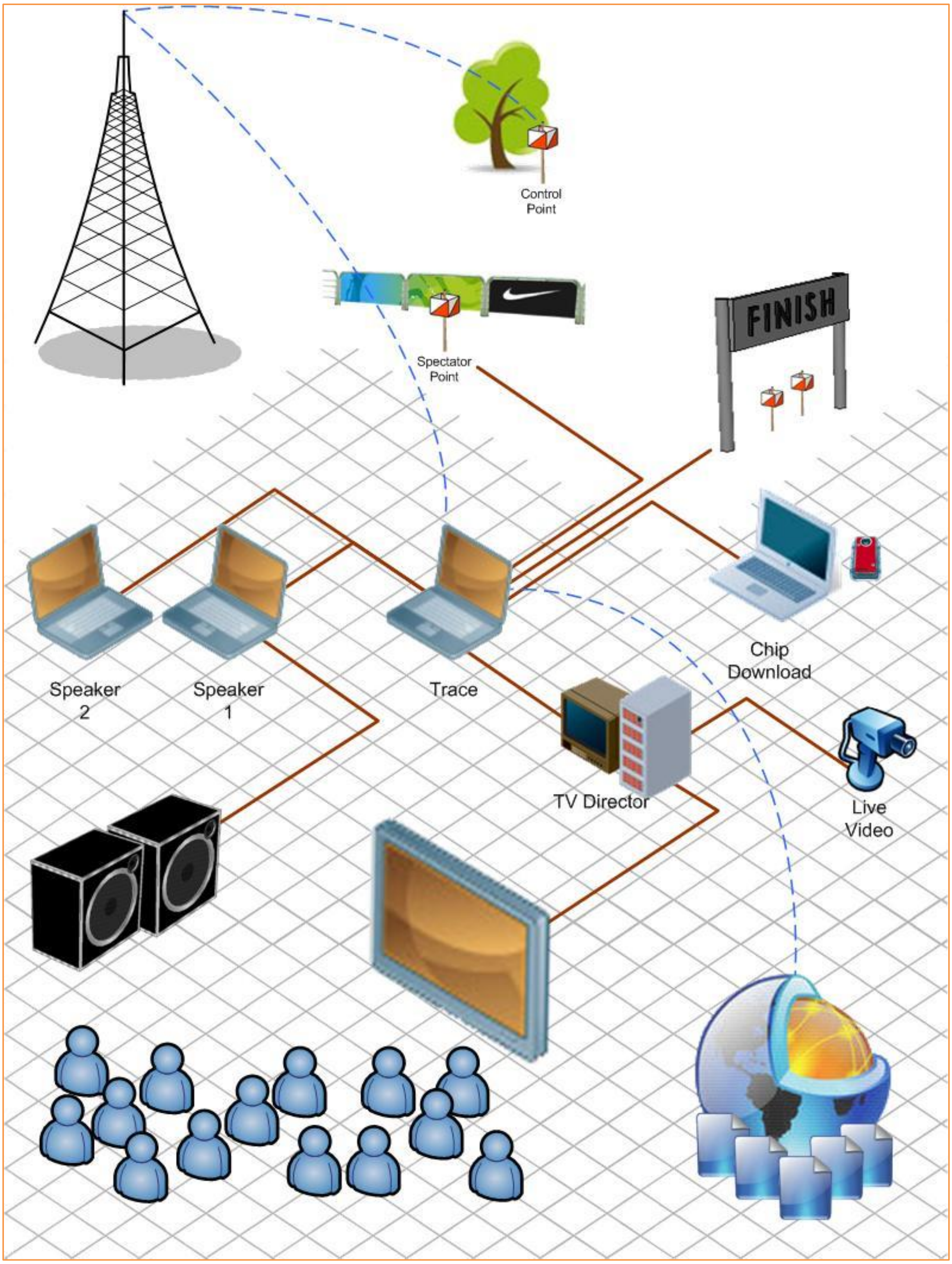


Figure 3: Ori-live architecture (Ori-Live, 2010)

2.2.4 Gpsseuranta.net

Gpsseurnata.net (GPSS) is a platform created for orienteering competitions. This platform integrates multiple service/devices into one single map for one single competition where competitors' positions can be seen real-time. The real-time map is based on Javascript, and it offers a free and open source API: GPSsbit. GPSsbit only plays back past events based the uploaded results. GPSS does not have its own hardware device, but the website mentions devices that are supported: Tracker Inc. and Tracker Security. Both of these devices use mobile internet transmitting data to their central server (Tracker Oy, 2015; Tracker Security Ltd, 2010).

2.2.5 Overview

This section describes some solutions from other sports and related industries. Four different solutions are briefly explained. All solutions use mobile internet as the communication channel between the competitor and the central data server. Furthermore, these solutions can be categorized according to the following criteria:

- Does the solution have an API? If yes, is it open?
- Does the solution have a self-built device?
- Does the solution support external devices?
- Does the solution support any common GIS standard? If yes, which?

Tracker Inc. and Tracker Security are only listed because they are device manufacturers. Since they are not mentioning on their profile supporting sport event API availability and external device supporting is irrelevant (not applicable, N/A.).

	(open) API	**Self-made device**	**External device**	**GIS standard**
Bike spike	Coming soon	yes	no	no
Garmin Connect Web service	Yes, but proprietary	yes	unknown	yes
Ori-live	Can be customized, depends on the client	yes	no	no
GPSS	Very basic level	No	Yes	No
Tracker Inc.	N/A.	Yes	N/A.	No
Tracker Security	N/A.	Yes	N/A.	No

It is clear that only one solution support open GIS standards: the Garmin Connect Web service. The other solutions are non-compliant to open standards but they are "ready to use".

2.3 Glidertracking.com

Glidertracking (GT) is a Dutch initiative by three glider pilots, Frank Hiemstra, Jens Bouma and Jip van Akker. This section describes their architecture based on their website and a short interview. Their system is based on two devices: ADS-B tracker and SPOT tracker.

ADS-B stands for “Automatic Dependent Surveillance-Broadcast”. ADS-B is information that is transmitted with the transponder signal. This information contains GPS/NMEA data (position, height and speed), airplane identification and transponder identification.

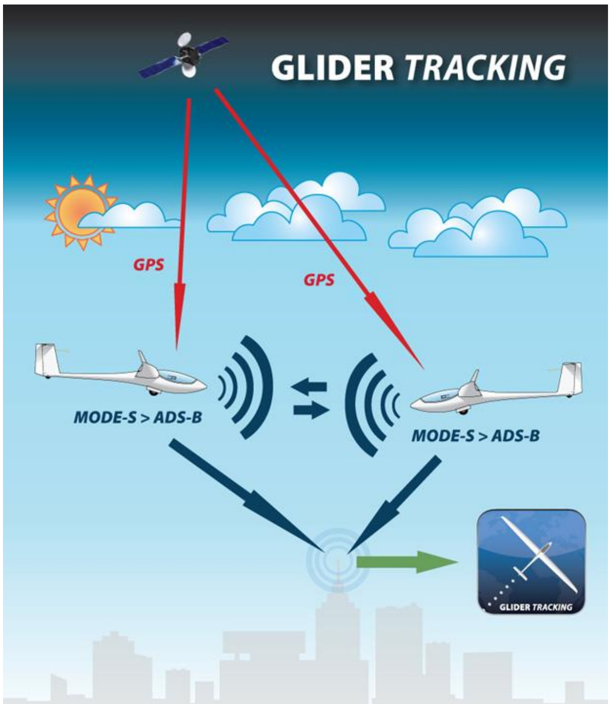


Figure 4: ADS-B architecture of GT (GliderTracking.com, 2012)

The advantages of ADS-B:

- Live tracking capabilities
- Enhanced visibility and accuracy, compared to the conventional radar systems
- Through ACAS (Airborne Collision Avoidance System) possible collisions between aircraft can be detected and prevented
- ADS-B has a greater range, compared to Flarm
- Possibility for Search & Rescue to determine a position fix, in case of emergency

However, ADS-B transponders have to be attached to a suitable GPS source. To do so, a GPS source with NMEA-out of 4800 baud is required. (GliderTracking.com, 2014). The interviewees with Jip van Akker explained that using an ADS-B receiver is almost obligatory for all the gliders in the Netherland because the country’s airspace is very dense with air traffic.

A SPOT tracker is a very small device that sends its location one time every ten minutes through a satellite connection. That’s why a SPOT tracker has worldwide coverage (GliderTracking.com, 2014). However, this makes SPOT tracking very expensive.

GT created a website where ADS-B location data and SPOT data are combined. The interviewee explained the difficulties of using ADS-B data, since commercial aircrafts use the same service. Filtering gliders from ADS-B data is not obvious because the registration sequences vary per country. Registration numbers consist of a country code (e.g. HA = Hungary, D = Germany) and followed by letters or digits. The second part is based on national regulations, therefore they do not follow any international standards.

The question was asked, if GT plans to use any GIS standards like WFS or WMS for disseminating data and the answer was no.

2.4 Open Glider Network

The objective of the Open Glider Network (OGN) is to create and maintain a unified tracking platform for gliders and other GA aircraft. Currently OGN focuses on tracking aircraft equipped with Flarm, Flarm-compatible devices or OGN tracker (OGN, 2014). Their initiation is based on volunteers. They ask glider clubs to purchase credit-card sized computers like Raspberry Pi,Cubieboard2 or Odroid U3 and install their software and connect to the OGN network (Figure 5).

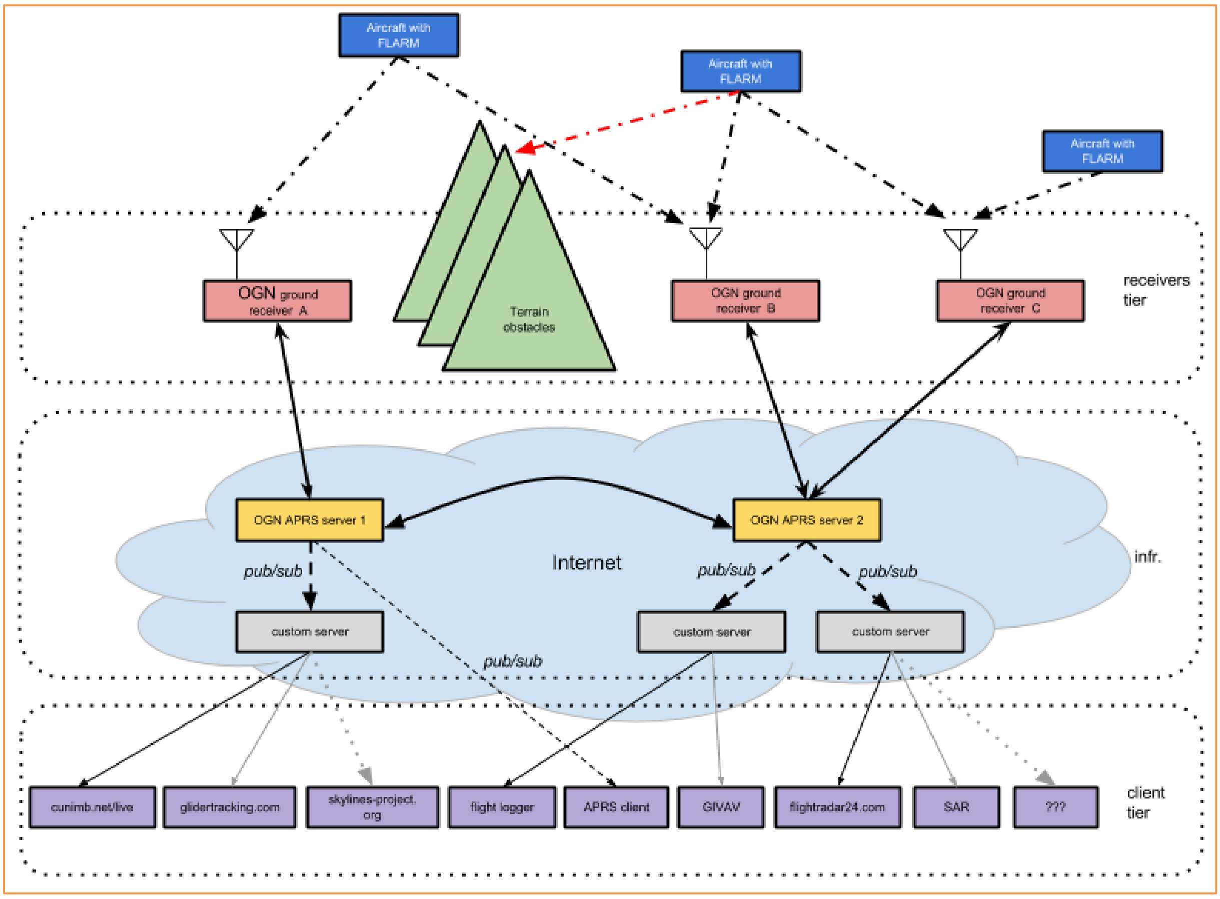


Figure 5: OGN architecture[3]

OGN only uses Flarm devices and ground receivers, however, Flarm has a very short range which requires a very dense network. A snapshot is made about the network on 14-02-2015

[3] For a more detailed description of the OGN architecture, refer to http://wiki.glidernet.org/.

representing its coverage and it is clear that a country like Germany would require hundreds or nearly thousands of ground receivers to cover the entire country.

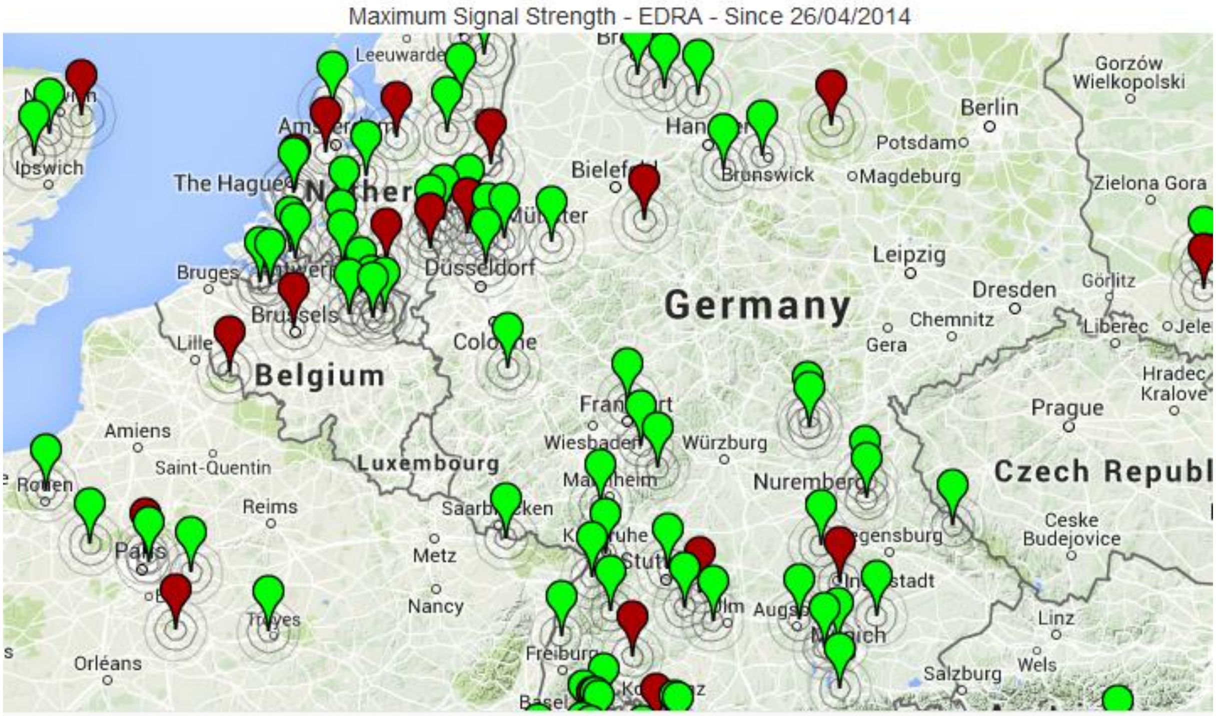


Figure 6: OGN network coverage. The outermost circle around the marker shows the maximum range of the receiver

2.5 Real-time sensors

The study of Bröring et al. (2011) discusses the Sensor Web Enablement (SWE) standards developed by OGC. *"SWE standards enable developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and useable via the Web."* (OGC, 2015). This study also provides terminology about sensors, sensory network and sensors resources which are adopted by this research. The terminology is as follows.

- *Sensor* is the most basic unit.
- *Sensor system* is an aggregation of sensors, attached to a single platform.
- A sensor or a sensor system may be abstracted as a *sensor resource*.
- A *sensor network* consists of a number of spatially distributed and communicating sensor resources.

The study gives a deep insight about SWE standards; therefore it is recommended literature, only the essential parts are discussed. SWE can be seen as a framework which includes multiple standards described by OGC (2015). These standards are as follows:

- Observations & Measurements (O&M)
- Sensor Model Language (SensorML)
- Sensor Observation Service (SOS)
- Sensor Planning Service (SPS)

In case of this research, SOS and O&M are found relevant; furthermore these standards show strong interdependency. O&M standard models and XML schema encode observations and measurements from a sensor, both archived and real-time (Bacharach, 2007). SOS is a standardized access to a sensor observation and sensor metadata. "*This service is a mediator between a client and a sensor data archive or a real-time sensor system. In functioning applications, the raw data measured by sensors is first processed, enriched and encoded as O&M before it can be inserted to the SOS (Figure 7). Hence, in real world deployments there are usually data acquisition systems and middleware components located between sensors and SWE services. Once the observations are uploaded to the SOS, applications can retrieve the data through the standardized interface and can visualize it, for example, as time series charts or on maps. The core comprises the mandatory operations for retrieval of the service metadata and its content (GetCapabilities), for accessing observations (GetObservation), and for querying sensor descriptions (DescribeSensor)*" (Bröring et al., 2011).

The 52°North Initiative for Geospatial Open Source Software GmbH developed an application system for SWE which supports many corresponding standards and services including SOS and O&M. All these software contributions are published under a Free and Open Source Software License. This system supports three database management systems (DBMS): PostgresSQL/PostGIS, Oracle and MySQL (52°North GmBH, 2013).

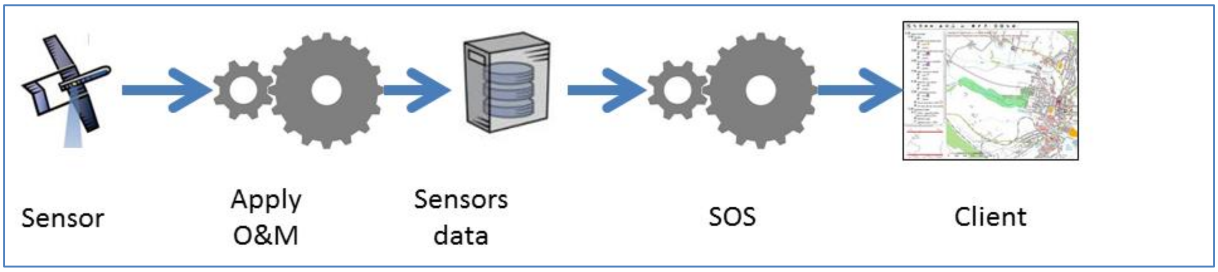


Figure 7: O&M and SOS flowchart

Several clients exist to access data via SOS protocol: ArcGIS (52°North), gvSIG (Tamayo, Huerta, Granell, Díaz, & Quirós, 2009), Java 2 Enterprise Edition (J2EEE) Web service technology (Chen, Di, Yu, & Min, 2009), or Python programming language combined with GDAL library (Kooistra, Bergsma, Chuma, & de Bruin, 2009).

It is arguable that direct access to raw measurements using SOS protocol fulfils the targeted user group needs, because no processing has been done on the dataset yet. If more than one sensor is planned to stream the location of the same glider, then spatio-temporal overlaps likely occur. This can be handled either by the exchange mechanism or by the user of the exchange mechanism, but these roles are not settled in this section.

It can be concluded that the SWE framework with SOS protocol and O&M schema is sufficient to handle the real-time aspect of data of this research. Several clients are listed including GIS applications and programming languages to request data via SOS protocol. Therefore it is a possible, but not the only way of data streaming to the targeted user group.

2.6 Interfaces and data formats

The previous sections discussed system interoperability where a suitable solution is found: SWE. Although SWE provides an interface to request data (SOS), that is not the only possibility because data are not processed.

A case study by Krisbiantoro, Hindersah, & Mardiono (2012) provide an example how OGC standards can be used to develop an application for aircraft search and rescue operations. This case study is consistent with Case study 2: Mobile app for rescue team. The case study proves that data can be given simultaneously in different ways to end users (Figure 8**Hiba! A hivatkozási forrás nem található.**). One way would be using services such as

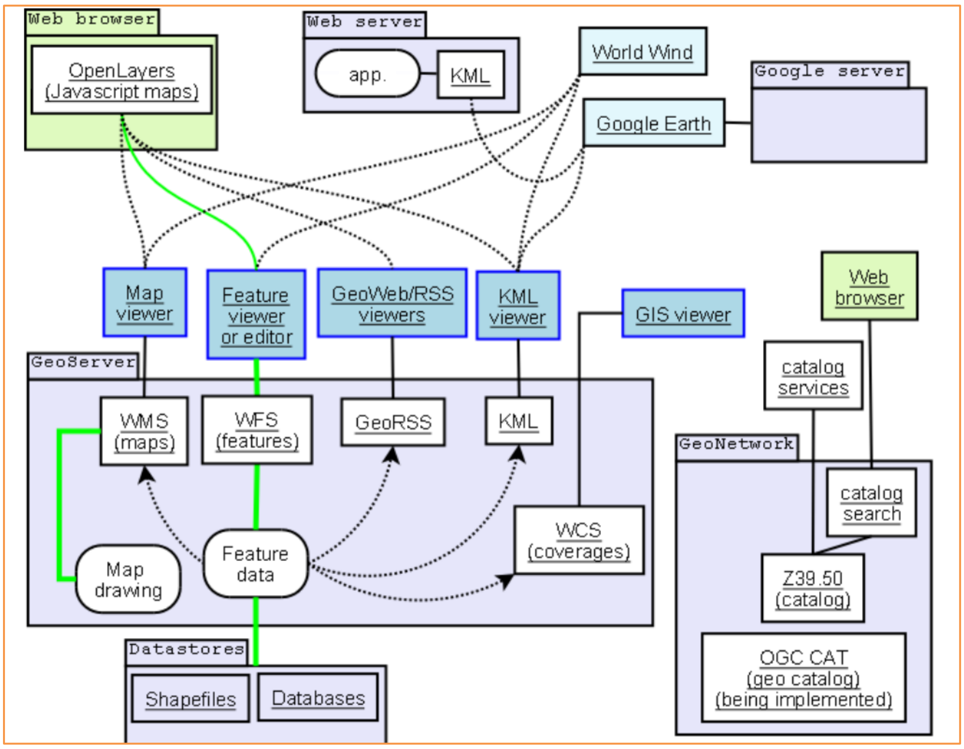


Figure 8: Architecture of Krisbiantoro et al. (2012)

Web Map Service (WMS), Web Feature Service (WFS) and Web Coverage Service (WCS).The other way is to make data downloadable in a GIS file format, in this case KML. The first is a dynamic connection between the server and the client which is continuously updating. The second is static where a file is generated and updating, and it has to be generated again from the database. The fundamental differences between WFS, WMS and WCS are the following.

1) *"WMS provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases. A WMS request defines the geographic layer(s) and area(s) of interest to be processed. The response to the request is one or more geo-registered map images (returned as JPEG, PNG, etc) that can be displayed in a browser application. WMS has three core operations: GetCapabilities which returns with the all available layers, GetMap which returns the requested layer,*

and GetFeatureInfo returns the attribute data of the feature on the map, however this is optional.

2) *WFS protocol gives vector data to the client which is encoded in Geography Markup Language. This allows the user to do spatial analysis and to edit the data. WFS has many more operations than WMS.*
3) *WCS is a protocol enabling the server to send draw data to the client, with not only vector but also raster data. WCS allows clients to choose portions of a server's information holdings based on spatial constraints and other query criteria.* (OGC, 2015)*"*

The previously mentioned data format is KML, which is a specialized format of the Geography Markup language. The most important value of GML lies in the fact that it is an open standard, so it has ability to integrate all forms of geographic information (Yao & Zou, 2008). This language helps in the storage, exchange and modelling of geographic information containing both spatial and non-spatial attributes (Lu, Dos Santos Jr, Sripada, & Kou, 2007). GML 3.0 released in 2003 provides a variety of kinds of objects for describing geography, including features, coordinate reference systems, geometry, topology, time, units of measure and generalized values (Lee, Kim, Kim, Joo, & Jang, 2004). GML is based on XML, the query languages and other data processing capabilities available to XML can also be used in GML. A GML schema is an XML schema, which means that a single interpreter can be sued for both the schema itself and GML document. This aspect of GML makes this format very flexible. The drawback of GML is that it is trade-off between performance and interoperability, because GML is text based, unlike ESRI shape files, which are binary. However a GML document can either be stored as is or the data can be stored in a database and converted to GML when required (Lu et al., 2007)

If WMS, WFS or WCS are to be connected the SWE framework, a middle bridge has to be found that is able to communicate with the DBMS of SWE and can provide these interfaces. Krisbiantoro et al. (2012) say that the free and open source GeoServer is able provide data over protocol WMS, WFS and WCS. Furthermore, GeoServer is also able to understand PostGIS database and is able to create GML files.

Finally, some lessons can be drawn from technology used in the maritime sector. *"The NMEA0183 (National Marine Electronics Association) standard defines an electrical interface and data protocol for communications between marine instrumentation (Berte, 2000)."* NMEA devices have two components: talkers and listeners. A device can be only one of them or they can have both properties (Betke, 2000). Further details and examples can be found in Appendix A.

Certain FR (Flight Recorders) not only use NMEA as an internal protocol, but they provide NMEA as output. LX20 type FR can provide GPS protocols to other devices which are connected properly to the NMEA-port (LX Navigation, 2003). LX Navigation suggests either to use GGA or RMC sentence. Sample NMEA sentence specifications are listed in Appendix A.

2.7 Gossip network

The core issue of the system interoperability is that several different sensors have to be used because one single sensor is incapable of real-time tracking of a glider in a cost efficient way in the current technical circumstances (Section 2.3). Gliders can be tracked using mobile network, however the signal strength is an issue. Gliders can be tracked using transponder or satellite based technologies, but all of them has drawback because they are focusing on a glider as a single entity. Since gliders can see each other on a short range using transponder or Flarm, all the competitors can be used as one single sensor instead of sensor system applying the terminology of Bröring et al. (2011) because these sensors depending on each other. The idea using gossip network came from an interview (3.2.2), but the scientific nature of it is discussed here.

Selen et al. (2013) describes gossip network in which the nodes wish to maintain an updated situation awareness view of the information sensed by all other nodes in the network. Using the gossip paradigm, this is done by having nodes transmit both their own sensed information and information that they have received from others. Thus nodes act as sensors, relays and receivers. Bandwidth is limited and communication channels are imperfect, thus the decision of what and when to transmit may often greatly affect performance. A natural application for gossip networks is intelligent transport systems (ITS) in which vehicles wirelessly share information relating to traffic congestion, road conditions and route alternatives, in order to improve safety and reduce congestion.

Interestingly, the IGC file format supports the gossip network on some level. On the E records of the file format (see Section, 2.1.2 and Appendix A/A.1), there is a Three Letter Code, (OA1, OA2, OA3 etc.) where other aircrafts location can be logged (for further details see Appendix A.3/OA1).

2.8 Discussion

This chapter reviewed the GIS standards in aviation, investigated the available open standards for sensor data and described protocols and data formats. It took a look at the live tracking solution in other sports and described the gossip network.

All open standards are of the OGC. It is clear that there are successful attempts in commercial aviation using open GIS standards, but it is questionable if they are useful for gliding. An open free framework is offered by OGC with SWE and several services including SOS. The 52°North GmbH implemented this framework with open and free software. One version of this is based on PostGIS DBMS. Other possible interfaces by OGC are found to share data: WMS, WFS and WCS. GML is also found as a possible exchange format, however it has performance issues. An overall framework application is found which is able to connect the 52° North SWE implementation to the OGC interfaces; furthermore it is able to create GML: GeoServer. GeoServer also allows processing of the data.

It can be implied that the end user may request the data directly via SOS, or the data can be further processed by the GeoServer. GeoServer is able to provide data with WFS, WMS and WCS protocols or generate GML documents.

Unfortunately, only one real-time tracking solution was found, which supports any open GIS standard. The rest are very closed systems, or their API has not been launched yet. Besides, they are based on merely mobile internet and their usability in case of gliding is questionable. In the case of gliding, other communication channels like Flarm or ADS-B receivers have to be taken into consideration (see 2.3 Glidertracking.com or 2.4 Open Glider Network).

3 User needs analysis

3.1 Case study analysis

The described case studies (1.4, 1.5 and 1.6) give a brief overview on a specific use case of the exchange mechanism. Some constraints have already been mentioned, further technical requirements are listed in these sections.

3.1.1 Public entertainment

The most interesting part of this case study is if users can make well understandable maps about the current location of the gliders. Therefore, the target users in this case study are digital map makers, map designers, cartographers. They are referred to as users in this section

A rule of thumb for knowing the current or last known location of every competitor is with the elevation information of the glider. However, a glider is a 3D object, which has a relative orientation and certain acceleration, therefore this information cannot be neglected. If a glider has an accelerometer, compass, then its current position and movements can be calculated very well. On the contrary, in this case, users are not interested how these information are calculated, because they wants to entertain public rather than solving very complex navigational issues.

In gliding, besides the current location, one parameter is very informative: the vertical speed: if the vertical speed is above 0, it means that a glider is thermaling[4] (gaining elevation, circling), but if it is below zero, the glider is dropping altitude. The vertical speed tells a lot about the current weather conditions which is extremely important. Vertical speeds can be gained not only from thermaling, but also if the pilot uses the kinetic energy of the craft to turn it into potential energy. In other words, pulling the control wheel, flying upwards and slowing down. Here comes the need of an accelerometer, because if the glider's acceleration does not change even though its vertical speed has increased, the glider is thermaling. This requires an accelerometer on board and very complex calculations to process the data. Users, however, are not interested in high level calculations, they need the calculated data.

A very crucial part of a competition is the metadata of the competitors. Momentarily, competitors are often treated as flying object instead of human competitors flying the craft. A pilot has a name, nationality, age etc. and a glider has a type, category, registration number, competition id etc. All this is relevant to the audience and the purpose of public entertainment.

Every competition has an objective. Objectives are very strictly specified flight challenges with different objects, like points, lines and polygons. They also have 3D aspect, since often there

[4] "Thermals" is the word used for the general phenomenon of warmer air rising through cooler air (Martens, 2007). Thermaling is circling inside thermals and using its rising movement gaining altitude. It is an axiom that gliders continuously sink, hence a glider as an aircraft always has a negative vertical speed component. However, if the vertical movement of the air inside a thermal is higher than the vertical sinking velocity of a glider, then the glider's absolute vertical speed becomes positive.

is a minimum or maximum elevation. Due to its complexity, users may not want to understand how the tasks are stored and how the objective's specific geometry looks like, but they do want to have a service which returns the geometry with accompanying attributes, like the maximum altitude and minimum flying hours. Mapmakers definitely want to access these metadata and pair the real-time position with a name or call sign. Overlaying objectives with gliders real-time position may be the most interesting, including the pervious tracks.

In gliding, the scores are always calculated at end of the day, after the black boxes are collected (or their IGC files were uploaded). The scores are calculated on the basis of who has completed the objectives most optimally. This is the most interesting part for the audience, but it is very difficult to calculate real-time. It is because gliders have different performances, thus they receive a multiplier balancing the differences. This means that the fastest is not necessarily the winner. Often not only speed matters, but also the flown distance with the average speed. The flown distance may vary, if very large areas are given as turn points (for example 20-50 km radius). It is very unpredictable, where the pilot will turn, because the time for turning is limited due to the weather. The unpredictable weather, the unpredictable turn points and the index number creates a very complex mathematical problem of ranking. Therefore, if any ranking is calculated real-time, it must happen at the server side and mapmakers only want numbers to visualize quickly and nothing more.

It is expected that a real-time connection with gliders is often lost. Ensuring continues entertaining, a little trick can be applied: data streaming is delayed with an amount of time (10-30 min). Thus mapmakers may not want the request the current position, but they want to request what was the position 10 minutes ago. Thus, the system shell supports such a service, which responds the positions at a given time.

Taken together, map makers are interested in services, which return an understandable format of the data. Some services return with static metadata. Another service returns with the current, real or delayed position of the competitors, including much other information, like ranking, vertical speed etc. Mapmakers do not want to do complex calculations, those have to be done server side. The following table shows the most relevant user needs of mapmakers.

Information	**data**
Glider position	**Latitude, longitude, elevation,** acceleration, heading, roll, pitch, jaw
Metadata	**Competition id, registration number, pilot name, glider type,** glider parameters, blood type, age, nationality
Ranking	**Real-time ranking list**
Delaying	**Continuous data with delays (10-20 min) is preferred**

Table 1: User needs derived from case study 1

3.1.2 Mobile app for rescue team

The rescue team needs are eventually very simple. They are interested in the landing coordinates and the time when the landing happened. If the connection is lost, they want to know the last known position with time stamp. If rescue authorities are involved like ambulance, police etc., they are also interested medical information about the pilot like blood type, allergies etc. Thus, the medical records of the pilot has to be available.

Rescue teams are always interested in one single pilot and not in all competitors, thus they must be able to access individually the positions and metadata. They also should not receive any unnecessary data like type of the glider, daily task, flown distance etc.

In case of a smooth outlanding event, when no accident happened and the pilot was able report his condition, only his private team needs the coordinates. In general, each team has its own car navigation where the coordinates can be entered manually and no further information is needed.

Information	**Data**
Landing position	**Last known position (latitude and longitude)**
Pilot meta data	**Blood type,** other medical reports

Table 2: user needs derived from case study 2

3.1.3 Google Glass

Google Glass (GG) are expected to be an innovative invention which can revolutionize the info communication sector. Besides obligatory instruments, there is at least one piece of navigation equipment on board, but they are barely interoperable with the real-time tracking systems. Using GG would help the pilots to focus more on flying. GG are connected to smartphones, thus via smart phones, the exchange system can be reached. The nearby opponents and team members can be shown on the GG and would facilitate the job of the pilots. The GG have relatively small information displays and it works as a location based service. Hence, only data is needed about the nearby gliders, thus the system must support partial data streaming.

The users of the GG are the pilots and they are asking often these questions:

- How far are the others and what are their directions?
- If they are thermaling, what is their vertical speed?
- How far is the next turn point and in which direction?

To answer these questions, the objective is needed in combination with the real-time position of the “nearby” competitors. Since the GG has a very small display, not all the other competitors can be shown. It cannot be decided yet, which is the best to show: those who are very close and may be observed by eye, or those who are far, but within a reachable distance. Therefore, it is suggested that GG receives everybody’s real-time position and an algorithm decides what is shown.

But it is very important to know the vertical velocity accurately because if other competitors found a much stronger thermal, the pilot may want to move there. To calculate the velocity an accelerometer is required. For the accurate orientation, the ground heading is required.

The true heading shows the motion of a glider, but due to the wind component, the glider flies a bit tilted, against the wind (Figure 9). That is called ground heading. This means, the real-time tracking devices must have an internal compass, which can provide a reference.

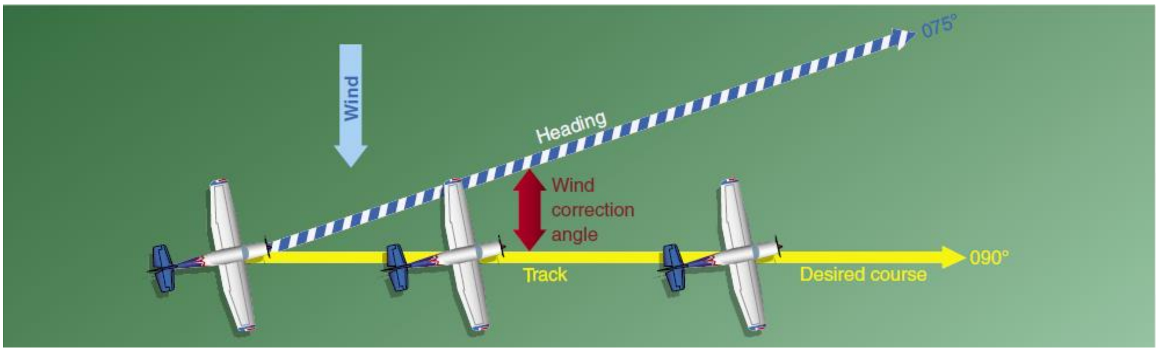


Figure 9: Effect the wind on the heading

Information	**Data**
Positions of nearby competitors	3D coordinates with vertical speed and acceleration
Self 3D orientation	Own roll, pitch and yaw

At the start of the research in September, 2013, GG was a very innovative product with promising utility. Unfortunately, the Google Glass developer team announced that the Glass Explorer Program shut down on 19th January 2015 and public sales of the current state of GG are terminated (Google Glass, 2015). Several rumours circle on the internet about the reason, however these are scientifically irrelevant. None of the rumours contradict the possible usefulness of GG in gliding.

3.2 Interview based analysis

Since this vision exchange mechanism is designed to use by third parties, therefore attempts were made interviewing possible users of it. The driven principle of the selection criteria was to find interviewees, who are familiar with aviation, preferably with gliding, and simultaneously familiar with GIS: No such a person has been found yet. Therefore, the constraints become less strict: the interviewee either must be GIS developer and shows interest for gliding or he has to be familiar with gliding and have a very good sense using IT devices like PDAs, PNAs etc. In the first cases, a crew member of a glider pilot was interviewed. In the second case, two GIS developer was interviewed.

3.2.1 First interviewee: mobile app for outlanding

The first interviewee wants to develop an app for the pilot's supporting team notifying if outlanding happened. If the competitor was able to complete the objective and returned, the support team has radio and visual confirmation, therefore its usefulness is limited only for outlanding events.

The developer said, that direct continuous communication between the mobile app and the server is unnecessary. He expects an SMS from the central server which contains the relevant information. His app is running in the background and that app is able to recognize that SMS and it offers a navigation to the outlanded pilot. The interviewee is not interested in the communication between the server and gliders nor the on board devices used.

This means, the exchange mechanism must be able to detect if a glider is landed and the mechanism must be able to send an SMS. Smartphones are able to read incoming SMS and perform actions, if these messages contain commands within, for example using the Redmond Pie application (Redmond Pie, 2014). To summarize, the interviewee as a user expects only an SMS, which is already a standard. Therefore no GIS standard has to be used between the users and a server, but the communication between the server and the glider is not discussed. The following diagram shows the exchange mechanism.

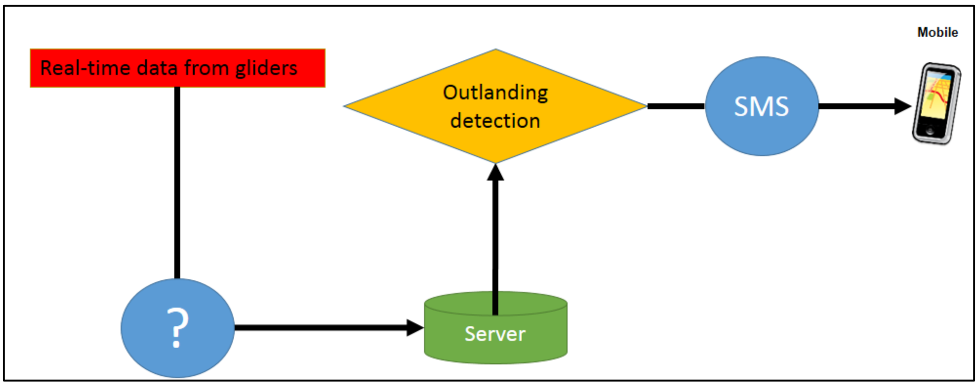


Figure 10: Outlanding mobile app based on user needs

3.2.2 Second interviewee: professional developer

The second interviewee would like to design a webpage for public entertainment. He is unfamiliar with gliding and its characteristics but he sees its potential. Because of this, he cannot give any answers on the exchange mechanism between glider and the surface. Due to the nature of the real-time manner of the information, he suggests using AJAX (Asynchronous JavaScript and XML) calls. It is because of the fact that the ability to fetch information from a remote server in anticipation of the user's action and provide interaction without the need to refresh the whole Web page. This changes the user experience dramatically and makes the Web application more similar to a desktop application where the interaction mode is smooth (Zucker, 2007). He is familiar with the GeoJSON and therefore wants to receive the information in this format. He suggests using MapServer for data streaming.

He wants to receive data in a point cloud so he can build the track lines from the point cloud. It is because the continuous communication is not guaranteed between the glider and the server. He is only interested in the last known location which has point geometry, he does not want to show the tracks of the gliders. He would like to reduce the requested information to the minimum, he only needs the coordinates and the elevation. He also explained that he is not familiar with glider specific data, but he does not want to receive calculated data, for example ground speed. He also expects accessing data about the gliders and pilots objectives.

However, as he is unfamiliar with gliding he cannot suggest data formats. The following figure depicts his ideas.

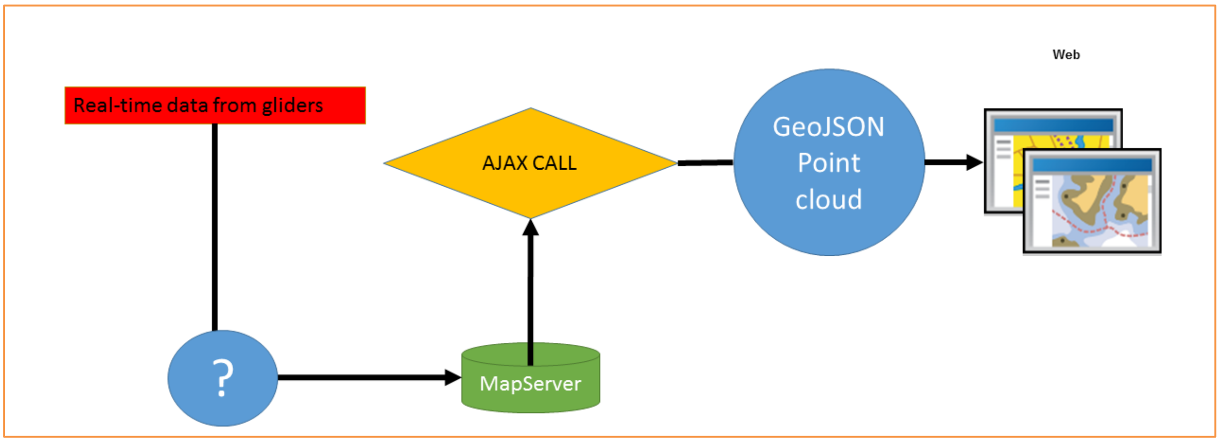


Figure 11: Design of the professional developer

3.2.3 Third interviewee: Lazy developer

The third developer considers himself as lazy developer because he does not want to do any calculation on the data. He says that he wants to use WMS and customize it using Styled Layer Descriptors (SLDs) because SLDs allow you to publish various symbolization schemes for your WMS service using an XML specification defined by OGC (ArcGIS Server .NET Help, 2013). He expects also receiving the completions task declaration form the server as a WMS layer. He says that .getFeatureinfo request satisfies all his requirements. The last demand of this developer is a real-time video streaming from gliders which can be embedded in web pages. He suggests GeoServer as backend because it is able to maintain WMS. His schematic ideas are pictured below.

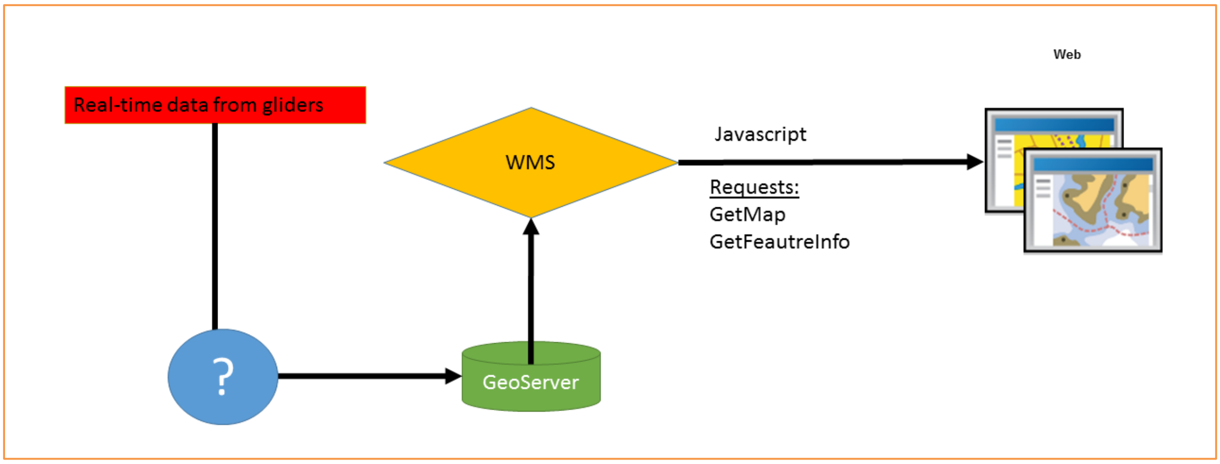


Figure 12: design of the lazy developer

3.2.4 Fourth interview: Optin Ltd.'s hardware developer

The fourth interviewee designed the IRIS on-board device which was used for the test flights. This interview focused on the communication between gliders and the ground. This interview was done during the test flights, this allowed for interaction between the interview and the results of the test flight as they unfolded. It became clear that one single IRIS device cannot satisfy all requirements. It was explained to him that there exists a device which is called Flarm was also explained that Flarm can be attached to the official flight recorders (FR). FRs can have NMEA outputs (see NMEA document). The interviewee said that IRIS devices can be developed to understand NMEA sentences receiving from FRs, or it may can be attached directly to Flarm. If it is the case, they can design a so called gossip network where nearby gliders need only one communication channel. Therefore, gossip network was discussed within the literature review section.

3.3 User needs analysis based on test flights

As part of this research a cooperative party was found which provided its infrastructure for real time tracking. The company is Optin Ltd. (Optin), its headquarters is located at Szeged, Hungary. Their real time tracking system is designed for car or truck tracking. Their infrastructure was still under development and commercially not available during this research. This chapter describes the devices, hardware and software provided by Optin and gives an overview of the acquired datasets. This chapter explains the issues experienced. It is beyond the scope of this research conducting deep statistical analysis on the acquired data.

Test flights were done using two different solutions provided by Optin. One was the self-made, so called IRIS device (see next section, 3.3.1), and an app developed by Optin for Android. In all tests an official flight recorder was carried collecting reference data (Figure 13). The hosting airport of the test flights was Airport Szentes, Hungary and flights were conducted within the country, in a 100 km radius of the airport. This area is flatland, without any significant elevation. Take-offs and landings happened at Szentes, except in the event of an outlanding.

Optin Ltd. provided very strong support during the test flights. If any issues occurred with the devices, two or three people would work on the problem remotely if possible. Around 10-15 flights were conducted using an IRIS device together with the official flight recorder, but the mobile app did not work satisfactorily and no useful data was captured by the mobile app. Therefore, the nature of the mobile app is not described, but it did not influenced negatively this research.

Figure 13: Flight recorder (left), radio and navigational PDA (middle) and IRIS (right) with extra batteries

3.3.1 IRIS device and On.Gouard

Optin Ltd. provided two of its own built IRIS devices. IRIS is a GNSS receiver attached to a GSM module. The GNSS antenna is externally attached to the device and it is located inside the cockpit, on the top of the dashboard for a clear view (Figure 14). IRIS is capable of real-time streaming the location and caching the data if the signal is lost.

IRIS is designed for cars, therefore IRIS should be attached to the ignition circuit. If the car's engine is started, it signals the "ignition on" event to IRIS and data collection starts with a one second frequency. If the engine stops, IRIS goes to standby mode and only sends data every 10 minutes. Since a glider does not have an engine[5], therefore no ignition circuit is available. Two custom solutions were made by the hardware developer team; they are explained in Appendix C/C.2. Several issues occurred during the test using these devices, which are listed in the next section, 3.3.3.

Both IRIS and the mobile app are attached to the On.Guard object surveillance and telemetry service developed by Optin (Optin Ltd., 2014). It visualizes the data received from the kinds of devices using customized Google Maps. On.Guard was under development during the test flights, but in some cases the glider's real time location was well visible.

[5] Some gliders do have an engine, but their engine is only used for take off, or to avoid outlanding. It is shut down after take-off; or turned on in the last minute in order to avoid outlanding. The „ignition-on" or „ignition-off" signal would not make any sense in case with IRIS.

Figure 14: IRIS device external GNSS antenna (left) and IRIS device next to navigational PDA

3.3.2 Acquired data

Result data were provided in comma separated (CSV) files. Optin provided the datasets per day and per device. Writing the CSV file starts when connection to the GMS network is successful and lasts until the GSM signal is lost. If IRIS reconnects to the GSM network, it results in a new CSV file. Since one device was used multiple times per day, with multiple gliders, reference IGC files serve as a good basis for matching the logged tracks with the glider and pilot.

Each file starts with a header which lists the coma separated column names of the data. Since the captured attributes change over the time, a new headline is inserted, in case of attribute changes. Changes occur in case of events, for example in case of low battery, if the connection is lost, if the panic button is pressed, etc. An example is provided in Appendix C/C.1: The most important attribute information of a point is listed below:

- *moduleid:* ID of the used device.
- *timpestamp: point capture time in UINX time format*
- *gpsbasiclat*: WGS84 latitude
- *gpsbasiclon*: WGS84 longitude
- *gpsbasicalt*: GNSS altitude
- *gpsbasicspeed*: GNSS speed
- *gpsbasiccourse*: GNSS basic curse
- *gpsaccuracysats*: GNSS accuracy statistic
- *gpsaccuracyqos*: GNSS accuracy QOS,
- *carriercsq*: service signal level
- *gpsaccuracyhprecision*: vertical GNSS accuracy

IRIS has several other hardware specific attributes, some of them, but not all are described. IRIS has an inbuilt sensor which determines if the device was opened and exposed which is called the sabotage attribute. IRIS gives warnings, if its internal or external voltage become low *(externalvoltagelow, internalvoltagelowvoltage*), and IRIS measures the internal and the external battery level. IRIS measures the GSM network service strength *(carrier.csq*).

Optin Ltd. provided a lot, but unstructured data. Several steps were taken to make the data more useful. Split data was merged using timestamp as the primary key. Python was used to convert the Optin universal unix format to a readable format. In addition, it is known that many segments are missing from flights. Otpin Ltd.'s algorithm automatically ties the missing segments with a straight line. In such cases, the data had to be checked manually and those straight segments had to be deleted. Reference IGC files are used to determine when a flight started and ended, besides the glider and pilot can be read out from IGC files.

3.3.3 Issues

IRIS strongly interferes with communication FM radio when data transmission is in progress using the GSM network[6]. This is very strange because cell phones do not have such an issue. Hardware developers had some guesses, but this issue remained unresolved. Due to these radio issues, pilots needed to manually turn off IRIS that resulted in discontinuous tracks.

The web based map viewer (On.Guard) was working twice perfectly during the test. In the other cases, it was under development, therefore the real-time tracking was barely visible. However, IRIS has an SD card, and therefore data loss rarely occurred.

Due to a lot of signal losses and reconnections, both IRIS and smartphones crashed the backend servers sometimes. This caused the Android app to not work well.

Both IRIS and On.Guard are connected to the same database, therefore they are using the same data format namely CSV. These .csv file are easy to understand, however they are not compatible with any GIS software because Optin's protocol is not compliant to GIS-readable standards. Track files are split into separate CSV files if a signal is lost. After a signal is lost, devices cache the data and try to restream, to check if there is service again. A problem occurs if many data is cached and those data are streamed together with the real-time data. This can cause inconsistency which means the cached data is older than the newer data. As a conclusion, captured data must be in the order of the timestamp.

The official flight recorder uses both GNSS altitude and barometric altitude. Barometric altitude is more accurate than GNSS. Improving the accuracy of the captured data, barometric altitude can be used to enhance the precision of the altitude attribute of the captured data.

It is a source of issues because the capture frequency for the test data is 1 second and the reference data varies, but always less than 10 second. Either the reference data has to be densified or the test data has to be simplified.

Service signal loss caused lot of issues with the caching algorithm. The complete system only worked with the IRIS, but not with the mobile app. Optin has no other negative experience with caching at signal losses, only these test flights were problematic. These facts call for analysis about the service strength in the air, however that is beyond the scope of this

[6] Flying a glider without radio is allowed in some circumstances. Airports Szentes does not oblige radio communication, but it is always better to have one. Test pilots avoided any airspace where radio communication was obligatory and air traffic regulation was never violated.

research. One obvious factor is the altitude: the higher the altitude the lower the signal strength, this could be stated as a clear hypothesis. Another factor comes from an observation during the tests: if gliders were flying above urban areas signal loss rarely occurred, not even at high altitudes. Whether there is any correlation between signal strength and urban areas is subject to further research. At the time writing of this thesis there was no research found on focusing the vertical distribution of the signal strength. However, Popoola and Oseni (2014) did a research on a similar subject, where they investigated how GMS electromagnetic wave propagations through space is influenced by terrain contours, environment (urban or rural), the distance between the transmitter and the receiver and the height and location of antennas. Unfortunately, the research only focused on the horizontal distribution of the GSM network, but not the vertical.

3.3.4 Summary

The test flights were very useful to understand how a third party's device can be used for glider tracking. It became clear, that self-constructed GSM based devices may compromise the instruments of a glider, in this case the radio. Therefore their usability is questionable. Further GSM based devices should be tested, because cell phones do not cause any issues.

Another relevant issue is that any device must have a very good caching algorithm because of the frequent service losses. Further analysis is recommended about finding correlation between the GSM service strength and the terrain or the altitude.

4 Conceptual modelling of a tracker system

4.1 Vision of a future OGC standard

The sport aviation agencies (FAI, FAI-IGC) have their own open specification (IGC) for tracking gliders, but it does not explicitly support real-time tracking. However, IGC already supports the NMEA format in several manners. The official flight recorder (FR) supports both NMEA input and output. Furthermore, the IGC file format supports logging nearby aircraft, which can be very useful information.

Section 2.1 described that the aviation authorities already made very good progress in open aviation information exchange mechanisms, but those are designed for commercial aircraft. Since gliders are strictly separated from commercial aircraft, it would be unwise to broaden the scope of any of these exchange formats (AIXM, WXXM and FIXM) to glider competitions. Furthermore, these exchange models consider one aircraft as a single entity, but in case of gliding the competition circumstance cannot be neglected. Competitors should be treated together and not one by one. It is very advantageous that these standards are based on GML because it is well known in the GIS community.

The previously discussed standards are provided by OGC, and OGC offers several well-known GIS standards (WFS, WMS) for disseminating data. Furthermore, OGC has standards for sensors, which are capable of real-time data communication between sensors, server and clients. Using the advantageous parts of these standards for establishing a new standard as a part of the Aviation Information Management branch of OGC, for example as a Glider Information Exchange Model (GIEM, Figure 15).

Similar to AIXM, FIXM and WXXM, GIEM should be based on the GML data format. GIEM must be compatible with the IGC file format remaining interoperable with the official glider standard. The content of the new standard has to take into account the Three Letter Codes of IGC (Appendix A.3). The second relevant and obligatory part of this new standard supports the data storage based on gossip network (see section 2.7 and section 4.3). FAI and FAI-IGC have to play a significant role in working together with OGC on this standard. External parties, like OGN should be invited for such a standard. Other parties like EUROCONTROL and FAA should be involved, if this standard should be connected to the different air traffic control authorities[7].

[7] There are several levels of controlling the air traffic, but this is beyond the research scope.. To give information about the known air traffic is one task of air control, but not the only one. Gliders are usually not controlled by air traffic.

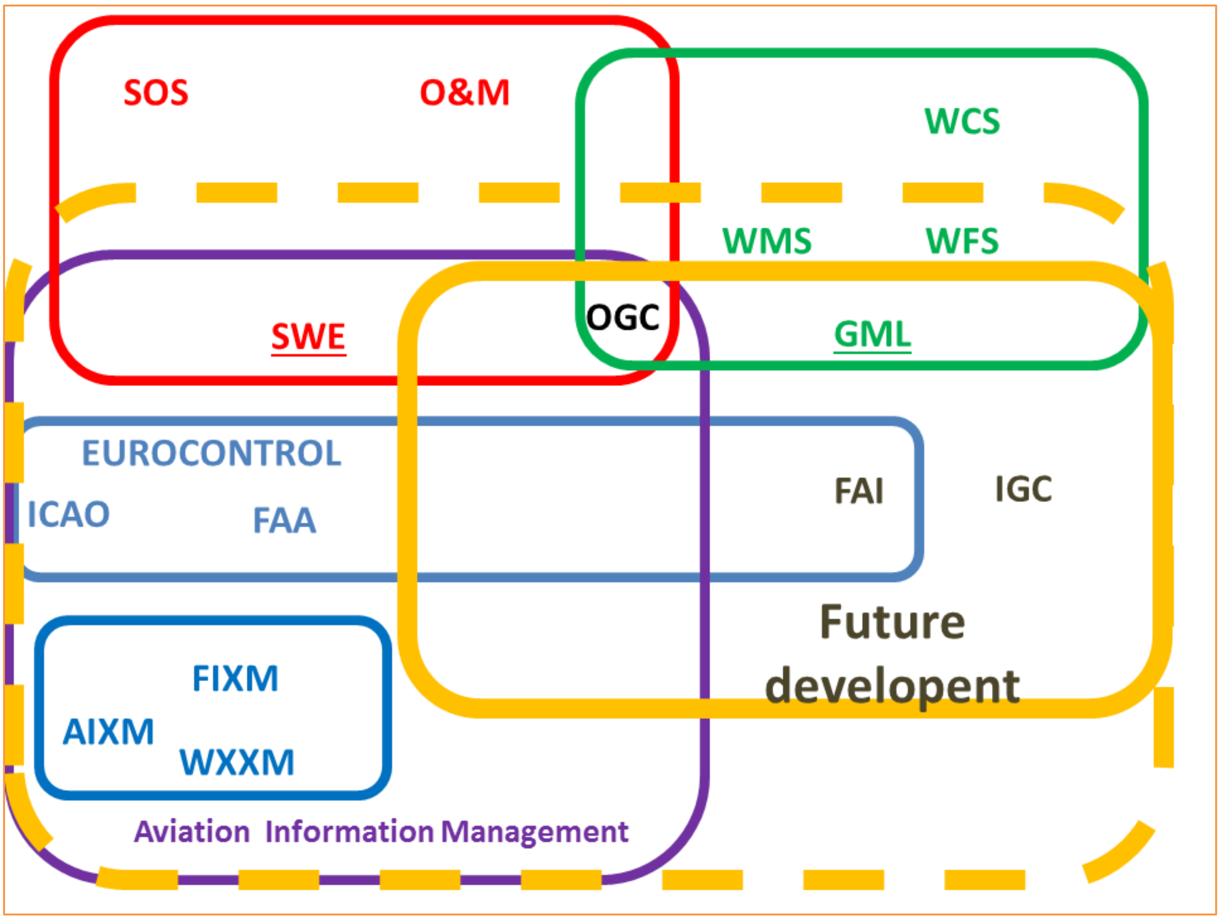


Figure 15: Vison of a new OGC standard: Glider Information Exchange Model

4.2 Architecture

Based on the currently available open GIS software, standards and programming languages, a generic architecture is described. The architecture is centred around GeoServer and PostGIS database software because both are able to understand several standards for both input and output. The SWE framework is used to receive data from gliders and store them in a PostGIS database. GeoServer is used to process the incoming information and provide services like WFS or WMS or create GML. Users can also retrieve glider data using the SOS standard accessing glider data as sensor data, in this case no data processing is done. How the users interpret a WFS service or a GML is not dependent on the exchange mechanism.

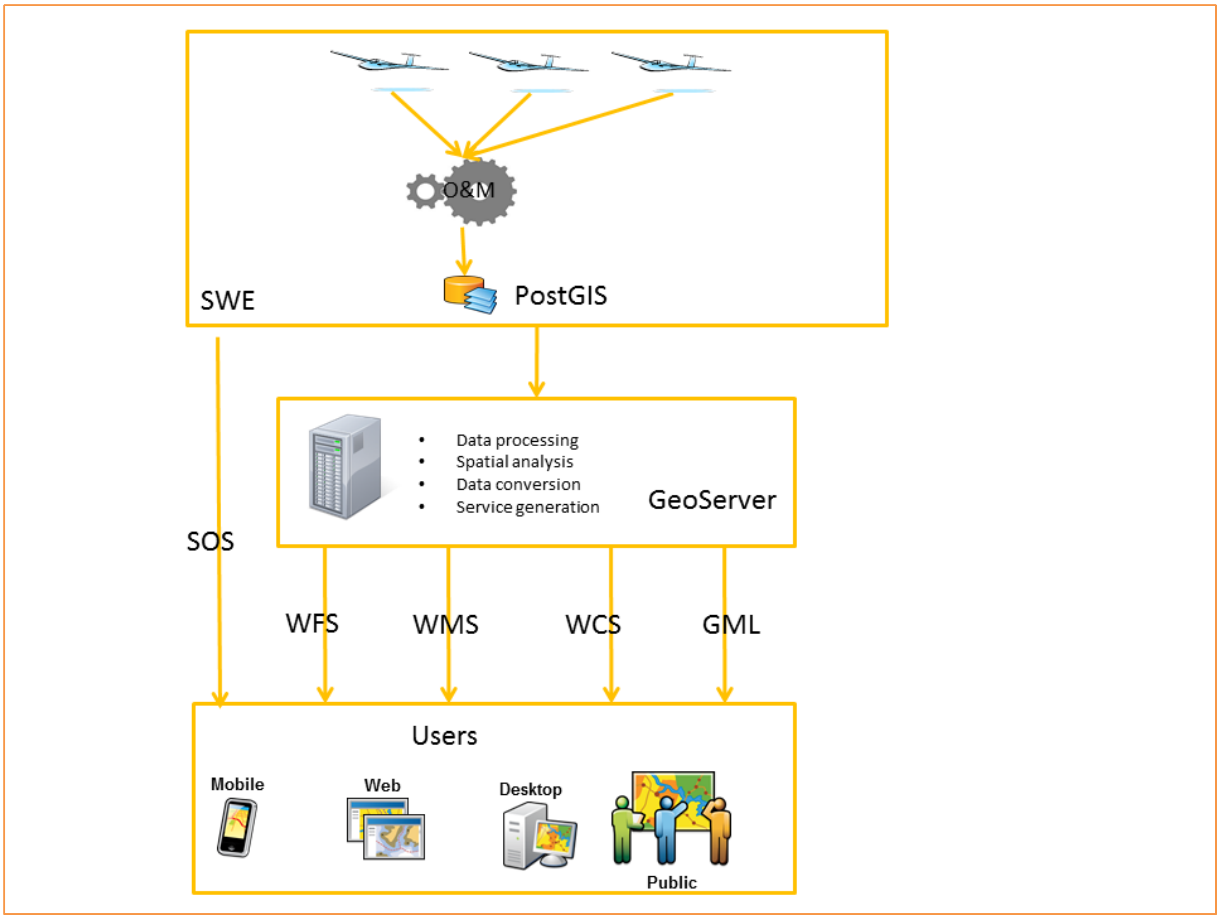


Figure 16: Proposed architecture

4.3 Real-time data integration – Gossip network based system

A gossip network based sensor system can be sustained by just using a mobile network communication channel between the air and the ground. It requires that all the gliders are part of a network, an imaginary single graph. The nodes in this graph are the competitor gliders and the edges are the direct two-directional links between gliders in the air. Theoretically, only one node requires a mobile network communication to the ground. This implies that the higher the number of participants, the higher the chance of sustaining this communication channel between the gliders and the ground.

However, no existing Flarm or ADS-B transponder supports this concept: Flarm only shows nearby aircraft, much in the way a traditional radar would show information, but no other aircraft which are farther away. Unlike a the imaginary graph, which shows all aircraft that are connected in the network through proximity.

This exchange mechanism shell supports the information exchange between a glider and the ground where information is not only provided about the source glider, but also about those gliders in the vicinity of the source glider. The following example explains it:

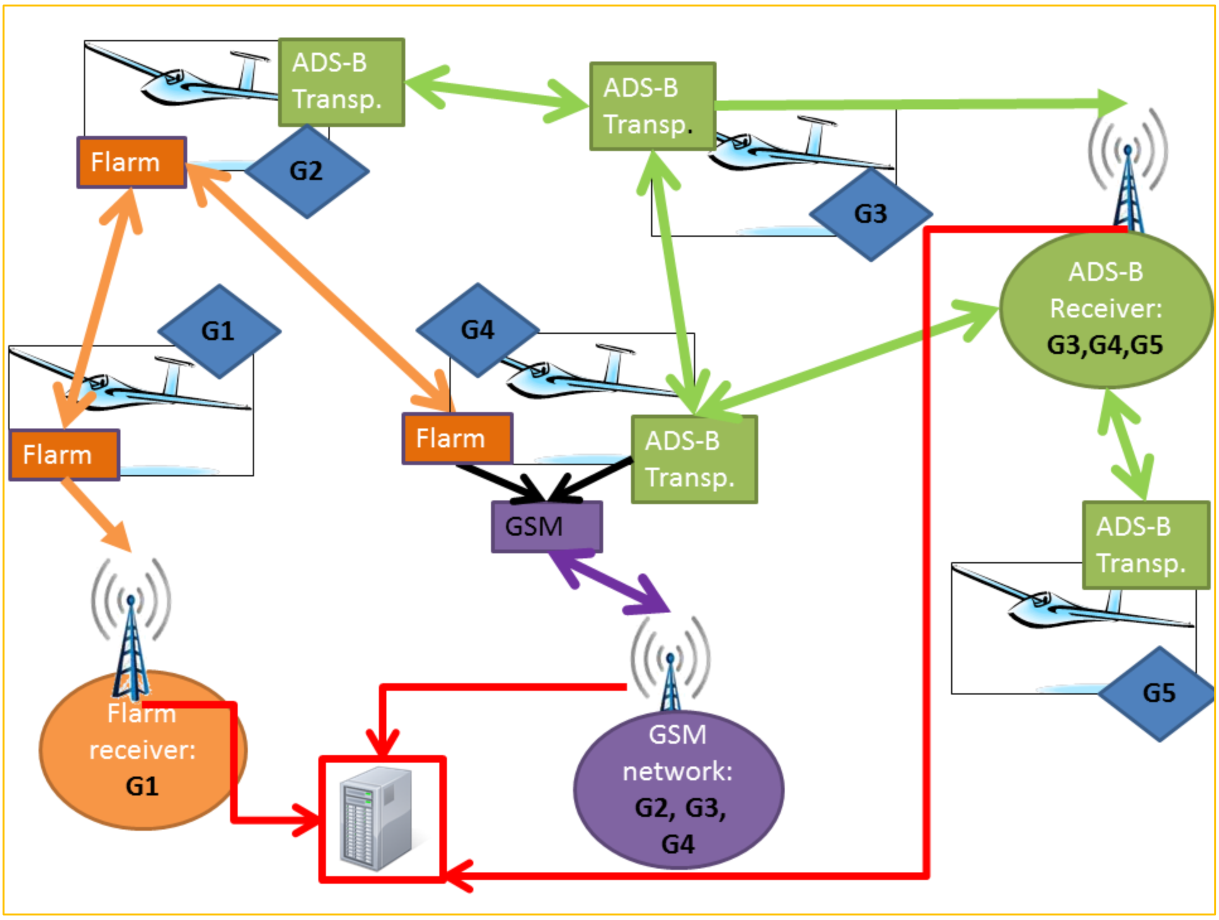


Figure 17: gossip network example

In this give example, the G1, G2 etc. represents gliders. Colours represent the communication channel between gliders and the ground. Orange means Flarm is used as the communication channel, green means ADS-B transponders are used as communication channels and purple means GSM (mobile) network is used as communication channel.

Receiver towers represent the ground and list those gliders which can be seen by each tower. Arrow heads indicate if the connection is one-directional or bidirectional. Flarm and ADS-B receivers are one directional, but GSM network is bidirectional.

Those gliders which are not connected, but which have a common device on board (e.g. G4 and G5), show that not everybody can see everybody because they are out of the each other's range.

The key of the example is that G4 has both devices ADS-B and Flarm, and those are connected to a GSM module which is able to send not only the G4's location but, according to the hypothesis, also sends the surrounding glider's locations. Therefore G2 become visible, otherwise it would become invisible in spite of it being equipped with both transponder and Flarm.

Since all those ground stations already exist, they can be connected to a central database where the need for a standard comes in. ADS-B and Flarm have a different format, besides data stream via GSM which contains multiple glider's location are not yet defined. That can be using the IGC file format option, although it is not the best solution.

This example also points out the data redundancy, because information about G3 and G4 are twice received, once as data of the transponder and another as data from a GSM module in a different format, maybe even with different information.

4.4 Relevant issues and potential solutions

There are several issues for what purpose the previously envisioned standard can be used. A collection of issues can be derived from software, which are able to process IGC files. The results of processed IGC files show, what kind of data can be extracted from IGC files. Acquiring those kind of data in a real-time way is the purpose of the exchange mechanism.

A widely used and commercially available (not free) software is SeeYou, developed by Naviter (www.naviter.si). The advantage of SeeYou, is that it is made for pilots and easy to use, however as software itself is a very complex GIS software.

Other issues are derived from the case studies, but those solutions not merely can be used for one case study, but for more of them. They are described below (Sections 4.4.1-4.4.3). There can be other very specific user groups for these solutions like air traffic control, competition organizers, but their exact needs were not discussed on a very detailed level. For example, overlaying real-time glider data with thematic layers or calculating statistics of competitors can be used for both Case study 1 (section 1.4) and Case study 3 (1.6). Air traffic control can overlay glider data with their own solution, but the way they would do is their responsibility.

4.4.1 Thematic layers

For glider pilots and experts meteorological layers are very important. One good collection of meteorological maps for Hungary is provided by the "Self-Briefing" site of Eötvös Lóránd University (http://meteor24.elte.hu/wrf/self_briefing/). This site is developed for glider pilots, those maps are collected which are relevant for glider pilots. These maps are freely available for everyone, but they are images, they are not georeferenced. A graphical overlaying was done, (see Figure 19 and Figure 18) using the prototype flights from section 5. In an ideal case, if these maps would be available via WMS for the users of the exchange mechanism (e.g. cartographers), than users could combine it with real-time positions.

For the organizer team and air traffic control, the official aviation chart is relevant (Figure 20). They can see if any participant accidently entered restricted or prohibited areas and they can warn accordingly.

3D visualisation of GIS data is a relevant topic in these days and several program exists visualizing 3D data. Since gliders have always 3D aspects because they are rising and sinking continuously (Figure 21).

Flightradar24 is a website (http://www.flightradar24.com), which allows people real-time track commercial aircrafts, according to flight number. If they want to broaden their scope integrating glider tracking, an example map was created.

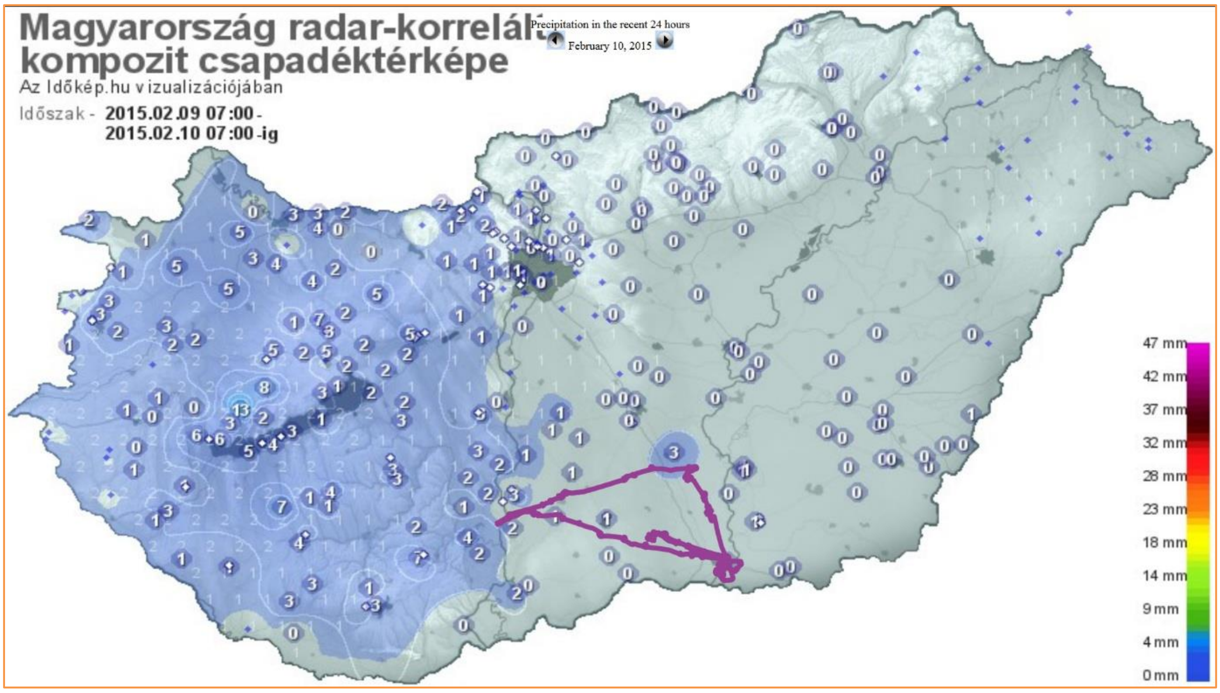


Figure 18: radar correlated composite precipitation map of Hungary

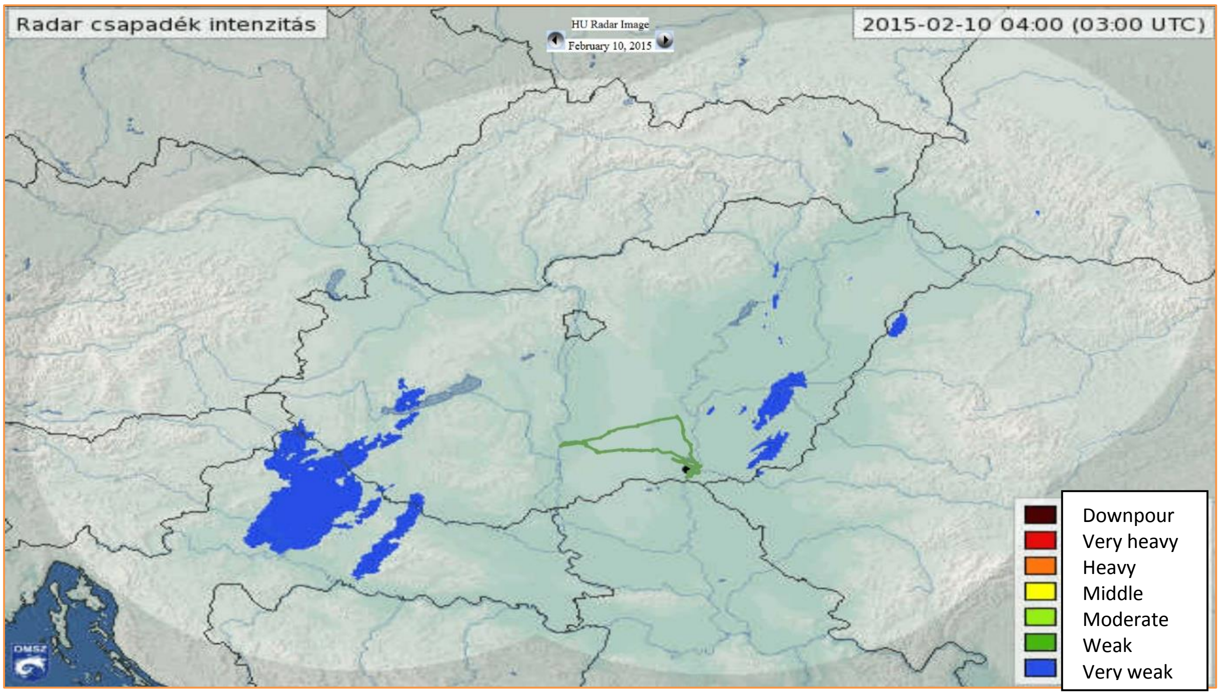


Figure 19: Radar based precipitation intensity of Hungary

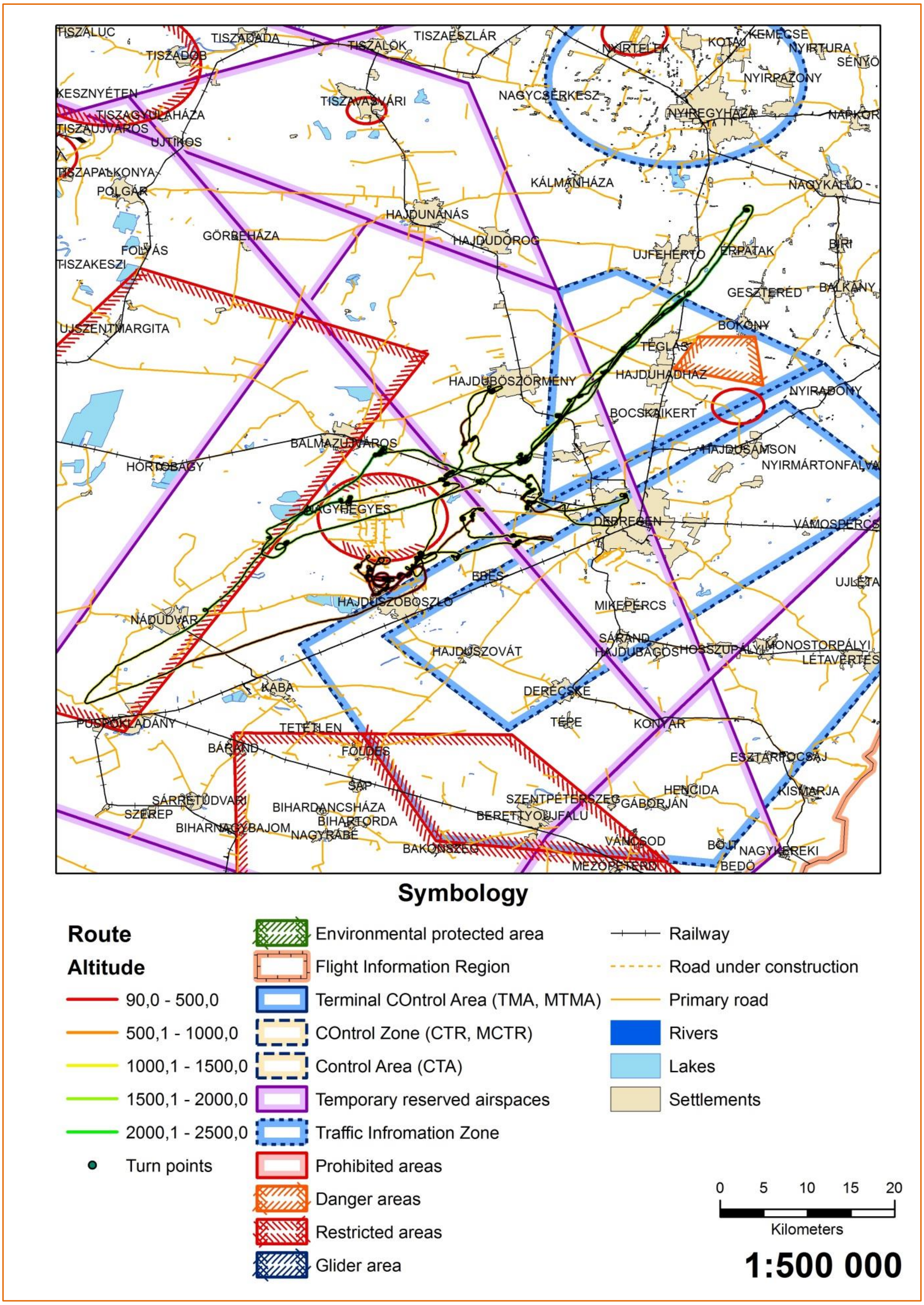


Figure 20: Aviation Chart

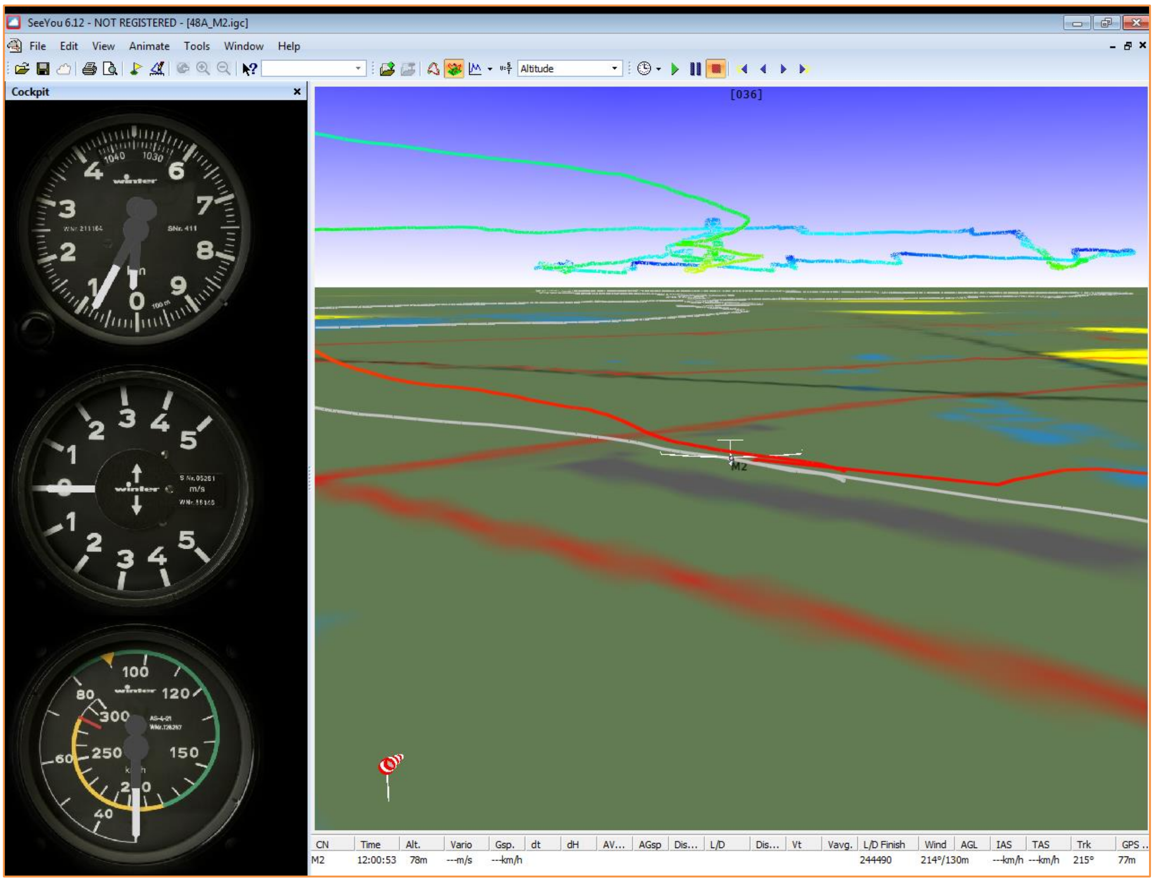
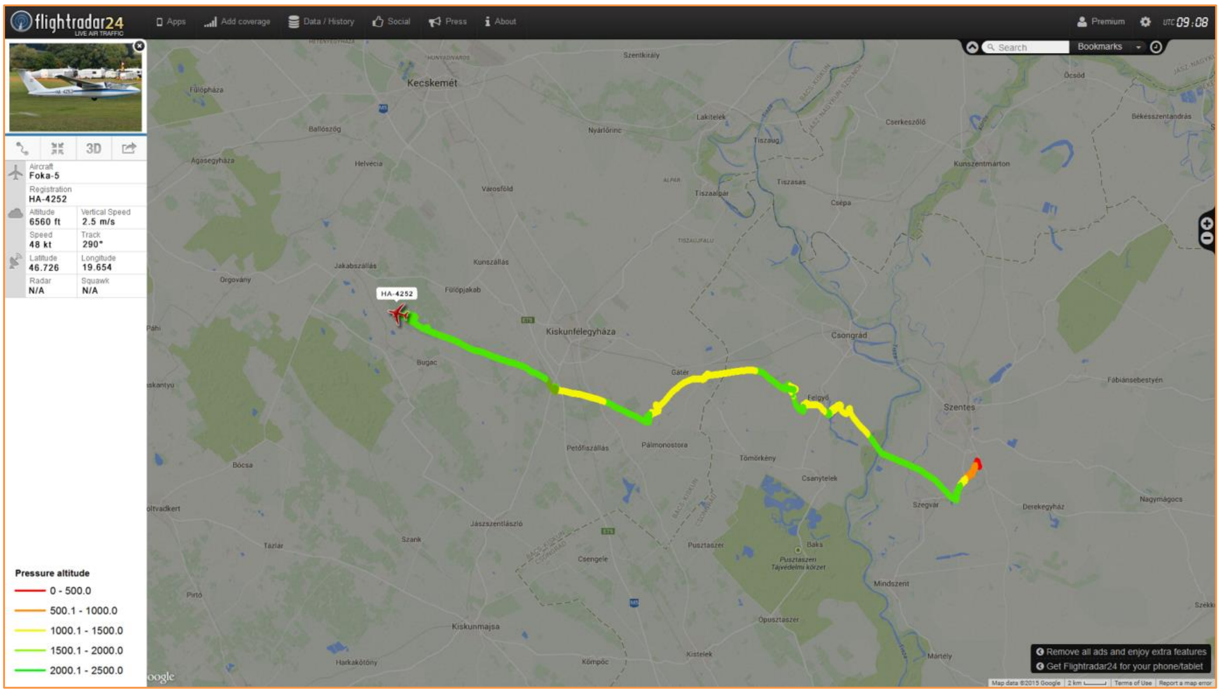


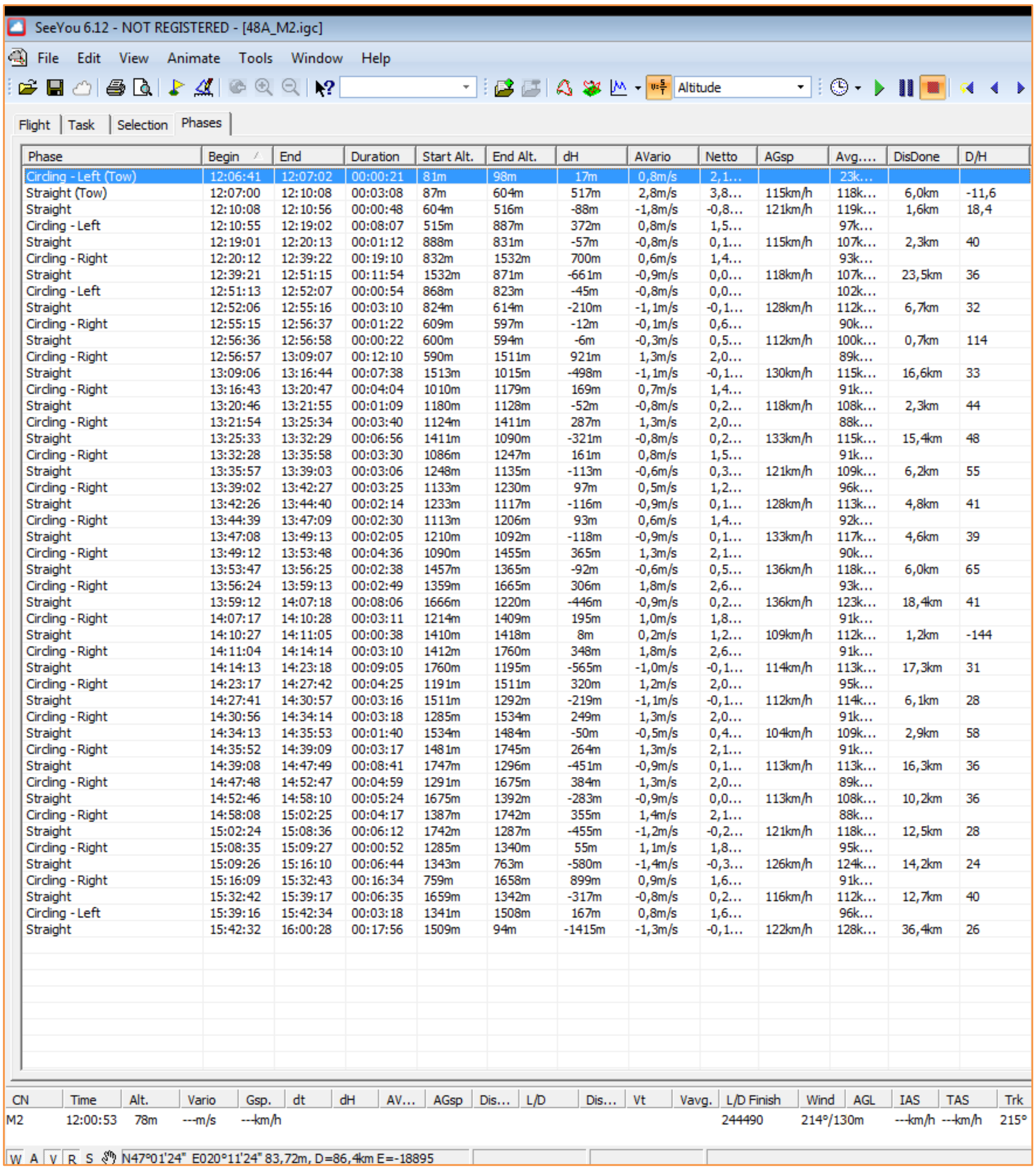
Figure 21: 3D visualisation of a single flight



4.4.2 Glider statistics – thermaling

SeeYou gives a very nice statistical overview how the daily task was completed. Most of these attributes can be calculated in a real-time manner, furthermore streaming back to competitors in a real-time can significantly influence the competition (Figure 23: Statistical data of a task).

For experts in gliding, the top most relevant information is how a pilot can catch thermals and how fast can he gain elevation. Besides, it is very interesting having a real-time statics about current average strength of a thermal. If a pilot is only climbing with 1 m/s, but the current statics says that others are able to climb with 3 m/s, than the pilot should find a stronger thermal. This exchange mechanism provides the possibility for experts calculating more and more accurate statistic about thermals in a real-time manner (Figure 22).



Phase	Begin	End	Duration	Start Alt.	End Alt.	dH	AVario	Netto	AGsp	Avg....	DisDone	D/H
Circling - Left (Tow)	12:06:41	12:07:02	00:00:21	81m	98m	17m	0,8m/s	2,1...		23k...		
Straight (Tow)	12:07:00	12:10:08	00:03:08	87m	604m	517m	2,8m/s	3,8...	115km/h	118k...	6,0km	-11,6
Straight	12:10:08	12:10:56	00:00:48	604m	516m	-88m	-1,8m/s	-0,8...	121km/h	119k...	1,6km	18,4
Circling - Left	12:10:55	12:19:02	00:08:07	515m	887m	372m	0,8m/s	1,5...		97k...		
Straight	12:19:01	12:20:13	00:01:12	888m	831m	-57m	-0,8m/s	0,1...	115km/h	107k...	2,3km	40
Circling - Right	12:20:12	12:39:22	00:19:10	832m	1532m	700m	0,6m/s	1,4...		93k...		
Straight	12:39:21	12:51:15	00:11:54	1532m	871m	-661m	-0,9m/s	0,0...	118km/h	107k...	23,5km	36
Circling - Left	12:51:13	12:52:07	00:00:54	868m	823m	-45m	-0,8m/s	0,0...		102k...		
Straight	12:52:06	12:55:16	00:03:10	824m	614m	-210m	-1,1m/s	-0,1...	128km/h	112k...	6,7km	32
Circling - Right	12:55:15	12:56:37	00:01:22	609m	597m	-12m	-0,1m/s	0,6...		90k...		
Straight	12:56:36	12:56:58	00:00:22	600m	594m	-6m	-0,3m/s	0,5...	112km/h	100k...	0,7km	114
Circling - Right	12:56:57	13:09:07	00:12:10	590m	1511m	921m	1,3m/s	2,0...		89k...		
Straight	13:09:06	13:16:44	00:07:38	1513m	1015m	-498m	-1,1m/s	-0,1...	130km/h	115k...	16,6km	33
Circling - Right	13:16:43	13:20:47	00:04:04	1010m	1179m	169m	0,7m/s	1,4...		91k...		
Straight	13:20:46	13:21:55	00:01:09	1180m	1128m	-52m	-0,8m/s	0,2...	118km/h	108k...	2,3km	44
Circling - Right	13:21:54	13:25:34	00:03:40	1124m	1411m	287m	1,3m/s	2,0...		88k...		
Straight	13:25:33	13:32:29	00:06:56	1411m	1090m	-321m	-0,8m/s	0,2...	133km/h	115k...	15,4km	48
Circling - Right	13:32:28	13:35:58	00:03:30	1086m	1247m	161m	0,8m/s	1,5...		91k...		
Straight	13:35:57	13:39:03	00:03:06	1248m	1135m	-113m	-0,6m/s	0,3...	121km/h	109k...	6,2km	55
Circling - Right	13:39:02	13:42:27	00:03:25	1133m	1230m	97m	0,5m/s	1,2...		96k...		
Straight	13:42:26	13:44:40	00:02:14	1233m	1117m	-116m	-0,9m/s	0,1...	128km/h	113k...	4,8km	41
Circling - Right	13:44:39	13:47:09	00:02:30	1113m	1206m	93m	0,6m/s	1,4...		92k...		
Straight	13:47:08	13:49:13	00:02:05	1210m	1092m	-118m	-0,9m/s	0,1...	133km/h	117k...	4,6km	39
Circling - Right	13:49:12	13:53:48	00:04:36	1090m	1455m	365m	1,3m/s	2,1...		90k...		
Straight	13:53:47	13:56:25	00:02:38	1457m	1365m	-92m	-0,6m/s	0,5...	136km/h	118k...	6,0km	65
Circling - Right	13:56:24	13:59:13	00:02:49	1359m	1665m	306m	1,8m/s	2,6...		93k...		
Straight	13:59:12	14:07:18	00:08:06	1666m	1220m	-446m	-0,9m/s	0,2...	136km/h	123k...	18,4km	41
Circling - Right	14:07:17	14:10:28	00:03:11	1214m	1409m	195m	1,0m/s	1,8...		91k...		
Straight	14:10:27	14:11:05	00:00:38	1410m	1418m	8m	0,2m/s	1,2...	109km/h	112k...	1,2km	-144
Circling - Right	14:11:04	14:14:14	00:03:10	1412m	1760m	348m	1,8m/s	2,6...		91k...		
Straight	14:14:13	14:23:18	00:09:05	1760m	1195m	-565m	-1,0m/s	-0,1...	114km/h	113k...	17,3km	31
Circling - Right	14:23:17	14:27:42	00:04:25	1191m	1511m	320m	1,2m/s	2,0...		95k...		
Straight	14:27:41	14:30:57	00:03:16	1511m	1292m	-219m	-1,1m/s	-0,1...	112km/h	114k...	6,1km	28
Circling - Right	14:30:56	14:34:14	00:03:18	1285m	1534m	249m	1,3m/s	2,0...		91k...		
Straight	14:34:13	14:35:53	00:01:40	1534m	1484m	-50m	-0,5m/s	0,4...	104km/h	109k...	2,9km	58
Circling - Right	14:35:52	14:39:09	00:03:17	1481m	1745m	264m	1,3m/s	2,1...		91k...		
Straight	14:39:08	14:47:49	00:08:41	1747m	1296m	-451m	-0,9m/s	0,1...	113km/h	113k...	16,3km	36
Circling - Right	14:47:48	14:52:47	00:04:59	1291m	1675m	384m	1,3m/s	2,0...		89k...		
Straight	14:52:46	14:58:10	00:05:24	1675m	1392m	-283m	-0,9m/s	0,0...	113km/h	108k...	10,2km	36
Circling - Right	14:58:08	15:02:25	00:04:17	1387m	1742m	355m	1,4m/s	2,1...		88k...		
Straight	15:02:24	15:08:36	00:06:12	1742m	1287m	-455m	-1,2m/s	-0,2...	121km/h	118k...	12,5km	28
Circling - Right	15:08:35	15:09:27	00:00:52	1285m	1340m	55m	1,1m/s	1,8...		95k...		
Straight	15:09:26	15:16:10	00:06:44	1343m	763m	-580m	-1,4m/s	-0,3...	126km/h	124k...	14,2km	24
Circling - Right	15:16:09	15:32:43	00:16:34	759m	1658m	899m	0,9m/s	1,6...		91k...		
Straight	15:32:42	15:39:17	00:06:35	1659m	1342m	-317m	-0,8m/s	0,2...	116km/h	112k...	12,7km	40
Circling - Left	15:39:16	15:42:34	00:03:18	1341m	1508m	167m	0,8m/s	1,6...		96k...		
Straight	15:42:32	16:00:28	00:17:56	1509m	94m	-1415m	-1,3m/s	-0,1...	122km/h	128k...	36,4km	26

CN	Time	Alt.	Vario	Gsp.	dt	dH	AV...	AGsp	Dis...	L/D	Dis...	Vt	Vavg.	L/D Finish	Wind	AGL	IAS	TAS	Trk
M2	12:00:53	78m	---m/s	---km/h										244490	214°/130m		---km/h	---km/h	215°

W A V R S N47°01'24" E020°11'24" 83,72m, D=86,4km E=-18895

Figure 22: statistical data of the circling in thermals on one day

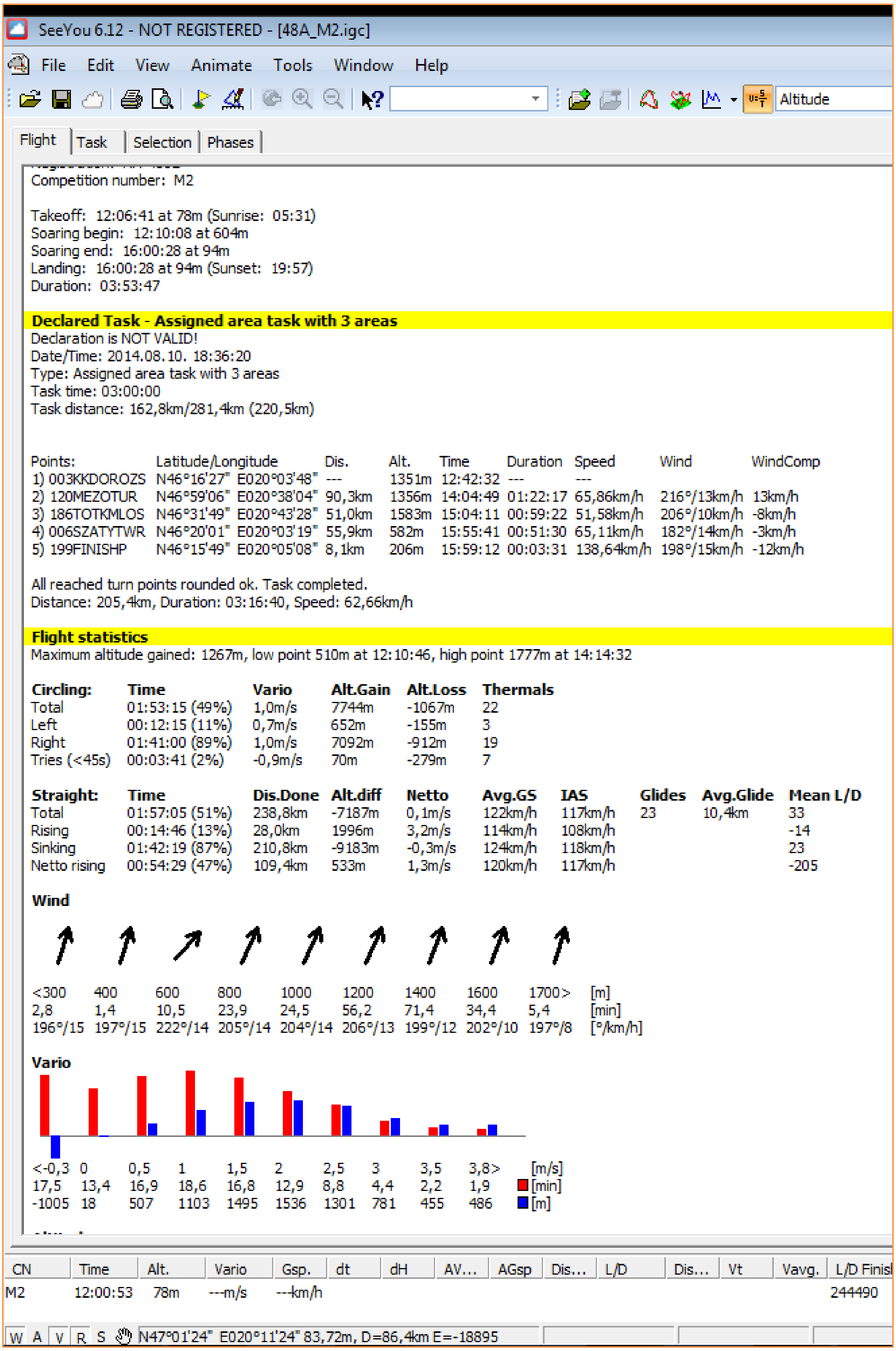


Figure 23: Statistical data of a task

All the previously collected data are point clouds with which the users of the exchange mechanism can calculate data as they want. They want to access coordinates, elevation, acceleration etc., and this exchange mechanism would be able to do so. An additional way of data visualisation is possible for example using simple diagrams (Figure 24).

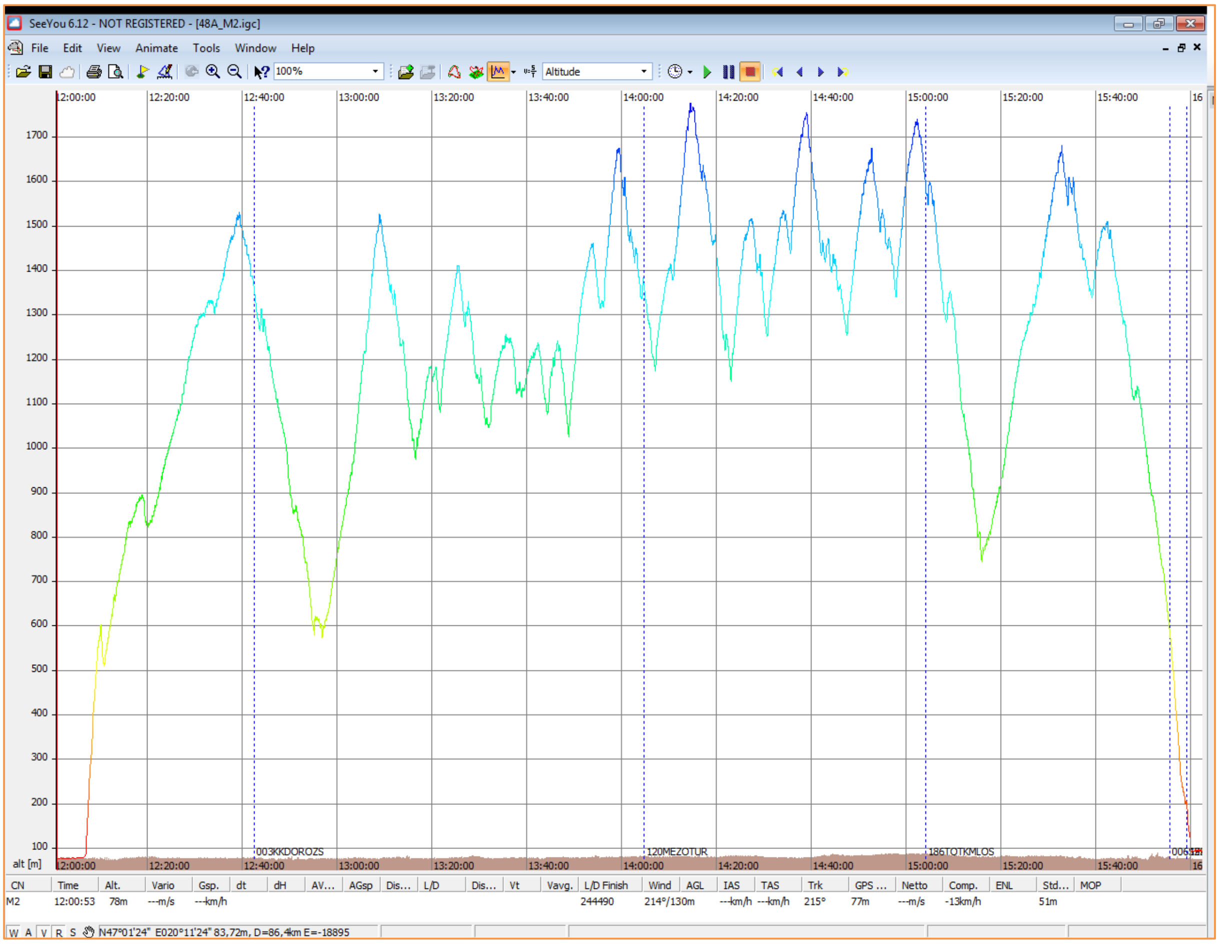


Figure 24: elevation (y) and time(x) line diagram of a flight

4.4.3 Ranking

Case study 1 mentioned the demand of real-time ranking. The author of this research doubts if any good way of real-time ranking calculation can be done, and even when it is done, it may not have anything in common with the final results. It is because ranking is based on the approximations, taking into account the average speed between two turn points, the average vertical speed in gliders and the glider's aerodynamical parameter on top of weather predictions. The problems are about predicting the locations and strength of thermals. Locations of thermals are unpredictable for a computer, pilots only use their instincts and experience because there is no numerical science behind it. Anything can trigger thermals, like lakes, single houses, power plants, black soil, farms, train stations etc. These are such small and dense phenomena, that no data is available about them.

Even if any generic thermal location predication would be available, the strength of thermals are again very important. The strength of thermals change over the day, but no two days have the same thermals. For example on day 1 there are thermals were gliders can climb up averagely 5 m/s, but on day 2 average climb rate may be between 0,5 and 1 m/s. Besides, two different gliders climb differently in the same thermal because of the different aerodynamics parameters. Furthermore, the vertical speed in thermals and between thermals is the choice of the pilot. It is because the faster he flies, the sinking speed rises[8]. Pilots have to find the optimal speed to fly with, but how can an external person describe behaviours of different pilots, if a pilot often changes his mind on this subject?

Regardless of any of these difficulties, at least this exchange mechanism allows external experts to take on the abovementioned challenge of calculating the ranking. Any results would only be an approximation. The official scores are calculated based on the official flight recorder IGC files.

[8] This is not entirely true, but discussing the correlation between vertical and horizontal speed of a glider is far beyond the scope of this research.

5 Prototyping

In order to confirm or reject the previously designed architecture, a prototype was designed, implemented and tested. The prototype is based on case study 2, public entertainment. The goal was to establish the exchange mechanism to provide real time data to a website designer. The goal was not to create an appealing website with many features, but only to establish the connection between gliders and the website designer.

5.1 Design

The core issue of this problem is that testing such a solution with actual real-time data is not possible because having a glider with any device on board in the air is very expensive and highly dependable on the weather conditions. To avoid this problem a simulation is chosen as an appropriate solution.

This simulator requires flight data of gliders. Two options were considered: (1) to use the test flight data for the simulation and (2) to use IGC files. The second option was chosen, because the IGC files are more reliable, since test flights data are discontinuous.

Many IGC files are publicly available because being on a competition requires sharing your result. The most common glider competition data repository is Soaring Spot (http://www.soaringspot.com/). The competition Flatland Cup 2014 was chosen, the category "Hun Club". Two days were selected, 8th August and 10th August 2014, where the first place in there. Their IGC-files served as the basis of the simulation.

The aim of this simulation is to run all three files simultaneously whereby their timestamps correspond. Simulation shells stream only three gliders per day, as if it happened at current time. At midnight, the other day's data had to be loaded and streamed. This means that the simulator was running non-stop. As a result the chosen two days are switched day by day and they are in an infinite loop.

Data are sent to PostGIS/Postgres database and using Geoserver, WMS and WFS services are provided. Using those services, the information can be overlaid on any base map, and a very simple webpage is used for display. A complete overview of the design is given in Figure 25. The utilized programming languages are also given in that figure, but the roles of which are explained in the next sections.

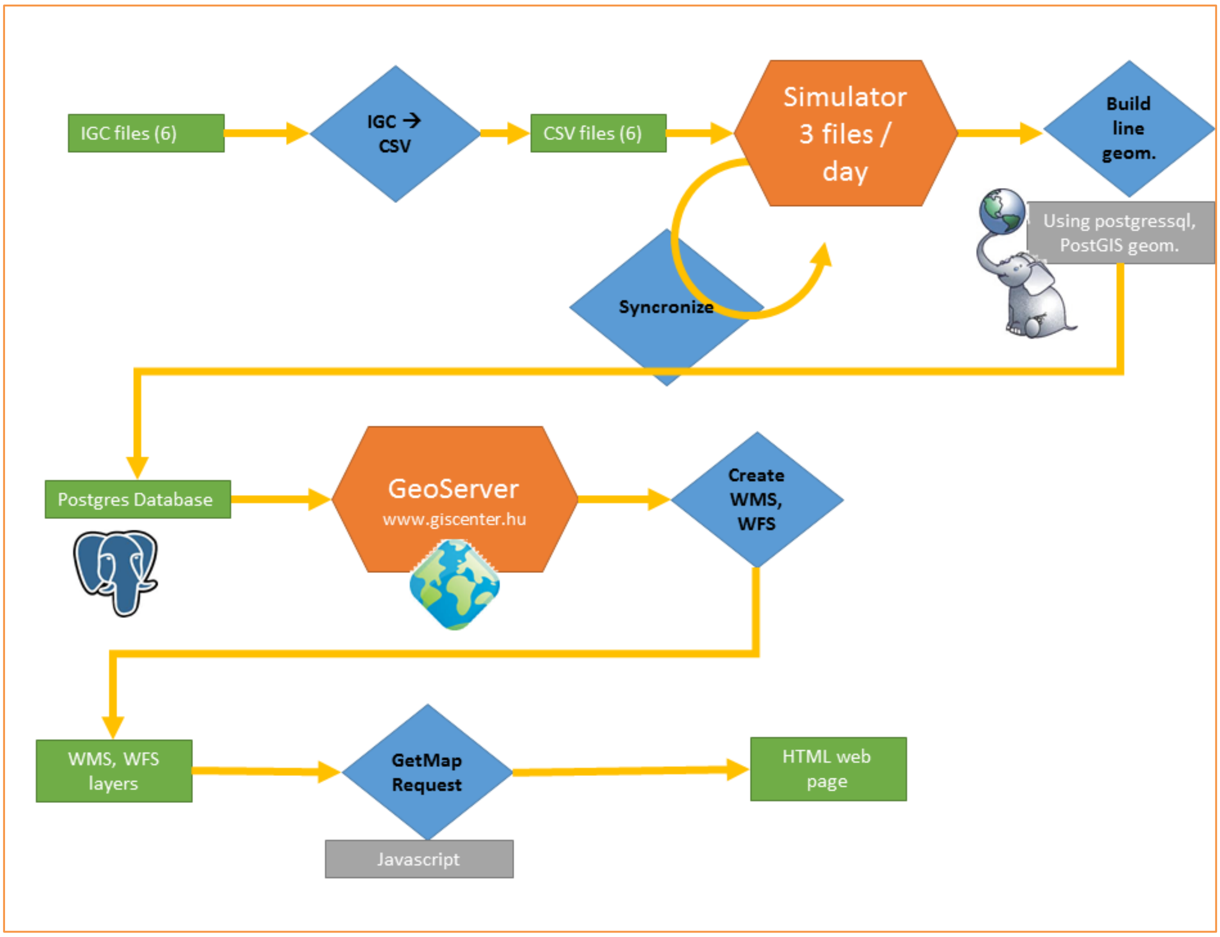


Figure 25: Prototype design

5.2 Implementation

This section describes how the design was implemented in detail. Firstly, data preparation is explained which is followed by the simulator. Lastly the created website is briefly explained.

The following software was used to implement the design.

- The underlying server is Suse Linux server, provided by www.giscenter.hu
- The data simulator was programmed in JavaScript language, in a Node.js environment.
- The PostgresSQL 9.3.5 database was selected for storing data with PostGIS geometry.
- GeoServer is used provide WMS and WFS service
- HTML +JavaScript was used for creating the website

The GeoServer uses the PostgresSQL database tables to generate services. All services are available from this link: http://giscenter.hu:8080/geoserver/Glider/wms?version=1.1.0

5.2.1 Data preparation

IGC files are source of the data, but IGC format is difficult to read. Therefore, a conversion script was used to make it better understandable. B records are interleaved with E records (see A.1), because B contains the coordinates, altitude and the timestamp of the capture time with optional attributes defined by I record and E records store some special events, listed in

Appendix AA.3. According to IGC specification (FAI, 2011), E record timestamp must match with exactly one B record timestamp.

A script was developed in Python by the author, (Kun, 2011) converting IGC files to Shape files. This script was modified to export only the B together with E records to coma separated CSV file. The CSV files starts with a header, an example is given

```
FID;PressAlt;GNSSAlt;Time;X_coor;Y_coor;EventType;EventAdd;ENL
;B_empty1;B_empty2;B_empty3;B_empty4;B_empty5;B_empty6;B_empty
7
```

B_emty1 means, there is no optional attribute is defined by I record. If it would be, the Three Letter Code (Appendix A/A.3) of the attribute would be used as field name. The rest of the CSV file is are the attribute values, listed in orders as defined by the header.

5.2.2 Simulator

The purpose of the simulator sending data database using SQL commands and building the line geometry of the flights. The simulator reads all the CSV files arrange them according to the timestamps and builds the new segments of the track as time passes by matching the current time and the timestamps of the CSV. The simulator works as if the data stream would be continuous from a glider and signal losses event never occurs.

The simulator sends the data directly the Postgres database and directly builds line geometry form the CSV data. Simple SQL queries are used to do that, each tuple in the database reference to a time stamp and to a line segment. The simulator program was developed together with Tamás Hódi, developer of Optin Ltd.

5.2.3 Web site

Geoserver is used to serve both WMS and WFS services which are publicly available using this link: http://giscenter.hu:8080/geoserver/Glider/wms?version=1.1.0. In this case, only the WMS service is used representing the real-time data.

A very simple website was created with JavaScript based on a Leaflet framework using OpenStreetMap as base layers. Leaflet is a modern open-source JavaScript library for mobile-friendly interactive maps. "*Leaflet is designed with* simplicity, performance *and* usability *in mind. It works efficiently across all major desktop and mobile platforms out of the box, taking advantage of HTML5 and CSS3 on modern browsers while still being accessible on older ones"* (Agafonkin, 2015). Leaflet was chosen because of the well described API documentation and good tutorials

The website shows all the six available tracks and layers are redrawn in every second. The website is available here: http://www.giscenter.hu/glider/[9].

Several issues can be observed on this web site, but it is beyond to scope to deal with them. The first issue is the blinking effect due to the second refreshment. It can be due to the visualisation engine used, Leaflet. The second issue is also connected to the refreshment: in spite of the WFS layers being refreshed, it is graphically is not displayed in the browser. However, if the user manually zooms in or out, the new line segments can be observed.

5.3 Testing

In order to test the results, the original IGC to Shape converter was used to convert IGC files to shape files. The WMS and WFS layers added to QGIS together with reference IGC files (Figure 27: WMS layers in QGIS). The map had to be manually refreshed, but the results were satisfactory, the movement of the gliders was well seen. The refresh frequency normally was 2-3 seconds or higher. If the refresh frequency went below 1 second, QGIS sometimes crashed with connection error. The WMS layer was opened with a commercial software like ArcGIS and it worked with scanned and georeferenced aviation map (Figure 26).

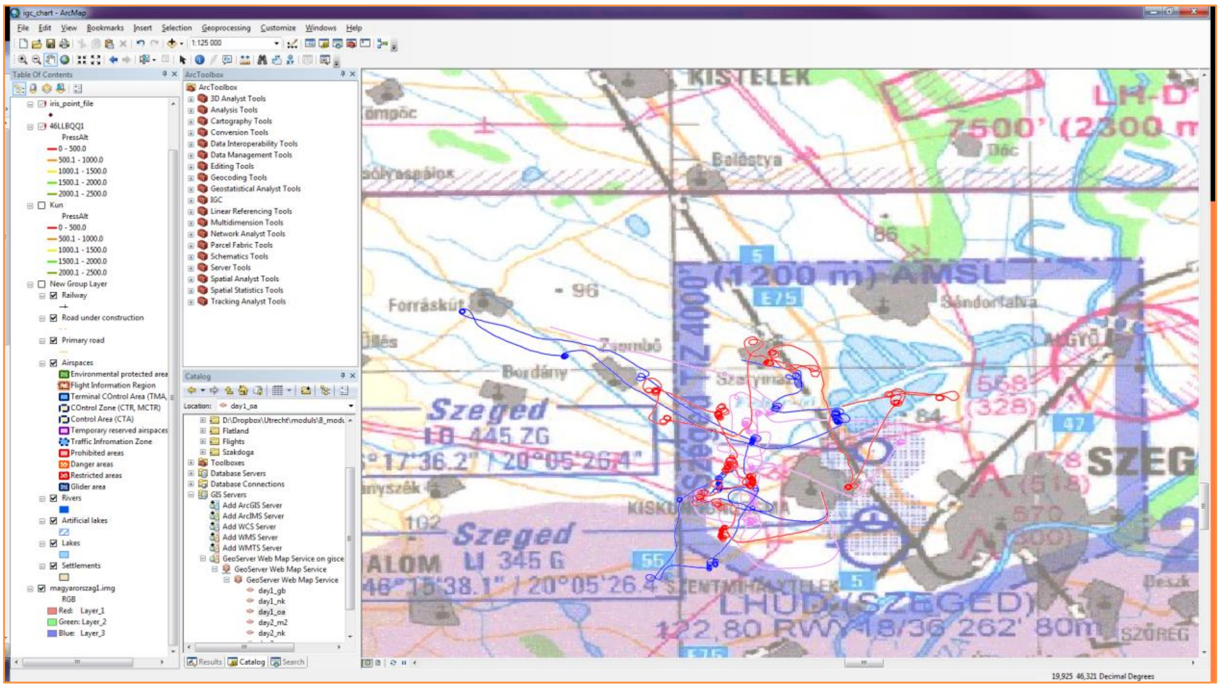


Figure 26: WMS layers in ArcGIS

Using Leaflet in combination with WMS service is not the best solution due to the blinking effect of the map refreshment. It might be possible that other frameworks can solve this issue.

[9] Please keep in mind that the layers only change when a flight is in progress. If day 1 is simulated, changes in routs can be observed between 9:54 and 15:50 (GMT+1), if day2 is simulated, changes can be seen from 9:55 until 15:19 (GMT+1).

Another solution can be that the WMS services are processed before disseminations and no direct overlay with WMS and base map is done.

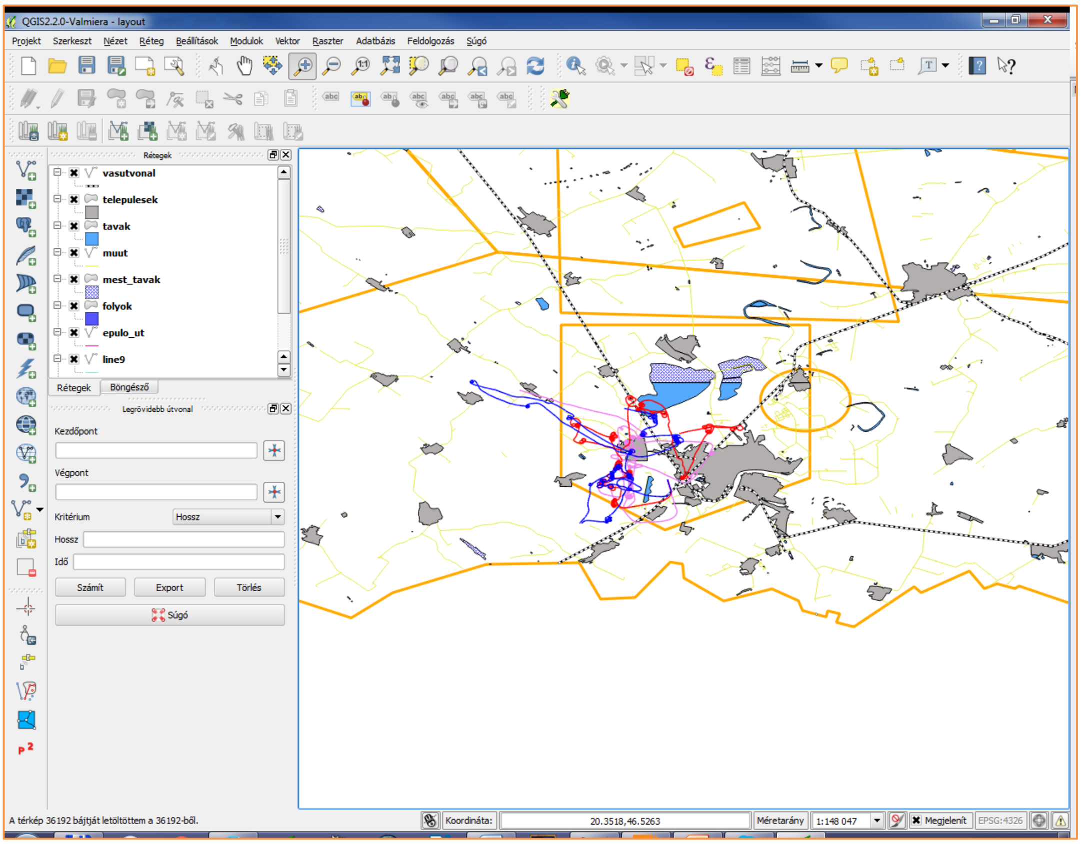


Figure 27: WMS layers in QGIS

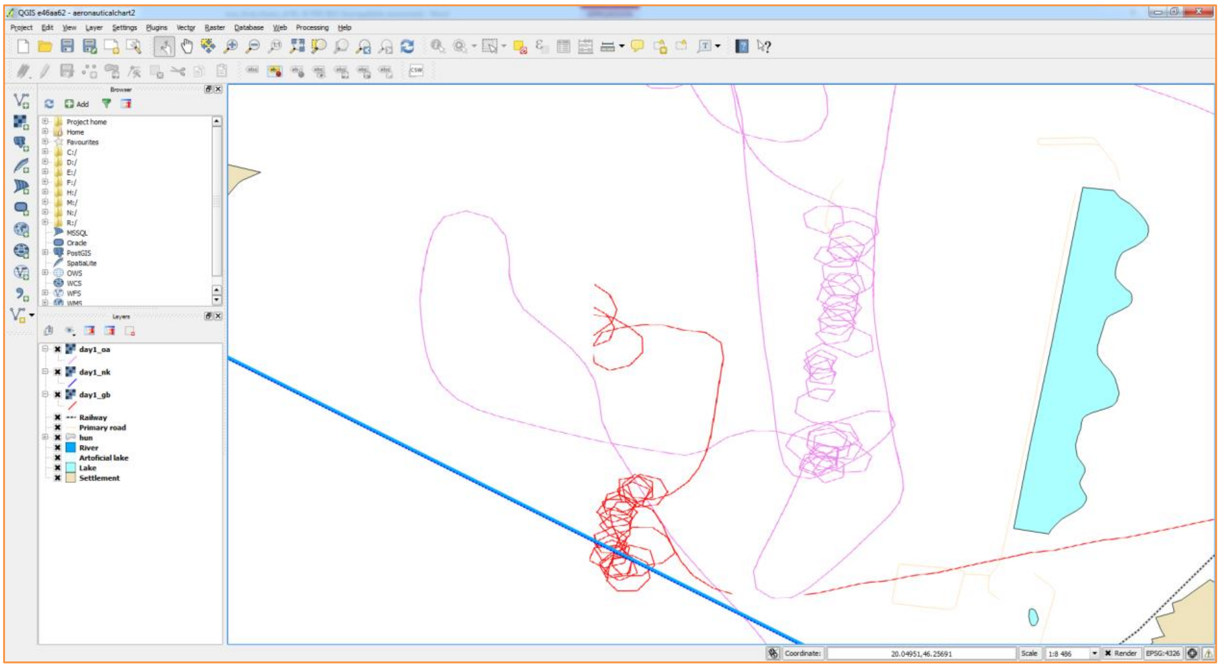


Figure 28: WMS layers in QGIS zooming on a thermal

6 Discussion

In the previous chapters case studies were developed with the purpose of establishing a real-time exchange mechanism for tracking gliders on competitions. After the case studies were explained, available standards, sensors and tracking solutions in other sports were investigated; user needs were derived from case studies and interviews, a conceptual model about a tracking system was designed including the envisioning of a new standard and a software architecture and methodology interleaving scattered and diverse real-time sensors into one network system. As a final step, a prototype was developed based on case study 1: public entertainment.

This chapter reflects on case studies about the findings reported in previous chapters. Four topics are highlighted, and relations, if any, with the case studies are discussed. The first is about the GSM network. On a commercial aircraft, everybody knows, cell phones must be turned off and test flights showed that IRIS interfered with radio. The second section discusses if both Flarm and ADS-B transponder should be taken into account, or sooner or later the gliding community will decide, which device will be used and which one will be disregarded. The third section points out of the weakness of using WMS. The last section discusses if there is an actual need of the envisioned standard from the gliding community. It points out if there is anybody who would finance the development of such a standard. Lastly, the section points out of the lack of regulations in gliding as a sport about the real-time data dissemination for pilots.

6.1 GSM: why cell phones are forbidden on airplanes

In this research the idea was tested to use the mobile internet (GSM) network for streaming glider positions. In order to do so, test flights were conducted using a simple Android mobile app for tracking and a company's custom-made car-track devices (IRIS). The first flight failed due to the immature status of the mobile app, however, the test with IRIS yielded several useful results. The most important being, that IRIS interferes on-board devices like radio. Strangely, cell phones do not compromise radio. Hardware engineers of Optin Ltd could never really found out why IRIS interferes with radio. Some statistical calculations could have been done about finding a relation between the altitude, terrain and mobile service strength, but these results would be very doubtful due to the low number of tests flight and due to the homogenous terrain (flatland).

In the case of Case study 2, using GSM network is a very simple solution, like building a mobile app which detects out landings. Four Case study 1, combining GSM devices in a gossip network with other real-time tracking devices like Flarm or ADS-B transponder can highly improve the real-time data coverage of competitors. However, the usability GSM for Google Glass is questionable, since it requires a strong bidirectional communication channel, and as test flights revelled, GSM is suitable for that.

6.2 Gossip network

The idea was formulated to use the gossip network in combination with Flarm, ADS-B network and with the GSM network. One factor was not taken into account: country regulations. ADS-B is a Dutch initiative which was a consequence of changing Dutch air traffic regulations, since ADS-B transponders have become an obligatory device in many more airspaces for gliders, and ADS-B is more for air traffic control, than for the glider community. Flarm has mainly been a German initiative for anti-collision and tracking purposes. In retrospect, the hypothesis that both devices would be on-board gliders is questionable. What device would be used, ADS-B or Flarm, would very much depend on the country where the solution is applied. Either it has to be decided, if both devices really have to be supported by any new standard or chose one. Furthermore, Open Glider Network is a very young initiative, and it can succeed only if Flarm is used without gossip network.

The idea of using the gossip network suits well for case study 1 and for case study 3, but not for case study 2. Case study 2 describes a special event, for what purpose only very simple GSM based devices can be used since GSM works very well on the ground almost everywhere. In the case of case study 1, cleaning up redundant data from different sources happens on a theoretical server. However, in case of case study 3 it is different. No stable bidirectional and suitable communication channel was found from the ground to the air. It implies that using the GSM network is partially suitable, but if any devices like Flarm or ADS-B transponder are on board, the data must be interleaved with data received via GSM. Doing such calculations may require computation capacity which requires energy and gliders lack energy resources. It is questionable, if this issue can be solved on board.

Gossip network also does not take into account the amount of data that transferred via the GSM network. This research did not investigate the data traffic on the GSM network. This is a weak part of gossip network because the test flights revealed that caching data with a weak signal is difficult, and can cause problems.

6.3 Web site

A prototype was developed based on case study 1, about public entertainment. The purpose of the prototype was to show how this exchange mechanism can work. Unfortunately there was not enough time to work out a complete metadatabase about the visualized gliders. The prototype also had the issue that WMS caused a blinking effect, but be no solution was sought. It is not proven, nor rejected, that other frameworks than Leaflet have the same issue. The work shows that WMS and WFS can be used, but have their limitations.

Not much effort was put into the aesthetic appearance of the site because it was not necessary for completing the research objective.

6.4 New standard by whom? Missing regulations!

The OGC Aviation Information Branch was initiated by ICAO, EUROCONTROL and FAA because in civil aviation standards are very important. There are thousands of commercial aircrafts, millions of people travel day by day. This generates revenue which is necessary for establishing standards. Gliding is a sport and it is not an attractive sport like football, and one cause is that the public does not see what happens which leads to the vicious circle. If the public wants to be entertained, some standards are needed, and if a standard needs to be developed then finance is needed, etcetera.

Who would pay for such a standard and who would enforce it? At this moment, no evidence was found of whether competitors would influence gliding as a sport if they would see each other, for example if any regulation would be needed. But in practice, it does influence the sport. Real time information on board takes away the spirit of gliding, and it is the personal point of view of the author that pilots should not see each other real-time, or where and how others look for thermals. Using devices like Google Glass would harm the sport, and would overly emphasize the technology. Regulating new technology in gliding is still ahead.

7 Conclusions

7.1 Research questions

Before the research questions are answered in detail, this section will briefly outline the general conclusions of the research. The aim was to develop an exchange mechanism for the live tracking of glider aircraft in competition circumstances. This aim was achieved in the sense that it was partially developed and enough evidence has been found which supports the hypothesis that it is eventually possible, but technical work remains to be done in order to fully realize the mechanism. The extent to which open standards can be utilized in the mechanism was found to be limited. The OGC, as the main organization for developing such standards, does have an Aviation Information Management branch, but their work was found to be of limited use because it focuses on commercial aircraft. Furthermore, the empirical research into planning, developing and simulating the architecture revealed that it can indeed work in spite of some constraints.

This thesis' research questions are revisited below.

1. *What are the characteristics of real-time glider competition data?*

It was investigated to what extent the glider competition influences the characteristics of the data. First the limitations of the glider were investigated. Gliders lack an engine and therefore have no power supply for a powerful transponder, also they lack cargo space. Therefore glider transponders have a very low range, and require a dense ground network to function. Second it was found that regulations are required if two directional systems are to be designed. Currently competitors can use real-time data if any are available. It would be a positive feature if competitors can see each other and a gossip network system would help to improve the coverage. As for the glider flight data, the minimum requirement found was a 3D positioning capture every 1 to 10 seconds. These data are then stored as points from which line geometry can be generated. Obligatory attributes of these data are the pilot's name, glider ID, competition ID and the type of glider. In addition, the FAI-IGC provides some well described attributes which are of relevance and which are listed in Appendix A.3. Optional attribute data could entail the true heading, 3D acceleration, roll, pitch and yaw. If the availability of real time positioning solutions in gliding is observed, then devices like Flarm or ADS-B transponders can be suitable on the grounds that they are able to transmit the real time position. However, ASD-B and Flarm has the disadvantage that it requires a dense network which is not commercially viable in gliding. Gliding differs from other sports that utilize real time positioning in that the common GSM network is not automatically suited for the task. The service strength in the air is simply not good enough. Therefore on-board devices such as Flarm or ADS-B transponders should be connected to the GSM network, which in turn would be based on a gossip network solution.

2. *What are the needs of developers?*

For the development of the mechanism the needs of developers were investigated. The empirical research by means of the interviews clearly revealed a preference for direct data requests and return via a format like GeoJSON. The developers emphasized open and cloud-based solutions. OGC standards like WMS, WFS, SWE and GML were considered promising but, they have limitations for the purpose of this research, as will be discussed under research question 3.

As for the technical components, there must be a central server which receives data from the glider and provides access to the data. Accessing data must be in a real-time way, where the update frequency should be around at least 1-10 sec, furthermore, data access must be standardised. This standardized way can be either using the previously mentioned OGC standards, GeoJSON data format or a brand new standard which was described in Section 4.1. Accessing data in IGC file format would be unwise because they describe one flight as a whole and redundant metadata information would occur, besides IGC is text file based and the IGC file format is not well known in the GIS community. In case a gossip system is used to stream the data to the ground, overlapping information from other gliders can interfere. This interference needs to be cleared in that case. And in case data are provided through services like WMS or WFS, then server-side applications like GeoServer are required as middleware. In terms of data availability no constraints were found which could hinder developers. Unlike commercial air traffic, gliding is not subjected to strict security and anti-terror regulations. Therefor developers have the freedom to develop many use cases.

3. *What are the minimum requirements for a real-time exchange mechanism?*

Although several solutions like GSM, WFS or WMS can be used to track gliders if certain conditions are met, the real-time aspect of the exchange mechanism makes it difficult to really make these technologies work. The data stream would simply not be continuous, in case of GSM due to insufficient service strength and in case of WFS and WMS the static nature of the service provision. The static nature in this sense means these services are not designed for 1-10 seconds update requests because it causes the annoying blinking as it can be seen in the prototype (Section 5.2.3). This requires, that the exchange mechanism must support frequent data requests like every 1-10 seconds. A delayed data request has to be allowed if users of the exchange mechanism want to know what happened 10 minutes ago. Delayed data streaming and visualisation enhance the continuous dissemination for the public, thus public entertainment can be more successful. Intentional delays allow time for data preparation and processing overlapping data.

A more useful solution was found in the gossip network as for the input data. This will enable data not only to describe the properties of the source (glider) but also that of neighbouring gliders that are in proximity of the source. Other minimum data requirements were mentioned previously: the IGC file format, geolocation and the attribute data including those mentioned in Appendix A.3.

The interoperability of the mechanism is a key feature, especially when speaking in the context of the output data. These data should be compliant with OGC standards so various services can be used to disseminate and visualize the data. Also GeoJSON can be of much value if direct access to the data is allowed. The GeoJSON format would allow users access to data as point clouds or line geometry. A constraint, however, is the fact that the gossip network causes redundant, overlapping information in the output. This should be cleaned before using the data in visualization.

The legal consequences of the mechanism using this solution were considered, but few reasons for concern were found. For the purpose of air traffic control it is always better if gliders, too, can be displayed real-time, and no instances are known of authorities trying to regulate the dissemination of real-time glider positioning.

4. *What are the relevant available open source solutions and standards and how can they be applied?*

Several open standards have been mentioned, but an in-depth study of the OGC framework was conducted as part of this research. In summary it can be said that WMS and WFS are usable, although the SWE framework with SOS has not been tested. The disadvantages of WMS and WFS are their limited usability for real-time data dissemination and their need for backend solutions.

The IGC file format would be a candidate for the basis of a new open gliding standard even though it is hard to read. There is a prospective new OGC standard which combines IGC with GML as part of the Aviation Information Management Branch of the OGC. Using GML has some constraints though. GML is text based and therefore more computational performance is needed. Generating and reading GML documents in a real-time manner causes performance issues. A trade-off can be made by storing data in databases and only generating GML if it is needed, or restrict the update frequency to a longer period. Another solution can be to use a light-weight version of GML which only contains the topmost relevant information, especially for bidirectional data exchange like Google Glass where the amount of transmitted data must be reduced to the minimum.

Additional open source solutions were found in GeoServer and Mapserver as server middleware for serving the OGC services. PostgreSQL and PostGIS are suitable open database solutions. PostgreSQl/PostGIS and GeoServer are recommended, because literature research in Section 2.5 and 2.6 provided examples how they can be combined with OGC standards like WMS or WFS, besides their support of GML. Furthermore, these solutions are developed and maintained by an active community. Lastly, the prototype showed that this combination works even with some constraints. This is not to say there are no suitable alternatives, but these were not looked for or used in this research.

7.2 Recommendations

This chapter gives some recommendations for practical work that can be done as a result of this research.

The first recommendation is the often mentioned new OGC standard. FAI-IGC as the responsible world authority of gliding and OGC should cooperate and develop a new standard which is based on GML and which has all the features of the IGC file format. This standard should focus on the glider competition as a whole and not only on a single glider. This new standard should support the gossip network data exchange. Parties like Glidertracking.com or Open Glider Network should be involved contributing their practical experience.

The second recommendation is engineering a new device which supports the previously envisioned standard. This device should be able to connect to ADS-B transponder, to Flarm and to official flight recorders. Alternatives like Spot satellite based tracking device never became popular due to its very high price, although coverage of Spot is world-wide and it has a strong stable connection. Due to the maintenance cost of Spot, it is left out from the recommended devices, though it can be connected to the exchange mechanism, Glidertracking.com has already proved that it is open to some degree. Connection is meant here as understanding the data format of these devices, not necessarily having all the possible physical ports like USB, COM, RJ45 etc. This device can also be connected to smartphones using mobile internet or have an inbuilt GSM module.

The base hardware of such a device should be cheap and commonly available for developers, for example a credit card sized computer like Raspberry Pi. Raspberry Pi-2 Model B+ is the newest product and its price at RS Components Ltd. was £20.35 on 15-02-2015. It has four USB ports, therefore four devices can be attached (smartphone, Flarm, ADS-B transponder, flight recorder) and it still has HDMI output for visualisation. Full technical specification of Raspberry Pi-2 Model B+ is given in Appendix D. Flight recorders give self-position, Flarm and ADS-B gives nearby positions and smartphone gives internet. Raspberry Pi interleaves all data into the standard and sends it the ground via smartphones mobile internet.

The third recommendation is to test the gossip network hypothesis of to what extent GSM based gossip network is suitable. It requires an extensive research and data collection about GSM signal strength in the air, of which no current research was found. Simple mobile apps can be developed which log the path and service strength. Then conclusions can be made about vertical distribution of the mobile internet availability in the air taking into account the terrain influence.

Afterwards, a simulation can be done using IGC files of competition with the hypothesis that gliders randomly have Flarm or an ADS-B transponder on board and they are connected to the GSM network and it works as a gossip network. Taking into account the range of Flarm and the range of ADS-B adding the currently existing ground receiver networks, analysis can be done of the designed exchange mechanism coverage.

The last recommendation is beyond the scope, but during this research several expert were involved and it was asked if this exchange mechanism can be used for other sports or for other cases. The answer is no, because this exchange mechanism considers aviation specific devices like Flarm or transponder on board. It is unlikely that any other sport would think of using such an expensive devices and thinking of gossip network. GSM based tracking devices satisfies their needs.

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Appendix A: IGC file format

A.1 IGC records

IGC file format is based on single instance records and multiple instance records. In both case the type of the records are marked with a capital letter (A, B, C, D, E, F, G, H, I, J, K or L).

Single instance can only occur once in an IGC file, however multiple rows can describe them. These records store the different kind of metadata about the flight. Information about the glider, the FR and the pilots are ˝H˝ records. In the ˝C˝ records, the task information is stored including the takeoff, landing, start, end and checkpoints locations; however the not all elements of ˝C˝ record is mandatory, but this question remains out of the scope of this research. ˝A˝ record is always the first record and includes the three-character GNSS FR Serial Number (S/N) unique to the manufacturer of the FR that recorded the flight. G record is an encrypted part of the file which ensures the validity of the log file. I and J records describe the optional parts of multiple instance records, both are one line if any. I record gives optioal part of the B record and J record describe the optional parts of the K records. I and J records using the so called Three-Letter Codes (describing optional attributes

From the multiple instance records (B, D, E, F and K), the most important and always mandatory part is the B records. The B records or fixes are point measurements in a defined time interval where the geographical coordinates of the FR, the pressure altitude, the GNSS elevation and timestamp is stored. The E record is used to record specific events on the IGC file that occur at irregular intervals. Such events include a pilot-initiated event (PEV code), switching a Blind Flying instrument on or off (B FION or B FIOFF), or, for recorders fitted with proximity sensing devices with respect to other aircraft (for traffic avoidance purposes), a proximity event using one of the appropriate Three-Letter Codes as defined in A.3.

The ˝L˝ record is reserved for comments. Other programs may use ˝L˝ record to store program specific information in the igc file.All specifications are extracted from FAI (2011). For full specifications, please visit http://www.fai.org/gnss-recording-devices/free-software.

A.2 Sample IGC file

```
ALXNABCFLIGHT:1
HFFXA035
HFDTE160701
HFPLTPILOTINCHARGE:BloggsBillD
HFCM2CREW2:Smith-BarryJohnA
HFGTYGLIDERTYPE:SchleicherASH-25
HFGIDGLIDERID:ABCD-1234
HFDTM100GPSDATUM:WGS-1984
HFRFWFIRMWAREVERSION:6.4
HFRHWHARDWAREVERSION:3.0
HFFTYFRTYPE:Manufacturer,Model
HFGPSMarconiCanada:Superstar,12ch,max10000mCRLF
HFPRSPRESSALTSENSOR:Sensyn,XYZ1111,max11000mCRLF
HFCIDCOMPETITIONID:XYZ-78910
```

```
HFCCLCOMPETITIONCLASS:15mMotorGlider
I033638FXA3940SIU4143ENL4446RPM
J010812HDT
C150701213841160701000102500KTri
C5111359N00101899WLashamClubhouse
C5110179N00102644WLashamStartS,Start
C5209092N00255227WSarnesfield,TP1
C5230147N00017612WNormanCross,TP2
C5110179N00102644WLashamStartS,Finish
C5111359N00101899WLashamClubhouse
F160240040609123624221821
B1602405407121N00249342WA002800042120509950
D20331
E160245PEVTest1
B1602455107126N00149300WA002880042919509020
B1602505107134N00149283WA002900043221009015
B1602555107140N00149221WA002900043020009012
F1603000609123624221821
(satellitesinusereducefrom9to8asID04isnolongerreceived)
B1603005107150N00149202WA002910043225608009
E160305PEVTest2
B1603055107180N00149185WA002910043521008015
B1603105107212N00149174WA002930043519608024
LXXXRURITANIANSTANDARDNATIONALSDAY1
LXXXFLIGHTTIME:4:14:25,TASKSPEED:58.48KTS
GREJNGJERJKNJKRE31895478537H43982FJN9248F942389T433T
GJNJK2489IERGNV3089IVJE9GO398535J3894N358954983O0934
GSKTO5427FGTNUT5621WKTC6714FT8957FGMKJ134527FGTR6751
GK2489IERGNV3089IVJE39GO398535J3894N358954983FTGY546
```

A.3 Three letter codes

Three letter codes were mentioned in previous sections, their meanings are listed below together with the Records in the IGC file in which they can be used (that is, the first letter of a line in the IGC file, such as B for a fix line, E for an event, line, etc). This table is extracted from FAI (2010), please visit http://www.fai.org/gnss-recording-devices/free-software the specification, if unknown abbreviation is given. Some terminology is strongly relates to gliding, but those are the discussed because they are irrelevant for this research.

TLC	Record Letter(s) used with the TLC	TLC meaning and notes on how it is to be used
AC X, AC Y, AC Z	I, B	Linear accelerations in X, Y and Z axes, for aerobatic aircraft equipped with appropriate sensors feeding to the recorder and IGC file. X = longitudinal, Y = lateral, Z = vertical (so-called "G")
ANX, ANY, AB Z	I, B	Angular accelerations in X, Y and Z axes, for aerobatic aircraft equipped with appropriate sensors feeding to the recorder and IGC file. Pitch = X, roll = Y, yaw = Z.
ATS	H E	Altimeter pressure setting in hectoPascals (the same as Millibars) with 4 numbers and one decimal point (for instance, 1 01 3 .2, 0 995 .7). Although an altimeter pressure setting may be recorded (for instance where the FR feeds a cockpit display), it must not be used to change the pressure altitude recorded w with each fix, which must remain w with respect to the IS A sea level datum of 1 01 3 .25 mb at all times
BFI	E	Blind Flying Instrument. Recorded as O N or O FF in the format B FIO N or B FIO FF, followed by a space and then AH (Artificial Horizon) for an instrument displaying the horizon, or TI (Turn Indicator) for one giving rate of turn, change of heading, or similar. If the O N/O FF status is uncertain, use the format B FIU N (for Status Unknown n). A Text String (optional) may follow to give more detail of the instrument and its status. The initial state shall be reported in an E record at the time of the first B record in the IG C file w with the Fix V validity byte set to A (3 D Fix, see A4.1 .2).
CCL	H	Competition class
CCN	E	Camera Connect

CCO	J, K	Compass course (from the aircraft compass sensor). Three numbers based on degrees clockwise from 000 for north.
CDC	E	Camera Disconnect
CGD	E	Change of geodetic datum
CID	H	Competition ID
C	LBH	Club or organisation, and country, from which flown or operated (e.g. Elmira US , Lasham U K). For Nation, use the IS O 3 1 66 two-letter codes, some of which are given in A3 .3 .3
CM2	H	Second Crew M ember's Name, family name first then given name(s) as required (same format as PLT for pilot-in charge). For aircraft with more than two crew, use C M 3 and so forth if required.
DAE	I, B, J, K	Displacement east, metres. For W west use negative sign
DAN	I, B , J, K	Displacement north, metres. For S south use negative sign
DB1	H	Date of Birth of the pilot-in-charge (aircraft commander) in the previous line of the H record (D D M M YY)
D B2	H	Date of Birth of second crew m ember in format D D M M YY. For aircraft with more than two crew, use D B 3 , D B 4 etc.
DOB	H	Obsolete code, now use D B 1 . Was Date of Birth of the pilot in the previous line of the H record (D D M M YY)
DTE	H	Date, expressed as D D M M YY
DTM	H	Geodetic Datum in use for lat/long records (for IGC purposes this must be set to W GS 8 4)
EDN	E	Engine down. See note on line for EO N
ENL	I, B	Environmental Noise Level, recorded from 000 to 999. This is the preferred M opt recording m method because it requires no cables or sensors external to the FR, and is self-validating, recording a positive value with each fix.
EOF	E	Engine off. See note on line for EO N
EON	E	Engine on. Note: In some legacy recorders where ENL (now mandatory) and M O P (where required) are not used, the EON/EOF or EUP /EDN codes were used instead. EON/EOF was based on functions such as ignition ON/OFF, generator output, etc. EUP/ED N was used for a micro switch sensor for engine bay doors open/closed or pylon up/down. Continuation of these functions is at the discretion of GFAC . (AL1)
EUP	E	Engine up. S see note on line for EO N
FIN	E	Finish
FLP	E	Flap position, three characters such as FLP060 for 60 degrees of positive flap. If negative, use a negative sign before the numbers, such as FLP-20 for minus 20 degrees flap.
FRS	H	Flight Recorder S security. To be used where a security fault has been detected such as the recorder internal security system (micro switch) having operated.
FTY	H	FR Type (M manufacturer's name, FR M model Number)
FXA	B , I, J, K	Fix accuracy. When used in the B (fix) record, this is the EPE (Estimated Position Error) figure in metres (M M M M) for the individual fix concerned, to a 2-S igma (95 .45 %) probability
FXA	H	Fix Data Accuracy Category. When used in the header record, this is a general indication of potential fix accuracy and indicates a category of receiver capability rather than an exact figure such as applies to each recorded fix in the B , I, J or K records, see above. If in doubt, use a three figure group in metres that refers to a typical EPE radius achieved by the receiver in good reception conditions.
GAL	H	Galileo (European GNS S system), followed by receiver maker, type & version letter/number. See 3 .3 .1 above.
GCN	E	GNS S (Separate module) Connect
GDC	E	GNS S (Separate module) Disconnect
GID	H	Glider ID
GLO	H	GLONASS (Russian GNS S system), followed by receiver maker, type & version letter/number. See 3 .3 .1 above
GPS	H	GPS (US GNS S system), followed by receiver maker, type & version letter/number. See 3 .3 .1 above.
GSP	I, B , J, K	Groundspeed, three numbers in kilometres per hour
GTY	H	Glider type, manufacturer, model
HDM	I, B , J, K	Heading Magnetic, three numbers based on degrees clockwise from 000 for north
HDT	I, B , J, K	Heading True, three numbers based on degrees clockwise from 000 for north
IAS	I, B, J, K	Airspeed, three numbers in kilometres per hour
ADI,	B	The last places of decimal minutes of latitude, where latitude is recorded to a greater precision than the three decimal minutes that are in the main body of the B -record. The fourth and any further decimal places of minutes are recorded as an addition to the B -record, their position in each B -record line being specified in the I-record.
LOD	I, B	The last places of decimal minutes of longitude, where longitude is recorded to a greater precision than the three decimal minutes that are in the main body of the B -record. The fourth and any further decimal places of minutes are recorded as an addition to the B -record, their position in each B -record line being specified in the I-record.
LOV	E	Low voltage. Must be set for each FR at the lowest voltage at which the FR will operate without the possibility of recorded data being degraded by the voltage level. Not to be used to invalidate

		a flight if the flight data appears correct when checked in the normal way, but a warning to check fix data particularly carefully.
MAC	E	MacC ready setting for rate of climb/speed-to-fly (m/sec)
MOP	B , I	Means of Propulsion. A signal from an engine-related function approved by GFAC and placed on the IGC file in the fix record. For details, see the definition of M O P above in Para A5 .
OA1, OA2, OA3, etc.	E	Position of other aircraft (if this is recorded by the system), data fields after the C odes being separated by colons. Format after the Three Letter C ode is the identification of the aircraft concerned (if this is recorded by the system, otherwise insert N K for not know n) followed by a colon, letter P for polar or C for C artesian followed by the co-ordinates. Polar co-ordinates are with respect to the recorder. Format is numbers for horizontal distance in metres from the recorder followed by a colon, followed by 3 numbers of degrees clockwise from 000 for north, followed by a colon and vertical distance in metres from the recorder, a negative sign before the numbers meaning negative vertical distance. After the numbers for vertical distance, the letter G should be used for GNSS data and P for Pressure Altitude, both can be used if the data is available. Alternatively, C artesian co-ordinates can be used for the 3 D position of the Other Aircraft (for instance from AD S -B and similar position reporting systems). Format is lat/long followed by pressure and G PS altitudes (if thes e are recorded by the system) in the same order and format as for the B record (para A4.1), omitting the fix validity character. W here a type of altitude is not recorded, zeros should be substituted.
OAT	J,K	Outside air temperature (Celsius). If negative, use negative sign before the numbers.
ONT	E	On Task – attempting task
OOI	H	OO ID – OO equipment observation
PEV	E	Pilot Event - Pilot initiated action such as pressing a button. A sequence of fast fixes follows (see para 3 .6 in the main body of this document).
PFC	L	Post-Flight Claim. For Free Flights where waypoints are claimed post-flight.
PHO	E	Photo taken (shutter-press)
PLT	H	Pilot-in-charge (aircraft commander), family name first then given name(s) as required
PRS	H	Pressure Altitude S ensor, manufacturer, model, etc.
RAI	I, B , J, K	RAIM - GPS Parameter, see Glossary
REX	I, B , J, K	Record addition - Manufacturer defined data defined in the I or J record as appropriate, normally in the form of a TLC (which, if a new variable is agreed, may be a new TLC allocated by GFAC at the time). Any use must be approved by GFAC , and published so that there will be no doubt on how it is being used. RFW H Firmware Revision Version of FR RH W H Hardware Revision Version of FR
SCM	H	Obsolete code, now use C M 2. Was Second Crew M ember's Name
SEC	G	Security - Log security data
SIT	H	Site, Name, region, nation etc.
SIU	I, B	Satellites in use. A two-character field from the NM EA GGA or GNS sentences, as appropriate, or equivalent data agreed by GFAC .
STA	E	Start event
TAS	I, B , J, K	Airspeed True, give units (kt, kph, etc.)
TDS	I, B , J, K	Decimal seconds of UTC time, for use with systems recording time to this accuracy. Time in seconds is recorded in the main body of the B -record and decimal seconds are recorded as an addition to the B -record, their position in each B -record line being specified in the I-record. Similarly with the K and J-records. For an example see A2.4 under Time.
TEN	I, B , J, K	Total Energy Altitude in metres
TPC	E	Turn point confirmation - Equipment generated event (not valid for flight validation which requires independent checking of fixes and relevant Observation Zones)
TRM	I, B , J, K	Track Magnetic. Three numbers based on degrees clockwise from 000 for north
TRT	I, B , J, K	Track True. Three numbers based on degrees clockwise from 000 for north
TZN	H	Time Zone Offset, hours from UTC to local time.
UND	E	Undercarriage (landing gear), recorded as UP or D N, in the format UND UP or UND D N.
UNT	H	Units of Measure
VAR	J, K	Uncompensated variometer (non-total energy) vertical speed in metres per second and tenths of metres per second with leading zero and no dot (".") separator between metres and tenths. Valid characters 0-9 and negative sign " -". Negative values to have negative sign instead of leading zero VAT J, K Compensated variometer (total energy/N ETTO) vertical speed in metres per second and tenths of metres per second with leading zero and no dot (".") separator between metres and tenths. Valid characters 0-9 and negative sign "-". Negative values to have negative sign instead of leading zero
VXA	I, B , J, K	Vertical Fix Accuracy, Three characters in metres from the VD O P part of the NM EA GS A sentence, or equivalent data agreed by GFAC .
WDI	I, B , J, K	Wind Direction (the direction the wind is coming from). Three numbers based on degrees clockwise from 000 for north
WSP	I, B , J, K	Wind speed, three numbers in kilometres per hour
XN*	As Appropriate	A manufacturer-selected code where N is the manufacturer's single-character IGC name (para A3 .5 .6) and * can be any character. The manufacturer must specify its meaning and usage in the documentation for the recorder and its use must be approved by GFAC before IGC -approval. The

		X prefix is intended to allow a trial with a provisional new code before deciding whether it is worthwhile adding to the full list.

Source: FAI (2010, page 35-36)

Appendix B: NMEA protocol

The usefulness of NMEA as a protocol was described in Section 2.6. In this section, further relevant technical details are extracted from the NMEA specifications and relevant sample sentences are listed below.

Only printable ASCII characters are allowed, plus CR (carriage return) and LF (line feed) in NMEA sentences. Each sentence starts with a "$" sign and ends with <CR><LF>.There are three basic kinds of sentences: talker sentences, proprietary sentences and query sentences (NMEA). One of the talker sentences is compatible with the IGC file format. If the FR internal GNSS receiver module communicates with the device using NMEA protocol, it should be either GGA sentence or GNS sentence (IGC tech spec, p. 55). For example, the specification of GGA sentences is listed in Appendix A. Not only predefined sentences are available, but so called user defined proprietary sentences can specified. A few other possible sentence specifications are also listed in Appendix A.

B.1 GGA sentence

GGA: Global Positioning System Fix Data. Time, Position and fix related data for a GPS receiver

```
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
| | | | | | | | | | | | | | |
$--
GGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xx
xx*hh
1) Time (UTC)
2) Latitude
3) N or S (North or South)
4) Longitude
5) E or W (East or West)
6) GPS Quality Indicator,
0 - fix not available,
1 - GPS fix,
2 - Differential GPS fix
7) Number of satellites in view, 00 - 12
8) Horizontal Dilution of precision
9) Antenna Altitude above/below mean-sea-level (geoid)
10) Units of antenna altitude, meters
11) Geoidalseparation, the difference between the WGS-84earth
ellipsoid and mean-sea-level (geoid),"-" means mean-sea-level
below ellipsoid
12) Units of geoidalseparation, meters
13) Age of differential GPS data, time in seconds since last
SC104
type 1 or 9 update, null field when DGPSis not used
14) Differential reference station ID, 0000-1023
15) Checksum
```

B.2 MWV sentence

```
MWV Wind Speed and Angle
1 2 3 4 5
| | | | |
$--MWV,x.x,a,x.x,a*hh
1) Wind Angle, 0 to 360 degrees
2) Reference, R = Relative, T = True
3) Wind Speed
4) Wind Speed Units, K/M/N
5) Status, A = Data Valid
6) Checksum
```

B.3 OSD sentence

```
OSD Own Ship Data
1 2 3 4 5 6 7 8 9 10
| | | | | | | | | |
$--OSD,x.x,A,x.x,a,x.x,a,x.x,x.x,a*hh
1) Heading, degrees true
2) Status, A = Data Valid
3) Vessel Course, degrees True
4) Course Reference
5) Vessel Speed
6) Speed Reference
7) Vessel Set, degrees True
8) Vessel drift (speed)
9) Speed Units
10) Checksum
```

B.4 RMC sentence

```
RMC Recommended Minimum Navigation Information
12
1 2 3 4 5 6 7 8 9 10 11|
| | | | | | | | | | | |
$--RMC,hhmmss.ss,A,llll.ll,a,yyyyy.yy,a,x.x,x.x,xxxx,x.x,a*hh
1) Time (UTC)
2) Status, V = Navigation receiver warning
3) Latitude
4) N or S
5) Longitude
6) E or W
7) Speed over ground, knots
8) Track made good, degrees true
9) Date, ddmmyy
10) Magnetic Variation, degrees
11) E or W
12) Checksum
```

Appendix C: Test flight

C.1 Sample data of IRIS device

This appendix provides an example part of a file generated by IRIS. In this case, flip.pos and flip.to events occurred; therefore a **new header (in bold)** was introduced. After this event, a normal capture continued and therefore the **header** was changed again. Since no event happened during the subsequent capture, the header remained the same.

A flip event means that one of the digital inputs received a new signal, for example the ignition turned on or off, or the panic button was pressed. Flip.pos describes which digital input changed and Flip.To describes the new value of the input. In our case, digital input 0 changed to 0, by words the ignition turned off.

moduleId,timestamp,type,GPSBasic.lat,GPSBasic.lon,GPSAccuracy.sats,GPSAccuracy.qos,GPSAccuracy.hPrecision,Flip.pos,Flip.to

319309220,1404896751000,1,462394300,201402683,132,132,1,0,0

moduleId,timestamp,type,GPSBasic.lat,GPSBasic.lon,GPSBasic.alt,GPSBasic.speed,GPSBasic.course,GPSAccuracy.sats,GPSAccuracy.qos,GPSAccuracy.hPrecision,Voltage.internal,Voltage.external,Analog.0,Analog.1,Ignition.ign,Digital.0,Digital.1,Digital.2,Digital.3,Digital.4,Digital.5,Digital.6,Digital.7,Carrier.csq

319309220,1404896752000,1,462394300,201402683,101,1,33790,132,132,1,4311,12576,0,0,0,0,0,0,0,0,0,0,0,14

319309220,1404896753000,1,462394300,201402683,101,0,33790,132,132,1,4311,12538,0,0,0,0,0,0,0,0,0,0,0,14

319309220,1404896754000,1,462394300,201402683,101,1,33790,132,132,1,4311,12615,0,0,0,0,0,0,0,0,0,0,0,14

319309220,1404896755000,1,462394300,201402683,101,1,33790,124,124,1,4311,12615,0,0,0,0,0,0,0,0,0,0,0,14

319309220,1404896756000,1,462394300,201402683,101,0,33790,132,132,1,4311,12615,0,0,0,0,0,0,0,0,0,0,0,14

319309220,1404896757000,1,462394316,201402683,101,0,33790,132,132,1,4311,12615,0,0,0,0,0,0,0,0,0,0,0,14…

C.2 Ignition solutions

In section 3.3.2 it was described that IRIS devices attached to the ignition circuits of cars, but gliders do not have an engine. Therefore Optin Ltd. Desgined two custom solutions for the test flight. The first was based on a direct ignition circuit and the second was based on reprogramming the reset button.

The first solution was the direct ignition: if IRIS was attached to an external battery, the battery also sent the ignition signal. When IRIS was attached to an external battery, it automatically starts charging IRIS's internal battery. If the external battery was removed, IRIS went to standby mode until it run of energy. This was not very efficient solution because external batteries can be only stored in the trunk of the glider which is not easily available. This solution forced IRIS unnecessarily capturing data, even if glider was in parking position. Therefore a second solution was designed.

IRIS has a reset button, which is very similar to any routers reset button. It can only be pressed with a needle (Figure 28). Hardware developers designed firmware for the test flights. If the reset button is pressed, the "ignition on" event happens. If the reset button is pressed again, the "ignition off" event happens. Since IRIS is small enough to be stored in the cockpit where pilots can reach it easily, it allows pilots to turn it on or off at will without the need to unplug the external battery.

Figure 28: IRIS device, reset button is highlighted in red circle

Appendix D: Raspberry Pi technical specification

The Raspberry Pi 2 Model B is the second generation Raspberry Pi. It replaced the original Raspberry Pi 1 Model B+ in February 2015. Compared to the Raspberry Pi 1 it has:

- A 900MHz quad-core ARM Cortex-A7 CPU
- 1GB RAM
- Like the (Pi 1) Model B+, it also has:
- 4 USB ports
- 40 GPIO pins
- Full HDMI port
- Ethernet port
- Combined 3.5mm audio jack and composite video
- Camera interface (CSI)
- Display interface (DSI)
- Micro SD card slot
- VideoCore IV 3D graphics core

Because it has an ARMv7 processor, it can run the full range of ARM GNU/Linux distributions, including Snappy Ubuntu Core, as well as Microsoft Windows 10 (see the blog for more information).

The Raspberry Pi 2 has an identical form factor to the previous (Pi 1) Model B+ and has complete compatibility with Raspberry Pi 1.

We recommend the Raspberry Pi 2 Model B for use in schools: it offers more flexibility for learners than the leaner (Pi 1) Model A+, which is more useful for embedded projects and projects which require very low power.

Source: Raspberry Pi Foundation (2015)