Literature Review

This deliverable is the first part of the summative assessment and feedback from this submission will help you in the focus and direction of the main report and project implementation. The purpose of this submission is to demonstrate your understanding of the wider issues related to the project through an extensive literature review. The literature review should provide justification of your project and set the context by discussing and critically evaluating the past and current relevant literature sources. The review should conclude with a summary highlighting the main gaps and opportunities discovered and proposing the future direction of the research/ implementation.

The Literature Review will be graded based on the following aspects (the grading grid is available in Appendix C and on moodle.)

* Relevance and quality of sources
* Use of academic references
* Analysis of context and consideration of alternatives
* Evidence of systematic review of appropriate sources of information
* Evidence of critical appraisal of techniques and practices used in previous research or professional practice
* Evidence of organisation of an clear argument
* Summary of literature review and presentation of research question
* Overall presentation and structure

**Titles Sections**

Background

Augmented Reality

Metro AR google WebGL or WebJL globe

Chrome experiments

Amcharts

Usability Concepts

User Experience

Desirability

Comparison of Features and Design

This review aims to research into flight tracking technology, how augmented reality aids in user experience, the use of augmented reality in other fields of mobile applications, and techniques used to assist in usability of mobile applications. It also compares current flight tracking mobile applications and critically evaluates relevant features with the study of reviews.

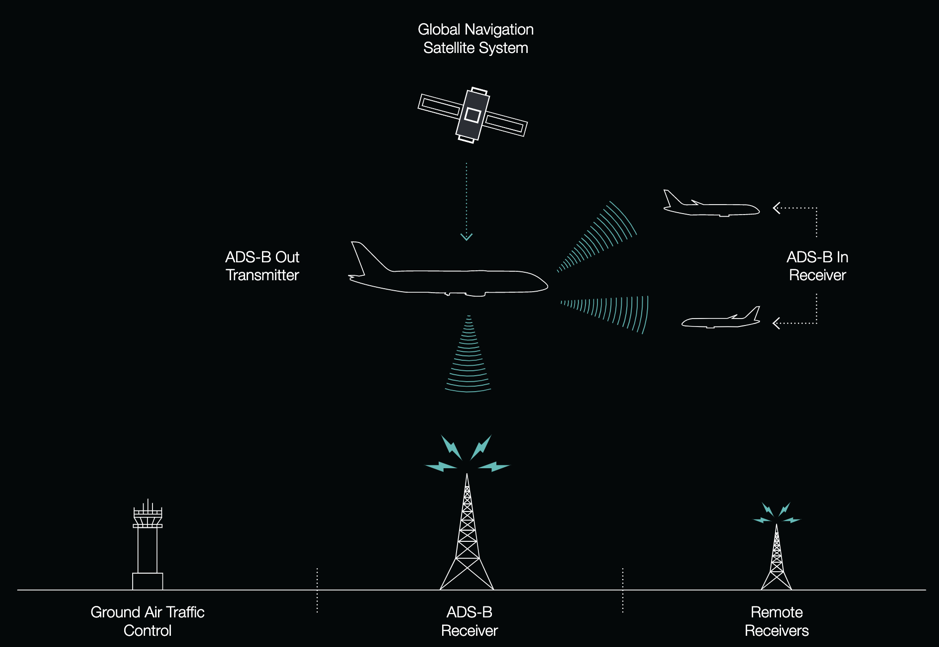
* 1. Flight Tracking Technology

The technology behind flight tracking comes from combining multiple data sources such as ADS-B and MLAT. This data is combined with aircraft schedules and statuses of flights which are acquired from airlines and airports. Newer aircraft such as all Airbus models, Boeing models between 737-787 are equipped with Automatic Dependent Surveillance-Broadcast (ADS-B) transceiver whereby it transmits signals containing data about the flight such as location, altitude etc. (“How flight tracking works - Learn how we track flights | Flightradar24,” n.d.) The data is transmitted at a frequency of 1090 MHz with a transmitting pulse length of 120 μ s allowing for data to be received by anyone/network with the appropriate ADS-B receivers. (Huang, Narayanan, & Feinberg, 2008) Older aircraft which are not equipped with the newer ADS-B transceivers can be located by calculating their position using Multilateration (MLAT). This uses a method called the Time Difference of Arrival which measures the time a signal is received from an aircraft using an older transponder, the Mode S, whereby the position can then be calculated. (“How flight tracking works - Learn how we track flights | Flightradar24,” n.d.) The literature will convey the benefits and disadvantages of the data receivers to convey which one is better suited to retrieve flight data or if a combination of the two is more beneficial.

1.1.1 Automatic Dependent Surveillance-Broadcast (ADS-B)

Air Traffic Management systems will face considerable challenges over the coming decades due to rapid growth in air traffic and demand. America alone expected in 2015 for air traffic to increase by 25-30% and in some cases exceed that prediction. (Huang et al., 2008) Modernisation of flight tracking has been gradual with places such as western China beginning to consider ADS-B tracking due to restrictions of terrain and meteorological conditions preventing construction of new radar stations. (Zhang, Liu, & Zhu, 2011) Developed countries/continents such as Europe, United States, Australia, Canada and others are beginning to enforce/drive ADS-B as a mandatory requirement on aircraft by 2020 (“How flight tracking works - Learn how we track flights | Flightradar24,” n.d.) within their respective airspace making ADS-B data sources favourited by tracking applications for future data retrieval due to the drive to expand the network world-wide. (“ADS-B: 2019 & Beyond,” n.d.) ADS-B is a composition of CNS/ATM (Communication, Navigation and Surveillance/Air Traffic Management) using Mode S transponders capable of ADS-B transmissions and the recommended surveillance method by the ICAO (International Civil Aviation Organisation) for the future generation of ATM.

With the use of ADS-B, air traffic control will change from a radar-based system into a satellite-derived location system. The change will increase safety as aircraft will no longer rely solely on ATC as aircraft will have surveillance of other aircraft. (Part III Department of Transportation Federal Aviation Administration 14 CFR Part 91 Automatic Dependent Surveillance-Broadcast (ADS-B) Out Performance Requirements To Support Air Traffic Control (ATC) Service; Final Rule mstockstill on DSKH9S0YB1PROD with RULES3, 2010) This surveillance will greatly improve a pilot’s situational awareness of the traffic environment due to data of location and bearings being transmitted by aircraft in close proximity. (Huang et al., 2008) Additionally from this change brings enhanced accuracy and speed of data beneficial for precise flight positioning for tracking applications. (Part III Department of Transportation Federal Aviation Administration 14 CFR Part 91 Automatic Dependent Surveillance-Broadcast (ADS-B) Out Performance Requirements To Support Air Traffic Control (ATC) Service; Final Rule mstockstill on DSKH9S0YB1PROD with RULES3, 2010)



*Figure 1: How ADS-B works* (Richards, O’Brien, & Miller, 2010)

Although many clear advantages of ADS-B for airlines related to safety and fuel efficiency, from more direct routings, (Richards et al., 2010) airlines such as JetBlue Airways are difficult to persuade due to historic tendencies to not invest in technologies unless a compelling safety and business case is given. (“Unlocking the Benefits of ADS-B In - Aviation Today,” n.d.) However, due to the lesser cost of older technologies and the reliability of current global infrastructure ADS-B in comparison lacks the overall worldwide coverage its counterparts have established. (Zhang, Liu, & Zhu, 2011) Hence airlines are discussing whether to outfit their aircraft with newer ADS-B enabled Mode S transponders compared to the traditional Mode A, B, S transponders rendering some aircraft hidden to ADS-B tracking. Flight tracking applications require accurate data for users and with limitations of reduced aircraft activity shows an obstacle for app developers. The problem shows that the data source is crucial for the most accurate data.

1.1.2 Multilateration (MLAT)

The International Civil Aviation Organisation (ICAO) in the early 1990s approved the model of the Future Air Navigation System (FANS) to be based on satellite and data link technology, later this would be known as CNS/ATM. As traditional air traffic control surveillance had limitations that would have constrained future air traffic growth. The solution was to upgrade to newer technologies such as ADS-B, as already discussed, SSR and MLAT. (Xu, He, Tang, & Li, 2015)

Aircraft that do not broadcast their latitude and longitude through ADS-B transponders such as older Boeing models (737-200) Bombardier CRJ/Dash models, Embraer models, Fokker 50 and most helicopters and propeller aircraft (“How flight tracking works - Learn how we track flights | Flightradar24,” n.d.) use another tracking technology called Multilateration. This uses 1090 MHz signals broadcasted by Mode A, B or S transponders to determine the aircraft’s location from locating the source of the transmission (Xu et al., 2015) using a method called the time difference of arrival (TDOA).

This method involves using four or more receivers/ground stations to detect aircraft by taking the time for a signal to be received by one receiver at a stationary point and the time taken for the signal to be received by at least 3 other different receivers. (“Multilateration (MLAT) - FlightAware,” n.d.) As the data is transmitted the position of the aircraft will be at different distances to each receiver, therefore, the data will be received at marginally different times. The different times at which the transmissions are received can be used to accurately determine the aircraft’s position. (Xu et al., 2015) The data is transmitted to a server to be combined to calculate the latitude and longitude as shown in Figure 2. The signals also broadcast the aircraft’s transponder identification and the altitude. Using a collaboration of the information, real-time flight tracking can be provided. However, aircraft must be within line-of-sight with the receivers for an accurate position to be determined. (“Multilateration (MLAT) - FlightAware,” n.d.) Although considered real-time, calculation delays and processing latency hinder true real-time flight activity with a 4-6 second delay. (“Multilateration (MLAT) - FlightAware,” n.d.) MLAT coverage is limited to areas with receivers/ground stations present and normally only achieved at altitudes between 3000-10000 feet. Due to this limitation general aircraft flying below the range may be hidden to MLAT surveillance. (“How flight tracking works - Learn how we track flights | Flightradar24,” n.d.)

A picture containing sky, green

Description automatically generated

*Figure 2: How MLAT works* (“Multilateration (MLAT) - FlightAware,” n.d.)

Another disadvantage to MLAT can be the positioning accuracy as it can be greatly affected by the factor of Geometric Dilution of Precision (GDOP). This can be due to a large surveillance area and positioning of fixed ground stations/receivers. As the distance increases from the aircraft to the polygon created by the multiple receivers the larger the GDOP and consequentially the less accurate the positioning of the aircraft. (Xu et al., 2015)

As current airspace contains a variety of old and new aircraft successful tracking applications must be open to multiple tracking technologies to give users the full airspace traffic. Users limited to one dimension of traffic would not be drawn to an application with reduced availability. The main audience of flight trackers being plane enthusiasts diverges into different categories of interest such as airplanes (single-engine/multi-engine), rotorcraft (helicopter/gyroplane) and gliders. The different audiences should be taken into account with the choice of the data source to maximise user interest in an application.

1.1.3 ADS-B and MLAT Comparison

All flight tracking technologies available have different advantages and disadvantages against their tracking methods. ADS-B uses dependent surveillance based on GPS making position accuracy greater than MLAT TDOA tracking techniques. MLAT, however, has proven to be less costly than older methods such as radar by 20-35% (*Multilateration era Corporation*, n.d.)and currently outfitted by more aircraft world-wide compared to ADS-B. However, with the current push for ADS-B tracking to be the world-wide choice of flight tracking the current weight will shift to ADS-B being more prominent. (“How flight tracking works - Learn how we track flights | Flightradar24,” n.d.)

As both technologies use Mode S transponders they share a high update rate in the case of ADS-B an update rate of two positions per second (*Non-Radar Surveillance ADS-B/MLAT/WAM Products HOLGER NEUFELDT*, n.d.) allowing for clear and accurate data for flight tracking applications. The data for both ADS-B and MLAT is combined at central servers which are used to retrieve flight data. Although ADS-B only requires one single ground station/receiver for coverage and MLAT requires multiple the cost of ground equipment and infrastructure are relatively equal with both having an overall low lifecycle cost. (*Non-Radar Surveillance ADS-B/MLAT/WAM Products HOLGER NEUFELDT*, n.d.)

Current security concerns only relate to ADS-B. Such security concerns are ADS-B spoofing and ADS-B meaconing. ADS-B signals are not authenticated or encrypted so spoofing can occur where falsified data is inserted into the ADS-B system by transmitting a signal on ADS-B frequencies. The FAA claims “We have ways of validating the data that shows up on a controller’s screen so that spoofed targets are filtered out … An FAA ADS-B security action plan identified and mitigated risks and monitors the progress of corrective action. These risks are security sensitive and are not publicly available”. This validation technique used by ATC is not publicly available so flight tracking applications are at risk from ADS-B spoofing as they have no method to filter false data. (Thurber, 2012) The process of ADS-B meaconing involves the capturing of transmissions whereby are altered and retransmitted after a short delay. (Gouripeddi, 2016) The attack is primarily a man-in-the-middle attack which is another way in way inaccurate data is accepted by flight tracking applications.

To ensure accurate data for users of flight tracking applications a combination of old and new, MLAT and ADS-B, tracking technologies should be used to give a wider range of aircraft traffic so limitations are not preventing the applications user base.

1.2 Flight Tracking Application Programming Interface

An Application Programming Interface (API) is an intermediary software which allows two applications to communicate. An application will connect to the internet sending data to a server. The data is received by the server and interpreted where the server will execute the required action(s) and transmit data back to the application. The application will interpret the received data and present the data in a format to be used by the user. The process is achieved through an API. (“What is an API? (Application Programming Interface) | MuleSoft,” n.d.) The general term of an API is a connectivity interface to an application however modern APIs have characteristics that extend their value and usefulness. They follow standards such as HTTP and REST making them developer-friendly and easily accessible. New APIs are well documented for easy consumption and versioning. (“What is an API? (Application Programming Interface) | MuleSoft,” n.d.) For a developer, APIs provide a range of operations that developers may use to their advantage with the documentation for ease of implementation. The fundamental work is done by the API reducing the level of code required to be implemented by the developer. (Steven Willmottb, 2011)

APIs provide a layer of security for users whilst retrieving data as applications are not fully exposed to the server in which the data required is held nor is the server exposed to the user. The communications only comprise of small packets of data containing only relevant data. (“What is an API? (Application Programming Interface) | MuleSoft,” n.d.) APIs also control access to resources, hardware and software. (Steven Willmottb, 2011)

A range of APIs exist for developers providing flight data. Such APIs are the OpenSky Network, FlightAware, Flight Tracker API of Aviation Edge, ADS-B Exchange and RadarBox. The literature will communicate the variety of data available given a select two APIs. The APIs to be investigated are the OpenSky Network and FlightAware.

1.2.1 OpenSky Network

The OpenSky Network was developed as a research tool to conduct experimental studies based on real flight data. A partnership between the University of Oxford (UK), the University of Kaiserslautern (Germany) and the armasuisse (Switzerland) had developed the participatory sensor network. (Strohmeier, Martinovic, Fuchs, Schäfer, & Lenders, 2015) The network uses ADS-B sensors distributed to volunteers throughout central Europe. In 2014 the network covered 720,000 km2 and captured 30% of the commercial aircraft traffic in Europe (Schäfer, Strohmeier, Lenders, Martinovic, & Wilhelm, 2014) and by 2015 the network captured 40% of the traffic covering over 1 million km2. The network comprised of 27 sensors in 2015, as shown in Figure 3, which are low-cost and connected over the Internet. (Strohmeier et al., 2015) OpenSky currently has more than 2000 sensors around the world with coverage in all continents shown in Figure 4. (“Opensky network,” n.d.) The network continues to grow as more volunteers add sensors. Due to the low-cost of equipment participants can join with little difficulty. (Schäfer et al., 2014) The network exhibits the largest dataset of aircraft surveillance data of its kind. (“Opensky network,” n.d.)

*A close up of a map

Description automatically generatedA picture containing tree, light, outdoor, text

Description automatically generatedFigure 4: OpenSky world-wide coverage* (“OpenSky’s reception coverage (July 2017) based on crowdsourced ADS-B... | Download Scientific Diagram,” n.d.)

*Figure 3: 27 OpenSky Network sensors 2017*

(Strohmeier et al., 2015)

Commercial flight tracking networks such as the market leader Flightradar24, FlightAware and Plane Finder do not store the raw ADS-B or Mode S messages for experimental purposes. (Schafer et al., 2016) OpenSky offers more 15 trillion historical ADS-B, Mode S and FLARM messages. (“Opensky network,” n.d.) It records all messages as they are received by the sensor nodes and stored on a MySQL database server. (Schäfer et al., 2014) The data is accessible by a REST API represented as state vectors were Java or Python can be used to bind to the API. The state can be retrieved as a vector in the form of a JSON object. (“The OpenSky Network API documentation — The OpenSky Network API 1.4.0 documentation,” n.d.) The state vector of an aircraft is a summary of the tracking data from the ADS-B and Mode S messages. The data within the state consists of primarily the position, velocity and identity at a given time. Each aircraft/transponder is identified by a unique ICAO 24-bit address presented by its hexadecimal representation. As a message is received to the server a record for the aircraft is created (state vector). The data required to track the aircraft such as the ICAO address, call sign, Unix timestamp and spatial data (position, velocity and heading) will coincide with the state vector. (The OpenSky Network, 2017) If a member of the OpenSky Network, developers can use the 15 trillion historical ADS-B, Mode S and FLARM messages. However if not a member, the user may only use current flight data i.e. real-time data. (“OpenSky REST API — The OpenSky Network API 1.4.0 documentation,” n.d.)

Flight vectors are updated periodically, however, if no updated position or velocity is received within 15 seconds the position and velocity are omitted from the state vector. The API would consider the state vector obsolete and not return further state vectors. No received data before 15 seconds the position and velocity remain the same to the previous received.

Several functions are available to receive state vectors, flights and tracks for the entire OpenSky Network or to receive a particular aircraft from the REST API. The root URL of the API “http://opensky-network.ord/api” allows for the functions to be appended to the endpoint of the path. The following parameters are a sample of requests that can be made to the API. (“OpenSky REST API — The OpenSky Network API 1.4.0 documentation,” n.d.)

|  |  |  |
| --- | --- | --- |
| **Property** | **Type** | **Description** |
| time | integer | Time in seconds since epoch (in Unix time stamp to retrieve states at given time or current time used if omitted) |
| icao24 | string | One/multiple transponder address to give property of that address (if omitted all aircraft state vectors are returned) |
| lamin | float | The minimum bound of the latitude (decimal degrees) |
| lomin | float | The minimum bound of the longitude (decimal degrees) |
| lamax | float | The maximum bound of the latitude (decimal degrees) |
| lomax | float | The maximum bound of the longitude (decimal degrees) |

A query request example to the REST API with the parameters of time and ICAO transponder address using URL:

### http://opensky-network.org/api/states/all?time=1572618734&icao24=c0ff33

The JSON response by the API gives properties of the following:

|  |  |  |
| --- | --- | --- |
| **Property** | **Type** | **Description** |
| time | integer | The time which the aircraft state vectors from the response are associated. |
| states | array | The aircraft state vectors |

The property “states” are a two-dimensional array containing multiple state vectors with fields such as icao24, callsign, origin\_country, longitude, latitude, velocity and vertical velocity.

The OpenSky Network API gives accurate and detailed data ideal for use as a data source in a flight tracking application. However, coverage of the network does not cover the main areas of Scotland or outskirts of Europe. It focuses on central areas of Europe and the United States providing a lesser range of air traffic available and excluding users from these key locations. The network is primarily used for research where the data is optimal for that area of use however not optimal for the use of tracking individual flights a prominent use of flight trackers today.

1.2.2 FlightAware

FlightAware, founded in 2005 in Houston Texas, is an aviation company operating the world’s largest flight tracking and data platform. The network has global connectivity in every segment of aviation. The network receives data from multiple different data sources in collaboration with other companies. They receive data from ATC systems in over 45 countries, have ADS-B ground stations/receivers in 195 countries, gain data from Aireon space-based ADS-B and have datalink access to every major satellite provider such as ARINC, SITA, Satcom Direct, Garmin, and Honeywell GoDirect. FlightAware’s receivers are distributed worldwide with over 20,000 currently issued to FlightAware users. The network’s coverage is shown in Figure 5, yellow representing MLAT and ADS-B represented in green.

A picture containing tree

Description automatically generated

*Figure 5: FlightAware ADS-B/MLAT coverage* (“FlightAware ADS-B Coverage Map - FlightAware,” n.d.)

FlightAware collaborates the sources of data using AI models and algorithms, this collaboration is achieved by FlightAware’s HyperFeed engine. The data can be accessed through FlightAware’s API called FlightXML. Applications can query the API for the live flight data similarly to the OpenSky Network. The network servers store data of up to two weeks before the current time. Significantly less than the vast network data store OpenSky possesses. When queried the user can request the API to return a set of matching aircraft based on different attributes example attributes follow:

|  |  |  |
| --- | --- | --- |
| **Property** | **Type** | **Description** |
| type | string | The aircraft type ID |
| origin | string | Airport code of origin |
| destination | string | Airport code of destination |
| airline | string | Airline code of the carrier |
| flightno | string | Flight number of the aircraft |

The API once queried responses and returns aircraft matching the query giving data of flight number, aircraft type, origin, destination, longitude/latitude, and groundspeed. A feature FlightXML provides unlike the OpenSky Network is airport queries, a beneficial feature for the user base of plane spotting hobbyists. Queries specific to airports can return a list of scheduled flights, departed flights, en route flights to the airport and arrived flights.

Developers can access the FlightXML data by having a FlightAware account. When queries are made to the API requests must contain the user’s username and API key. The requests are transmitted by the HTTP Authentication standard for each request made to the server. Similarly to OpenSky developers can retrieve data from FlightAware using Representational State Transfer (REST) giving responses encoded in JSON format. The network can also be accessed using Simple Object Access Protocol (SOAP) however responses returned in JSON allow for the data to be used in environments such as mobile phone applications and web browser applications. Unlike the OpenSky Network, multiple languages can be used to bind to the REST API such as JavaScript, Microsoft Classic ASP, Objective C, and Ruby.

The FlightXML API gives accurate data through the many data sources it compiles its data from. The use of HyperFeed allows for the most accurate data through filtering multiple data sources using the AI models and algorithms. Although similar to the OpenSky Network having users deploy receivers to advance the network due to the collaboration with companies and ATC systems allows for a vastly larger coverage in comparison. This coverage would allow for a greater proportion of flight traffic to be accessible to the proposed application users.

* 1. Augmented Reality

Augmented Reality (AR) is defined as a real-time or indirect view of a physical real-world environment that has been enhanced by the addition of virtual computer-generated data creating a mixed reality. Augmented Reality is interactive by combining real and virtual objects to users in the aim to simplify the user’s life and enhance their perception by bringing virtual information to a surrounding. The first form of Augmented Reality dated back to the 1950s where a cinematographer, Morton Heilig, thought by bringing the viewer into the onscreen activity by taking in all the senses would encourage the viewer perception. Heilig built a prototype in 1962 of the concept called Sensorama which predated any digital form of computing. (“Handb. Augment. Real.,” 2011)

Augmented Reality today is presented as a futuristic technology with users primarily being exposed to it by companies incorporating the technology within mobile applications. (“What is Augmented Reality? | Live Science,” n.d.) Mobile devices provide advanced technical abilities such as motion sensors, a GPS sensor, and a high-resolution camera. Mobile applications using technologies such as AR have to be developed for different operating systems to ensure spread of user base may use the application. However, must deal with the current capabilities the operating systems support while simultaneously utilizing the technical capabilities proposed to be implemented. (Geiger, Schickler, Pryss, Schobel, & Reichert, 2014)

Current applications available using AR are Vito Technology’s Star Walk app which allow users to point their phone camera towards the sky to see the names of stars and planets. An application which uses similar technology to the proposed flight tracking application uses the user’s GPS location and their camera to collect information about the user’s surrounding. From this, data is displayed about the nearby restaurants, stores and points of interest within the user’s surrounding. (“What is Augmented Reality? | Live Science,” n.d.)

Two forms of simple augmented reality exist, Marker based AR and Location based AR. Both use the user’s camera however Marker based uses visual cues where Location based uses positional data from the user’s mobile phone such as the GPS and compass. (Patkar, Singh, & Birje, 2013) Marker based AR uses images that can be detected by a user’s camera and used to project a virtual item into the scene as shown in Figure 6.

A picture containing person

Description automatically generatedA picture containing person, sewing machine

Description automatically generated

*Figure 7: Location based AR*

*(“Everything You Need… App (Updated) – Vakoms Blog,” n.d.)*

*Figure 6: Marker based AR*

*(“example of marker-based AR | Download Scientific Diagram,” n.d.)*

Location based AR unlike Marker based is not bound to a select area to project its image. The application using Location based AR does not require a marker to display content it only requires the GPS location of the user’s phone, the direction in which it is pointed and the location of where the content is to be displayed as shown in Figure 7. Location based AR is more interactive in comparison to Marker based and its functionality more aligned to how content would be displayed for use of augmented flight tracking. (Patkar et al., 2013) Developers can use a range of libraries to incorporate Augmented Reality onto mobile applications such as AR.js.

1.3.1 AR.js

AR.js is an online library accessible on the web for use of Augmented Reality within web applications. The library has features which enable Marker based AR and Location based AR. As it runs purely on the web browser it requires no installation. AR.js runs on all mobile platforms such as Android, iOS11 and Windows mobile.

Depending on your device, it can run very fast, up to 60fps on 2year-old phones! On top of that, the code is open source and all available on [github](https://github.com/jeromeetienne/ar.js" \t "_blank).

References

Figures

Figure 1: How ADS-B works (Richards et al., 2010)

Figure 2: How MLAT works (“Multilateration (MLAT) - FlightAware,” 2019)

Figure 3: 27 OpenSky Network sensors 2017 (Strohmeier et al., 2015)

Figure 4: OpenSky world-wide coverage (“OpenSky’s reception coverage (July 2017) based on crowdsourced ADS-B... | Download Scientific Diagram,” 2019)

Figure 5: FlightAware ADS-B/MLAT coverage (“FlightAware ADS-B Coverage Map - FlightAware,” n.d.)