Technical Milestone Report - Aircraft Data Logger

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Abstract

Pilots use aircraft performance charts to calculate take off and landing distance and it is important that these charts are accurate for the pilots safety. Charts are construed from test data and so this test data must also be accurate, but this comes at a cost, especially if using an 'off the shelf' solution. In this report, the project plan for an 'Aircraft Data Logger' is laid out, showing current progress including researching a cheaper and simpler alternative to Differential GPS.

1 Introduction

In order for a pilot to safely take off or land an aircraft, they must know the aircrafts take off distance and distance to clear 15m. Conditions such as ambient temperature, pressure, wind speed, runway surface and gradient and aircraft weight all affect this distance. So pilots can determine this distance, aircraft performance charts are used. Given the weather conditions, runway conditions and aircraft weight, the pilot can read off take off distance form the chart. Constructing these performance charts so there take off distances are accurate is therefore of great importance for the safety of the pilot and others on board an aircraft.

There are well know equations or software that will take test data of take off distance and distance to clear 15m as well as the weather and runway conditions and produce a performance chart by extrapolating from the data. So for the performance chart to be accurate, the test data must be accurate. This however, for light aircraft, isn't the case. Test pilots acquire this data 'by eye', using markers on the runway and the aircraft's altitude meters to try and determine these distances. This method is prone to human errors due to the test pilot also trying to operate the aircraft at the same time and runway distance markers may be incorrect.

Accuracy is obtained in commercial aircraft testing by several methods, including using a Differential Global Position System (DGPS) solution, which has cm accuracy in surveying use. These however are expensive, with an 'off the shelf' DGPS staring at around £500, meaning test pilots either not being able to afford them for testing light aircraft, or think that the gain in accuracy is not worth the cost. Furthermore, the determination of altitude using GPS results in significantly less accurate results when compared to results of altimeter. There is therefore a need for a cheap but accurate method of collecting test data to construct aircraft performance charts. This is the goal of this project.

2 Background

2.1 GPS

A GPS receiver uses the location of at least 4 satellites and the time it takes for each signal to reach the receiver to compute a receivers location using trilateration. With timing being the crucial component to accurate location, any error or delay in this signal will result in an inaccurate or incorrect location. A main source of errors is propagation errors, which are introduced as the signal slows as it passes through the ionosphere (caused by ionized particles slowing the signal down) and troposphere (caused by changing refractive index). Deviations in satellite behaviour, including incorrect potion and number of satellites visable, also affect the accuracy of the position.

2.2 Differential Global Positioning System (DGPS)

To overcome the error in position due to signal delay, DGPS can be used. This involves two receivers, a base receiver at a fixed, known position, and a roaming receiver.

Over time propagation errors average out to zero as they are random. So if a receiver doesn't move, its average location will be correct. So when a delayed signal is received a from satellite, it knows what the signal should be instead so calculates the difference between the delayed signal and the signal it should have received from this satellite. This error for this satellite is then transmitted to a roamer station which can then correct the signal it gets from this satellite. By doing this for all the satellites both receivers see and then using these corrected signals for the position calculation, error from propagation delay can be removed. This greatly increase the accuracy from 3m to a few centimeters for surveying grade DGPS.

3 Project Goal

The goal of the project is to create a cheap module that can measure accurately take off distance, distance to clear 15m and distance to descend 15m for aircraft.

Such a module has to meet the following requirements:

- 10Hz data acquisition rate: To allow a high enough resolution to determine take off and 15m so distances can be calculated.
- Altitude accurate to within 0.3m: At 15m, this is an error of 2% which is has been deemed acceptable as it is relatively small.
- Distance accurate to within 2m: Take-off instances range from between 1500m to 2000m, meaning an error of around 0.1%, which is less then the 'by eye' approach and is a small enough error to be acceptable.
- Standalone module: Can be taken from aircraft to aircraft, and also have an external antenna plugged in so it has a clear line of sight with the sky.
- Removable memory: This allows for the data to be post processed by some software.

- Easy to use: This includes things such as 2 status LEDs to ensure the user knows if the GPS has a fix and if the module is logging, and the post processing being 'plug and play', meaning only the SD card needs interesting and a simple process followed to get results.

And the end of this project, the solution will be assessed against these requirements to evaluate the project.

4 Project Timeline

The project is broadly split into 3 parts:

- Research phase: During Michaelmas term, investigating hardware to be used and assessing their suitability was key. DGPS alternatives where investigated. Decision where then made on if DGPS is needed as well as the architecture of the data logger.
- Design and make phase: This is where the PCB for the module is designed and fabricated, the casing designed, firmware written and post processing code written. This is to be done in Lent term.
- Test and reporting phase. A testing plan will be drawn up and testing will hopefully take place using the engineering departments aircraft. The entire project will then be written up. This takes place at the end of Lent term as well as during Easter term.

I've chosen not to plan the project in the form of a Gantt chart as with some aspects of the project being new to me, such as ECAD design and writing firmware from scratch, means I don't know how long they will take. Also, testing will be ongoing as features are added to the module. Instead, the rest of the project is planned in a series of milestones to reach:

- Milestone 1: Decide on PCB architecture.
- Milestone 2: Send PCB off to be fabricated. This means it must be designed as well.
- Milestone 3: Write completed firmware for the module, so it reads GPS and pressure sensor data and save the data to the SD card
- Milestone 4: Get take-off distance and distance to clear 15m from via post processing the data.
- Milestone 5: Successful testing of the module.

5 Current Progress

5.1 GPS

The MTK3339 GPS mould was chosen at it has 10Hz data acquisition rate, comes in a breakout board package, and outputs NMEA sentence via UART. This allowed for quick set up and prototyping through connecting it to an Arduino, allowing for an alternative DGPS to be experimented with.

5.1.1 Investigating DGPS alternatives

Conventional DGPS removes the error caused by propagation delays before calculating position. However, if two GPS modules are close enough together they should see the same section of sky, so see similar satellites and have similar propagation delay errors. Therefore the error in their position calculations should be similar so instead of using the signal error, by averaging the base location over time and using the difference in location of a reading at time t and the average base location as the error and communicating this to the roaming receiver, it can subtract this error from its location which should improve the accuracy of the reading. This is the method behind our 'cheap' DGPS.

To test this method of correcting GPS readings, 2 modules where placed at a fixed distance apart for a length of time. One module was used as the base module, with readings denoted $\mathbf{b_i}$, and its average location was calculated ($\overline{\mathbf{b}}$). Then each roaming station reading ($\mathbf{r_i}$) was matched to the base location reading taken at the same time ($\mathbf{b_i}$). The difference in average base location and measured base location ($\mathbf{e_i} = \mathbf{b_i} - \overline{\mathbf{b}}$) was then subtracted from the roaming reading to create a corrected roaming reading ($\mathbf{r_{i,c}} = \mathbf{r_i} - \mathbf{e_i}$). The great circle distance between any two readings can then be calculated.

Figure 1 shows a plot of the great circle distance between two points minus the true distance apart (91.44m due to the length of the rugby pitch) plotted over time.

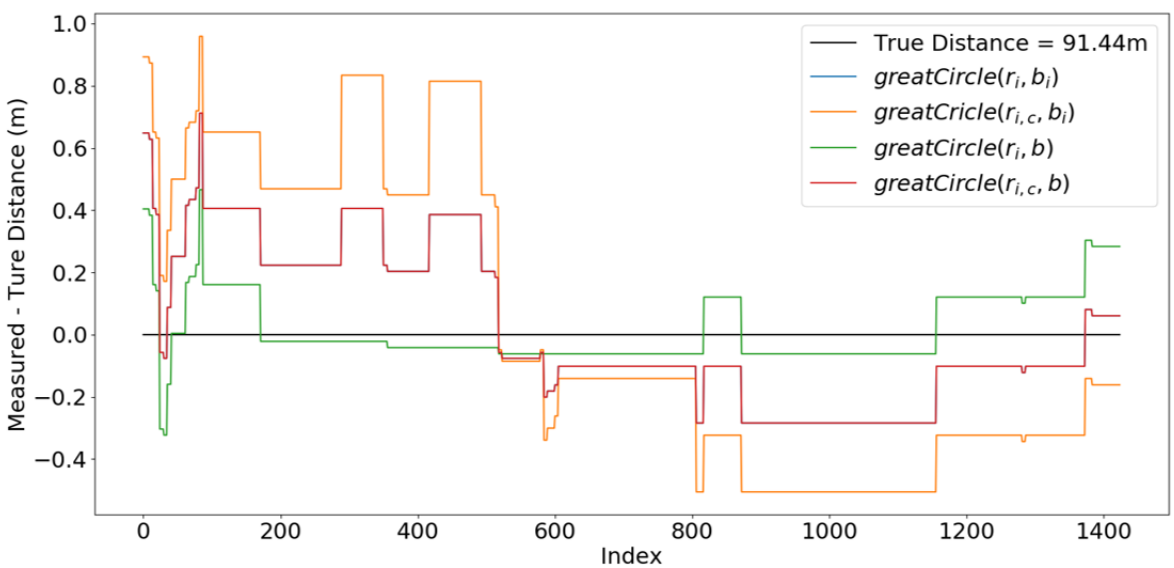

Figure 1: Plot of the error in distance between two points over time. b_i represents a base module reading and b the average base location reading.r_i represents a raw, uncorrected roaming station reading while $r_{i,c}$ a corrected roaming reading

Interestingly, the distance between uncorrected base ($\mathbf{b_i}$) and roaming ($\mathbf{r_i}$) readings (blue line, not visable) is the same as the distance between the average base location ($\overline{\mathbf{b}}$) and corrected roaming ($\overline{\mathbf{r_{i,c}}}$) readings (red line, on top of blue line). This makes sense as by subtracting the error vector $\mathbf{e_i}$ from both ($\mathbf{b_i}$) and ($\mathbf{r_i}$), the distance between the two points has not changed as $\mathbf{e_i}$ is parallel to itself.

One thing that does improve the accuracy and removes large jumps in readings is by using the average base location ($\overline{\mathbf{b}}$) and the uncorrected roaming readings ($\mathbf{r_i}$), as this removes the variation in the base location. Of course this could be further improved by averaging the roaming receiver location but this would be counter productive when the roaming receiver starts to move, such as when taking off. However, if we average the location of the module when sat still before taking off, we can use that average location the measure distances from, which should improve the distance accuracy. This is one of the next things to test.

Furthermore, the GPS module being used comes with Satellite-Based Augmentation System (SBAS) enabled which delivers to the module the corrections and integrity data as well as some ancillary information (timing, degradation parameters, etc.) through messages encoded in the signal. The GPS module can use this information to correct signals and position much like DGPS and this is enabled on the MTK3339 by default. So if corrections have already been made to the signal, this further correction post processing is not only unnecessary, but may be introducing error due to different satellites being in view for each module or multipath errors, resulting in a worse reading.

5.1.2 Data acquisition rate

In this test, the GPS module was placed stationary in a field, got a location fix and logged data for 10 minutes. Table 1 shows the mean and standard deviation in latitude and longitude as well as the maximum variation in distance at each frequency.

Statistic	1Hz	5Hz	10Hz
μ_{lat}(decimal degrees)	52.201457	52.201462	52.201493
μ_{lon}(decimal degrees)	0.0993762	0.0993744	0.0993608
$\sigma_{lat}(\times 10^{-6})$	2.610	3.985	7.020
$\sigma_{lon}(\times 10^{-6})$	3.363	3.834	0.9329
$\delta d(m)$	1.44	1.68	2.60

Table 1: Results of the data acquisition rate test, showing standard deviation in latitude, longitude and greatest distance between two points

As the table shows, the 1Hz and 5Hz agree well, having similar variation and position. At 10Hz however, there is a larger variation and the location doesn't agree. This is because the SBAS (described above) is disabled above 5Hz, even if the NMEA sentence says it is active. Without SBAS, the datasheet claims the position accuracy drop from 2.5m to 3m. This explains the greater variation in position and the shift in position, as the GPS module isn't making the signal corrects as it hasn't received the data to do so. This means there is a trade off of having a high data acquisition rate for greater resolution when moving at take off speed, or a lower acquisition rate to ensure better accuracy in position.

5.2 Pressure Sensor

The MPL3115A2 pressure sensor has been chosen for altitude measurement as it fulfills the requirements over having a 10Hz data acquisition when in polling mode, and gives altitude accurate to 0.3m.

During testing it was found that temperature effects the pressure reading, as well as wind speed and other effects, such as being inside or outside. To avoid fluctuations when the pressure sensor is used to measure altitude, it will be key to keep the pressure sensor in a controlled environment.

6 Conclusions and next steps

So far in the project, the research portion is coming to and end and the design is beginning. From the research we have concluded:

- The 'cheap' DGPS doesn't increase the accuracy of positioning as subtracting either adds error (in the $greatCircle(r_{i,c}, b_i)$ case) or makes no difference (in the $greatCircle(r_{i,c}, b)$ case). Furthermore, any increase in accuracy isn't sufficient enough to warrant the design of another module, so 'cheap' DGPS will not be used.
- While the GPS module can operate at 10Hz, the SBAS correction that it can do to improve accuracy can only operate up to 5Hz. Therefore operating at 10Hz decreases the accuracy of the module but does increase the resolution of the data. This trade off needs to be considered.
- As the pressure sensor warms up or the ambient air changes temperature, the changes the pressure reading. Also other conditions such as wind affect pressure readings. So the pressure sensor on the device will need to be isolated to try and keep it at a constant temperature and shield it from wind in order to measure the true ambient pressure.

The next steps in the project are:

- The trade off between accuracy at 5Hz using SBAS and resolution at 10Hz needs to be considered.
- The idea of averaging the location of a stationary aircraft before take off in order to improve accuracy needs to be tested.
- The architecture of the PCB needs to be finalized including choice of micro-controller, power supply and method of attaching the sensors.
- As this a stand alone module, considering the packaging of the module is also key.

7 References

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