P6.13

Attitude Accuracy Improvement of Ultra Low-Grade MEMS INS using Alignment of GPS Antenna

Masaru Naruoka

(The University of Tokyo,
Department of Aeronautics and Astronautics,
Graduate Student)

Paper ID is 483.

Abstract

This study proposes a method to improve the accuracy of attitude estimation of an ultra low-grade inertial navigation system (INS) by integration of a GPS receiver and smart placement of the GPS antenna. The proposed method utilizes the "lever arm effect" originating from the difference in the locations of the inertial measurement unit (IMU) of the INS and the GPS antenna. The method enhances the observabilty of the attitude, which can neither be correctly estimated by such a low-grade IMU nor be obtained directly from the GPS receiver's measurement values, and its advantage is shown experimentally with a prototype system. Furthermore, analysis of covariances matrices reveals further hints to use the method effectively.

1

Introduction

Navigation instruments should be smaller, lighter, and more cost-effective.

Not only for conventional aerospace field, but also for applications such as small unmanned aerial vehicles, and car navigation.

The integration of an ultra low-grade INS which consists of micro-electro-mechanical system (MEMS) inertial sensors and civil-use GPS receiver is one of the best solution.

Kalman filtering compensates for the low accuracy of MEMS inertial sensors.

However, the accuracy in attitude, especially heading, is not sufficient, and should be improved.

According to the author's previous study, the error in heading is about 10 degrees.

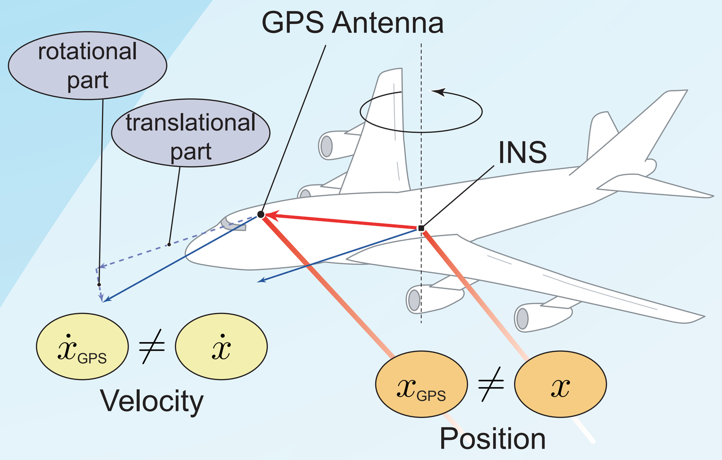
2

Lever arm effect

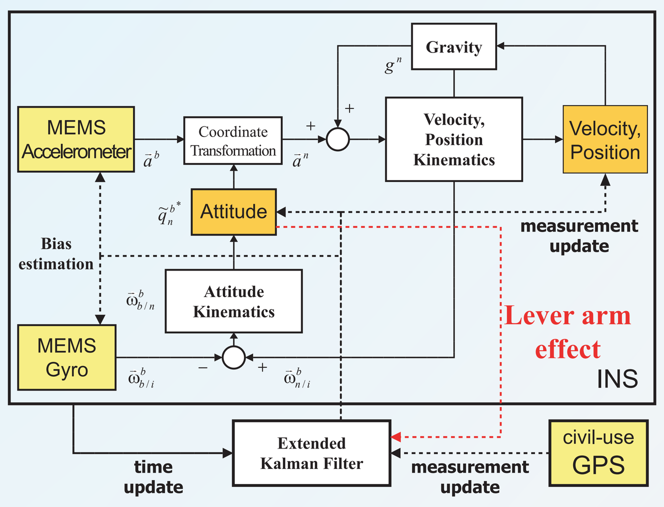
If the GPS antenna is fixed at the location different from the IMU, the linealized observation equation of Kalman filtering is derived like:

$$\begin{bmatrix}\dot{x}\\ x\end{bmatrix}_{\mathrm{GPS}} = \begin{bmatrix} I & 0 & \not{0} & \not{0} \\ 0 & I & \not{0} & 0\end{bmatrix}\begin{bmatrix}\dot{x}\\ x\\ a\\ b\end{bmatrix} + v,$$

where $\dot{x}$, x, a, and b stand for velocity, position, attitude, and sensor biases respectively, and $\not{0}$, and v indicate a non-zero value and the error of observed value. This equation shows that the outputs of a GPS receiver include clues of the attitude indirectly, and can be used to help the estimation. This is "lever arm effect".



Due to the "Lever Arm Effect", the outputs of the GPS receiver is not equal to those of the INS.

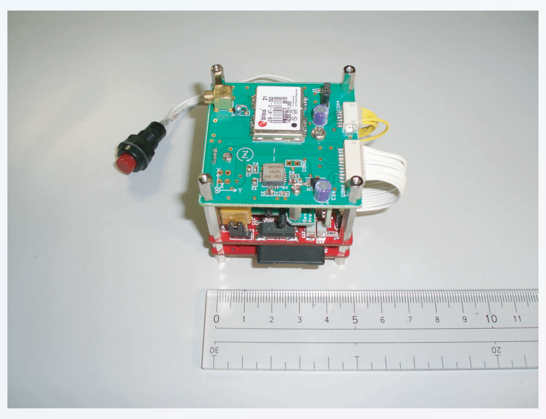


Improved INS/GPS algorithm

3

Experiment with a prototype system

To evaluate the effectiveness of the proposed method, experiments to compare the flight log obtained by a prototype system with that of a high-precision INS/GPS device, GAIA, are performed.

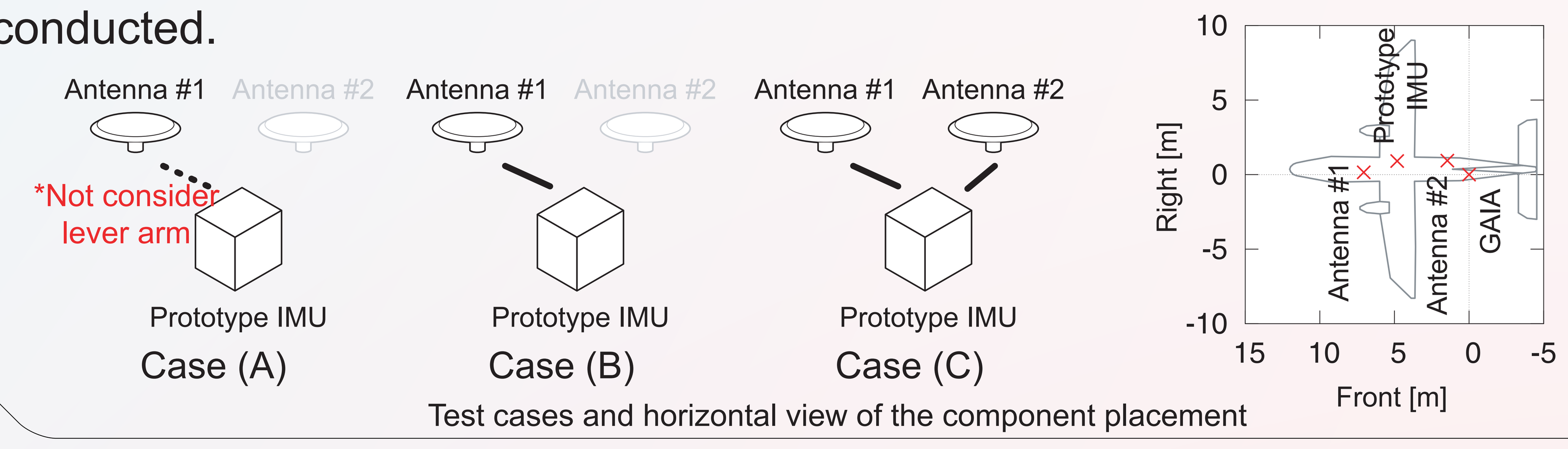


Prototype System

Specification of prototype

Item	*Description*
Accerlerometer	STMicroelectronic LIS3L02AS4 (MEMS)
Gyro	Analog Devices ADXRS150 (MEMS)
GPS receiver	u-blox LEA-4T (4Hz update, L1-signal)
A/D converter	Analog Devices AD7739 (24bits, 100Hz)
Processors	200MHz DSP, 8bits-MCU, FPGA
Size	51 x 51 x 60 mm (W x H x D)
Weight	121 g
Material cost	about US$ 500 per unit

In order to clarify the effectiveness of the proposed method, three cases are conducted.

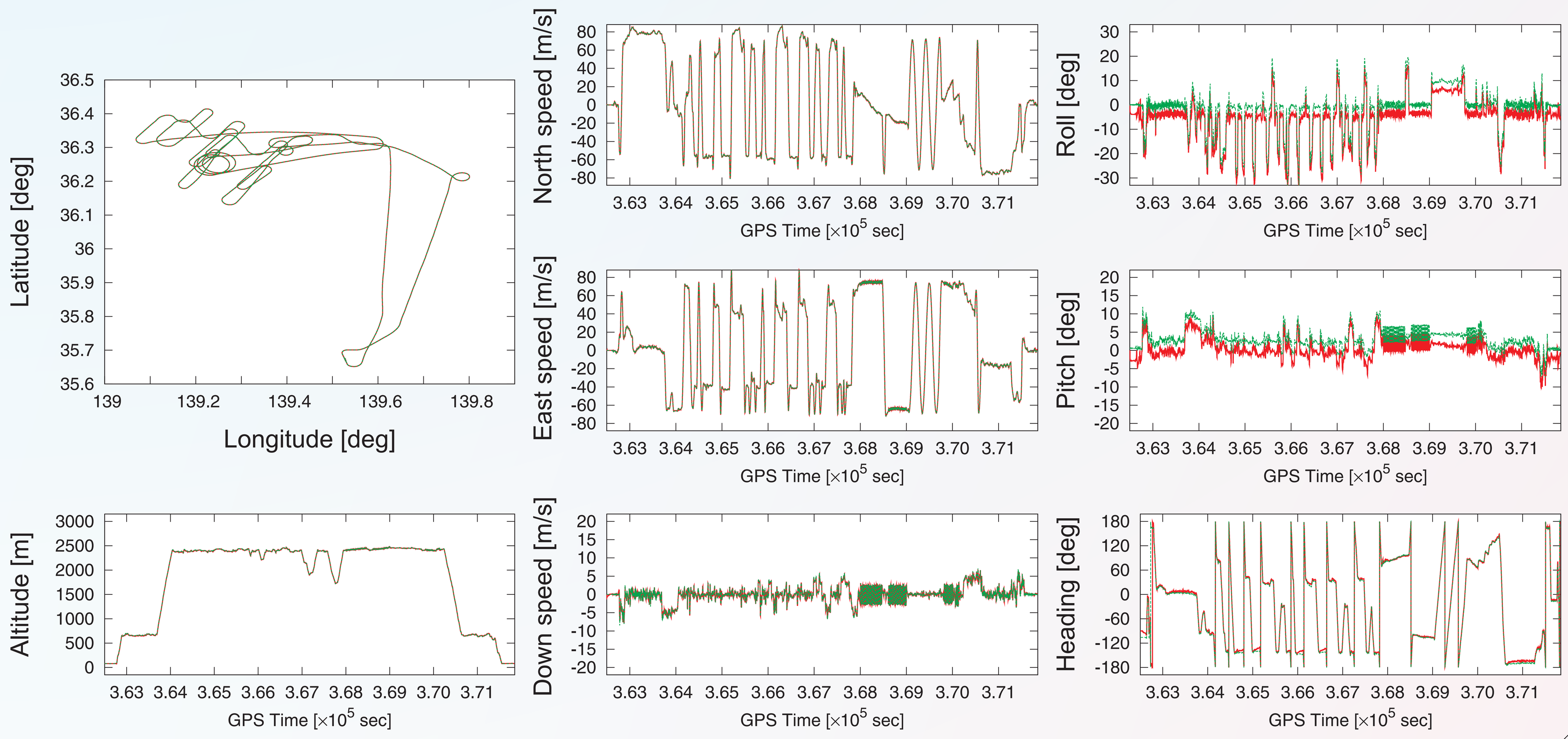


Test cases and horizontal view of the component placement

4

Experiment results (1)

In all cases, the outputs of the prototype system do not diverge and are nearly equal to those of GAIA. A comparison of the time history between the case (C) of the prototype and GAIA is shown below.



Comparison of the time history between the case (C) of the prototype and GAIA
(Prototype: ……… , GAIA: ——)

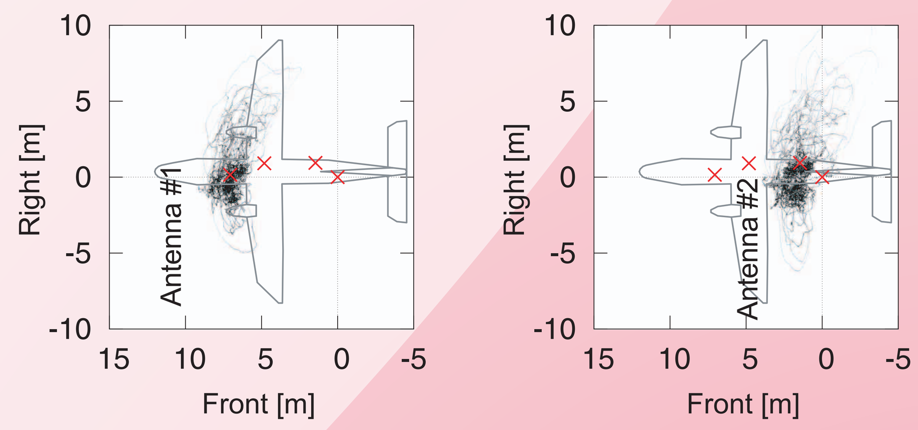
5

Experiment results (2)

Statistical summaries of the error

	Case (A)		Case (B)		Case (C)	
	Mean	*Standard Deviation*	*Mean*	*Standard Deviation*	*Mean*	*Standard Deviation*
Horizontal distance [m]	3.51	1.37	2.39	1.93	2.41	1.83
Altitude [m]	-2.97	3.05	-1.55	3.03	-1.70	3.05
North Speed [m]	-0.01	0.21	-0.01	0.24	-0.01	0.18
East Speed [m]	0.01	0.25	0.01	0.27	0.01	0.21
Down Speed [m]	-0.03	0.22	-0.03	0.21	-0.03	0.16
Rolling [deg]	-3.51	**0.64**	-3.50	**0.65**	-3.53	**0.54**
Pitching [deg]	-2.73	**0.68**	-2.83	**0.53**	-2.66	**0.52**
Heading [deg]	0.37	**4.60**	0.72	**3.72**	2.94	**2.99**

The standard deviation of the attitude error in cases (B) and (C) are smaller than in case (A) shows that the proposed method improves the attitude accuracy, especially in heading. The results also show that the position outputs obtained by the GPS receiver does not strongly contribute to the improvement, because they are not accurate enough.

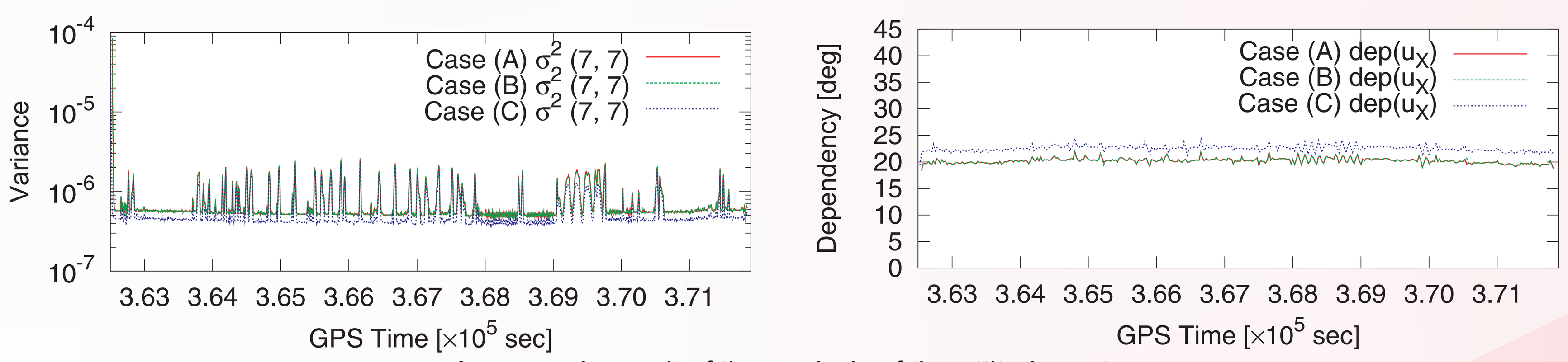


Position outputs of the GPS receiver

6

Covariance matrix analysis

The system covariance matrix of Kalman filtering contains infomation on how accurate and correlate the estimated values are, when the optimal estimation is conducted. If the proposed method is effective, the part of the matrix related to the attitude should have smaller variances, which means it has the possibility of the estimation being more accurate. It should also have stronger dependencies to other parts, which indicates that there are more hints.



An example result of the analysis of the attitude part

In case (C), the variances are the smallest and the devendencies are the strongest among all cases. In case (B), those values are smaller and stronger than in case (A). However, the difference between the two is slight.

7

Discussion

The proposed method is effective, because the attitude accuracy, especially in heading, is improved. It is also worth to stress that even though the outputs of the GPS receiver are not accurate for the attitude determination, the standard deviation of the attitude error is settled to only 3 degrees in case (C).

The covariance analysis supports the fact that case (C) is the most effective. However, it cannot explain the difference between cases (A) and (B) clearly. This would be due to the poor accuracy of the MEMS gyros, because the "lever arm effect" utilizes the angular velocity sensed by the MEMS gyros. On the other hand, in case (C), that disadvantage is overcome by its 5 degree of freedom, which is larger than the 3 of cases (A) and (B).

Without changing the MEMS gyros, the further improvement will be achieved by 1) using the longer arm, and 2) using more gyros.

Conclusion

This study proposed a method to improve the attitude accuracy of an ultra low-grade INS by utilizing GPS antenna placement, and comparison experiments showed its effectiveness. The covariance analysis revealed that the poor accuracy of the MEMS gyro degraded the performance of the proposed mehtod.

8