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Concept Refinement of a Payload Derived Position Acquisition System for Parachute Recovery Systems

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The paper covers the continued development of a Payload Derived Position Acquisition System (PDPAS) to overcome current limitations posed on recovering the trajectory data for a generic parachute recovery system (PRS). The PDPAS is an instrumentation set and software algorithm that is to be installed onto PRS in order to estimate PRS state vector parameters in real-time for testing and operational use. The development of the PDPAD has progressed to a point where it is providing quality data and is ready for development into a usable instrumentation package. The paper discusses the concept of the PDPAS, the first implementation of the PDPAS, changes made to the PDPAS due to continued development, and the steps for needed for the PDPAS to be a validated instrumentation package.

I. Introduction

Currently, there are limitations in generating trajectory information via optical tracking and Global Positioning System (GPS) for Parachute Recovery Systems (PRS).[1,2] Trajectory information is utilized in PRS testing to characterize the systems opening performance, flight performance, and to provide real-time situational awareness of PRS location. For operational utilization, PRS trajectory information is used in the guidance and control algorithms of precision guided systems. Payload trajectories for testing applications are currently generated using a series of optical ground tracking stations, which independently track the payloads from aircraft exit to ground impact. The primary limitations of optical ground stations include the following: tracks only one PRS at a time, requires significant manpower requirement, requires days to process data, is cost prohibitive to many testing programs, and is a limited material resource. In addition, most Precision Guided PRS (PGPRS) utilize GPS systems for real-time operational trajectories. However, the GPS systems take approximately 30 seconds after aircraft exit to produce a solution and are susceptible to GPS jamming in the combat environment.

The Payload Derived Position Acquisition System (PDPAS) is a solution developed to overcome the limitations of optical tracking and GPS for the generation of trajectory information. The PDPAS is a system installed onto a PRS, which contains an instrumentation set and software algorithm that generates the trajectory information. The PDPAS, when fully developed and implemented, will be able to generate PRS trajectories in real-time for testing and operational use in future versions. The trajectory generation of the PDPAS can be done without the required use of GPS when initialized by aircraft data, can be initialized using GPS data only, and would produce a trajectory solution for a PRS from aircraft exit to ground impact.

This paper refines the previous concept laid down in Ref.3 and presents the current state of development on improvements in the instrumentation. To this end, Section II describes background of applications of the PDPAS, discusses the concept of operation for the PDPAS including data processing flow. Section III presents the results of PDPAS algorithm using simulated sensor data. Section IV introduces a hardware setup to be used in the second generation of PDPAS. The paper ends with conclusions and recommendations.

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II. Overview of the PDPAS Concept

PRS trajectory data is primarily utilized in two functions. The first function is for testing of a new PRS. In testing, position trajectory data is utilized to characterize a system's performance at canopy opening, during flight, and upon landing. The attitude data is utilized to characterize the stability of a system and the effect of the wind on flight performance. The position and attitude data are critical in evaluating the suitability, performance, and safety of systems prior to being fielding, and can also be utilized in real-time to monitor the safety of range operations. The second area where PRS data are utilized is in the real-time control algorithms of PGPRS. The current technology utilized in the PGPRS is primarily GPS derived, which provides only position data to the control algorithm.

The PDPAS concept is designed to overcome the limitations of the Kineto Tracking Mount (KTM) derived solution[4] for testing and to provide improved robustness to the design of the PGPRS. To overcome these limitations and provide a robust design, the trajectory data generated must only be from sensors on the payload during the drop, which will provide real-time data for the PGPRS and allow transmission of the trajectory data off of the payload. Having the sensors contained on the payload will allow any number of systems to be instrumented on a drop during a test.

The suggested solution to address these limitations for the PDPAS is a "strap down" Inertial Measuring Unit (IMU) and GPS system. An IMU is a sensor that provides at least three orthogonal accelerometers and three orthogonal rate gyros. Using the IMU data, with initial conditions for the position and Euler angles of the IMU, the trajectory data can be integrated. This IMU generated trajectory data provides the capability to fill in position trajectory data when the GPS solution is lost. Also, the IMU generated trajectory data will provide additional information about the attitude of the PRS throughout the drop, which is an increase in valuable data for testers and PGPRS algorithms. The product of this sensor combination will be a 6DOF solution from aircraft exit to ground impact. Information regarding the integration of IMU data and GPS can be found in Ref.5.

In addition to the IMU and GPS data on-board the payload, additional sensors on the aircraft are utilized to generate the initial conditions for the integration of the trajectory solution. The sensors on-board the aircraft are a 1553 Bus data recorder, GPS re-broadcast kit, and tilt sensors. The 1553 Bus provides a wealth of information regarding the position, velocity, attitude of the aircraft, and general aircraft conditions. The GPS re-broadcast kit provides the GPS satellite signal from the aircraft GPS antenna inside of the aircraft's cargo bay. The PDPAS utilizes the re-broadcast signal to acquire a GPS lock prior to aircraft exit, which eliminates the need for ephemeris and almanac data to be reloaded when the GPS signal is reacquired after aircraft exit. The tilt sensors provide more aircraft and payload attitude data, since the attitude data captured from the 1553 Bus is coarse. Figure 1 shows that the IMU data alone will be used to fill in the position trajectory data until the GPS data can be incorporated.

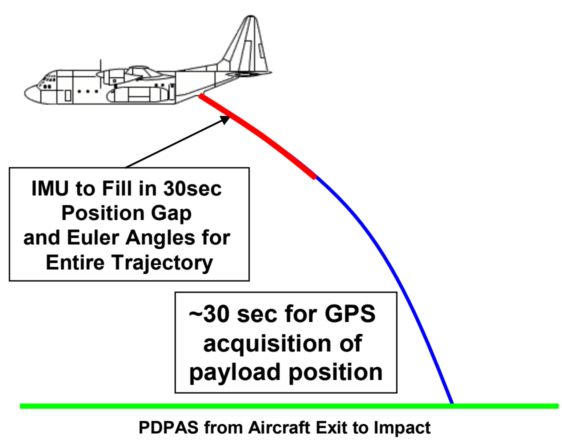

Fig. 1 PDPAS position solution throughout PRS trajectory.

The data sources for the Inertial Navigation System algorithm used in the PDPAS are the aircraft position/attitude, the IMU rate gyros, the IMU accelerometers, and the GPS position data. This data is utilized to initialize the INS, correct for biases in the IMU data, and provide updates to the position solution. Figure 2 shows the input and data flow of the INS model. The flow for the INS model is broken up into three segments; initializing INS, free running INS solution, and GPS updated INS solution. During the initializing segment the initial location and attitude of the IMU that is located on the PRS, are calculated for the initial conditions of the INS solution. The second segment of a free running INS solution is where the trajectory solution is only calculated from the IMU data, and not updated by any external data sources. The third segment is where the INS position solution is corrected using GPS data, due to its independence of INS error and high accuracy.

III. Validation of the PDPAS Trajectory Solution using Simulated Data

Typically, when a model of an engineering system is produced it is verified utilizing truth source data. There are two types of truth source data that are utilized in this thesis. The first is the utilization of validated data sources during the test of a real system. The data generated by the PDPAS using real data is compared to the validated data source for analysis of quality of the PDPAS.

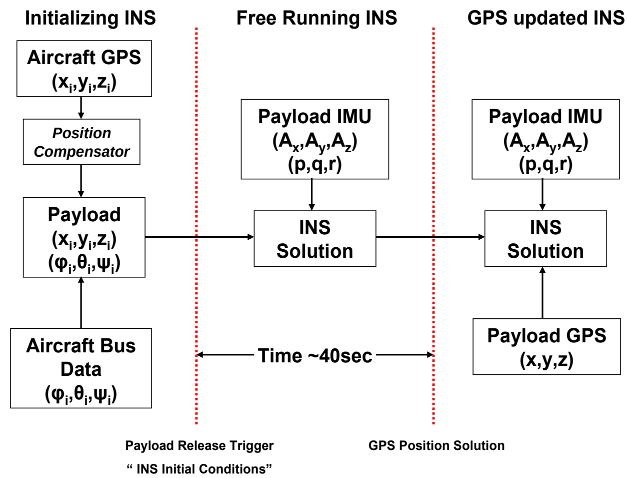

Fig. 2 The INS solution inputs during different segments of the PRS drop.

The second source of truth data is simulated data, data that is completely computer generated. To generate this type of data a model of the system's dynamics is generated, from which simulated data for use with the PDPAS computer algorithms is generated. The strength of utilizing simulated data is that the exact solution is known, the dynamics of the system can be controlled, error sources are controlled, and the data rates are controlled. The limitations of simulated data are that it does not truly represent real data, there may be mathematical errors in the model of the system dynamics, and the physical hardware that captures the data is not in the loop. This chapter shows the dynamic model used, the process used to generate the data, and example runs of the PDPAS computer algorithms with the simulated data.

The Mathworks' Simulink® development environment was used to generate a dynamics model of a PRS. The dynamics are broken up in to phases of the system dynamics, where only the forces acting upon a PRS during that phase are used. The top level of the model is depicted in Fig.3. Figure 4 is the "System Dynamics" block, which is where the dynamics of the system are compiled. The dynamics that are incorporated into this model are system rotation, parachute drag relative to the body, load drag relative to the free steam, and gravity. The "Rotation Matrix" block design is shown in Fig.5. The rotation of the system is not derived from the dynamics of the system, but modeled to approximate the rotation of a real system, which done so that the effect of rotation of the PDPAS solution can be examined. The incorporation of gravity, Coriolis effects, and errors is completed in the "Sensor model" block (Fig.6).

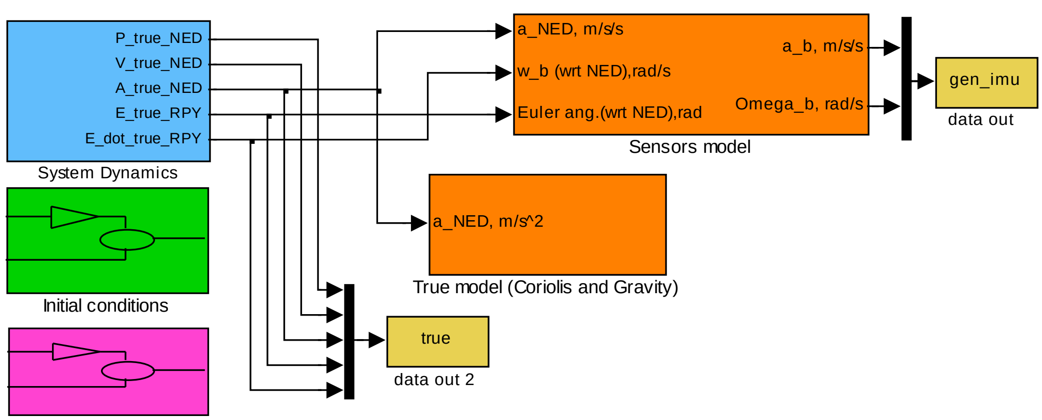

Fig. 3 Top level of the Simulink® system dynamics processing model.

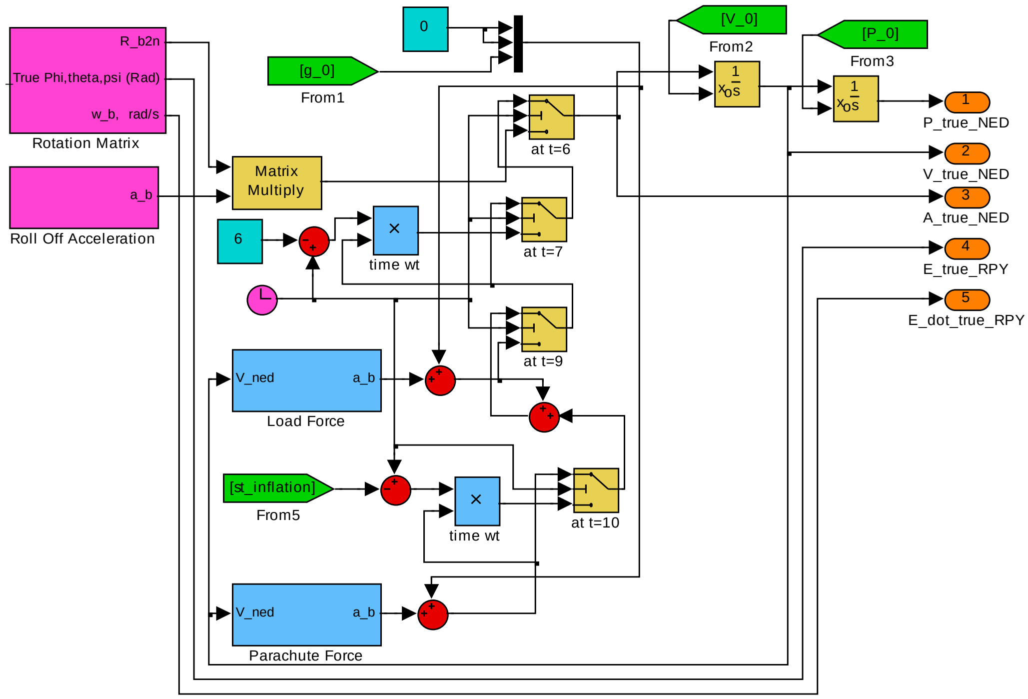

Fig. 4 "System dynamics" block.

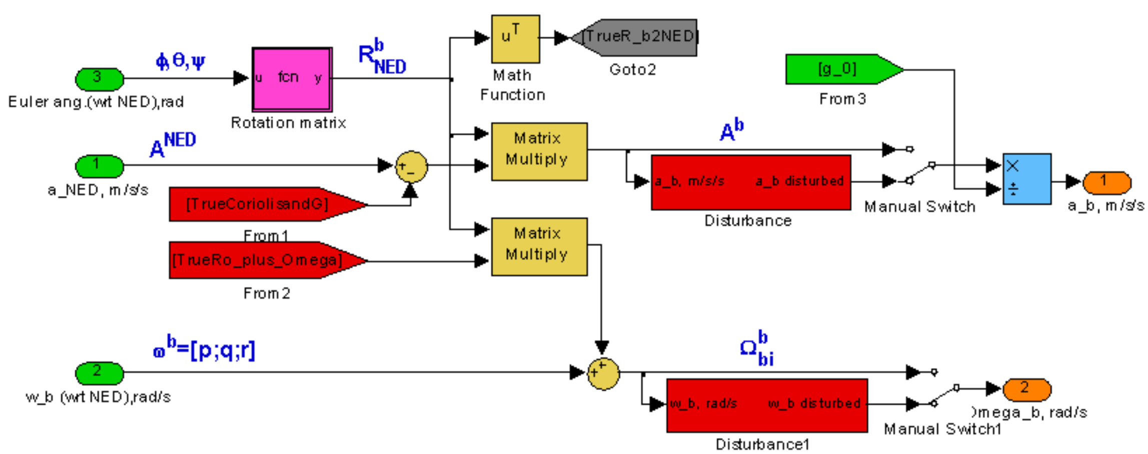

Fig. 5 "Rotation matrix" block.

The outputs of the Simulink® model and script are a set of data files that match the format of a real data set, which was done to reduce errors in the implementation and to provide break in the data flow from the simulation to the INS model. The data file generation provided a method to test the effects of variables such as data rate, data quality, and data drop outs; which helps to provide a robust INS model that is well understood. Figures 7 and 8 are the acceleration and rotation rate simulated IMU data, respectively. Within both of these data sources are all of the dynamics of the system, Coriolis effects, and gravity effects that represent what a real IMU would have seen. The IMU data errors can be introduced, but are not to demonstrate the accuracy of the INS solution without errors. Figures 9 and 10 show the INS solution's total velocity and Euler angle plots with no introduced IMU errors respectively. The total velocity and Euler angle plots show that the INS model developed for the PDPAS matches the truth source data accurately.

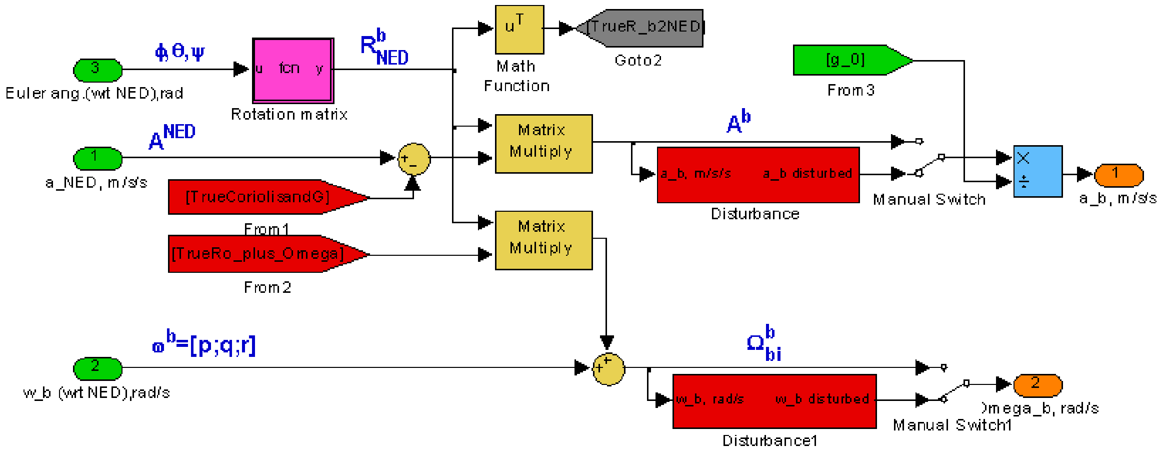

Fig. 6 "Sensor model" block.

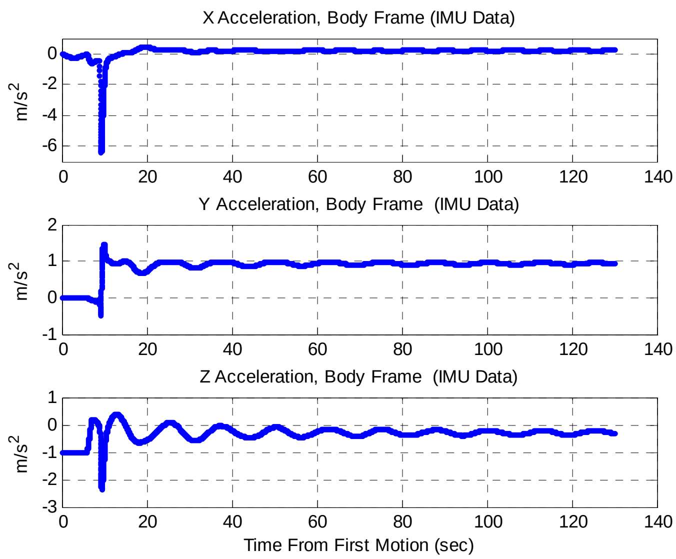

Fig. 7 Simulation generated IMU acceleration data.

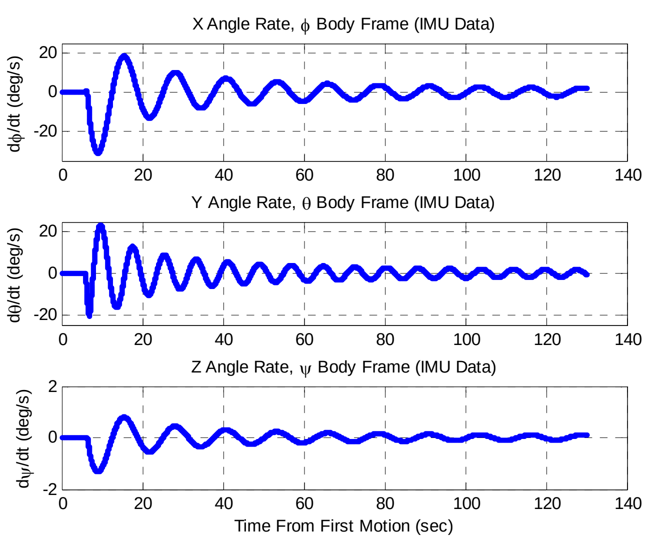

Fig. 8 Simulation generated IMU rotation rate data.

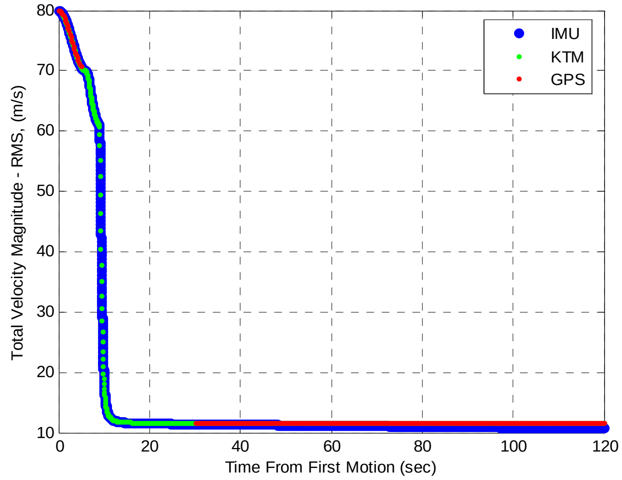

Fig. 9 Total velocity with the PDPAS INS solution vs. KTM and GPS solutions.

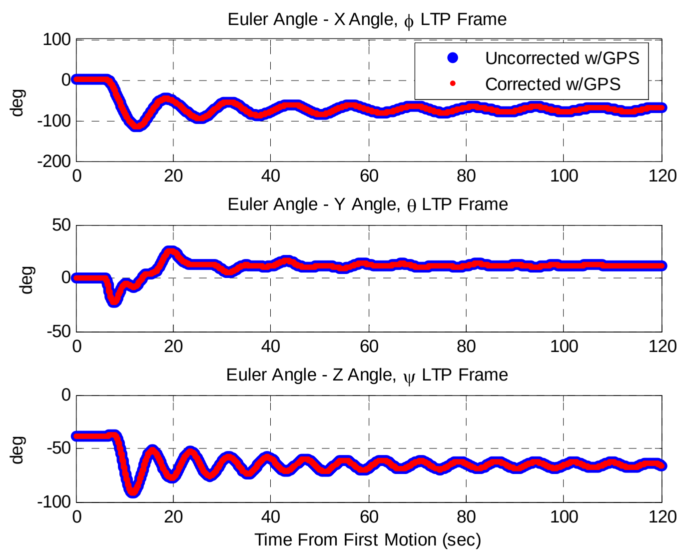

Fig. 10 Euler angles solution with the PDPAS INS.

IV. Hardware Setup for Flight Test Validation

This section talks about hardware to be used in the future tests of PDRAS. The IMU is the Microbotics, Inc. MIDG II (Fig.11), which was chosen for its small size due to space limitations on PRS. The Differential GPS system to be used is a system developed for the U.S. Army Yuma Proving Ground by Cibola Information Systems Inc. There are several vendor parts utilized in the system that are not described here. The accuracy of system is ~1m in position and ~0.2m/s in velocity. The Clinometer is the Schaevitz® by Measurement Specialist's AccuStar® Electronic Clinometer (Fig.12). The 1553 Bus Data Recorder is the model DATaRec D200f from Heim Data Systems (Fig.13). All components were chosen for their availability and the ability to record all of the required bus data.

The PDPAS payload hardware is mounted, as shown in Fig.14, to a mounting plate for incorporation into the PRS. The design of the mounting plate and location on the PRS allows the GPS antennas to be exposed to the sky, the IMU to be hard fixed to the PRS, data to be recorded on-board of the payload, and the system to be activated when the PRS is fully rigged.

One airdrop test was completed utilizing this setup and the results are presented in Ref 3. The results of this airdrop test were that the hardware and software produced a accurate solution when there was GPS and IMU data concurrently. However, when there were GPS data dropout the solution started to diverge after 5 seconds. This was determined to be due to the limited accuracy of the MIDG II when the solotion is integrated only and not corrected by GPS data. This is a significant limitation for the PRS application because the GPS solution is lost for approximately 30 seconds after aircraft exit, which is a critical time period for PRS. Further testing is planned with an IMU with lower errors that should reduce the error of the solution without GPS.

Fig. 11 The Microbotics IMU.

Fig. 12 Schaevitz® clinometer.

Fig. 13 Data recorder.

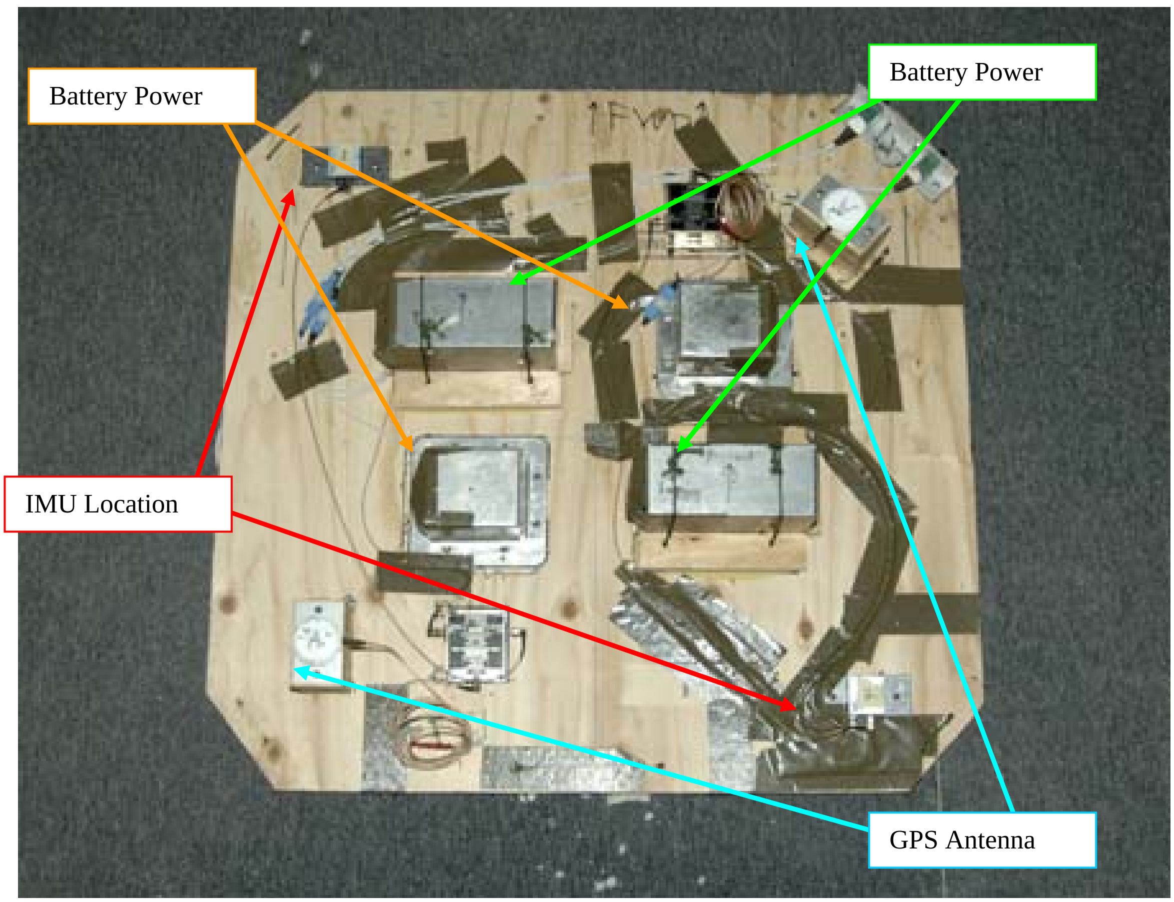

Fig. 13 PDPAS mounting plate configuration.

V. Conclusion

Incorporation of a PDPAS would significantly improve an operational system's performance and would improve the data collection required to support PRS developmental testing. The primary limitation of the PDPAS as demonstrated in this configuration is the selection of the IMU. The IMU utilized did not provide data at the level of accuracy necessary for the INS solution to run without GPS updates. The accuracy of the PDPAS in its current configuration does not meet the accuracy needs of an operational system or for use in testing programs. Further developments should be focused on the selection of an IMU that meets the need for accuracy of the solution for the duration of time when the system will not have GPS updates. The simulated data shows the quality of the PDPAS algorithm with correct data that is continuous. This demonstrates the algorithm is able to integrate all of the sensors and data into a solution for PRS. The problem with the operational system is the quality of the data is not ideal without significant filtering and the quality of the IMU data is critical to a solution the can be implemented as a truth source for position and attitude data of a PRS. Additional work is being conducted on the quality of IMU required for the system to provide a cost effective solution in the testing environment.

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