Optimal Proportional Navigation Guidance Using Pseudo Sensor Enhancement Method (PSEM) for Flexible Interceptor Applications

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Abstract— Proportional navigation (PN) is the guidance law used by most missiles in operational use today. This method of guidance generates missile acceleration commands in proportion to the line-of-sight (LOS) rate. Flexible interceptor defines as a fast maneuverable fighter plane. So, optimal homing missile guidance must be required to improve realism in missile behavior. In the case of sensor(s) transient faults, the disconnection of the readings causes inappropriate actions. So the need for sensor fault detecting and estimating multiple sensor faults becomes an important issue to optimize and enhance the system performance. Redundant sensors can provide highly accurate sensor data and also reconfigure sensor network systems if some sensors failed. In this paper, optimal sensor configurations are investigated using a new proposed pseudo sensor enhancement method (PSEM). Fault detection prediction analysis of multi-sensor architecture is introduced to study different number of sensors with different arrangement architectures and to detect transient faults in each sensor. Then, the proposed PSEM is investigated to isolate and compensate for the transient faults. Finally, the optimal inertial navigation multi-sensor configurations using PSEM have been applied to the proportional navigation guidance (PNG) laws to investigate the optimal proportional navigation guidance. The simulation results of different sensor architecture configurations with applying the PSEM and PNG have been obtained and analyzed to demonstrate the performance. The comparison between the traditional (without PSEM) and the proposed (with PSEM) methods has been introduced to illustrate the enhancement in operational performance of the proposed method to meet the requirements for flexible interceptor applications.

Keywords—Proportional navigation guidance (PNG); multiple sensors; fault detection and isolation (FDI); pseudo sensor enhancement method (PSEM); transient faults compensation; flexible interceptor applications.

I. INTRODUCTION

Proportional navigation (PN) works on the principle of constant bearing decreasing range (CBDR), i.e., two objects are heading in the same direction with no change in line of sight (bearing) angle, the objects will collide. Line of Sight (LOS) is an imaginary sight-line between missile and the target; when target is moving from left to right in the missile field of view, it means that the LOS angle is changing from left to right. If however, missile was to also run from left to right and accelerate appropriately to keep the target centered in missile field of view, it is then said the rate at which LOS angle is changing, i.e., LOS rotation rate is zero or null. Continuing missile to run with LOS rate maintained at zero will result in intercept and lead to pursuit collision with the target [1]-[6]. Two-dimensional missile-target geometry has been shown in Fig. 1 [7].

![Figure 1. Missile-target geometry [7].](image)

Redundant inertial measurement unit is an inertial sensing device composed by more than three sensors [8]. So, multi-sensor data fusion architecture creates the fundamentals for the design of fault-tolerant navigation systems and the achievement of reliability and integrity of inertial navigation systems. In this paper, first, the optimal sensor configuration with 5, 6, 7 and 10 sensors are investigated through the use of a new proposed pseudo sensor enhancement method (PSEM) [9]. Second, fault detection prediction analysis of multi-sensor architecture has been introduced to study different number and arrangement of sensors architecture and detect the transient fault of each sensor. So, a fault must be isolated during its fault transient rather than after a new steady state has arrived in order to overcome the problem with controller compensation using the proposed PSEM which has been presented and investigated to illustrate the behavior of each configuration using the specific pseudo sensor whose placement has been chosen related to the real sensor location that possess the most error transient fault detection. The simulation results of different sensors architecture configurations with applying the proposed PSEM for optimal configurations, fault detection and isolation (FDI) and transient fault compensation have been introduced and analyzed to demonstrate the optimal performance of the inertial navigation sensors using the proposed PSEM. Finally, the optimal inertial navigation multi-sensor configurations using PSEM have been applied to the proportional navigation guidance (PNG) laws to investigate the optimal PNG.
comparison between the traditional (without PSEM) and the optimal (with PSEM) multiple sensor configurations with 5, 6, 7 and 10 sensors have been introduced to demonstrate the excellent performance of the proposed PSEM with the proportional navigation guidance to meet the requirements for flexible interceptor applications.

II. TRADITIONAL AND OPTIMAL MULTI-SENSOR CONFIGURATIONS

The optimal configuration problem of redundant inertial sensors was studied in [10], where redundant MEMS-IMU integration with GPS is considered. In the last decade, finding the optimal sensor configuration for passive source localization [11] or mobile sensor networks [12] has been studied. Recently, finding the optimal sensor configuration has attracted considerable attention [8], [13], [14]. The optimal sensor configuration is necessary to optimize the position, velocity and acceleration estimations. So, the optimal sensor configurations are investigated through the use of the proposed pseudo sensor enhancement method (PSEM), as optimal configuration tool. Refer to reference [13], the necessary and sufficient condition for the sensor configuration with measurement matrix, H to be optimal for the navigation performance is

$$H^T H = (n/3) I$$  \hspace{1cm} (1)

where, $H = [h_1, ..., h_n]^T$; n×3 measurement matrix with rank $(H) = 3$, $|h_i|=1$, $i=1, ..., n$ and $n$ is the number of sensors.

Therefore, the entire optimal sensor configuration with 5, 6, 7 and 10 sensors must satisfy the condition in Eq. (1) according to the number of sensors. The configuration approach of the redundant sensors using the proposed PSEM have been suggested such that the measurement sensed by one sensor can be decomposed into three orthogonal components (red) along the body axes ($x^b$, $y^b$, $z^b$), as shown in Fig. 2. Therefore, the measured states of real (blue, up) and pseudo (green, down) sensors are coupled with each other in the redundant sensors system measurements. This configuration approach is true for even and odd number of sensors except for odd number of sensors; the single sensor location has been chosen carefully to satisfy the condition in Eq. (1) for optimal performance.

Figure 2. The sensor configuration approach using the proposed PSEM.

Fig. 3 shows different traditional and optimal sensor configurations and their measurement matrix. The configuration number denoted by C# while sensor number denoted by $S#$. Also, $\theta$ is the optimal start angle of sensor location arrangement and $\phi$ is the optimal half cone solid angle.
In this section, a robust analysis of traditional and optimal using PSEM multi-sensor architecture fault detection has been introduced to study different arrangement sensors architecture and detect the transient fault of each sensor. Also, the proposed PSEM has been presented, as FDI tool and applied to the different sensor configurations to compensate the transient fault and when a new steady state has occurred. The proposed method depends on the optimal multi-sensor configurations where each real sensor has a specific pseudo sensor, as shown in Fig. 2, and both of them work together as a couple.
So, there is no critical sensor whose error and/or transient fault give(s) inappropriate actions. The study of pseudo sensor placement has been investigated and applied to the different sensors architecture configurations with 5, 6, 7 and 10 multiple sensors to investigate and illustrate the proposed PSEM performance. A sample of the simulation results in X-position of different sensor architecture configurations for traditional and optimal using the proposed PSEM have been shown in Figs. (4) to (7) where ‘No Fault’ or ‘NON’ means all sensors operate correctly and in case of fault detection prediction; it is obvious that every coupled (real and pseudo) sensors has the same error effect. So, each configuration has optimal sensors arrangement using the proposed PSEM, as optimal configuration tool whose maximum transient fault error affects the configuration performance with minimum error compared with conventional architecture configuration. Applying the proposed PSEM, as FDI tool satisfies the detection of the presence of failure and the isolation of the component responsible of the irregularity. Also, the presence of pseudo sensor gives the inertial navigation system the ability to compensate the transient fault of the real sensor, instantaneously.

IV. OPTIMAL PROPORTIONAL NAVIGATION GUIDANCE

For homing guidance, missile having a seeker onboard means additional cost, but at the same time delivers improved guidance accuracy results since the seeker is continuously approaching the target as time progresses. In general, regardless of command or homing guidance, a guidance law ultimately acts as the determinant on how a particular set of commands for guidance is to be generated [6]. In this section, the optimal inertial navigation sensors using the proposed PSEM introduced in the previous sections will be applied to the PNG laws to investigate the optimal proportional navigation guidance. A missile can be launched at the target and be expected to hit. The missile is assumed to be launched directly at the target at all heading angles. The missile subsequently glides to the target while slowing down due to drag forces. The target is assumed to maintain a constant speed with fast maneuverable. For the noise study, a white noise is added to the seeker system. Different scenarios have been studied to compare between the traditional and optimal using the proposed PSEM inertial navigation sensor configurations with 5, 6, 7 and 10 multiple sensors in case of no fault and presence of transient fault. The studies of different scenarios are shown in Fig. 8.
Figure 8. The simulation results of different scenarios for traditional and optimal multiple sensor configurations with 5, 6, 7 and 10 sensors.
From Fig. 8, it was clear that there is a significant improvement to the performance of the missile in case of the optimal sensor configurations using the proposed PSEM with or without transient fault compared with the traditional sensor configurations without transient fault and the collision has been occurred at different points. But, in case of the traditional sensor configurations with transient fault, it has a missing distance between the missile and the target and the collision did not occur. The value of the missing distance depends on the number of sensors in the inertial navigation configuration, as shown in Fig. 8.

V. CONCLUSIONS

An inertial navigation system (INS) with multiple sensors will provide better awareness about its state and the operating conditions thus reducing operational uncertainty. In this paper, the optimal sensor configurations are investigated using a new proposed pseudo sensor enhancement method (PSEM), as optimal configuration tool. Fault detection prediction analysis of multi-sensor architecture is introduced to study different number of sensors with different arrangement architectures and to detect transient faults in each sensor. Then, the proposed PSEM, as FDI tool, is investigated to detect, isolate and compensate for the entire sensors transient faults. Finally, the optimal inertial navigation multi-sensor configurations using the proposed PSEM have been applied to the PNG laws to investigate the optimal proportional navigation guidance. Different scenarios have been studied to compare between the traditional without PSEM and the optimal using the proposed PSEM inertial navigation sensor configurations with 5, 6, 7 and 10 multiple sensors in case of no fault and presence of the transient fault. The simulation results of different scenarios have been analyzed to demonstrate the excellent performance of the proposed PSEM with the proportional navigation guidance. The proposed optimal PNG using PSEM has the merits: i) it forces the missile to lead its target, without having to know anything about the target’s speed, or range to target; ii) it is very effective and simple to implement on any missile; iii) it improves the fault detection; iv) it increases the robustness of isolation and compensation of the transient fault during its fault and when a new steady state occurs to enhance the temporal coverage and v) it produces a more efficient intercept trajectory to meet the requirements for flexible interceptor applications.

REFERENCES


