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A Novel Method to Develop High Fidelity Laser Sensor Simulation Model for Evaluation of Air to Ground Weapon Algorithms of Combat Aircraft

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ABSTRACT

Successful release of any air to ground weapon from a combat aircraft is determined based on the positional parameters received from the sensors and the mission cues. Laser designated pod is one of the most sought weapon sensor, which gives the accurate data for Air to Ground weapon aiming. Laser designated pod being hardware intensive system, works with real world environment, it increases the development and integration effort towards finalising the weapon aiming algorithms and also pilot vehicle interface requirements. A novel method using mathematical models and the atmospheric error models is proposed to develop a high fidelity laser designated pod simulation model for functional and performance evaluation of weapon algorithms. The factors affecting the weapon trajectory computations are also considered in the sensor model outputs. The sensor model is integrated in the high fidelity flight simulator, which consists of both aircraft and Real world systems either as actual or simulated for close loop pilot evaluation. The behaviour of the sensor model is cross validated and fine-tuned with the actual sensor output and confirmed that the developed laser designated pod sensor simulation model meets all the requirement to test the air to ground weapons in the flight simulator.

Keywords: High fidelity flight simulator; Laser designation pod; Aircraft system and environment simulation; Field of view; Air to ground weapon algorithms

1. INTRODUCTION

Weapon algorithm testing in actual scenario will result in high material loss, effort and time, which can be reduced with the help of sensor models integrated in the high fidelity flight simulators[1]. Laser designated pod (LDP) is one of the sensor used in the aircraft to provide inputs for the same in actual flight conditions. LDP is an advanced airborne infrared targeting and navigation pod to improve both day and night attack capabilities in all weather conditions. It performs the tasks namely viz; Detection, Recognition, Identification, Designation of surface targets, accurate delivery of guided bombs and accurate ranging[2] .

It is found from the research survey that the static LDP models are used in the rig to test the functionality[3]. It is also found that the algorithms are developed for tracking of ground moving targets for ideal condition[4]. However, the performance of the weapon algorithms evaluation require high fidelity sensor model with the capability to simulate real world characteristics of sensor data.

A novel method to develop high fidelity LDP sensor model for evaluating the weapon release performance of Mission Computer on the ground to reduce the flight test effort and also the development life cycle effort is proposed. The simulated LDP model is integrated with other simulation elements namely flight dynamics models, weapon models, synthetic environment, etc., to bring the system in a dynamic environment to accomplish the mission goals[5,6,7]. Acceptance test plan and procedures are made to ensure the fidelity of the model for testing the avionics and weapons system. With the above model, Weapon algorithm performances and the Pilot Vehicle Interface requirements of weapon system and Avionics is carried out successfully and the performance of the model is same as that of actual LDP sensor.

2. SENSOR MODEL DEVELOPMENT APPROACH

LDP simulation model provides slant range, azimuth, elevation, position of the target etc., to evaluate the weapon algorithm performance. It reflects the behaviour of the actual sensor in the high fidelity flight simulator (HFFS) as close as possible with a realistic outputs. The mathematical model of simulated LDP is implemented using Triangulation method, Axes Transformations, Cartesian Coordinate System Conversion, Slewing Algorithm and FLIR using Image processing to simulate the model behaviour[8,9].

This simulated model consists of detector model, designator model, sensor error models and Sensor camera simulation model implemented as single system and interfaced with other avionics and weapon system models as per the actual Military standard protocols and Ethernet.

The LDP model receives the aircraft position and the attitude values from aircraft model (FDM) and navigation

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model (INS) as input. LDP Look angle and the mode commands are received from Mission computer and provides the camera angle i.e., LDP FOV and focus values to sensor camera simulation model. Detector model receives laser beam intersection point with respect to the sea level altitude and computes the target azimuth and elevation angles. True slant range is computed using the ground terrain database available in the Environment model. With this, sensor Error model computes attenuation parameters and other sensor errors and the same is used for calculating the target position parameters. Finally LDP simulation model sends the computed target position in terms of latitude, longitude, altitude, Range, Azimuth and Elevation to Mission Computer through MIL-STD 1553B interface to mission computer weapon algorithms.

The block diagram of the sensor model functional flow with other systems, and its interfaces are depicted in Fig. 1. The detailed LDP simulation model algorithm steps are described as follows

i. For the gimbals lookup azimuth and elevation, the laser beam intersection point with respect to the sea level altitude is computed using triangulation technique.
ii. From the aircraft location and the sea level position computed in step (i), the terrain intersection point is computed using the bi-section method, which gives the target true slant range.

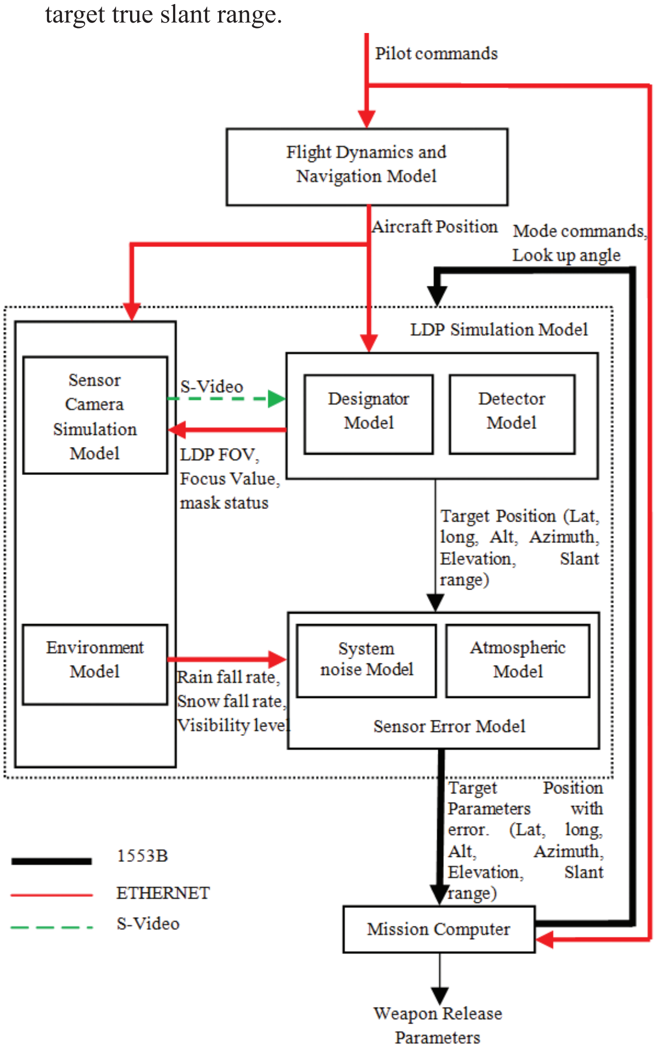

Figure 1. Block diagram of LDP simulation model.

iii. Now, the modeled errors as given in section 3 are added to the true slant range, azimuth and elevation data.
iv. Target location in terms of NED frame xyz and Latitude, Longitude and Altitude is computed from the true slant range, azimuth and elevation as follow:

The computed spherical coordinate parameters azimuth (β), elevation (α) and slant range (r) from step (iii) are converted into NED three dimensional Cartesian coordinates,

$$x = r * \cos(\alpha) * \cos(\beta) \tag{1}$$

$$y = r * \cos(\alpha) * \sin(\beta) \tag{2}$$

$$z = r * \sin(\alpha) \tag{3}$$

To convert the NED-x,y,z coordinates to geodetic latitude and longitude, the radius of curvature in the prime meridian (R_M), the radius of curvature in the prime vertical (R_N) are used. R_N and R_M are defined by the following relationships,

$$R_N = \frac{R}{\sqrt{1-(2f-f^2)\sin^2\mu_0}} \tag{4}$$

$$R_M = R_N \frac{1-(2f-f^2)}{\sqrt{1-(2f-f^2)\sin^2\mu_0}} \tag{5}$$

where,

μ_0 - aircraft latitude, f - flattening of the planet and R - equatorial radius of the planet.

The difference between aircraft and target latitude, longitude and altitude are computed from NED-x,y,z component, which is given by,

$$d\mu = a\tan\left(\frac{1}{R_M}\right)x \tag{6}$$

$$d\lambda = a\tan\left(\frac{1}{R_N * \cos(d\mu)}\right)y \tag{7}$$

$$dh = -z \tag{8}$$

where, $d\mu, d\lambda, dh$ are offset latitude, longitude and altitude component.

The target latitude, longitude and altitude are obtained by adding $d\mu, d\lambda, dh$ with present aircraft latitude (μ_0), longitude (λ_0) and altitude (h_0).

$$\mu = \mu_0 + d\mu \tag{9}$$

$$\lambda = \lambda_0 + d\lambda \tag{10}$$

$$h = h_0 + dh \tag{11}$$

where μ is target latitude, λ is target longitude, h is target altitude.

Error models referred in step (iii) are developed using probabilistic/statistical models. Such models, with parameter values chosen to represent a particular class of equipment are used to generate error values as in real time. These errors are then added to the true simulated values of the signals to generate the realistic sensor outputs as in step (iv).

The target detection and identification delays are budgeted in the error simulation model. The target detection properties are assumed in such a way that the model identifies the target, irrespective of the target size and calculate the parameters. The sensor model terrain database is currently limited to a specific area, which can be enhanced for future requirements.

3. SENSOR ERROR MODELS

Actual sensor error tolerance limits are considered as a design input for the error simulation model, which can be customised to any actual sensor specification. However the sensor error tolerance limit considered in the model for Azimuth and Elevation is ±3 milli- radians (±0.17deg) and for the range is ±5 m. To achieve this, system noise and Attenuation due to atmosphere are modeled in the LDP simulator as these determines the model fidelity for weapon algorithms. The bore-sight angles and lever-arm offset of the sensor are also considered[10,11].

3.1 System Noise

System noise (S_{noise}) is characterised using deterministic and stochastic models to estimate the errors in system measurements. The deterministic noise is modelled as per the laser sensor specifications. Random noise component is estimated within a certain boundary such that the error in the final output of the simulated model is within the actual sensor performance specifications.

3.2 Attenuation due to Atmosphere

The LDP sensor signal strength and signal path is affected by weather factors and atmospheric medium[12,13]. It reduces the signal strength and induces the time delay due to attenuation, which impacts the computed slant range[14]. The attenuation of Laser signal in atmospheric medium due to rain, snow and fog are as follows

$$\tau = e^{-\int_0^z \gamma(z)dz} \tag{12}$$

where τ - the atmospheric transmittance in terms of percentage.

$\gamma(z)$ - the total atmospheric attenuation coefficient (km^{-1}) considering rain, fog and snow.

z - distance of the transmission slant path.

The total attenuation coefficient due to atmosphere is defined as,

$$\gamma_{total} = \gamma_{rain} + \gamma_{snow} + \gamma_{fog} \tag{13}$$

Attenuation of rain at higher frequency is considered as 2 GHz for a uniform rainfall[15,16]. The rain attenuation coefficient γ_{rain} is often expressed as,

$$\gamma_{rain} = mR^n \ dB/km \tag{14}$$

where R^n is rainfall rate in millimeters per hour and m and n are constants that depends on path direction, orthogonal polarization and temperature.

The atmospheric attenuation model under the influence of snow is,

$$\gamma_{snow} = K_c D \ dB/km \tag{15}$$

where K_c is constant, D is the rate of snowfall in g/m^3

The atmospheric attenuation model under the influence of fog is,

$$\gamma_{fog} = \frac{A}{v^b} \ dB/km \tag{16}$$

where A correspond to difference in wavelength in nm and v^b is visibility levels in km .

Now $\gamma(z) = \gamma_{total}$ the total attenuation error from Eqn. (12) is given by,

$$\tau_{total} = e^{-\int_0^z \gamma_{total} dz} \tag{17}$$

The τ_{total} affects operational range of LDP Simulation model. The operational range boundary for every cycle is dynamically set to detect the target.

3.3 Computation of Slant Range

The signal propagation delay due to atmospheric medium is simulated using linear error model as per the actual sensor specifications. This time delay affects the Slant range computed by the LDP simulation model. The error in the slant range, corresponding to the propagation delay is computed and added to the true slant range.

$$R_{error} = t_{delay} * v_c \tag{18}$$

where

R_{error} - Range error due to propagation delay (t_{delay})

t_{delay} - Signal propagation delay

v_c - Speed of laser light

$$Slant\ Range\ (r) = True\ Slant\ Range + R_{error} + R_{system} \tag{19}$$

where R_{system} - Range Error due to system measurements noise (S_{noise}) .

3.4 Computation of Azimuth and Elevation

Azimuth and Elevation errors due to gimbal misalignment and pointing error are linearly modeled as per the actual sensor performance specifications. LDP Azimuth (β) and Elevation (α) is calculated by adding this error.

$$Az_{total\ error} = Az_{a\ln} + Az_{ptng} \tag{20}$$

$$El_{total\ error} = El_{a\ln} + El_{ptng} \tag{21}$$

where, $Az_{a\ln}$ and $El_{a\ln}$ are errors due to misalignment and Az_{ptng} and El_{ptng} are errors in pointing the target.

4. EVALUATION APPROACH

LDP sensor model is evaluated to find out the functional and performance fidelity as per the actual system[17]. The sensor model was tested at different flight conditions in HFFS and the results were analysed with ideally computed values using MATLAB. The functional fidelity of the model is tested for evaluating azimuth and elevation computation of LDP simulated model in static and dynamic condition.

Aircraft is kept in a fixed position in air and tested azimuth and elevation computation for static and moving ground target. The data is recorded through Aircraft System and Environment Simulation (ASES) System and the same is verified by plotting the results in offline mode.

4.1 Static Mode

Azimuth and elevation parameters are computed ideally for the known ground position from the aircraft and the LDP simulated model output parameters are compared. Also LDP simulated model was tested with and without error model and the results are plotted against the computed parameters are as given in Figs. 2 and 3.

It is obvious that the simulated LDP with error model improved the model fidelity and achieved accuracy in terms of Azimuth error is 0.1 degree and average Elevation error is 0.015 degree, which is within the desired design accuracy

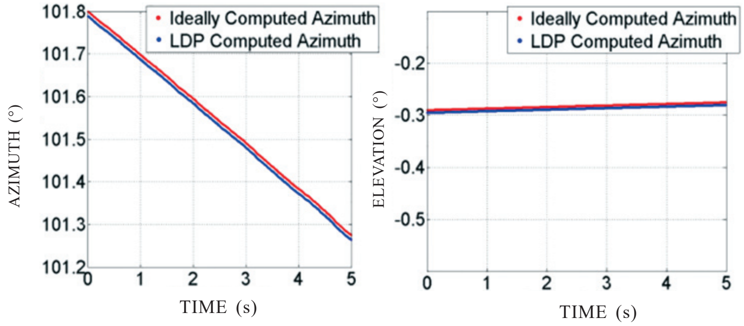

Figure 2. Comparison of target Azimuth, Elevation of ideal and simulated LDP (without error model).

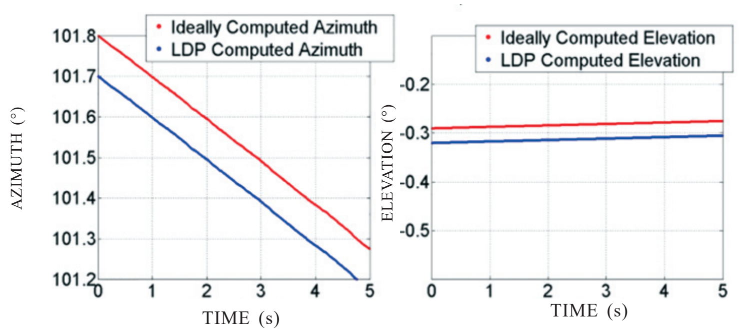

Figure 3. Comparison of target Azimuth, Elevation of ideal and simulated LDP (with error model).

limits.

Similarly, the target parameter computations are tested by positioning the targets in known position in north direction with respect to the aircraft and the results are tabulated in Table 1.

From the Table 1, the Azimuth output value from the simulated sensor model is ~ 0(deg), which indicates that the target is in front of the aircraft with respect to NED frame. The Azimuth and elevation error difference between simulated and ideal is 0.0002436 deg and 0.0185723 deg respectively, which is within the desired design accuracy limits.

Table 1. Target Azimuth, Elevation checks in North Direction

Input parameter	Value	Output parameter	Value
Target latitude (°)	13.26189	Simulated sensor output	
Target longitude (°)	77.97084	Azimuth (°)	0.0002436
Target altitude (M)	1236	Elevation (°)	-0.01947
Aircraft latitude (°)	13.132479	Ideal output	
Aircraft longitude (°)	77.97084	Azimuth (°)	0.0
Aircraft altitude (M)	1236.12	Elevation (°)	-0.0008977

4.2 Dynamic Mode

In dynamic mode, aircraft is kept in a fixed position in air and continuously tracking ground moving target. A case study with ground target (vehicle) moving in and out of tunnel is taken in the HFFS and the test results are as shown in Fig. 4.

Blue and red line in the Fig. 4 indicates the trajectory of the ground moving target where LDP simulator tracked trajectory is shown in blue color. When the target enters into the tunnel, LDP stop tracking and stays at the entrance of the tunnel and it points to the location where line of sight is lost.

When the target returns through the same entrance of the tunnel, LDP is still in track mode searching for the target. It again starts tracking the target. The CCD image of LDP simulation model is also shown in Figs. 5(a) and 5(b) and target position is highlighted using arrow symbol. It is confirmed from the test carried out that the target tracking and detection of LDP simulated model algorithms is as desired and the results are satisfactory.

4.3 Model Validation

Sensor data from actual flight sortie data is used to validate the model fidelity in terms of it usage for weapon algorithm evaluation. Firstly, the simulated LDP model outputs are compared with actual LDP output data from aircraft to confirm whether the model is orienting and lasing the targets accurately. Secondly, the LDP model fidelity is tested with Mission Computer for determining the impact point accuracies. The details of the test case are as follows

Case-1: The actual LDP flight data was replayed for specific time period as an input to the model in the flight simulator. The model outputs are recorded using ASES system and plotted both actual LDP and simulated LDP output in Mat lab. The position computed by actual LDP and simulated LDP model is plotted in Fig. 6 where red line indicates the actual LDP output and the blue line indicates the simulated LDP output.

It is found that the average position accuracy for the profile achieved is 2.3 meter, which is within the actual LDP accuracy limit of ±"5 meters.

Case-2: The fidelity of the model is tested for evaluating the weapon algorithms for both guided and unguided bombs. The model is initialised to airborne condition and the recorded flight data of actual LDP is fed as input from the time sensor

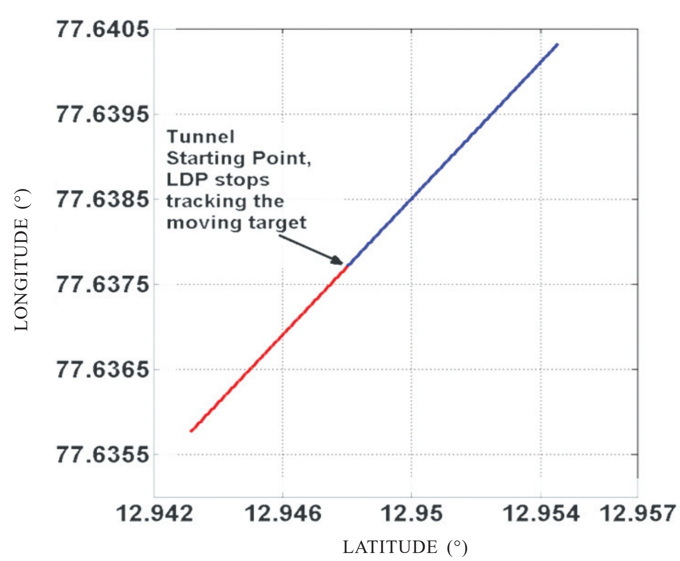

Figure 4. Ground moving target trajectory.

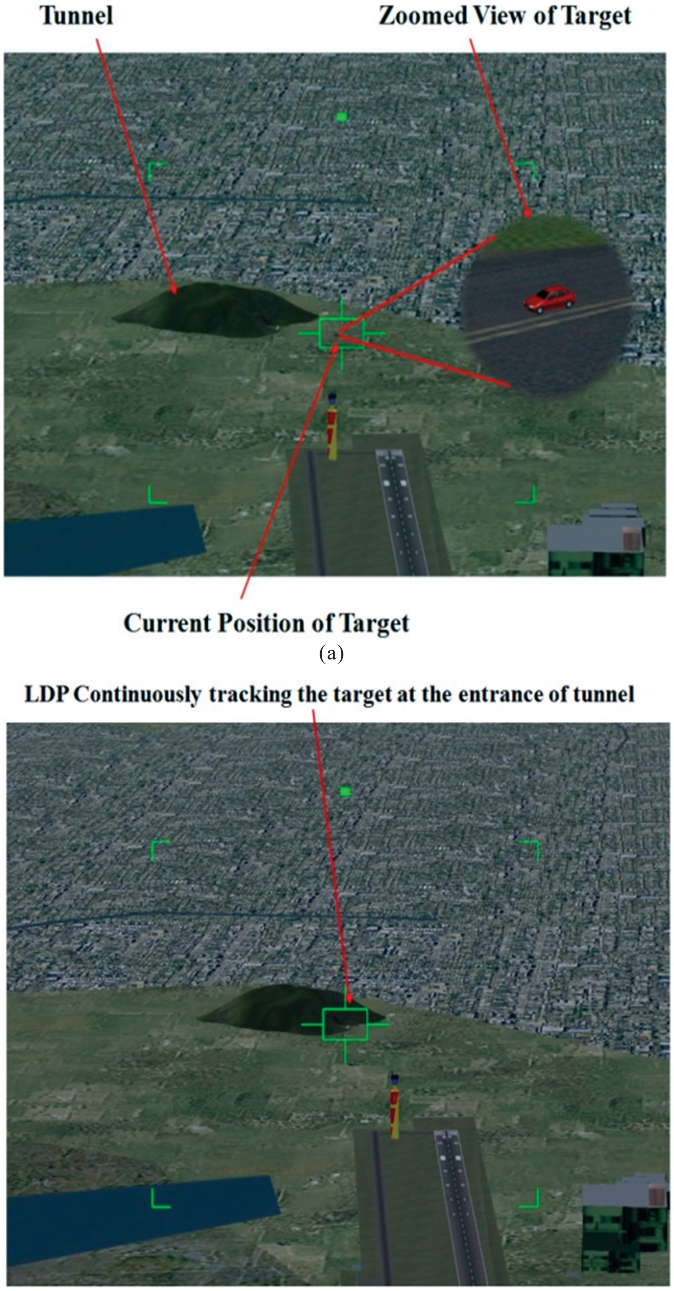

Figure 5. (a) CCD image of moving target tracking outside the tunnel and (b) CCD image of moving target tracking inside the tunnel.

engaged for finding the impact point. Based on the hit position, the accuracy of the sensor model is established and found that the model performance is close to actual sensor. The trajectory plot for the guided mode weapon trajectory profile is as given in Fig. 7.

The target position, impact point of actual and simulated LDP weapon release are as tabulated in Table 2. The difference between impact points of actual and simulator is 1.78 m, which is within the range accuracy limits.

Similarly, LDP model is validated for unguided weapon. The trajectory plot for the unguided mode weapon trajectory profile is as given in Fig. 8.

The target position, impact point of actual and simulated

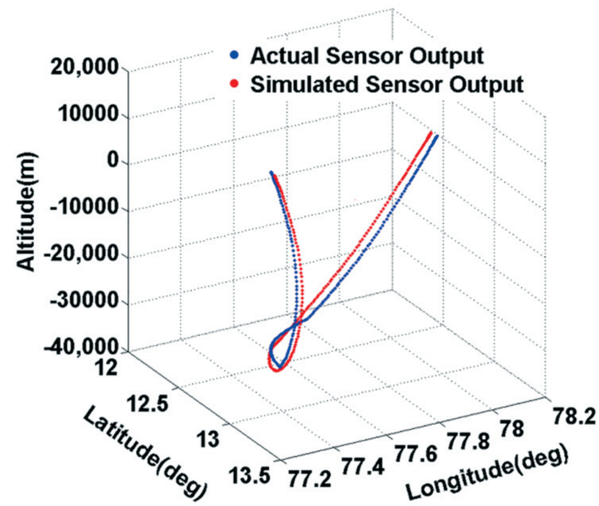

Figure 6. Position comparison between simulated LDP and actual LDP outputs.

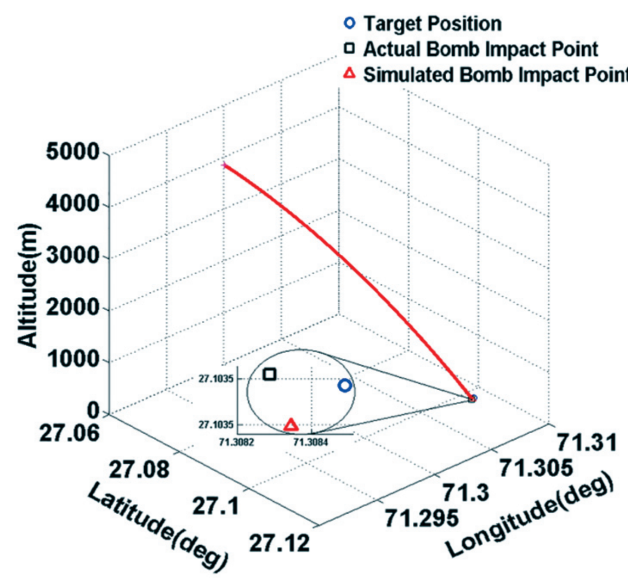

Figure 7. Guided bomb trajectory profile.

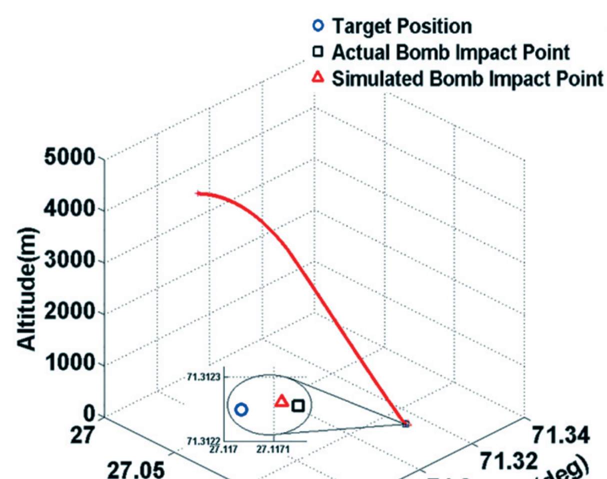

Figure 8. Unguided bomb trajectory profile.

Table 2. Impact point between actual and HFFS for Guided Mode attack

Parameters	Target position	Bomb impact point	
		Actual	Simulated
Lat (°)	27.1170675	27.1171247	27.1171076
Long (°)	71.3122485	71.3122548	71.3122605
Alt (m)	134.88	133.90	135.25
Error difference (m)		6.402	4.6178

LDP weapon release are as tabulated in Table 3.

Table 3. Impact point between real and HFFS for Unguided mode attack

Parameters	Target position	Bomb impact point	
		Actual	Simulated
Lat (°)	27.1035433	27.1035553	27.1034980
Long (°)	71.3084888	71.3082879	71.3083452
Alt (m)	65.44	66.8	64.98
Error difference (m)		19.92	15.07

From the above results the difference between Impact points of actual and simulator is 4.85 m. It is within the actual range accuracy of 50 m.

5. CONCLUSIONS

The method proposed in this paper for modelling the LDP sensor brought out the requirements to be addressed for weapon algorithms evaluation. The model is validated with actual flight data and found that simulation result shows that LDP sensor model behaviour is close to the actual sensor accuracy limits. It is evident from the results that the model fidelity depends on the sensor errors, where the atmospheric error modelling requires further fine tuning. Further study on the effects of atmospheric conditions associated with dynamic variations of weather patterns are needed to improve the model fidelity.

Augmentation of sensor models enhances the level of realism of the simulator thereby allowing the facility to be used for a wider range of tasks like design assessment of various avionics and weapon systems/technologies and pilot training. Thus for a high fidelity simulation model for the weapon trajectory the factors affecting the trajectory from least to utmost intent is also considered and the results found satisfactory.

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