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The Design of Autopilot's Ship Path Planning and Obstacle Avoidance Steering Control

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Abstract: **The design of Autopilot ship steering control system involves many concentrations in the design algorithm because the dynamics of ships are not fixed and involved nonlinearities in the system. In addition, finding obstacle avoidance path is complicated that a ship must identify and bypass it with an automated decision-making system. In this Regard a robust data association-based path tracking system called integrated probabilistic data association (IPDA) algorithm has been applied for tracking the path of desired trajectory. The proposed algorithm initializes tracks for path planning and trajectory referencing using the sensor measurements. The track updates the trajectory state to obtain state estimate. The results are taken using MATLAB simulation**

***Index Terms*— IPDA, FPDA, SMC, UAS-IPDA, CACFAR, CUT, Kalman Filter**

I. INTRODUCTION

The design of Autopilot ship steering control system is famous topic of interest because parameters as well as dynamics both are not permanent having nonlinearities in the system. Hence Attentiveness is required while designing it will also reason for the reduction in propulsion losses due to steering, but also maintain tight control when operating in clutter region and harsh environment. Almost all conventional control algorithm has been developed but still there is divine need of a powerful control system that can achieve good results for Unmanned Autopilot ship's heading motion. SMC (Sliding Mode Control) algorithm for Autopilot has already been developed without any consideration on obstacle avoidance & climate forecasting information. This Paper shows the Autopilot design consideration for ship, basically dynamics of ships are not fixed having many nonlinearities and hydrodynamics are key factors affecting steering system of ship In [1], the authors designed a ANN (Artificial Neural Network) method for the Control of a Surface ship[2]. utilized the Radial Basis Function for a Ship Steering Control system. In [3], the authors applied D-lite method with smoothing technique for the path planning problem in cluttered environment.

In surveillance region the target tracking become more difficult due to presence of detection that are originated from various objects having no particular information about the source. And In addition, the target tracking system do not know the exact trajectory as well track that Autopilot ship must follow. In this complex environment, the target motions and path planning is very challenging task because availably of uncertainty with a very low PD (Probability Distribution) in each scan of target discrimination. Therefore, a robust target tracking system is needed to identify and confirm the target existence in the surveillance region for Ship Autopilot so that Obstacles and clutter can be avoided using Data Association.

This paper represents the development of Robust algorithm for Autopilot ship called Integrated probabilistic data association (IPDA) model which is basically a statistical approach in a Radar/Sonar tracking system that assign the validated object's measurements to a track in a probabilistic way, it calculates data association probabilities and target existence probabilities to estimate a target in each scan. A track quality measure called track existence probability is utilize for false track discrimination (FTD) performance. The FTD confirms the true and eliminates the false tracks. This algorithm is called unmanned autopilot ship based on IPDA (UAS-IPDA).

This method is used in this paper for path planning and Trajectory tracking. Path planning for ship under cluttered environment is also challenging task, previously Authors have worked on rudder-based ship control.

This paper further represents algorithm for reducing false alarms produced from sensor which is obtained from Ship called Constant False Alarm Rate (CFAR) Detection algorithm.

II. SHIP DYNAMIC MODEL

Hydrodynamics equation of kinematics and kinetics are very important, our Autopilot's Ship mathematical model is derived from these equations.

These two equations determine the reference frames of the Autopilot ship and are used for Body fixed and Earth fixed reference frames respectively. Hydrodynamics of the ship have two type of velocities i.e (linear and angular velocities) as shown in eq.(1).Position and Orientation of ship is well defined and geometrical represented in Kinematics equation model relative to EF frame eq. (2). Force vector τ is important which is responsible for controlling heading/steering of the Autopilot ship eq (3). Whereas in BF frame $\tau_1$that is input thrust vector which is always toward X component. similarly, τ_2 ,τ_3 are the components of Y and Z-axis respectively, however M_1, M_2, M_3 are their moments that are acting on the autopilot ship in different directions.

$$v = [u, v, w, p, q, r]^T \quad (1)$$

$$\eta = [x, y, z, \phi, \theta, \psi]^T \quad (2)$$

$$\tau = [\tau_1, \tau_2, \tau_3, M_1, M_2, M_3]^T \quad (3)$$

Fig. 1 illustrates the relationship between the NED frame and the BODY frame. The complete ship dynamic model can be described by the combination of kinetic and kinematic equation expressed in equation below.

$$\begin{bmatrix} \dot{v} \\ \dot{\eta} \end{bmatrix} = \begin{bmatrix} -M^{-1}(C(v) + D) & 0 \\ J(\eta) & 0 \end{bmatrix} \begin{bmatrix} v \\ \eta \end{bmatrix} + \begin{bmatrix} M^{-1} \\ 0 \end{bmatrix} \tau \quad (4)$$

In this equation is Damping factor, C is the Coriolis term, J always denotes Rotational matrix based on Euler Theorem.
where J is the Euler rotational matrix relating the two reference frames, M is the mass and inertia matrix, C contains the Coriolis terms.

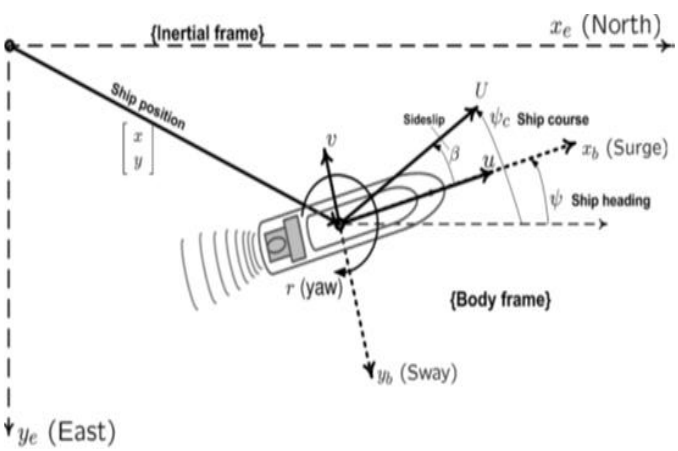

Fig 1. Body frame Representation of Autopilot ship.

III. UNMANNED AUTOPILOT SHIP BASED ON IPDA

The methodology for UAS-IPDA is given in figure 2. The reference trajectory is generated based on state propagation from initial scan k-1to the next scan k as given in (1). Track initialization method initializes the tracks based on the sensor measurements. The ship dynamics are integrated to the IPDA algorithm for track propagation and update. Finally, the output statistics is calculated based on Kalman filter estimation equation which is connected in feedback to the reference trajectory block for error correction. In addition, static Clutter and constant alarm Reduction (CFAR) algorithm is applied for clutter reduction as shown in Fig. 3.

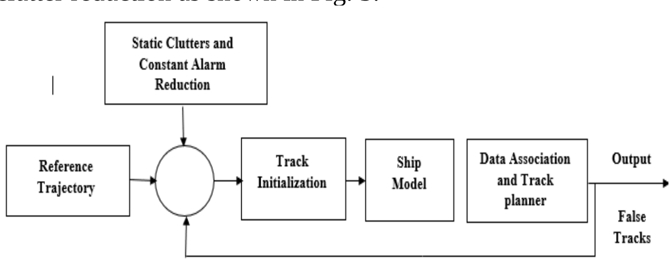

Fig 2. Block Diagram of Unmanned Autopilot Ship based on IPDA (UAS-IPDA)

IV. METHODOLOGY FOR THE DEVELOPMENT OF UAS-IPDA

Data association is an essential part of the target tracking system. Data association classifies each sensor measurement either a clutter or a target measurement. Data association provides track-to-measurement association. Track filtering and maintenance procedures are used to provide a confirmed target state estimates at each scan using the measurement received at each scan. In the surveillance region, a tracking filter receives unknown number of measurements from the sensor. Therefore, a gating procedure [4]is used to select the necessary measurements for track initialization and data association. Tracks are initialized and updated using the measurements obtained in each scan. The procedure is as follows.

A. IPDA NOTATION

"bar "represents prediction. k subscript denotes Index of the given scan. "hat" represent estimation. mean and covariance are denoted by $X_{k-1|k-1}$ & $P_{k-1|k-1}$ separately.

B. IPDA TRACK INITIALIZATION

Sensor plays fundamental role for the measurement and initialization of tracks. $P\{X_{k|}Z^{k-1}\}$ is target existence probability for Autopilot and also have different track identification number. Two-point differencing is the versatile method for initialization of new tracks for Autopilot trajectory [5].

C. IPDA PROMOTION OF TRACK

At periodic scan and updated track probability the density function is given by $P\{X_{k|}Z^{k-1}\}$ which uses "MARKOV ONE CHAIN MODEL" and denoted by the equation.

$$P\{X_{k|}Z^{k-1}\}=p_{1,1}P\{X_{k-1|}Z^{k-1}\} \quad (5)$$

where p1,1 is the target transition existence probability [4].
Now using Kalman prediction theorem for Track's prediction and estimation for Autopilot Ship which is given below.

$$[\bar{X}_{k|k-1}, \bar{P}_{k|k-1}] = KF_p(\hat{x}_{k-1|k-1}, \hat{P}_{k-1|k-1}, F, Q) \quad (6)$$

And formed matrix is

$$\hat{x}_k = F\hat{x}_{k-1} + v_{k-1} \quad (7)$$

D. IPDA TRACK MEASUREMENT SELECTION

For the scan k the verified data measurements Z_k are selected. The confirmed targeted measurements for Autopilot system is Models as below.

$$\boldsymbol{\Delta}_i^{\mathrm{T}} \boldsymbol{S}^{-1} \boldsymbol{\Delta}_i \le \eta \quad (8)$$

$$\boldsymbol{\Delta}_i = \boldsymbol{Y}_{k,i} - \boldsymbol{H}\bar{\boldsymbol{x}}_{k|k-1} \quad (9)$$

$$\boldsymbol{S} = \boldsymbol{H}\bar{\boldsymbol{P}}_{k|k-1}\boldsymbol{H}^{\mathrm{T}} + \boldsymbol{R} \quad (10)$$

Where "η" is minimum threshold value, which relays on Transition probability.

E. IPDA MEASUREMENT LIKELIHOOD

For every scan k likelihood probability is calculated and checked for the Autopilot system, based on the validated measurement and data association of the track, which can be updated by following Kalman filter formulae when i≥0.

$$L_{k,i}=P(Y_{k,i},\hat{x}_{k|k-1}|Y_{k-1})=\frac{N(Yk.i;\, H\hat{x}k|k-1,S)}{PG}$$

F. IPDA UPDATE STEP

At the update step the probability of targeted goal will be updated with the help of Kalman given is the mathematical formulae of IPDA update.

$$P\{\chi_k|Y_k\} = \frac{\lambda_k P\{\chi_k|Y_{k-1}\}}{1-(1-\lambda_k)P\{\chi_k|Y_{k-1}\}} \quad (12)$$

V. *CFAR ALGORITHM BASED ON UAS-IPDA*

CFAR (constant false alarm rate) is versatile algorithm used when the signal is weak or changing with time to overcome this certain threshold is very important that helps in losing of data or miss detection. This method is used in targeting and tracking more commonly used in RADAR system that detect unwanted noise also finding clutters in harsh environment [7].

In practice, when there are stationary clutters and having weak signal strength so there CFAR doesn't give sufficient performance for this (CA-CFAR) Cell Averaging CFAR detection is used [6]. Basically, it is composed of sliding window having three cells position namely reference cell (RC), guard cell (GC), and cell under test (CUT) as shown in Fig. 3. RCs are placed on the most front and rear of the window. In windowing, the signals in RCs are treated as noise signals. CUT is placed on the center of the window. Signals in CUT are compared with the average of RCs. If the signal strength of CUT is larger than the threshold which is determined from signals to the Reference Cell then the samples in CUT are treated as target signals. The signals processing from each cell can be expressed in (3) to (5) and shown in Fig. 2. GC is placed between RC and CUT to separate the two cells.

$$Pn = \frac{1}{2N}\left(\sum_{m=1}^{N} X_m + \sum_{k=N+NC}^{2N+Nc} X_k\right),\ \alpha = N\left(P_{FA}^{-\frac{1}{N}} - 1\right)$$

N, NG, and NCUT represents number of samples in RC, GC, and CUT respectively, and NC is the total sum of 2NG and NCUT. X indicates an amplitude of the signal. PFA is a desired false alarm rate, and d is a Boolean index of detection and Pn is the average noise amplitude of all signals.

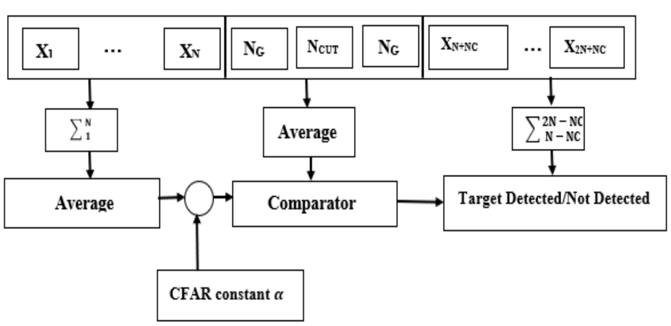

Fig III. Block diagram of CA-CFAR detection

VI. *SIMULATION RESULTS*

The simulation analysis for ship under obstacle condition of surveillance is done at 30 meters along x-axis and 30 meters along y-axis. The targeted trajectory state vector is denoted by x which is 2x2 dimensional position and velocity vector. The joint probability of returning measurement from sensor is pd=0.8 and noise covariance R=$25l^2m^2$ ρ= $1x10^{-4}m^{-2}$.

In the Figure IV obstacles are denoted by circles, and the ship initial position is represented by square shape and whereas final destination goal is denoted by cross.

Figure V shows the contour map of ship under obstacle conditions. Where initial position is represented with square and goal with x.

In figure VI Represent ship trajectory and its estimation the graph is plotted between position v/s Time in seconds.

Figure VII Represents Path generation from initial position square to final goal position cross. The simulation shows that the trajectory, which is generated in order to avoid obstacle condition and to reach goal.

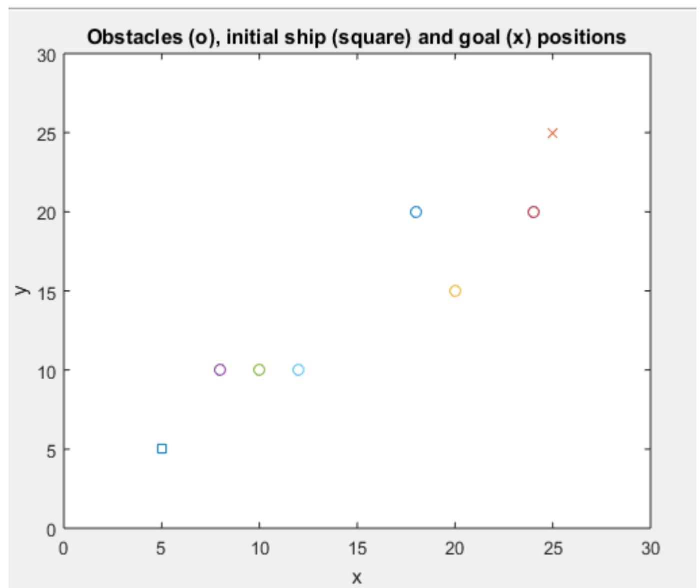

Fig IV. Obstacles in the given track initializes

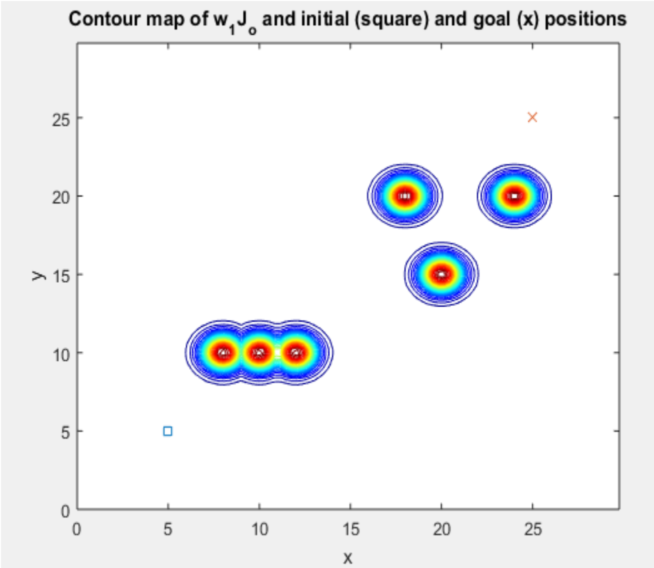

Fig V. Contour map of Autopilot ship

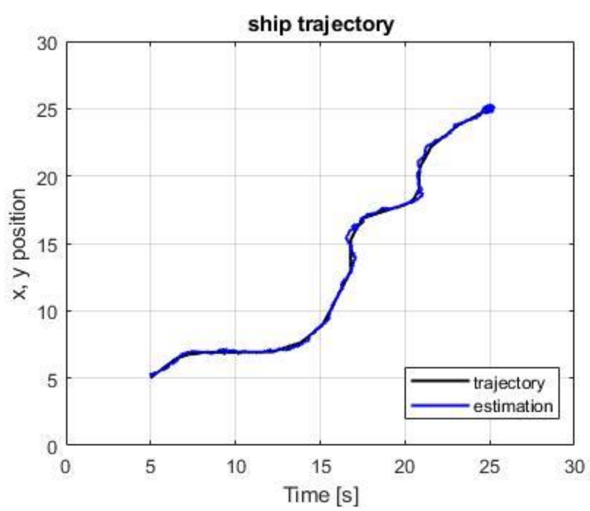

Fig VI. Ship Trajectory and Estimation

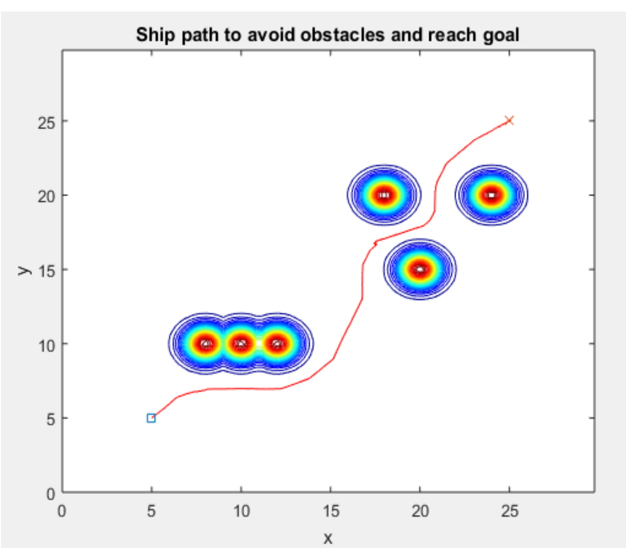

Fig VII. Autopilot to Reach Target Goal

VII. CONCLUSION

The proposed (UAS-IPDA) method is basically a tracking algorithm developed for finding path, desired trajectory and avoiding obstacles in cluttered region and also to obtains the best FTD performance of the trajectory of the Autopilot system with improved estimation and accuracy in the cluttered environment.

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