Cooperative weapons systems will be an integral part of future offensive and defensive warfare. Missiles and precision munitions capable of engaging a target in a coordinated and simultaneous manner can effectively defeat defensive countermeasures such as a ship’s close-in weapons system and/or create an element of surprise such as appearing simultaneously along a radar’s boundary range. Other applications include the timed approach of multiple interceptors to an estimated location of an inbound target threat.

In order for a weapons system to have a cooperative capability, control over the time-to-go until impact must be achieved. Missiles and precision guided munitions, however, are under-actuated systems which means that dynamically, certain degrees of freedom such as the longitudinal velocity, is not controllable. Therefore, imposing constraints on the impact time through velocity control is not a feasible approach and trajectory planning must be utilized. Additionally, the primary source of feedback for the impact time control is the time-to-go calculation, which is based on the relative line-of-sight between the missile and target and does not account for trajectory curvature, potentially causing error.

Currently, optimal guidance laws are used in simultaneous missile strikes but simplifying assumptions such as constant velocity and linear kinematics are made in the design of these laws in order to obtain a closed form solution, but result in possible sources of error. Velocity can change rapidly and the linearization of the engagement kinematics lead to a loss in motion constraints. In addition, optimal guidance laws, by nature, are explicit in the error prone time-to-go calculation.

Improvements can be made over existing methods for impact time control by designing a new guidance law such that motion constraints are maintained in the generation of the controls and time-to-go is computed based on a closed form solution for trajectory arc length instead of the standard line-of-sight methods. In the design of the Quad-Segment-Polynomial-Trajectory (QSPT) guidance law, segmented quadratic polynomials are prescribed to satisfy the nonlinear kinematic equations of motion as well as possess a closed form solution to arc length. Therefore, the simplifying assumptions previously noted become unnecessary and the final nonlinear guidance law maintains the kinematic motion constraints. Furthermore, enforcing the boundary conditions required to produce smooth continuous quadratic trajectories results in a free design variable which generates the family of trajectories required to control the impact time.

Simulation results show that the QSPT time-to-go algorithm effectively removes error from the calculation due to trajectory curvature, greatly improving the fidelity of the feedback signal to the corresponding impact time control. Simulation results also show that under inertial measurement unit sensor bias, scale factor, and noise, and varying levels of wind disturbance with nonlinear atmosphere and gravity, the QSPT guidance law was able to reduce the impact time error of a precision munition strike to fractions of a second under heavy wind disturbance and to zero error under light disturbances.

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