The impact time control problem can be stated as the requirement to hit the target with no other terminal constraint than achieving a specified final time. This specific terminal constraint HE impact time control problem can be stated as the requirement to hit the target with no other terminal constraint could provide survivability against close-in weapon systems by facilitating a salvo attack capability. In addition, impact time control could be employed to force the missile pass through a certain waypoint at a specified time. With rising interest over recent years, the literature on impact time control laws has been growing rapidly. One of the earliest studies was presented in [1], which was based on proportional navigation (PN) involving the difference of the desired and estimated time-to-go values as a bias term. The same authors extended the previous work, in which the design was based on linearized kinematics, in [2] to nonlinear kinematics. Another impact time control method via biased PN was considered in [3] for cooperative attacks. The bias term was a time-varying navigation gain that was adjusted based on the time to go of the individual missile and the times to go of the cooperating missiles. As well as PN-based impact time guidance laws, there exist numerous studies based on the nonlinear control theory. A Lyapunov-based approach was considered in [4] using the same
velocity is generally neither constant nor controllable. What makes the situation more problematic is
sufficient as long as the velocity of the missile remains constant. As mentioned previously, the
provides robustness against disturbing factors such as autopilot lag. However, adaptation will only be
updating the guidance gain is not only able to overcome the unmodeled nonlinearities but it also
nonlinear domain by considering an adaptive guidance scheme. Such adaptation through periodically
the range, the look angle, and the duration until impact. This solution is then extended to the
linearized kinematics is used to obtain an analytical solution for the guidance gain as a function of
The guidance laws in [7] are generalized using an nth order polynomial of the look angle. Unlike [7],
velocity and adjusted the guidance gain with respect to the predicted velocity. In [17], an extension to
impact time problem but also for the optimal guidance laws too. There are several studies that
cost functions for varying velocity. The study in [18] used a time-varying linear game
the previous study was presented while providing two schemes for updating the velocity and
in terms of the downrange, doing a preflight analysis was proposed as a first step in coping with the
velocity change. In [15], on the other hand, integral sliding-mode control was performed, taking into
account the rate of change of the velocity and its limits. However, a preflight analysis as in [14] might
not always be feasible, and having the terminal acceleration systematically diverging away from zero
as in [15] could be prohibitive. Moreover, varying velocity is assuredly a problem, not only for the
impact time problem but also for the optimal guidance laws too. There are several studies that
concentrated on this issue. An energy-optimized guidance law was presented in [16], where the
guidance gain was varied via a time-to-go-like function. This function considered the future missile
velocity and adjusted the guidance gain with respect to the predicted velocity. In [17], an extension to
the previous study was presented while providing two schemes for updating the velocity and
general-case cost functions for varying velocity. The study in [18] used a time-varying linear game
model for an interception scenario with a known velocity profile and a lateral acceleration constraint.
In addition to these studies, adaptive guidance schemes are also applied to provide robustness
under varying conditions. Here, adaptation means updating the guidance gains with respect to those
conditions, and no connection with the conventional adaptive control is implied. In this extent, the
impact-angle control problem was studied in the literature. In [19], a nonlinear parameter adaptation
constraint with zero miss distance. Also, the third-order approach is shown to produce trajectories close to
optimal ones. The guidance law in [8] was derived by shaping the range as a quartic polynomial. The
nonlinear design results in a closed-loop guidance law with constant coefficients, showing robustness under lagged response and seeker noise. In addition to these, guidance laws effective against
moving targets were presented in [9,10]. The study in [9] adopted the vector guidance approach,
directing the total acceleration to ensure the capture at the specified time. In [10], a twophased PN
guidance scheme is constructed, where the switching instant was calculated with respect to the
desired impact time. Both of these guidance laws require a controlled change of missile velocity. In
addition to the impact time control problem alone, simultaneous control of the impact time and angle
should also be mentioned here because it can also lead to a designated impact time. In [11], the
guidance command was composed of two parts, where the first part was for the impact-angle
constraint with zero miss distance and the second part was for the impact time constraint. The
sliding-mode control theory was used in [12] for simultaneous control of the impact time and angle. A
second-order sliding-mode control law was introduced using a backstepping concept to provide
robustness in the presence of uncertainties. The work in [13] provided a three-phased practical
law to control the impact time or/and the impact angle under look-angle and acceleration
constraints. The key assumption in all of these studies is that the velocity of the missile was either
constant or, on a few occasions, controllable. In contrast, the velocity is not even controllable in most
missile applications. Besides, it changes under the action of drag, thrust, and the trajectory being
followed. The works presented in [14,15] considered the impact time control problem under changing
velocity. In [14], which devised a quadsegment polynomial method via parameterizing the trajectories
in terms of the downrange, doing a preflight analysis was proposed as a first step in coping with the
velocity change. In [15], on the other hand, integral sliding-mode control was performed, taking into
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under varying conditions. Here, adaptation means updating the guidance gains with respect to those
conditions, and no connection with the conventional adaptive control is implied. In this extent, the
impact-angle control problem was studied in the literature. In [19], a nonlinear parameter adaptation
scheme for impact-angle control was presented for a hypersonic gliding vehicle. The study in [20]
developed two adaptive impact-angle guidance laws: one of which was based on the conventional PN
guidance and the other one based on controlling the turn rate of the relative velocity vector. In both of
these studies, the guidance gains were updated in a closed-loop manner; therefore, they were able to
deal with varying conditions. In this study, a feasible impact time control algorithm is proposed.
The guidance laws in [7] are generalized using an nth order polynomial of the look angle. Unlike [7],
the linearized kinematics is used to obtain an analytical solution for the guidance gain as a function of
the range, the look angle, and the duration until impact. This solution is then extended to the
nonlinear domain by considering an adaptive guidance scheme. Such adaptation through periodically
updating the guidance gain is not only able to overcome the unmodeled nonlinearities but it also
provides robustness against disturbing factors such as autopilot lag. However, adaptation will only be
sufficient as long as the velocity of the missile remains constant. As mentioned previously, the
velocity is generally neither constant nor controllable. What makes the situation more problematic is
that the velocity profile eventually depends on the trajectory, which is indeed the result of the
guidance law itself. If the future velocity profile or, equivalently, the mean value of this profile can
somehow be predicted, this information can be used to feed the adaptive guidance process. The
approach adopted in this work for predicting the mean velocity uses the analytical results extracted
from the linearized guidance loop. At each guidance step, in which the eventual objective is the
adaptation of the guidance gain, the mean velocity is predicted for the interval between the current
time and the final time using an iterative process. The prediction algorithm involves a mathematical
model of how the velocity is expected to change. In this predictive-adaptive guidance scheme, the
guidance gain is updated based on the predicted mean velocity. The outline of the Note is organized
as follows: In Sec. II, the impact time control problem is described and the general form of the
guidance command is presented. In Sec. III, the solution of the guidance gain is presented based on
linearized kinematics. Afterward, adaptive and predictive-adaptive guidance schemes for impact time
control are introduced. Last, the performance of the proposed guidance technique is demonstrated
with simulations in Sec. IV. After presenting idealized examples with constant velocity, more realistic
ground-to-ground and air-to-ground scenarios with nonconstant velocity profiles and autopilot lag are
exemplified. In addition to these simulations, which also include comparisons with optimal solutions,
a case that involves drag uncertainty is investigated.

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