Chapter 6

A Taxonomy of Guidance Laws

Module 5: Lecture 11
An Overview of Guidance Laws

Keywords. Classical Guidance, Modern Guidance

6.1 An Overview of Guidance Laws

As mentioned in the previous lecture the primary objective of the guidance subsystem in a tactical missile is to generate suitable commands so that the missile comes closer and closer to its target. This is a very broad definition and it is somewhat unsatisfactory when you consider the fact that there are many physical constraints under which a missile has to perform. The major constraint is that of time. Tactical missiles of the SAM or AAM category seldom have a flight time of more than 50 seconds. In this short time the guidance system has to generate a sufficient number of commands to enable the missile to fly in the proper intercept course and intercept the target. So the main concern here is the following: How can a guidance subsystem utilize the information available to it to generate proper guidance commands within the time limitations imposed upon it?

This was the concern of the guidance system designers in the early days of guided missile design. Of course, in those days it was more vital to design a proper propulsion
system that could carry the missile and its payload to the desired distance rather than
to design a guidance system that can accurately intercept a target. The reasons for this
were two-fold. The first was that guided missiles were used mainly for the psycholo-
gical advantage that they gave to an army rather than for their accuracy (to be frank,
this seems to be an important factor even now – if you go by the track record of the
Patriot missiles during the recent gulf war!). The second reason was that the targets in
those days were somewhat clumsy and slow moving – for example, Zeppelins during
the First World War (these were more like huge balloons that you could hit by throw-
ing a stone – well, almost!), or low-flying and low-speed aircraft. However, soon after
the Second World War, all this changed and demand on the guidance system went up.
They needed to be more accurate and more reliable. So well-defined guidance laws with
a firm grounding on a theoretical framework was essential. Even then, the Classical
Guidance Laws, which were proposed and tried out, were based on very simple ideas.
We will look at some of them in a short while. These simple ideas were intuitively ap-
pealing but did not initially have any firm theoretical basis. In fact, they were rather
empirical in nature. However, their major advantages were:

- They were easy to understand,
- easy to implement,
- needed simple information inputs, and
- by their very simplicity instilled a sense of confidence in their designers (which is
  perhaps the most important – and quite often the least understood – aspect of all
  pioneering and successful design activities).

It was not until the 1960s that a rigorous mathematical framework for these guid-
ance laws began to emerge with the rapid developments in the area of Optimal Control
Theory and its applications, which basically dealt with problems of dynamic optimization.
The kind of problems in which optimal control theory found applications were related
to the optimization of some performance criterion by a dynamical system working un-
der well-specified constraints. It is easy to see that many missile-target engagement
problems can be quite obviously formulated in this framework. However, formulation
of a problem is one thing and the solution of it is another. It was soon found that with
the available computing resources it was almost impossible to obtain a solution to a realistically formulated non-linear guidance problem. The obvious next step was to adopt a linearized formulation and hope for a solution that can be implemented easily and yield a close-to-optimal solution when implemented in a closed-loop manner. The fundamental principle behind this approach was that when you break up a real-life dynamical system into smaller time-frames then, within that time frame, it can be approximated as a linear system. This approach yielded rich results in more ways than one. The so-called linear quadratic formulation gave a simpler solution to the problem with the hope of achieving partial implementation at some future time when computing capability go up. But the more important benefit of this exercise was the realization that many of the empirical guidance laws could actually be shown to have a very good theoretical basis. In other words, it was found that the so-called empirical guidance laws were optimal under some simplified assumptions.

From the above discussion we can now classify guidance laws as:

- Classical or Empirical guidance laws
- Modern or Theoretically-rigorous guidance laws

Further, we can also classify guidance laws from the point of view of their implementability. This classification is not much different from what I have mentioned above. It is easy to see that most classical guidance laws were “fairly easy” to implement since they all arose from simple ideas.

You may wonder why I have put the words fairly easy under quotes. This is because the implementation of these guidance laws were easy from a conceptual viewpoint in the sense that all the necessary hardware were available or could be produced with little effort. But the actual implementation took many thousands of man-hours of intense effort by some of the best engineering brains of the time. If you want to catch a glimpse of the hard work, the euphoria, and the sense of serendipity that pervaded the dedicated team of people who handled these projects in the Raytheon Company in the USA then I suggest that you read an account of it in Mike Fossier’s 1984 paper that appeared in the Journal of Guidance, Control, and Dynamics and which I have referred to in my first lecture.
Coming back to the issue of implementability, the modern guidance laws were extremely elegant and, in computer simulations, gave wonderful performance results. But, alas, their requirement of large amount of time to complete all the intricate computations, and also their hunger for extra information which was impractical to obtain with sufficient accuracy, made them totally unimplementable. Even now, notwithstanding the tremendous strides made in harnessing vast computing powers in the space of a small silicon chip, these laws still remain unimplementable due to the strict time constraints imposed by the short flight time of a tactical missile. Optimal control theory was instrumental in putting man on the moon, sending spacecrafts on interstellar missions covering mind-boggling distances, and huge satellites in orbit in space, but when it came to tactical missiles, it still did not, and indeed even now does not, have the capability to deliver the performance that it promised in computer simulations.

In subsequent sections we will briefly discuss the several classical and modern guidance laws for tactical missiles. Our discussion will be confined to explain the working of these guidance laws, the fundamental principles behind them, and why they perform well or fail to perform at all. We will not go into any complicated mathematical framework or analysis to do this. The emphasis will be more on intuition and understanding rather than on rigorous analysis. A taxonomy of guidance laws for tactical missiles is given in Figure 6.1. From this figure you can see that the classical guidance laws have been further sub-divided into conceptual and implementable categories. In the following sections we will look at these separately.

Questions

1. Why are the classical guidance laws favoured by missile system designers?

2. What benefits did the modern guidance laws bring to the guidance law performance?

3. What was the motivation behind formulating guidance problems in the optimal control framework?

4. What are the drawbacks of the modern guidance laws as against the classical or
TACTICAL MISSILE GUIDANCE LAWS

Classical/Empirical

Conceptual

Implementable

Pursuit (Pure/Deviated)

Constant Bearing

Attitude Velocity

LOS PN

CLOS BR

TPN PPN

Optimal Control

Predictive Guidance

Differential Games

LPN APN MGS OCG SP

Pursuit Evasion Reachable Sets

LOS: Line of Sight
CLOS: Command-to-Line-of-Sight
BR: Beam Rider
PN: Proportional Navigation
TPN: True Proportional Navigation
PPN: Pure Proportional Navigation
LPN: Linear Proportional Navigation
APN: Augmented Proportional Navigation
MGS: Modern Guidance Scheme
OCG: Optimal Control Guidance
SP: Singular Perturbation

Figure 6.1: A taxonomy of tactical missile guidance laws
empirical guidance laws?

5. Draw a flowchart depicting the taxonomy of guidance laws.