Target Manoeuvre Detection Using Radar Glint

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Abstract

This paper describes a novel target manoeuvre detection system for radar guided homing missiles. The system operates by extracting glint noise to detect changes in orientation made as the target manoeuvres. A brief introduction to the detection principle is presented, along with feasibility study results from a fuzzy-logic based implementation.

1 Introduction

Current target tracking algorithms are very sophisticated and capable of tracking highly agile targets. Unfortunately, even agile targets spend most of their time in straight, level flight. Tracking algorithms that are designed to track manoeuvring targets are usually poor at following non-manoeuvring vehicles. The ability to switch rapidly between different tracking regimes is of paramount importance.

As current aircraft performance is often pilot limited, in order to perform a high-g manoeuvre, the aircraft must bank steeply. The rapid target rotation associated with the bank is likely to produce a stream of glint spikes in the seeker bore-sight error signal.

Any ability to detect potential manoeuvres can be used to greatly enhance the homing capability of missiles. The use of glint to augment target tracking is novel and could be used to create a significant tactical advantage for little cost in a radar guided missile.

2 Existing Techniques

Existing manoeuvre detectors either attempt to identify a manoeuvre by predicting the expected target position and comparing it to the measured track [1], or use optical techniques. Optical methods attempt to identify changes in the target's orientation by monitoring images of the target.

Prediction methods are quite slow and typically require a few seconds to detect a manoeuvre. This speed of reaction is satisfactory for a ground based tracking radar, but not for a missile. Most of the optical methods are based on the assumption that the target must bank before performing a high-g turn. The number of pixels in the image will change as the target rotates [2]. Optical detectors are fast but require large amounts of image processing. Some of the techniques require knowledge of the target structure and characteristics. This is undesirable. Optical techniques are more susceptible to climatic effects when compared to radar and are only practically suitable for medium to short range engagements.

3 Glint detection

The necessity for the target aircraft to bank before turning is exploited for the glint detector. As the target rotates, a fluctuating radar cross section pattern will be observed by the missiles mono-pulse seeker head. This will introduce glint errors in the seeker bore-sight error signal [3, Chapters 5&8]. The glint errors give a false indication of the angular error between the target's location and the seeker bore-sight. Target glint noise is highly non-Gaussian and is related to the relative rate of tangential rotation between the target and the missile. Target glint noise also occurs due to changes in range. This range-glint occurs mainly at short ranges and is the dominant source of noise in the last few kilometres of an engagement. Target glint noise has a long-tailed distribution.

Antenna noise is also seen in the bore-sight error signal and is a combination of channel noise, receiver noise and the thermal noise in the signal processing stages. The noise is approximately Gaussian and the processed signal from each antenna may be defined as $N(\mu, k^2)$, where μ is the mean of the signal and k^2 is the variance of the noise. The noise variance, k^2, is assumed to remain constant throughout the engagement. Equation 1 details the calculation of an approximation for k; where the RMS noise level k is set to give a unity signal to noise ratio of the received echo, at the range R_N metres against a $1m^2$ target. The source power of the missile is denoted by $\mathcal{S}$, normalised to give an antenna with unity gain. Antenna noise is the dominant source at long and medium range.

$$k = \frac{\sqrt{\mathcal{S}}}{4\pi R_N^2} \tag{1}$$

To detect the target glint noise, the antenna noise component of the bore-sight error signal is extracted. If a small number of bore-sight error and sum signal samples are taken (10 in this study), the mean radar cross section can be approximated from the mean of the sum signal, $\bar{\mathbf{s}}$. Thus the antenna noise may be approximated as shown in equation 2; where the signals now represent short vectors of samples and $\Im(\mathbf{d}/\mathbf{s})$ is the mono-pulse ratio. Equation 2 may also be applied to amplitude comparison monopulse where the real part of the complex difference is used instead of the imaginary part as here. More detailed coverage of the derivation of the equations is given in [4, Chapter 6]

$$\mathbf{N}_b = N(0, k^2) \approx \frac{\bar{\mathbf{s}}}{\sqrt{2}} \Im\left(\frac{\mathbf{d}}{\mathbf{s}}\right) \tag{2}$$

The set of samples, $\mathbf{N}_b$, may be normalised using equation 3 to give $\hat{\mathbf{B}}$, which is an approximation of the bore-sight error signal with an antenna noise component of zero mean and unity variance.

$$\hat{\mathbf{B}} \approx \frac{\mathbf{N}_b - \overline{\mathbf{N}}_b}{k} \tag{3}$$

The standard deviation of $\hat{\mathbf{B}}$ may now be monitored. The noise signal $\hat{\mathbf{B}}$, now corrected for range and radar cross section, should lie within two standard deviations for 95% of the time. Any signals outside this range are likely to be glint.

4 Detector Trials

As only a feasibility study was being performed into target manoeuvre detection using glint, a fuzzy-logic approach was adopted for speed of development and simplicity. Full details of the detector construction and operation may be found in [4, Chapter 6 & Appendix G] The engagement model consists of a homing guidance missile and a synthetic target and allows controlled missile–target engagements to be simulated in three-dimensions.

In order to determine the general performance of the manoeuvre detector, an experiment was devised that could characterise different features of the detection process, such as turn-on time, reliability of detection, turn-off time etc.. As the noise characteristics are range dependent, the performance criteria must be evaluated for engagements at different ranges.

The effects of different launch positions have to be minimised in this experiment, therefore the launch positions were chosen at random to give uniform 4π steradian coverage. The launch ranges were chosen at random from between 1km and 20km. A random delay lasting between 0.2 and 1 second was given before the manoeuvre to allow the missile to stabilise. The missile and target velocities were held constant at 660 m/s and 330 m/s respectively. The manoeuvre was a $6g$ coordinated turn lasting between 1.45 and 1.95 seconds. The engagement was terminated 0.5 seconds after the manoeuvre had been completed. A $6g$ coordinated turn is likely to seriously disturb the missile guidance and so there is no benefit in extending the simulation after the manoeuvre. The target model used in the simulation had a 20 metre wingspan and a realistic radar cross section that was correlated to the target manoeuvre. Five thousand trials were run.

The missile uses a proportional navigation homing guidance system with a phase comparison monopulse seeker. Table 1 summarises the main results of the experiments. The mean turn-on delay time is 96 milli-seconds. This delay is comparable to the reaction speeds of optical manoeuvre detectors. The mean turn-off delay time is 148 milli-seconds. Again, the turn-off time is comparable to optical systems. Full details of the experiments and its results are given in [4, Chapter 6].

There were only two engagements out of 5,000 where the manoeuvre detector failed to respond to the target manoeuvre. The turn-on failures occur most frequently at long range, although less than 0.3% of the trials were affected. The turn-off failures are mainly due to the missile loosing track of the target after the manoeuvre and are distributed across all ranges.

Parameter	Result
Number of trials	5000
Mean turn-on delay	96 milli-sec.
Mean turn-off delay	148 milli-sec.
No. of total failures	2
No. of turn-on failures	14
No. of turn-off failures	403

Table 1: Experiment results

5 Conclusions

Despite the fuzzy detector only being very roughly tuned, the detector only failed totally for 0.04% of the trials. The average detection time of 96 milli-seconds and the high reliability make target manoeuvre detection using glint very attractive. The main strengths of the method are: No *a-priori* target knowledge required; Fast response; Effective for long, medium and short range engagements; Reliable; Low processing overhead; Uses existing sensors.

The fuzzy-logic proof-of-principle target manoeuvre detector showed that the technique is effective and potentially very reliable. It is suggested that an extended Kalman filter or fuzzy-logic/artificial neural network solution is investigated. The noise characteristics developed for this study are only approximate. More rigorous analysis of the system noise characteristics need to be performed before a more robust detector can be constructed.

References

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