Aircraft Identification Using a Multi-Stage Fuzzy Neural Network

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Abstract: The effectiveness of time-frequency representation of ultra-wideband radar target signatures, in conjunction with a multi-stage fuzzy neural network (MSFFN), is investigated in the context of aircraft identification. Experimental results on the backscattered data of six aircraft models show that a good level of identification rate is possible at signal-to-noise ratios (SNR) as low as 5 dB.

I. INTRODUCTION

In recent years, considerable research has been carried out on the identification of aerospace objects by means of high resolution radar. There may be several reasons, two of which are the following. Firstly, with the development of modern ultra-wideband radar techniques, increasingly more high resolution radar systems are designed and put into practical use. Secondly, an ultra-wideband radar allows time-domain analysis with a high resolution to the backscattered echoes which often reduces the complexity of the complicated dependence of the scattering field on aspect angle, frequency and polarization, by concentrating on either the late-time resonant response (for low-frequency radar), or the early-time specular response of target (for high-frequency radar).

Target discrimination schemes based on the late-time natural resonance behaviour of conducting objects have been proposed by Kennaugh and Moffat [1,2], and Chen et al. [3-4]. A considerable amount of research has centered on identifying targets based on radar range profiles [5-9]. In this paper, we investigate the effectiveness of the time-frequency representation of ultra-wideband radar target signatures and a multi-stage fuzzy neural network (MSFNN) for such identification purposes. In section II, the time-frequency representation of ultra-wideband radar target signatures is briefly reviewed. The structure of a multi-stage fuzzy neural network and its self-organizing algorithm are discussed in section III. This is followed in section IV with identification experiments using the time-frequency representations of aircraft models.

II. TIME-FREQUENCY REPRESENTATION OF ULTRA-WIDEBAND RADAR TARGETS

The information concerning the dependence of scattering centers of an aircraft on the down range (known as range profile) can be obtained by Fourier transforming the backscattered signal recorded as a function of frequency. Thus, if \( f(r) \) indicates the functional independence of the scattering centers on the down range \( r \), and \( F(\omega) \) is the backscattered signal as a function of frequency, then

\[
f(r) = \int_{-\infty}^{\infty} F(\omega) e^{i2\pi \omega r} d\omega
\]

However, the dependence of the scattering centers on frequency is completely smeared out in the time domain because of the temporal variations involved. Indeed, this drawback of the Fourier transform is a fundamental in that it does not possess a good "time-frequency" localization. It can be alleviated to some extent by short-time Fourier transformation (or moving-window Fourier transformation) which allows for a finite resolution in both the time and the frequency domain. The short-time Fourier transformation of frequency-domain backscattered data \( F(\omega) \) is defined as

\[
S(r,\Omega) = \int_{-\infty}^{\infty} F(\omega) G(\Omega - \omega) e^{i2\pi \omega r} d\omega
\]

Equation (2) is very similar to the Fourier transform defined in Eq.(1) except for the presence of a frequency window function, \( G(\omega) \). The translation of the window as a function of frequency, \( \Omega \), results in a two-dimensional time-frequency representation, \( S(r,\Omega) \), of the original frequency function. In the context, we call \( S(r,\Omega) \) the time-frequency pattern of a radar target.

An example of time-frequency representation for a complex radar target is shown in Fig.1, where the locations and frequency-dependent amplitudes of each scattering center on the target are clearly indicated.

III. A MULTI-STAGE FUZZY NEURAL NETWORK FOR AIRCRAFT IDENTIFICATION

Motivated by the work of Kwan and Cai on a four-layer feedforward fuzzy neural network (FNN) for the recognition of English alphabets and Arabic numerals [10], we propose a multi-stage fuzzy neural
A comparison between the identification rates when the time-frequency patterns and the radar range profiles are respectively used as the inputs of the MSFNN is illustrated in Fig.4. It can be seen from this figure that, when the SNR is higher than 10 dB, the identification rates of both the cases are almost the same. However, at a SNR between -5 and 10 dB, a better level of identification rates can be reached when the time-frequency patterns are used.

V. CONCLUSIONS AND DISCUSSION

The time-frequency representation of ultra-wideband radar target signatures, together with a MSFNN for aircraft identification and its self-organizing learning algorithm, is investigated. Identification experiments on the frequency-domain backscattered data of six aircraft models are carried out. Our results show that, by using the time-frequency patterns of ultra-wideband radar targets and the suggested MSFNN, a high correct identification rate is possible even when the SNR is as low as 5 dB.

Further research is required in the following two aspects.

(a). The time-scale representation of ultra-wideband radar target signatures is to be represented through wavelet analysis which is expected to overcome the resolution limits of STFT at the time and frequency.

(b). The optimal structure of the MSFNN to be examined, especially the structures of the MEMBERSHIP NETs and the corresponding learning algorithms.

VI. REFERENCES

![Fig.1 The time-frequency representation of an aircraft model](image-url)