An adaptive weak signal extraction algorithm based on Four-element infrared detecting system

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ABSTRACT

The four-element infrared detecting system is a common used detecting system to detect a target from sky background. However, one of the main application limits of this system is the short detecting distance. Consequently, this paper presents an adaptive weak signal extraction algorithm, with which the weak distant target signal can be extracted, thus the detecting distance can be obviously lengthened.

The algorithm is designed as follows: Firstly, estimates the target signal when the signal is extremely weak. To a given detecting system, the target signal can be estimated by the geometry relationship among the physical references. Secondly, gets the initial normalized coefficients $h(i)$ of the BPFIR filter by sampling the first harmonic of the estimated target signal and then normalized coefficients $\sum_{0}^{N} h(i) = 1$ Thirdly, gets the amplification value k of the algorithm using the radiation equation L=$\sqrt{\dfrac{I\rho}{E_n K_c}}$ and the response property curve of the sensors. Finally, updates the coefficients of the BPFIR filter $H(i)$ using the output $y(i)$ of the detecting system and changes the amplification value k using PID method, The newer output of the BPFIR filter will be used to obtain newer updated coefficients of the BPFIR filter, and hence the adaptive weak signal extraction algorithm is realized.

With the application of this algorithm on a four-element detecting system, the distant weak target signal can be extracted properly. Experiments shows that the detecting distance is lengthened more than 20 percents.

Key words: adaptive; weak signal extraction; four-element infrared detecting system

I. INTRODUCTION

Due to the growth application of infrared technology, the demand for infrared information processing is getting higher and higher. Among these applications, the infrared detecting is one of the most important facets. On the surface to air and air to air detecting system, the four-element infrared detecting mechanism is a common non-imaging infrared detecting mechanism which is used to detect a target from sky background. However, one of the main application limits of this system is the short detecting distance, because the sensitivity of this kind of detecting system is limited, when the target is far from the detecting system, the noise of the system and sky background can submerge the real signal of the target when the target is far from the detecting system. Many methods have been used to improve the detecting system in order to lengthen the detecting distance such as enhance the sensitivity of the sensors, reforming the imaging quality of the optical subsystem, eliminating the noise of system and so on, but the detecting distance is not as lengthened as expected. Consequently, this paper presents an adaptive weak signal extraction algorithm based on four-element infrared detecting system, with which the weak distant target signal can be extracted, thus the detecting ability can be remarkably enhanced.

II. WORKING MECHANISM OF FOUR-ELEMENT INFRARED DETECTING SYSTEM

The four-element infrared detecting system is a complicated system which is composed of optical subsystem, mechanical subsystem and electrical subsystem. The optical subsystem is composed of a few lens that is used to focused the radiation of the target into a light spot and four sensors that are put as the 'cross' type to distinguish the four detections of the target. The mechanical subsystem has a 100 Hz conical scanning function with which the light spot will form a full circle, and when the light spot meets one of the four sensors, the signal of the target is generated. The electrical subsystem captures, samples, calculate the signal and gives out the detailed position information of the target.

As Fig. 1A shows, if the centre of the light spot circle is in the origin of coordinates, the target should be in the center of the optical axis, and the four signals generated by the sensors have equal intervals, but when the light spot circle is not in the origin of coordinates just as Fig. 1B demonstrates, the signals' intervals will no longer be equal, by using the intervals the electrical subsystem will calculate and provide the position information of the target.
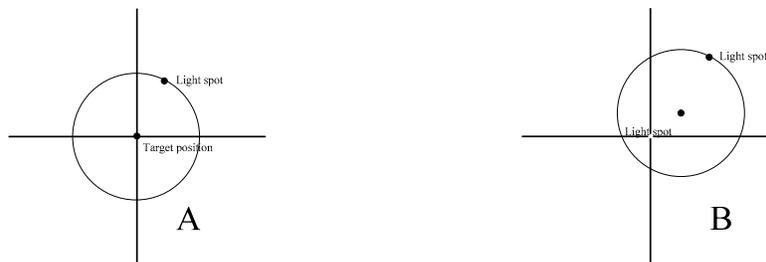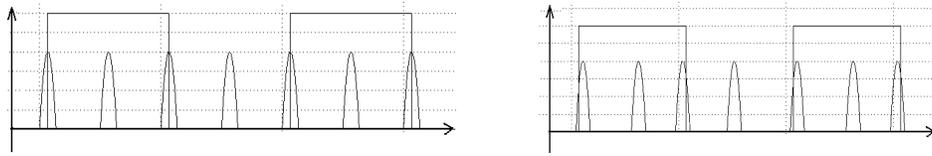
Fig. 1 Target position and the signals

III. ADAPTIVE WEAK SIGNAL EXTRACTION ALGROTHEM

Based on the system descript above, the weak signal extraction algorithm is to design an adaptive band pass finite impulse response (BPFIR) filter. Four main steps is needed as estimating the target signal when the signal is extremely weak, getting the initial normalized coefficients $h(i)$ of the BPFIR filter, setting the amplification value k of the algorithm and updates the coefficients of the BPFIR filter $h_u(i)$. The details of the method is descript as follows:

Firstly, estimates the target signal when the signal is extremely weak. Suppose the distance between the target and the detecting system is quite far, the weak target signal should be estimated as the signal is submerged in the noise and the target radiation can be deemed as a parallel ray, which means to a given four-element detecting system, the base form of the target signal S_{EB} is decided by the area of the light spot overlapping the sensor, and the amplitude of the signal has a direct proportion relationship with the radiation of the target and the sensitivity of the sensors, suppose k is the proportion coefficient, then the estimated target signal $S_E = k * S_{EB}$. The target signal can be estimated by the geometry relationship among the system references. Assume the radium of the light spot is R_L, the width of the sensor is D, the radium of the scanning circle is R_S and the scanning frequency of the mechanical system is F. According to the geometry relationship between D and R_L, three different types calculating methods are presented as Fig 2 shows.
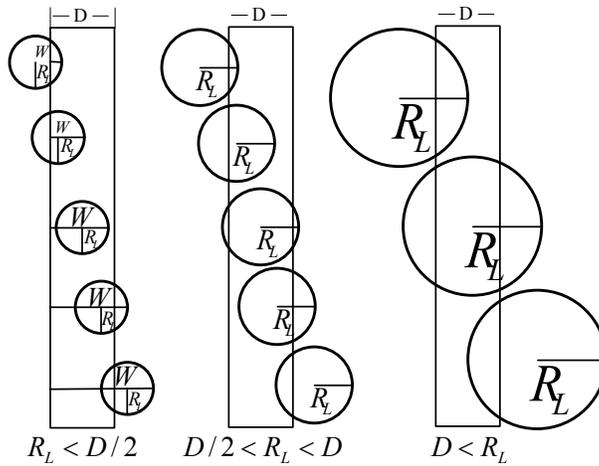
Fig. 2 Three main relationship between D and R_L

In most application especially when the target is quite far, R_L <D/2, and $R_S >> R_L$ +D, then the curve effect of the scanning radium can be neglected. Assume the overlapping depth is W:

$$W < R_L \quad S_{EB} = R^2 * \arccos(\frac{R_L - W}{R_L}) - (R_L - W) * \sqrt{2 * R_L W - W^2}$$

$$R_L < W < 2*R_L \quad S_{EB} = R^2 * (\pi - \arccos\frac{W - R_L}{R_L}) - (W - R_L) * \sqrt{2 * R_L W - W^2}$$

$$2*R_L < W < D \quad S_{EB} = R^2 * \pi$$

$$D < W < D + R_L \quad S_{EB} = R^2 * (\pi - \arccos\frac{R_L - (W - D)}{R_L}) + (R_L - (W - D)) * \sqrt{2 * R_L(W - D) - (W - D)^2}$$

$$D + R_L < W < D + 2*R_L \quad S_{EB} = R^2 * (\arccos\frac{W - R_L - D}{R_L}) - (W - R_L - D) * \sqrt{2 * R_L(W - D) - (W - D)^2}$$

With consideration of proportion coefficients K, $S_E = k * S_{EB}$.

Secondly, gets the initial normalized coefficients $h(i)$ of the BPFIR filter. Since the estimated target signal is obtained above, the frequency spectrum of the signal can be gotten using FFT method, Fig. 3 shows the estimated target
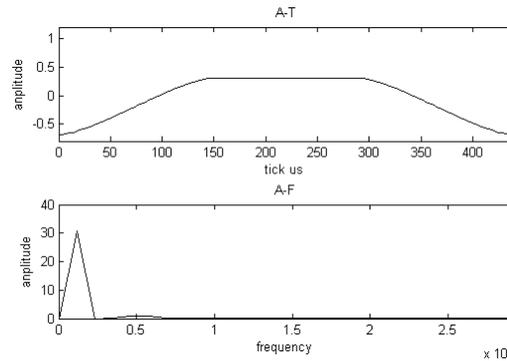
and its frequency spectrum.

Fig. 3 the estimated target signal and its frequency spectrum

It is clear that the first harmonic of the signal occupies most of the energy of the target signal; hence the coefficients of the initial BPFIR filter $h'(i)$ can be given by sampling the first harmonic. In order to reduce the calculating load and remain the fine property of the algorithm, the sample rate must be set to a proper value. Lots of experiments are needed to achieve a satisfied sample rate, and then the value is set to 64 times of the first harmonic in this paper. The normalize coefficients $\sum_{0}^{N} h(i) = 1$ will be generated by $h(i) = \dfrac{h'(i)}{\sum_{0}^{N} h'(i)}$.

Thirdly, sets the proportion coefficients k of the algorithm. There are two factors which can affect k, the radiation of target and the sensitivity of the sensors. The radiation equation is L=$\sqrt{\dfrac{I\rho}{E_n K_c}}$, in the equation, L is the distance between the target and the detecting system, I is the radiation intensity, ρ is the atmospheric transmissivity, E_n is the maxim distinguishing ability of the detecting system, K_c is the utilization coefficient of the specific band of the target radiation. Based on this equation, if the expected distance is set, the weather condition is selected, the radiation E_N on the sensor is gotten. By referencing E_N to the response curve of the sensors, the coefficient k can be attained. $H(i) = $ k* $h(i)$ is used as the coefficients of the BPFIR filter.

Finally, updates the coefficients $H_u(i)$ of the BPFIR filter. The output $y(i)$ of the electrical subsystem is the mixed signal of the target and the noise passing through the BPFIR filter designed before, which is not only the final output but also the feedback signal used to get updated coefficients of the BPFIR filter. If the output is big enough, then the initial

coefficients of the BPFIR filter can be neglected, and the first harmonic of $y(i)$ can be got by sampling and analyzing the

frequency spectrum of $y(i)$ using FFT method, subsequently the updated coefficients of the BPFIR filter $h_t(i)$ can be

generated by sampling the first harmonic, after that let us normalize the updated coefficients and get the uniformed

coefficients $h_u(i)$, then the next step is to change the amplification value k_u using PID method, the updated coefficients

of the BPFIR filter is obtained as $H_u(i) = k_u * h_u(i)$.

   The newly gotten output of the updated BPFIR filter will be used to obtain newer updated coefficients of the BPFIR filter, and hence the adaptive weak signal extraction algorithm is realized. Fig 4 demonstrates the designing steps of the algorithm.
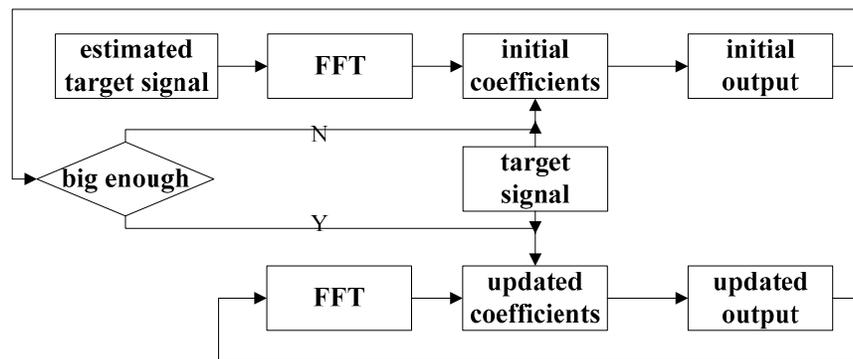

Fig 4 the designing flow of the algorithm.

IV. EXPERIMENTS AND CONCLUSION

   As Fig. 5 demonstrates, by using this algorithm, the target can be perfectly extracted even if the target signal is nearly completely submerged in the noise.
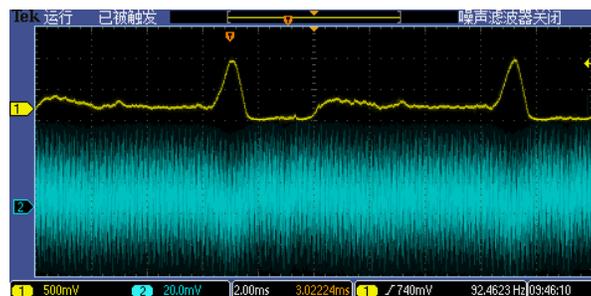

Fig. 5 weak signal extracting ability of the algorithm

In the experiment without this algorithm, the references of radiation equation are set to $I = 60 \, W/sr$, $\rho = 0.55$, $K_c = 0.1042$ and the maxim distinguishing ability E_n can only reach $4.5 \times 10^{-10} \, W/cm^2$, which means the maxim distance of the detecting system can be bestowed is $8.4 \, Km$, while by using this algorithm on the same detecting system, E_n can be enhanced to $2.68 \times 10^{-10} \, W/cm^2$, that means the maxim detecting distance is $10.87 \, Km$, hence the distance is lengthened more than 20 percents.

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