Passive Ranging Based on Accurate Prediction of Target Radiation Temperature

Fu Xiaoning\textsuperscript{1,a}, Xu Shiwen\textsuperscript{2,b}

\textsuperscript{1}Xidian University, School of Mechano-Electronic Engineering Xi’an, China
\textsuperscript{2}Xidian University, School of Mechano-Electronic Engineering Xi’an, China
\textsuperscript{a}xning_fu@163.com
\textsuperscript{b}1561130931@qq.com

Abstract—In this paper, a passive ranging method based on accurate prediction of target radiation temperature is proposed. Firstly, different wave bands are intercepted and the corresponding light radiation energy on two different wave bands are obtained; secondly, the temperature of target is estimated according to the linear relationship of the corresponding light radiation energy in two different wave bands; and the target can be equivalent to a blackbody of different temperature categories; thus, the range information of the target can be obtained, and the passive ranging error of air target can be realized. In this way, the target can be divided into different categories according to its own temperature, and the subspace of passive ranging can be effectively divided, which can provide a rule to avoid blindness for the subsequent target distance estimation. In the end of this paper, the accuracy of the method is verified by experiments, and the error of ranging accuracy is analyzed, which proves the feasibility of this method, and lays a foundation for future engineering applications.

1. Introduction
It has been more than 200 years since infrared radiation was discovered in 1800. During this period, the blank of infrared radiation theory and application has been filled continuously. In modern society, infrared technology is widely used in many fields such as life, medical treatment, industrial production and military. Compared with the traditional visible light detection system, the infrared detection system has the advantages of good environmental adaptability, strong anti-interference and high sensitivity. In the battlefield, the distance information of the target has a very important military value. If we can get the distance of the target in time, we can quickly make strategic and tactical adjustments, so as to obtain the initiative on the battlefield. Radar, laser and other ranging systems often adopt active ranging technology, which has poor concealment and is easy to be detected by the enemy when ranging. However, the infrared passive ranging system does not radiate energy, only receives the infrared radiation of the target in the passive form, and then converts the received infrared radiation into range information through a certain calculation method, which is better than the active ranging system such as radar and laser. Infrared passive ranging system has strong concealment and anti-jamming, so it has high military application value, and it is suitable for the military field with high concealment performance.

For example, "Passive Infrared Ranging Method for Ground Targets Under Various Weather Conditions" discloses a passive infrared ranging method for ground targets under various weather conditions. The method first evaluates the type and orientation of the target to be measured and intercepts different wave bands, on which obtains the corresponding light radiation energy, and calculates the
distance between the target and the observer; and finally outputs the distance between the target and the observer. The invention can expand the application range of the target, adapt to different weather conditions, and obtain a more accurate distance between the target to be measured and the observer. For example, "Adaptive Infrared Dual Band Passive Ranging Method" discloses an adaptive infrared dual band passive ranging method. Firstly, the infrared detector is used to measure the target, and the target type is evaluated according to the different irradiance proportion of the target radiation in different wave band sensors after the target radiation is attenuated through atmospheric transmission; secondly, the extinction coefficient and atmospheric transmittance are calculated by using the temperature and humidity parameters measured by the temperature and humidity sensor; then, the target is equivalent to a blackbody with different temperatures, and two types of radiation are selected. Finally, the infrared detector is used to measure the target in real time, and the passive ranging model is used to calculate the target distance. The invention has a high ranging accuracy for high temperature air target and ground normal temperature or low temperature target, and can be used for passive positioning of air and ground infrared targets.

Based on the above analysis of passive ranging methods, we present a method for linear estimating of temperature and passive ranging. The main difference between our study and the others mentioned above can be summarized as: the temperature of the target is estimated by the linear constraint relationship in the target irradiance curve, and the target can be equivalent to a blackbody of different temperature categories; thus, the range information of the target can be obtained, and the passive ranging error of air target can be realized. The simulation results show that the accuracy of the distance solved by this algorithm is accurate.

2. Principle of dual band passive ranging

Assuming that the detector of the passive infrared system works in two bands $\Delta \lambda_1$ and $\Delta \lambda_2$, the corresponding atmospheric extinction coefficients are $u_1(\lambda)$ and $u_2(\lambda)$, the spectral radiance corresponding to the target in the two bands is $M_{o1}$ and $M_{o2}$, the effective detection area of the infrared system detector is $S_d$, the sensitivity of the detector is $\eta$, and then the infrared radiation flux of the aerial target received by the infrared system at the distance are $I'_{o1}$ and $I'_{o2}$.

\[
I'_{o1} = \eta \times S_d \times M_{o1} \times \tau(\lambda_1) = \int_{\Delta \lambda_1} \eta \times S_d \times M_{o1}(\lambda_1) \times \tau(\lambda_1) d\lambda
\]

\[
I'_{o2} = \eta \times S_d \times M_{o2} \times \tau(\lambda_2) = \int_{\Delta \lambda_2} \eta \times S_d \times M_{o2}(\lambda) \times \tau(\lambda_2) d\lambda
\]

We can obtain:

\[
\frac{I'_{o1}}{I'_{o2}} = \frac{M_{o1}}{M_{o2}} \times e^{u(\lambda_1) - u(\lambda_2)} R
\]

In (3), $u(\lambda)$ is the extinction coefficient. The extinction coefficient of the atmosphere is closely related to the atmospheric environment. Different weather conditions have certain influence on the coefficient. The range information of the target can be obtained by measuring the radiation flux ratio of the target in two wave bands.
3. Technical solutions

![Figure 1 Principle flow chart of the method](image)

From Figure 1, the main method above can be summarized as: firstly, different wave bands are intercepted and the corresponding light radiation energy on two different wave bands are obtained; secondly, the temperature of the target is estimated according to the linear relationship of the corresponding light radiation energy in two different wave bands; and then, the target can be equivalent to different types of blackbody so as to estimate the distance error of the target.

3.1. Intercepting different wave bands

The infrared light wavelength radiated by the targets are collected; then a special infrared lens is used to intercept the medium wave narrow band $\Delta \lambda_1$ and long wave narrow band $\Delta \lambda_2$ of infrared light radiated by the target to be measured, where $\Delta \lambda_1$ is in the range of $3.7 \sim 4.8 \mu m$ and $\Delta \lambda_2$ is in the range of $7.7 \sim 10.3 \mu m$.

3.2. Estimating target's temperature

The two different wave bands intercepted in step A are integrated line by line to obtain multiple groups of optical radiation energy $E_1$ and $E_2$ corresponding to different target to be measured and transmission distance in the two wave bands, where $E_1$ is the light radiation energy of $\Delta \lambda_1$ wave band and $E_2$ is the light radiation energy of $\Delta \lambda_2$ wave band. Then the linear relationship is obtained by fitting the sum of the radiation energy $E_1$ and $E_2$, where slope is the coefficient depending on the target temperature, and the temperature of the target can be estimated according to the value of slope.

3.3. Obtaining the distance estimation error

- The target temperature estimated in step B is equivalent to blackbody of different temperature categories. The spectral radiance $M_\nu(\lambda)$ produced by blackbody in the medium wave window of $\Delta \lambda_1$ and the spectral radiance $M_L(\lambda)$ generated in the long wave window of $\Delta \lambda_2$ are calculated by Planck's law, where $\lambda$ is the wavelength.

- Meteorological parameters such as atmospheric humidity and temperature parameters were obtained by using the corresponding auxiliary system, and the extinction coefficient $\mu(\lambda)$ under
the meteorological conditions was calculated. Simultaneous interpreting the atmospheric transmittance \( \tau(\lambda, r) = e^{-\mu(\lambda)r} \) of the corresponding working wavebands under different working distance \( r \) according to Lambert-Beer law of absorption.

- Combined with the spectral radiance and atmospheric transmittance obtained in above steps, the multi group irradiances \( E_M \) and \( E_L \) of blackbody under different temperatures and transmission distances in the medium wave and long wave atmospheric windows are calculated respectively, where \( E_M \) is the medium wave irradiance and \( E_L \) is the long wave irradiance;

- The light radiation energy \( E_1/E_2 \) and the corresponding irradiance \( E_M/E_L \) on the medium wave double narrow band of the equivalent blackbody are calculated respectively, and the distance error of different temperature targets and equivalent blackbody under the same ratio is obtained.

### 4. Specific implementation mode

The experimental environment of this paper is Windows 8.0 system, and the processor model is Intel (R) core (TM) i5-3230m CPU@2.60GHZ, and Matlab r2018b is used for simulation on 4G video memory and 64bit operating system. The experimental data are generated by the U.S. Navy atmospheric transmission software MODTRAN, which is a kind of atmospheric radiation transfer simulation software package developed by the U.S. Air Force geophysics laboratory. It is considered to be one of the best atmospheric radiation transfer simulation models, so it is widely used in the study of various atmospheric physical characteristics. By setting different surface parameters, atmospheric parameters, sensor parameters, observation geometry parameters and other model parameters, we can get the atmospheric transmittance of different bands in different media, and through the basic law of spectroscopy, we can calculate the irradiance of different bands in a short time. There is a certain relationship between irradiance and distance.

#### 4.1. Experimental conditions

- The medium wave narrow band \( \Delta\lambda_1 \) and long wave narrow band \( \Delta\lambda_2 \) of infrared light radiated by the target what we choose is 3.8–4.0\( \mu m \) and 9.0–9.2\( \mu m \).

- Using a blackbody with a temperature of 600K, whose weather conditions are mid latitude summer and mid latitude winter; then Using a blackbody with a temperature of 580K, whose weather condition is mid latitude summer, and horizontal ground target with zenith angle of 50° respectively. Under the urban environment of 5km visibility, the altitude of the observation point is 0.1km, and, city aerosol 5km.

- Under the same meteorological conditions, the target temperature is 990K, 1000K and 1010K blackbody temperature, and the horizontal ground target with zenith angle of 50°is set. The distance between the target to be measured and the observer is 100-2000m, and the altitude of the observation point is 0.1km, and the urban aerosol is 5km, and the weather condition is mid latitude winter.
4.2. Experimental results

From Figure 2, we can see the working lines of the 600K blackbody target in mid latitude summer and winter conditions. The slope of 580K blackbody is obviously different from that of 600K blackbody. However, in the urban environment with 5 km visibility, the working lines of 600 K blackbody in winter and summer almost coincide. The linear constraint relationship in the target irradiance curve is almost unaffected by the changes of external environment and has relative stability. Each target’s working line is specific, so it is feasible to use the target line in the subspace division of the detection object.

Figure 3 is the working lines of different blackbody temperatures in the same environment conditions. When the temperature error is about 10K, the working lines of 900K blackbody are almost translational. By comparing the ratio of irradiance in horizontal and vertical coordinates in Figure 3, we can obtain the ranging error easily.
Figure 4 shows the ranging and error calculation under the simulation conditions listed. When the estimated temperatures are 990K and 1010K, the ranging error of 1000K blackbody target is less than 10%, which can be seen in the following TABLE 1.

| Distance of 1000K target(m) | Distance of 990K(m) | Error | Distance of 1010K(m) | Error |
|----------------------------|--------------------|-------|----------------------|-------|
| 200                        | 183.76             | 8.5%  | 218.43               | 9%    |
| 500                        | 458.23             | 8.4%  | 542.42               | 8.4%  |
| 1000                       | 916.15             | 8.4%  | 1093.19              | 9.3%  |
| 1500                       | 1360.87            | 9.33% | 1642.16              | 9.46% |
| 2000                       | 1804.59            | 9.8%  | 2189.64              | 9.45% |
| 3000                       | 2812.37            | 6.26% | 3298.72              | 9.93% |
| 4000                       | 3680.16            | 8%    | 4310.43              | 7.75% |
| 5000                       | 4524.45            | 9.52% | 5479.35              | 9.58% |
| 6000                       | 5450.32            | 9.16% | 6598.85              | 9.96% |
| 7000                       | 6375.29            | 8.92% | 7680.28              | 9.7%  |
| 8000                       | 7210.16            | 9.87% | 8786.43              | 9.82% |
| 9000                       | 8125.82            | 9.72% | 9885.87              | 9.83% |
| 10000                      | 9207.71            | 7.92% | 10929.12             | 9.29% |

5. Conclusions
In order to meet the needs of modern warfare, accurate estimation of the distance of targets is becoming more and more important. Due to the attenuation of infrared radiation of targets in the process of atmospheric propagation, the radiation of targets at different wavelengths will change with the change of transmission distance.

In this paper, the passive ranging method combined with linear prediction of target temperature can effectively divide the subspace of the detection object for passive ranging, and provide a rule to avoid blindness for subsequent ranging. Based on the above principles, this paper uses the MODTRAN to transfer atmospheric to generate the atmospheric transmittance data of airborne targets in different bands, and then uses the theodolite to obtain the zenith angle of the targets, and finally a passive ranging model based on the targets’ radiation temperatures. The simulation results show that the proposed method can effectively improve the feasibility of the estimation of the target distance and lay a foundation for future engineering applications.
Acknowledgment
Thanks to the project’s support and the experts’ research on passive ranging, on the basis of which I can study deeply and obtain some scientific research achievements. Then, I want to say thanks to my colleagues for their help and encouragement. Confucius said, "There must be one out of three who can be your teacher." Getting along with these excellent people, I benefited a lot. I learned from them constantly, so I can always face the problems in scientific research with a positive attitude. I would like to express my heartfelt thanks to them.
Finally, I would like to express my deep thanks to the experts and professors who have reviewed this article!

References
[1] Ferguson Eric L, Ferguson Brian G. High-precision acoustic localization of dolphin sonar click transmissions using a modified method of passive ranging by wavefront curvature. 2019, 146(6):4790.
[2] Yang Kang, Zhao Cui. Design of Tram Collision Prevention System Based on Infrared Ranging and Kalman Filtering. 2019, 1237(3)
[3] Fu Xiaoning, Chen Liqiang, Jing Zhao, Lei Xinzong. Passive infrared ranging method for ground targets under various weather conditions [P]. Shaanxi Province: CN107632299b, 2019-07-23.
[4] Fu Xiaoning, Lei Xinzong, Gu Lijun, Li Baoming. Adaptive infrared dual band passive ranging method [P]. Shaanxi Province: CN106872992b, 2019-04-23.
[5] Yu. G. Bulychev, S. S. Ivakina, A. A. Mozol’, et al. Analysis of modification of the energy method of passive ranging. 2016, 52(1):30-36.
[6] Y H Chi, Chi Y H, Hu L H, et al. Research on infrared passive ranging algorithm based on unscented Kalman filter and modified spherical coordinates. 2020, 1629(1):012066-..
[7] Sherman C. Lo, Per K. Enge, Mitchell J. Narins. Design of a Passive Ranging System Using Existing Distance Measuring Equipment (DME) Signals & Transmitters. 2015, 62(2):131-149.
[8] Gang Niu, Jie Gao, Taihang Du. Passive Localization Algorithm for Remote Multitarget Localization Information. 2020, 15(8):1183-1187..
[9] Wu Xin mei, Guan Fang li, Xu Ai jun. Passive Ranging Based on Planar Homography in a Monocular Vision System. 2020, 16(1):155-170..
[10] Liang Zhiyu. Research on passive location technology based on external emitter [D]. University of Electronic Science and technology, 2020.
[11] Eom Min Jeong, Kim Do Young, Park Gyu Tae, et al. Position error estimation of sub-array in passive ranging sonar based on a genetic algorithm. 2019, 38(6):630-636.