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Simulation and Realization of Linear Insects' Different Movement Forms Radar Echo Model Based On Point Target*

Xuqiang Lang[1], Jialin Hou*[1] and Kai Tang[2]

[1] *College of Mechanical and Electronic Engineering, Shandong Agricultural University, Taian, China*
[2] *State Key Laboratory of Mechanical Engineering and Controling, Beijing Institute of Technology BeiJing, China*

Lang0536@sdau.edu.cn, jlhou@sdau.edu.cn, tangkai0205@163.com

Abstract

In allusion to the importance of insects' movement forms detection, this paper puts forward an linear insects' movement forms detection method using Micro-Doppler radar. This paper have a point model classification on linear insects' body and get the vibration characteristics of each model point in different movement forms through experiments. It combines with Doppler echo equations of point model vibration, and builds the linear insects' Doppler echo model. This paper detect different movement forms of tenebrio molitor in larva period with real-time Doppler radar data acquisition system, compare the movement echo time-frequency diagram of different movement forms obtained by STFT with the simulation. It aims to verify the rationality of building the linear model of the insects using model points and the feasibility of applying the Micro-Doppler to the real-time detection of insect movement forms.

Keywords: *microwave, Micro-Doppler, concealed pests, time-frequency analysis*

1. Introduction

Studies of insect movement forms can increase human's understanding of insect movements and grasp their living habits better. The scientific data of insect movement forms under different environmental conditions can guide the future development of bionic micro-robot. The Micro-Doppler radar can make the detection to the hidden pests and also accurately orientate concealed pests, which can improve the pertinence and scientificity in pest control [1, 2].

Target motion Doppler detection technology based on radar is a new technology rising in recent years, the principle of which is that the reflected wave, generated when radar wave radiates to the target, will be modulated by target's movement, and the modulation wave contains the Doppler signals generated by target's movement [3]. By analyzing the radar echo Doppler signal characteristics and using Time-Frequency Analysis, the target's current movement form can be extracted, such as the direction of motion, speed, accelerated speed and amplitude and so on [4]. Micro-Doppler is a special form of radar Doppler. It mainly refers to the mechanical vibration or rotation existing in the object or part of it in the main

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direction relatively, and it is shown in the form of frequency shift sidelobe on the frequency spectrogram of radar echo [5-7].

Radar beam is disseminated through the electromagnetic wave, so it cannot be influenced by the environment and light so as to work day and night for the sensor. Radar beam can pass through the obstacle, detect the motion of the hidden object and get the information of it accurately. In a word, the technique for the object detection, based on radar Micro-Doppler effect, will have a bright future in the safety protection, diaster assistance, detection of moving object and the study of hidden object.

In this paper, based on point target motion model, we build a simple movement forms echo equations of linear insects. With tenebrio molitor being the target, we simplify the body with multiple model points to obtain their vibration performance of different movement forms, We can also combine with point target radar echo equations, build radar echo model of different movement forms of tenebrio molitor, and then, obtain the time-frequency diagrams of body echo in different movement forms by simulation with MATLAB. The body echo data can be recorded by Doppler echo signal acquisition system and the time-frequency diagram of movement echo can be obtained by STFT, comparing with the simulation results. Its purpose is to verify the rationality of building the linear model of the insects using model points and the feasibility of applying the Micro-Doppler to the real-time detection of insect movement forms.

2. Doppler Movement Model of Linear Insects

2.1 The model of linear insects

Every part of body in the process of linear insects' movement has a mutual restriction and a very complex structure. Referring to motion analysis of snake robot, in this paper, the linear insect bodies are simplified to N sections plane rod system [8], as shown in Figure 1. Because the length of each section is far less than the radar detection distance, the movement of each section can be simplified as a model point movement. The analysis of specific movement forms of linear insects can be decomposed into movement characteristics' analysis of each model point, so the echo signals of linear insects' current movements will be obtained after combining the echo signals of each model point.

As the body structure and the node number both have a great difference in different linear insects, the analysis of each node will cause a redundancy of system model, which is not beneficial to the construction and simulation of system model. Therefore, considering the movement characteristics of model points in normalized area at the same time are in unison, the model points with a similarity in structure and function can be normalized when building the model.

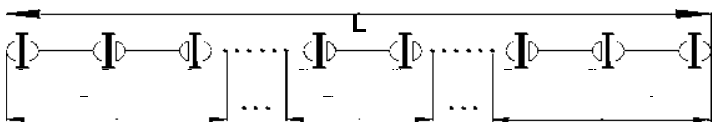

Figure 1. N sections system model of linear insects

2.2 Micro-Doppler echo wave equations of model points.

In this paper, the linear insects are divided into multiple model points, so we need to analyze the movement characteristics of model points first before analyzing the movement forms. Movements of Model points in space contain vibration, which the linear insects model points mainly own, and rotation. In this study, only the vibration mode of model points is analyzed.

Figure 2 shows the position of Micro-Doppler radar Q and insect model point P, which moves in regard to centre O with a instantaneous distance , an angle to the centre radar and a direction angle . The coordinate of model point P at time t in plane-coordinate system is (,)[9, 10]. So the distance from model point to the detection radar can be expressed as:

(1)

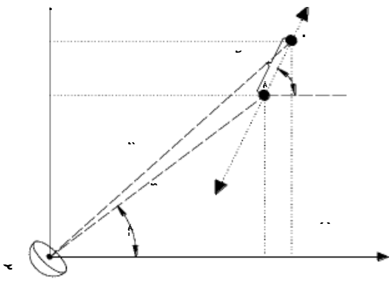

Figure 2. Geometric diagram of model point and radar

As the instantaneous vibration displacement of model point is far more less than real detection distance , so the distance can be simplified to:

D □ A0 + A1cos (x□*+) 1 B s□in

t

R (t) □ R t □ 0 R □ 0 A □ 1 Acos □ (t □ *) 1 B □ si

(2)

As the radar antenna pattern used in this system is wide, the linear insects which have relative short bodies can be seen as parallel beam. that is to say, the angle between movement centre O and radar direction , the instantaneous distance from model point to radar can be expressed as:

(3)

According to the linear insects' motion characteristics, the motion characteristics of model points can be seen as low frequency signals of cycle vibration under particular movement forms of linear insects. So the vibration equations of model points can be expressed with Fourier series. As the vibration frequency of linear insect model point is low, we express it with DC component and fundamental wave in Fourier series with an ignorance of the high frequency components [11]. So the instantaneous displacement of model points can be expressed as:

(4)

Where is the DC component of Fourier series, and are fundamental factors, is fundamental frequency. So the distance from model point P to radar Q is:

(5)

The general type of detection radar's launch signal is ,in which is the frequency of carrier frequency signal. The reflected wave signal of target body radar received is:

(6)

Where is the signal wavelength.

From equation(6) we can see a high-frequency component is included in the radar echo signal, the acquisition and analysis of echo signals cannot be done directly by data acquisition system. This paper mixes the radar echo signals and launch signals with frequency mixer, equation (7) describes the mixed signals:

(7)

Then the baseband signal can be obtained by low-pass filter.

(8)

Which can be expressed with plural form as:

(9)

2.3 Establishing the radar echo model of linear insects

As electromagnetic scattering calculation of the linear insects is very complicated, in this paper, the linear insect body is divided into multiple model points according to its structure. The motion equations under different movement forms can be drawn near with first-order Fourier. The linear insects' general movement form echo model constructed by Doppler echo wave equations of model points can be expressed as:

(10)

3. The Radar Echo Model of Tenebrio Molitor Movements

3.1 The body movement forms of tenebrio molitor

The growth cycle of tenebrio molitor, a kind of common linear insect, is divided into four periods as egg, larva, pupa and adult. In the larva period, body of tenebrio molitor is a linear form with 14 sections and a length of 35 ~ 38m, the body joint distribution is apparent and the motion rule is relatively single [12, 13]. This paper builds the echo signal model with the tenebrio molitor in larva period being the detection target. As we know, the link in head and tail in its movement process are intensive, and the movement forms of the two parts are basically the same. So when building the motion model, it can be considered to be an independent model and a method of combining some model points can be adopted because the motion relationship in body is tightness during the movement. Figure 3 shows the distribution of model points of tenebrio molitor.

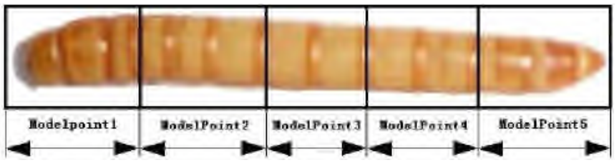

Figure 3. The distribution diagram of model points of tenebrio molitor

The motion process of tenebrio molitor manifests a motion of different frequencies and amplitude of model points. The frequency and amplitude of radar echo of each model point is related to the amplitude and frequency of vibration in the specific movements of insects, which can be measured by actual observation and statistics.

3.2 The model point parameters of tenebrio molitor

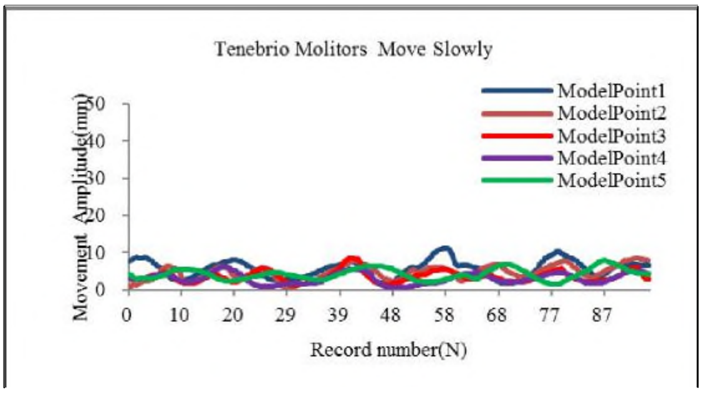

Figure 4. Model point data of gently moving

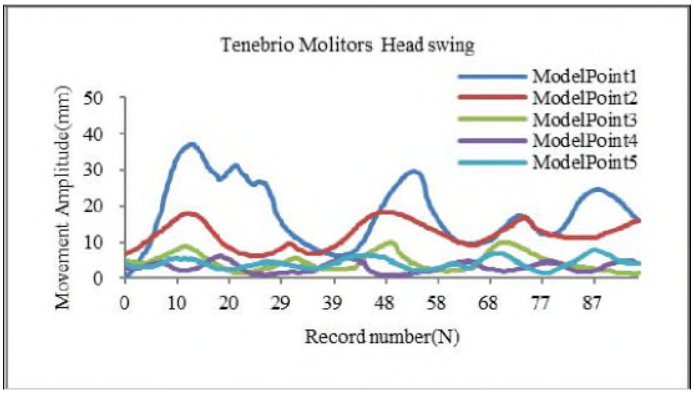

Figure 5. Model point data of swinging head

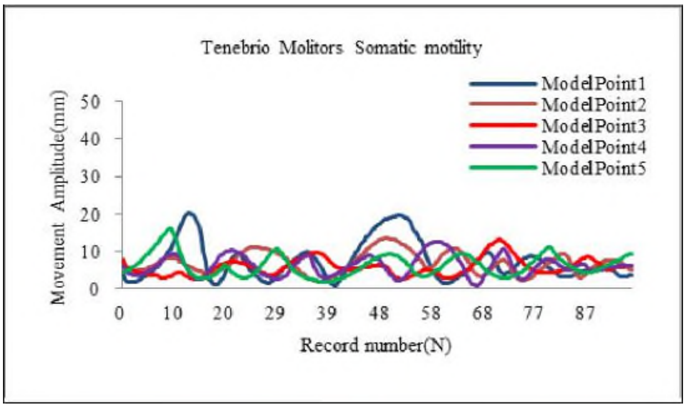

Figure 6. Model point data of creeping up and down

The parameters of model point's vibration characteristics can be obtained by the observation and statistics of experimental samples. In this paper, Legria Hf R46, a high definition camera, is used to record the movements of tenebrio molitor, which are divided into 3 categories according to the movement forms in an hour. After making a statistics of vibration characteristics of each model point in each movement form, the vibration amplitude are fitted, as shown in figures above. Figure 4 shows the vibration amplitude of each model point in gentle moving, from which we can see the amplitude is low and the vibration frequency of each model point, with a certain fundamental frequency, changes in a small range. We can see from Figure 5 that the vibration amplitude of tenebrio molitor in swinging head is general high and the vibration fundamental frequency is lower than gentle moving. Figure 6 shows the vibration characteristics of tenebrio molitor in creeping up and down, from which we can see that the vibration amplitude is low but the fundamental frequency is high. Then we do a first-order Fourier approaching to the data with CFTool in MATLAB, Table 1 shows the results.

Table 1. The movement parameters of each model point in different movement forms of tenebrio molitor

Move State / Model Point	Gently moving				Swinging head				Creeping up and down			
model point 1	5.53	2.526	0.425	1.05	17.4	-9.37	1.113	0.56	7.42	-2.54	-2.63	1.43
model point 2	4.76	-0.12	-1.08	1.44	11.7	-1.44	2.811	0.55	6.84	-1.55	1.252	1.22
model point 3	3.44	-0.74	1.213	1.16	4.48	-1.13	2.038	0.62	5.91	1.198	0.908	1.18
model point 4	3.03	1.019	0.311	1.04	6.21	1.775	-1.14	0.75	6.29	-0.44	-2.63	1.63
model point 5	4.33	-1.26	0.311	1.04	10.1	-5.09	2.045	0.69	6.42	-2.49	-0.61	1.33

3.3 The body movement forms simulation of tenebrio molitor

The radar echo equations in different movement forms of tenebrio molitor are built based on the movement model parameters of each model point which is combined with the insects radar echo model. Figure 7-Figure 9 shows the time-frequency diagrams of body echo obtained by simulating the echo model in different movement forms of tenebrio molitor with time-frequency analysis tools in MATLAB. From Figure 7 we can see that the insect motion is relatively slow in gentle moving, the energy spectrum of echo is low and the frequency is relatively stable with a certain fundamental frequency component. Figure 8 shows the radar echo in swinging head, from which we can see that the echo energy is high with a lower fundamental frequency than gentle moving, and the frequency changes with a certain regularity. Figure 9 shows that of creeping up and down, from which some high-frequency components can be seen apparently, which, with higher fundamental frequency component than the other two movement forms, can be distinguished.

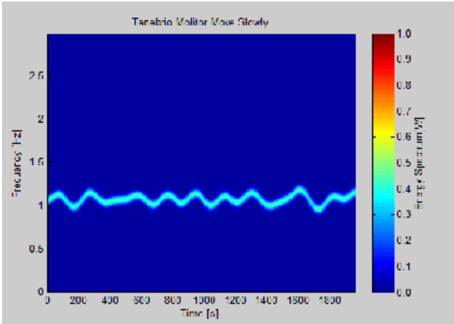

Figure 7. Simulation data of gently moving

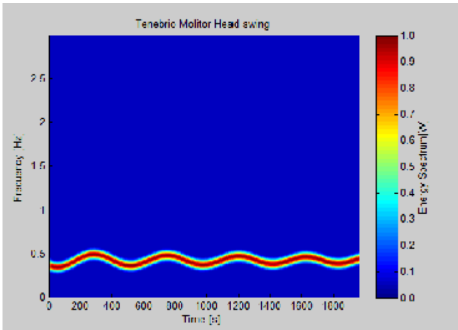

Figure 8. Simulation data of swinging head

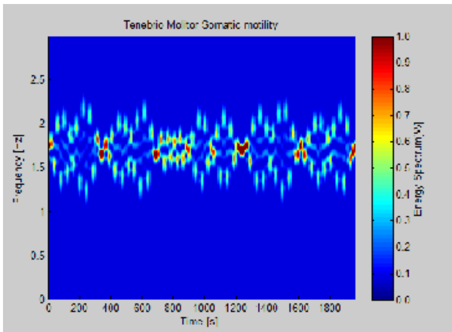

Figure 9. Simulation data of creeping up and down

4. Micro-Doppler Radar Detection of Linear Insects

4.1 Construction of system platform

Doppler detection platform mainly realizes the launching and receiving of microwave radar signals and the extracting and storing of Doppler signals. The system consists of Doppler radar module, ADC, DSP, upper computer data storage and display unit [14, 15], as is shown in Figure 10.

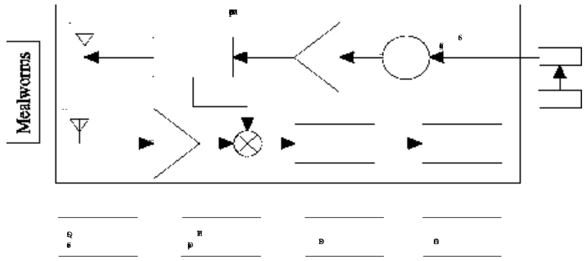

Figure 10. Doppler detection platform system construction

Doppler radar module is mainly designed to accomplish generating the signal with 24.125GHz centre frequency and 20dBm power, receiving the -95dBm signal and extracting Doppler signal. The system signal source can be generated by VCO, and the frequency can be controlled by upper computer .Some of the generated radio frequency signals, after power amplified by PA, are radiated to detection space by RF antenna, while the other are received by mixer. The received signals enter LAN through receiving antenna and the amplified signals enter the mixer to get the Doppler signal by mixing with local oscillator, which is now still mixed with high frequency components, so the baseband signals need to be output after low-pass filter.

The baseband signals can carry the Doppler signal of insect movement characteristics. As the amplitude of which is analog quantity and small, need to be filtered, amplified, turned into digital signals by ADC and then sent to the computer by central processing unit. In the computer, the signals will be processed and displayed and the local storage of data will be realized by SQL Server 2000 [16].

4.2 Detection method of tenebrio molitor’s movement forms

The body of tenebrio molitor, with flexibility and no regularity in motions, is a very complex radar target and hard to control. In the experiment, we adopt a method of recording the insect movement forms by cameras and a synchronized radar data acquisition platform. At the end of the experiment, the timestamps of the tenebrio molitor in different movement forms will be found by the cameras, according to which, the Doppler echo data information corresponding to the movement forms can be found.

The Doppler information of insects is mainly found at the frequency of motion and the energy the echo brings, so the echo data need to be STFT processed before being analyzed to obtain the time-frequency diagrams of Doppler echo and prominent the frequency and energy distribution the echo signals include, which will then be compared with the simulation data [17].

4.3 Data analysis of tenebrio molitor's movement forms

Figure 11 and Figure 12 show the data waveforms of tenebrio molitor in a period of gentle moving and the time-frequency diagram of Doppler signal, and we can see that the energy of Doppler signal in gently moving of linear insects is low and there is no sharp change of frequency. The Doppler frequency generated is mostly from the Doppler frequency generated by parallel translation of tenebrio molitor and the noise of the system, which is in accordance with the model built above.

Figure 13 and Figure 14 show the radar echo data and Doppler signal frequency spectrum in swinging head of tenebrio molitor, from which we can see a high echo energy and a low fundamental frequency, which are also shown in the simulation data.

Figure 15 and Figure 16 show the radar echo data and Doppler signal frequency spectrum in creeping up and down of the tenebrio molitor, from which we can see a relatively high echo energy and fundamental frequency including many high frequency components. These components can be well identified, so we can see that the real data characteristic conforms to the model data.

This paper makes a comparison on simulation and experimental data of Doppler echo of tenebrio molitor under different motion morphology, and it is found that the following three aspects of data characteristics can be utilized to distinguish different motion morphology of tenebrio molitor.

1) The body reflecting surface of tenebrio molitor determines the density of energy spectrum of Doppler echo. Most of Doppler echoes generated when the tenebrio molitor gently moves derive from the oscillation of tenebrio molitor on model point in the vertical radar radial direction, and most of movement processes of tenebrio molitor are horizontal movement along body direction; therefore, only few movements are mapped on model point in the radar radial direction, which results in low density of energy spectrum of radar echo. When tenebrio molitor swings its head and creeps up and down, the radar reflecting surface is whole body swaying, thus there is a high density of energy spectrum of its echo.

2) The fundamental frequency of Doppler echo signal reflects main echo frequency of oscillation at model point of tenebrio molitor. It can be seen from the echo time-frequency spectrum diagram that: when tenebrio molitor creeps up and down, there is a high frequency of oscillation at each model point of its body; this is reflected on large fundamental frequency of Doppler echo signal. Meanwhile, it can be seen from the simulated time-frequency spectrum diagram when the tenebrio molitor swings its head that: the fundamental frequency has certain rule; however, in the experiment process, due to complicated environmental condition, the rule of fundamental frequency is not obvious, but the overall frequency is relatively stable.

3) When the tenebrio molitor moves gently or swings its head, the Doppler echo frequency of its body is relatively stable, and both the simulation data and actually-measured data verify this characteristic. When the tenebrio molitor creeps up and down, the oscillation phase and frequency of its body model is different, which results in complicated echo frequency; this is reflected on large fluctuation of fundamental frequency in time-frequency spectrum.

Both experimental and simulation data show that different motion morphology of tenebrio molitor can be well distinguished according to time-frequency characteristics and density of energy spectrum of Doppler echo of linear insects.

Figure 11. Doppler waveform of gently moving

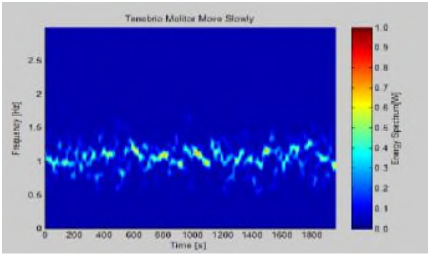

Figure 12. Time-frequency diagram of echo in gently moving

Figure 13. Doppler waveform of swinging head

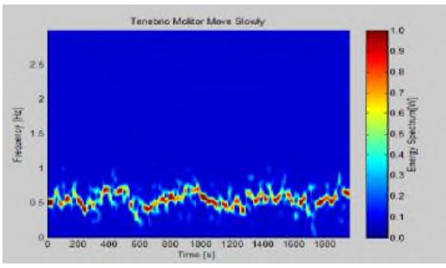

Figure 14. Time-frequency diagram of echo in swinging head

Figure 15. Doppler waveform of creeping up and down

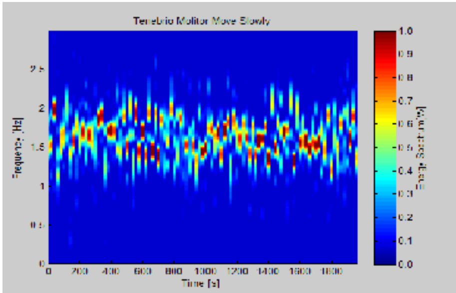

Figure 16. Time-frequency diagram of echo in creeping up and down

5. Conclusion

1) In this paper, the echo model of linear insects movements is built based on Micro-Doppler radar theory and Doppler echo vibration equations of point targets. Also the echo waveforms of tenebrio molitor in different movement forms are obtained by Micro-Doppler signal real-time data acquisition system. The radar echo characteristics of linear insects in different movement forms can be truly reflected by the echo model of linear insects movements built with Micro-Doppler echo of model points, which is obtained by comparing the experimental data with the simulation results of movement model. Using this method, microwave radar echo model of different insects in different motion forms can be built. The studying of movement characteristics which is achieved by analyzing echo data can guide the development of bionic-robot in the future.

2) High-definition cameras and Micro-Doppler radar are used in this paper to synchronously record the movement forms of linear insects. The results show an apparent difference of radar echo time-frequency diagrams in different movement forms, which proves the feasibility of detecting the insects' movement forms with Micro-Doppler radar effect. They also prove that it is feasible to detect the motion forms of hidden insects by Micro-Doppler radar and different motion forms in different times can promote the studying of their movement rules and life habits.

3) This paper also proves the feasibility of detecting the existence of hidden insect pests by Micro-Doppler radar, so it becomes more targeted and scientific to prevent and treat the hidden insect pests.

4) However, the Doppler radar detection also has some deficiencies. Its foundation refers to a variety of science. The simulation data will be different from the real movements if the model is built only with model points. Multi-component signal detection is also a big difficulty as the Micro-Doppler signals of every insect motion are difficult to be isolated accurately. This paper is a preliminary attempt with a follow-up study, and some more sophisticated Micro-Doppler synthesis algorithm and test data will be combined together to further improve the model.

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