ACTIVITY MONITORING AND MOTION CLASSIFICATION OF THE
LIZARD CHAMALEO JACKSONII USING MULTIPLE DOPPLER RADARS

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ABSTRACT

A simple, non contract and efficient tool for monitoring the natural activity of a small lizard (Chamaeleo jacksonii) to yield valuable information about their energy expenditure is presented. The tool allows monitoring in a non-confined laboratory environment and uses multiple Doppler. A classification algorithm is described, which can differentiate between fidgeting and locomotion through processing the quadrature baseband signals from the radars. The results have been verified by experiments using 10 GHz and 24 GHz radars, and indicate that the tool could also be used for automated monitoring of the activities of reptiles and other small animals.
ACKNOWLEDGEMENTS

This thesis would have not been possible without the encouragement, guidance, advice and assistance of several individuals. First, I would like to thank my advisor, Dr. Victor Lubecke for his mentorship and involvement with this thesis. I would like to thank my Graduate Committee members, Dr. Olga Boric Lubecke and Dr Marguerite Bulter for their valuable advice about my thesis. I would like to thank Dr Marguerite Bulter for using her facilities and providing knowledge about activity monitoring. I would like to thank the current and previous members of Dr. Lubecke’s research group for their assistance in lab. Finally, I would like to thank my parents and siblings for their assistance and constant support.
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CHAPTER 1 ACTIVITY MONITORING

1.1 Introduction

Doppler radars have the potential to revolutionize our understanding of how small reptiles (Chamaeleo jacksonii) perform certain motions by providing valuable information about their metabolic activity and energy expenditure. This thesis describes a simple, non-contact, and efficient tool for monitoring the natural activity of a small lizard using multiple radar modules operating in a non-confined laboratory environment. This tool is able to monitor the activity of small lizards using a classification algorithm that can differentiate between fidgeting and locomotion by processing the quadrature baseband signals from the radars. For this reason, we believe that Doppler radars can be used for automated monitoring of the activities of reptiles and other small animals.

1.2 Motivation

Activity monitoring of animals in their natural environment can yield important information about energy expenditure, thermoregulation, behavioral patterns, and even population health [1],[2]. As energetic plays a large role in ecology, behavior, and physiology, accurate methods for activity monitoring are critical for a wide range of animal studies. The standard technique for measuring Field Metabolic Rate is the doubly-labeled water technique which involved injecting animals with radio-labeled water and observing the rate of CO₂ production over several weeks [2]. Because the technique relies on the biological half-life of ¹⁸O, which is long relative to the duration of specific behaviors, it is not possible to measure the cost of specific activities such as foraging, mating, or locomotion. Recent advances in the miniaturization of electrical circuits have allowed measurements of activity using continuous heart-rate monitoring,
but as this technique uses implantable data-loggers, it is limited to animals 1kg or larger [3]. For smaller animals, the only available techniques are visual inspection or video recording. Both are extremely time-consuming, labor-intensive, and require extensive post-experiment effort in recording, transcribing, or analyzing the raw data.

Doppler radar motion sensing can provide a better tool for the automated activity monitoring in animals, as well as the detection of multiple behavioral events in real-time [4]-[6]. However, previous systems used only one Doppler radar and were not capable of classifying different states of activity, such as fidgeting, walking, or running, which differ tremendously in energetic cost and are important to distinguish in studies of activity.

1.3 Background

There are two methods for recording animal motion, which are the Lagrangian approach and the Eulerian approach [6]. The Lagrangian approach monitors and records a specific animal’s movement path, whereas the Eulerian approach monitors a specific location and records all animals’ movements within the confined area. The Eulerian approach is sometimes preferred because it is known to be less invasive, since it requires no capturing of an animal [7, 8]. In addition, it typically doesn’t provide detail information for biologists to conclude their questions on animal behavior. On the other hand, the Lagrangian approach repeatedly records the locations where the animal is moving. Observing the animal’s movements without tagging isn’t practical, therefore the use of sensor technologies are used, for example, radio-telemetry and GPS and Argos satellites [8]. Radio-telemetry was the first technique developed to track free-ranging animals [9], the most common method used based on its costs ($300), by using lightweight transmitters (size >0.2g) [10]. By using this technique, the information is
collected manually and limited to its intensity and scale when collecting samples, which is typically about 50 sample points per day. Satellite tracking can provide global coverage, however it requires large (size >10g) and expensive ($1000) tags and limits the types of animal to be tracked due to the animal’s size. In addition, vegetation can limit the functionality of satellite-based systems. However, these systems contain potential problems in data acquisition and management. In Table 1.1, it shows the different methods for recording animal motion and associated limitations [8].

**Table 1.1: Primary Automated Animal Tracking Methods [8]**

<table>
<thead>
<tr>
<th>Tracking Method</th>
<th>Smallest tags, animal weight</th>
<th>Automated data collection?</th>
<th>Interference by vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional radio telemetry</td>
<td>0.2g, 4g</td>
<td>No</td>
<td>Low</td>
</tr>
<tr>
<td>GPS satellite tracking</td>
<td>10g, 400g</td>
<td>Yes</td>
<td>Medium</td>
</tr>
<tr>
<td>Satellite tracking (ARGOS)</td>
<td>10g, 200g</td>
<td>Yes</td>
<td>High</td>
</tr>
</tbody>
</table>

**1.4 Doppler Radar for Motion Classification**

Continuous wave Doppler radar is a very useful tool for tracking motion and can be used to extract information about an object’s velocity. Quadrature Doppler radar provide two baseband output as in-phase (I) and quadrature phase (Q), that when plotted against each other form an arc of a circle in response to ideal linear motion as showed in Figure 1.1. The amount of arc transcribed is a function of detected motion and the frequency of operation of the radar. For a given displacement $X$, and transmitted frequency $f_2 > f_1$, $X$ would result in a bigger arc for baseband data obtained from $f_2$. In order to better detect signals reflecting off an object with a small radar cross-section, Doppler radars operating at frequencies of 24 GHz and 10.587 GHz have been used.
Two Doppler radars, one each for detecting motion in x-plane and y-plane were employed. With the information received, the target movement can be extracted from the change in frequency of the received signal to the Doppler shift of the moving target.

![IQ Channel Arc Formation](image)

**Figure 1.1. IQ Channel Arc Formation**

**1.5 Objectives**

The objectives are (1) monitoring the natural activity of a chameleon using a simple, non-contact and efficient tool and (2) determine whether or not each motion can be classified. Objective 1 was accomplished by monitoring in a non-confined laboratory environment and uses multiple Doppler radars operating at 10.587 GHz and 24 GHz. In principle, both frequencies were capable of detecting animal activity by changing the threshold value. Objective 2 was accomplished by developing a classification algorithm that can differentiate between fidgeting and locomotion by processing the quadrature baseband signals from the radars.

**CHAPTER 2 MOTION MEASUREMENT SYSTEM**
2.1 Construction of System

2.1.1 Environment Assembly

An environment was created to determine the placement of the radar modules. A given location on the floor was marked as the center (X), which is where the test subject will be located. An area of 46.0 cm x 20.8 cm surrounded the center (X) and was outlined with tape. The area was separated into 2.54 cm increments with tape strips and colored with black ink to easily identify the test subject distance through video reference. Two markers were placed at different locations on the floor and used as indicators for the placement of each radar module. The testing area was located in a closed environment which was surrounded with radiation absorbent materials (RAMs). RAMs are arrays of pyramid shaped pieces designed to stop any sound or electromagnetic waves by absorbing the wave’s energy when the waves are bouncing within the structure. The environment created is shown in Figure 2.1.

![Figure 2.1. Figure showing a schematic of the experimental set-up using two radar modules and mechanical target/linear mover (linear servo with an attached plate)](image)

2.1.2 Test Subjects
The test subjects were used as mechanical target to simulate motions that are commonly found in small reptiles, which are locomotion and fidgeting. Based on the information gathered, observations would be made to create parameters within the motion classification algorithm to distinguish these motions. A total of three test subjects were used.

The first test subject was a p12 linear servo from Firgelli Technologies. This test subject can’t operate nor move without an algorithm. Therefore, three algorithms were created using an Audino complier and then programmed into an Arduino board. The first algorithm was based on locomotion, whereas the second algorithm was based on the motion, fidgeting. The third algorithm was a combination of the two previous algorithms and simulates random motion. The reason behind the third algorithm is that animal movements are unpredictable to anticipate. The three motion patterns are tabulated in Table 2.1. In addition, an acrylic plate covered with aluminum foil was attached to the linear servo, so that a target can be tracked. The linear servo was then attached to metal stand by taping it down.

**Table 2.1: Displacement Values for Linear Mover: (A) Locomotion, (B) Fidgeting, and (C) Random**

<table>
<thead>
<tr>
<th>LOCOMOTION</th>
<th>MOTION PATTERN</th>
<th>DISTANCE</th>
<th>D. TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>START POINT</td>
<td>0 CM</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td></td>
<td>8SEC</td>
</tr>
<tr>
<td>FORWARD</td>
<td>2 CM</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td></td>
<td>3SEC</td>
</tr>
<tr>
<td>BACKWARD</td>
<td>2CM</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td></td>
<td>3SEC</td>
</tr>
<tr>
<td>REPEAT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(A)
## LOCOMOTION MOTION PATTERN

<table>
<thead>
<tr>
<th>FIDGETING</th>
<th>MOTION PATTERN</th>
<th>DISTANCE</th>
<th>D. TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>START POINT</td>
<td>0 CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>4SEC</td>
<td></td>
</tr>
<tr>
<td>FORWARD</td>
<td>0.5 CM</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>8SEC</td>
<td></td>
</tr>
<tr>
<td>BACKWARD</td>
<td>0.5 CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>3SEC</td>
<td></td>
</tr>
<tr>
<td>REPEAT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## FIDGETING MOTION PATTERN

<table>
<thead>
<tr>
<th>RANDOM</th>
<th>MOTION PATTERN</th>
<th>DISTANCE</th>
<th>D. TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>START POINT</td>
<td>0 CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>4SEC</td>
<td></td>
</tr>
<tr>
<td>FORWARD</td>
<td>0.25 CM</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>4SEC</td>
<td></td>
</tr>
<tr>
<td>BACKWARD</td>
<td>0.25 CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>4SEC</td>
<td></td>
</tr>
<tr>
<td>FORWARD</td>
<td>1.5 CM</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>10SEC</td>
<td></td>
</tr>
<tr>
<td>FORWARD</td>
<td>0.45 CM</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>4SEC</td>
<td></td>
</tr>
<tr>
<td>BACKWARD</td>
<td>2.0 CM</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>DELAY</td>
<td>-</td>
<td>8SEC</td>
<td></td>
</tr>
<tr>
<td>REPEAT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The second test subject was a Shelby Series 1 toy car from NewRay. This test subject was able to perform multidirectional motion pattern at various speeds and was controlled with a stopwatch remote control. The motions, locomotion and fidgeting, were also performed using the toy car. However, an indicator was placed on the ground to classify these two motions. If the car traveled past the indicator, the motion was considered locomotion and vice versa it was fidgeting.

The third test subject was a chameleon borrowed from Dr. Marguerite, a professor from the zoology department. The gender of the chameleon tested was a male. Each of these test subjects were placed in the center (X) between the two radar modules.

Figure 2.2: Test Subjects for Each Experiment: (1) Linear Servo, (2) Toy Car, (3) Chameleon
2.1.3 Radar Mounts Construction

For the experimental setup, 24 GHz radar modules from RFbeam were used. Mounts were created to secure the radar modules in place, since its physical structure was small and thin. A sheet of cardboard (10in x 10in) was used to create the radar mounts. Lines were drawn on the cardboard sheet using a sharpie to create four rectangular pieces, which represent the front (6in x 6in), side (1in x 6in), and the base (6in x 1in) panel of the mount. The cardboard sheet was cut and divided into four pieces. For the front panel, the center was located to create an area to place the radar module. From the center, an area of 25mm x 25mm was drawn and cut out with a razor blade. Tape was placed into the hollow area to provide strength in holding the radar module in place. The four cardboard pieces were then combined together with tape.

Additional mounts were created for the new radar mounts brought from Microwave Solutions. These radar modules operated at 10.587 GHz and contained no pin headers. An array of pins was broken into a pin array of four pins. The pin array was then soldered on the radar module with a soldering iron. The design of the mounts was the same as the one used for the 24 GHz radars. However, the cutting of the hollow area wasn’t required for the front panel because the radar module had plastic screws for mounting. The location of each plastic screw was measured with a ruler and marked on the front panel of the mount. A sharpened edge was used to puncture through the cardboard to create a hole for each plastic screw. The radar module was placed into the four holes and secured on with plastic nuts. The four cardboard pieces were then combined with tape.
2.1.4 Data Acquisition Algorithm

The data acquisition algorithm was used to collect the baseband outputs of each radar modules in real time. In Figure 2.4, it shows the GUI layout of the data acquisition algorithm using MATLAB ©.

2.1.4.1 Data Acquisition Assembly

The algorithm assembly began by typing the command “guide” into MATLAB. A window would be shown containing two options: create a new GUI layout or open an existing GUI layout. The option to create a new GUI layout was selected. A window was opened containing an empty grid layout and various components used to create structures on the layout. For the initial step, a design was developed to determine what structures were needed to be build and where would these structures be located on the layout. The design was divided into four sections. In the first section, structures for importing information were built using the label component, textbox component, and a push button component. First, the textbox was placed into the layout along with the label and push button and combined together without overlap. The structure was duplicated to provide six structures. However, the push button was deleted for one structure. The six
structures were aligned together and named as follow: “Sampling Rate”, “Numbers of Channels”, “Stop Time”, “Wait Time”, “File Name”, and “DAQ ID #”. In the second section, a structure for displaying error messages was built using a panel component and list box component. The panel was placed into the layout and extends to provide space for the list box. Within the panel, the list box was placed and expanded to fill the entire area. In the third section, structures for controlling the information were built using a panel component and various button components. A total of four structures were created and named as follow: “Control Panel”, “Channels”, “Save File/Run Clock”, and “Acquisition Type”. Each structure was created by placing a panel into the layout and expanding it to provide space for the placement of buttons. The structure called “Control Panel” is a panel containing three push buttons (start, stop, and reset) used to control the data acquisition. The structure called “Channels” is a panel containing eight checkboxes indicating each channel name the DAQ outputs. The structure called “Save File/Run Clock” is a panel containing two options to save the file and run a clock during the experiment. The structure called “Acquisition Type” is a panel containing a toggle button to allow the user to select the mode the user wants to run. In the four sections, structures for display information were built using two empty plots. The plots were used to display the raw information from each baseband outputs of each radar module and the IQ Plots. When all structures were created, the structures were aligned as shown in Figure 2.4.
2.1.4.2 Procedure

For the data acquisition algorithm to work, a DAQ is required. When the DAQ is inserted correctly, the algorithm would first locate the port where the DAQ is connected and determine the DAQ type. Next, the five parameters (sampling rate, numbers of channels, stop time, wait time, and file name) were declared by entering a number or name into the given textbox and pushing the corresponding button. If one or more aren’t entered correctly, an error message would be shown with a possible solution to the given problem. When the parameters are entered correctly, the control panel buttons are activated. The buttons are run, stop, and reset. Before running the algorithm, the user has an option to run a clock, save the information, and choose an acquisition type. When the user selects the clock button, a window would display the runtime and cover the entire monitor screen. When the run button is selected, two graphs would be shown, one showing raw information produce by the baseband outputs of each radar module and the
other showing the IQ plots. The graphs shown are color-coded and are distinguish based on the channel selected. When the algorithm is done, an array containing the baseband outputs of each radar module is created.

### 2.1.5 Setting Up for Recording

For each experiment, the equipments used were four Low-to Noise Amplifiers (LNAs), NI-DAQ, power supply, laptop, camera, and connectors (includes alligator clips and coaxial cables). First, the environment shown in Figure 1 was created. The cardboard mounts were placed on the marked location on the floor and taped for stability. As shown in Figure 2.5, the cardboard mounts are faced perpendicular to each other and placed straight facing the marked location ($X$) of the test subject. The radar modules were placed into the hollow area of the mounts and a test subject was placed at $X$. Each radar module was connected with a ribbon cable and each strand was given a label indicating the pin output. Two LNAs were stacked on top of each other and placed behind each cardboard mounts for easy access to connect cables. For one stack, a power supply was placed on top and connected two alligator clips to the red node (5V) and black node (0V or ground). The power supply was set to 5V and was check with a multimeter. A camera was placed on the floor for recording a video and a laptop was placed in a free zone from the testing environment. The laptop was used for data acquisition. The ribbon cable was separated into individual strands and stripped with a wire cutter to connect alligator clips and coaxial cables. Cables and clips were attached to expose wires by following the pin outputs of the 24GHz radar module. Pin 1 and 3 were baseband outputs and connected with coaxial cable with pin headers, the red pin went to the baseband output while the black pin went to ground of the power supply. Pin
2 and 4 were connected with alligator clips and leaded to the power supply. The ends of each coaxial cable were connected to the input node of a single LNA. The LNAs was set to given parameters for baseband signal conditioning. For experiment 1 and 2 was a cutoff frequency ranging 0.03Hz to 1 kHz, a gain of 200, AC coupling, and produce a bandpass filter. For experiment 3, the cutoff frequency was changed from the previous experiments and ranged from 0.03Hz to 300 Hz. Each of the LNA’s output nodes where fed through a NI-DAQ for data acquisition. A USB cord was connected to the DAQ and fed into the USB port of the laptop. A LED was placed into breadboard and was programmed to turn on when the data acquisition is running. A maintenance check was performed to find any crossing wires or bad connectors and checks if all LNA’s settings were identical. Lastly, all equipments were turned on. In Figure 2.6, it shows the overview of how the system was assembly.

Figure 2.5: Placements of Radar Module Mounts
2.1.6 Testing

2.1.6.1 Experiment 1: Linear Mover

In experiment 1, the linear mover was the test subject. The linear mover was programmed with three algorithms to perform the motions, locomotion, fidgeting, and random. For each experiment, the linear mover moved forward and backward with a distance ranging from 0.5 to 2 cm for 30 sec. The linear servo was placed at four locations within the enclosed environment to see any variations in the baseband outputs for each radar module. In the first experiment, the linear servo was placed at location $X$ and facing toward the front radar. In the second experiment, the linear servo was placed 23.16 cm away and facing toward the side radar. In the third experiment, the linear servo was placed at location $X$ and faced 45 degrees toward both radar modules. In the fourth
experiment, the linear servo was placed at location $X$ and faced 45 degrees away from both radar modules. The same procedure was done on the liner servo using the fidgeting algorithm.

### 2.1.6.2 Experiment 2: Toy Car

In experiment 2, the toy car was the test subject. The experiment was conducted by turning all equipments and running the data acquisition, a five minute delay time was set to walk out of the enclosed environment. When the data acquisition began, the toy car was controlled using a stopwatch remote control to perform locomotion and fidgeting. To perform locomotion, the toy car had to travel a distance ranging from 0.5 cm to 2 cm. For fidgeting, the toy car had to travel a distance of 0.5 cm or less. A total of 7 experiments were conducted on the toy car: four experiments relating to locomotion, two experiments relating to fidgeting, and one experiment combining both motions. In the first experiment, the toy car was placed at location $X$ and moved forward once toward the front radar module. In the second experiment, the toy car was placed at location $X$ and moved backward once away from the front radar module. In the third experiment, the car was placed at location $X$ and followed the motion pattern tabulated in Table 2.3. In the fourth experiment, the toy car was placed 45 degree to the right of location $X$ and performed five motions that are tabulated in Table 2.4. The experiments from 1 to 4 were locomotion.

#### Table 2.2: Motion Pattern for Experiment 3 and 5 (Toy Car)

<table>
<thead>
<tr>
<th>Motion Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backward</td>
</tr>
<tr>
<td>Forward</td>
</tr>
<tr>
<td>Backward</td>
</tr>
</tbody>
</table>
Table 2.3: Motion Pattern for Experiment 4 and 6 (Toy Car)

<table>
<thead>
<tr>
<th>Motion Pattern</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td></td>
</tr>
<tr>
<td>Forward</td>
<td></td>
</tr>
<tr>
<td>Backward</td>
<td></td>
</tr>
</tbody>
</table>

In the fifth experiment, it was the same as the third experiment however the distance traveled was shorter. In the sixth experiment, it was the same as the fourth experiment however the distance traveled was shorter. The experiments 5 and 6 were fidgeting. For the seven experiments, locomotion and fidgeting was both combined by having the toy car performing locomotion (distance >2cm) first and then fidgeting (distance <0.5cm) second. This motion pattern was repeated to perform a total of 6 motions. All experiments were done in the anechoic chamber in the bio-sensing lab and each had a runtime of 20 sec.

2.1.6.3 Experiment 3: Chameleon

In the third experiment, tests were performed with Chameleo jacksonii. The radars were set in similar configuration to Figure 5 but 10.587 GHz radar modules were used and a metal stand was used to hold a small branch on which the chameleon was let loose. The location of the experiment was at the fifth floor of Edmondson Hall at University of Hawaii at Manoa. The experiments were performed under natural light in the morning in a closed room. The sampling rate for the radar data acquisition was set to 100Hz. The photograph of the setup is shown in Figure 2.7. Measurements were made for 30 minutes. A standard digital camera was used to record (640 X 480) as reference. From inspection of the video, a table was created indicating the type of motion with time.
These reference values were then compared with the radar data analysis.

Figure 2.7: Photograph Showing the Set-Up for Monitoring Chameleon Activity
CHAPTER 3 MOTION CLASSIFICATION ALGORITHM

3.1 Introduction

Figure 3.1: Motion Classification Algorithm GUI Layout

Figure 3.1 shows the layout of the motion classification algorithm using the GUI layout editor in MATLAB. The algorithm was created to analyze the raw information and distinguish the motion pattern being performed. Two motion patterns were set in the algorithm, which were locomotion and fidgeting. A video reference was added as a checking parameter to verify whether the motion pattern matched up with the video recording. The GUI layout consists of various button, which works together to observe and analyze the imported information.

3.2 Algorithm Assembly

The algorithm assembly began by typing the command “guide” into MATLAB. A window would be shown containing two options: create a new GUI layout or open an existing GUI layout. The option to create a new GUI layout was selected. A window
was opened containing an empty grid layout and various components used to create structures on the layout. For the initial step, a design was developed to determine what structures were needed to be build and where would these structures be located on the layout. The design was divided into four sections. In the first section, structures for importing information were built using the panel component, two push button components, and a list box component. First, the panel was placed into the layout and extended to provide space for the other components. Within the panel, the two push buttons were placed next to each other while the list box was placed below the two push buttons. When the structure was constructed, the structure was duplicated to provide three structures. The three structures were aligned together and named as follow: “Add Lizard Video Files”, “Add Lizard Video Frames”, and “Add Lizard Data Files”. In the second section, structures for collecting and analyzing information and controlling video were built using the panel component and various push button components. A total of three structures were created and named as follow: “Lizard Control Panel”, “Lizard Video & Graph Control Panel”, and “Plot/Save”. Each structure was created by placing a panel into the layout and expanding it to provide space for the placement of push buttons. The structure called “Lizard Control Panel” was a panel that contains buttons for importing and analyzing the information (video reference and data produced by each radar module). The structure called “Lizard Video & Graph Control Panel” was a panel for controlling the video reference. The structure called “Plot/Save” was a panel containing buttons to display and save the IQ plots, motion pattern, and rotation pattern. In the third section, it contains empty plots used to display the motion pattern, rotation pattern, and IQ plots. A total of seven empty plots were placed into the layout. In the
fourth section, it contains an empty plot used to display the video. All four sections were combined together and aligned as shown in Figure 3.1.

3.3 Procedure

To activate the GUI, a video must be added by selecting the button, “Add Video File”. A window would be shown to allow the user to locate the path of the video file. Only AVI format video can be inserted into this GUI because MATLAB can only read AVI format videos. Therefore, the video must be converted if written in a different format. The video converter used was Window Movie Maker ©. When the video file is selected, the following button called “Import Video File” is enabled. In this process, the video get separated into individual frames and then converted into snapshots. The snapshots are labeled with numbers, which will later serve as indicators (in term of time) when placed in the video player. Next, the video frames must be added by selecting the button, “Add Video Frames”. When the video frames are added, the following button called “Import Video Frame” is enabled. In this process, it would count the number for frames inserted and placed the first frame selected into the video player, which is an empty plot. In addition, the status bar on the bottom of the video player would change by listing the amount of frames inserted and the number of the current frame showed in the video player. When the video frame is imported, the data file can be added by selecting “Add Data Files”. The data file will be analyzed using the concepts in Section 3.3. When the data is analyzed, the user can observe the result produce by the motion classification algorithm by selecting the buttons listed in “Plot/Save”. The results would be plotted into the empty plots. When the plots are display, the user can save the plot. The plots would be resized and can be saved in any format. When all plots are displayed,
the video player buttons are enabled, this provide users a visual on what is happening as shown in the motion pattern plots. When the experiment is complete, the user can export the information computed by the classification algorithm or reset the GUI to analyze a new experiment.

3.4 Methods

Figure 3.2: Classification Algorithm Used for Each Radar to Characterize Motion

Figure 3.2 shows the block diagram of how the algorithm characterizes motion for each radar module. The motion classification begins by using eigenvalue demodulation, which is where each baseband output is multiplied by an eigenvalue. An eigenvalue is a set of number created by multiplying a scalar factor to the eigenvector, which is a square
matrix containing non-zero vectors. In the following mathematical expression, it shows how the eigenvalues are formed.

\[ A \cdot v = \lambda \cdot v, \quad (1) \]

where \( A \) is a square matrix, \( v \) is an eigenvector, and \( \lambda \) is a scaling factor.

The information produced by eigenvalue demodulation is plotted and observed. From the plot, it shows the motion pattern in terms of time and amplitude. As a target move, a change in the amplitude of the baseband signal would occur and indicate as non-sedentary motion as shown in Figure 3.3.

![Eigenvalue Pattern](image)

**Figure 3.3. Eigenvalue Plot**

Before the information is passed through to the next step, the local maxima and minima are found by sampling 20 data points. During sampling, this process can lead to inaccurate measurements due to underestimating and overestimating the maximum and minimum points. Therefore, a rechecking process is used to verify each maximum and minimum point is accurate. A list of time intervals will be showed in Figure 3.4 containing activity and no movement. Before the activity periods are passed, a threshold is set. For each activity periods, the maximum and minimum amplitudes are subtracted to get a value. Not all values are considered as motion; therefore the algorithm would
eliminate the values that are less than the given threshold. The threshold value is changed for each test subject. For the remaining values, the amplitudes are converted to their corresponding time and tabulated in a table. In the table, it contains two columns which display the approximate starting and ending times. This eigenvalue demodulation was performed on both radars to see the target’s path within the enclosed environment.

During the observation, the information was dominated to the radar the target was facing if it moving in a straight path. If the target is placed at an angle toward and away from both radar modules, the information gathered in both modules would be identical. For the algorithm to conclude the right time pattern, the starting time of each radar module are compared and used the one of the following conditions.

Condition 1: If the time pattern (side) is greater than the time pattern (front), one motion pattern would be shown using the front time pattern.

Condition 2: If the time pattern (front) is greater than the time pattern (side), one motion pattern would be shown using the side time pattern.

Condition 3: If the difference between the front time pattern and side time pattern is less than 10 sec, two motion patterns would be shown using the time pattern following Condition 1 or Condition 2.
The time pattern is used as an index to locate the corresponding baseband outputs. The baseband outputs of each radar module are combined into a complex equation as shown in the following equation.

\[ c = I \ast (j \ast Q), \] (2)

where \( I \) is the in-phase channel and \( Q \) is the quadrature channel.

When the baseband outputs are combined, the motions would result in the formation of an arc in the I-Q plane. From the arc rotation, the motion direction can be classified. If the arc is rotating in the clockwise (CW) direction, the motion would be classified as moving away from the radar. On the other hand, if the arc is rotating in the counterclockwise (CCW) direction, the motion would be classified as moving toward the radar. The length of the arc is a good indication of the amount of motion. For a transmitted signal of 24 GHz (\( \text{lambda}=1.25 \text{ cm} \)), a movement of approximately 0.6125 cm should result in a complete circle. By counting the number of circles of closed loops in the I-Q plane, it is possible to quantify motion as fidgeting and locomotion. To determine the amount of circle, the phase angles were calculated using MATLAB©, however to obtain the correct phase values, the IQ plots were conditioned to be centered at the origin. After the phase angles were calculated, the algorithm would determine the numbers of rotation by counting how many times it passed the initial value of each circular pattern. For motion classification, the numbers of rotation were used. If the rotation is 2 or greater, it is classified as locomotion. On the other hand, rotation less than 2 is classified as fidgeting. For the 10.587 GHz radars, locomotion is classified as \( \geq 1 \) or more rotation, whereas fidgeting is classified as less than 1 rotation.
3.5 Results

The results are showed and plotted into the empty plots within the motion classification algorithm. The empty plots are shown in the right of Figure 3.1. The two plots located at the top would display the IQ plots of the front and side radar modules. The two plots located at the middle would display the motion pattern observed by the front and side radar modules. The two plots located at the bottom would display the rotation pattern observed by the front and side radar modules. The plots are displayed and saved by using the buttons stored within the panel called “Plot/Save”.

3.6 Synchronized Video Reference with Data

The video reference was controlled using various buttons stored in the video control panel. The buttons are play, stop, fast forward, rewind, and jump. When the video is playing, each snapshots imported would be shown in the empty plot as time change. The jump button was created to allow users to jump to a certain frame to see what motion was being performed as shown in the motion pattern.

3.7 Data Storage

After the completion of analyzing the raw information, a table is created for each radar module containing the starting time, ending time, motion direction, and amount of rotations. The user has an option to save the results by selecting the button called “Export”. This button would copy the information and store it into a spreadsheet in Excel.
CHAPTER 4 MOTION MONITORING EXPERIMENTS AND ANALYSIS

The plots showed below are results from each experiment using the motion classification algorithm. In each experiment, locomotion and fidgeting were performed and placed at different locations on the floor to see any variation in the baseband outputs. The plots showed are the motion pattern and the rotation pattern. The motion pattern shows the approximate time period when the target is performing motion and not. The rotation pattern shows whether the motion pattern was performing locomotion or fidgeting based on the number of rotations. Along with these plots, a table is shown which provide important information that was used to classify the two motions. The information stored was the time pattern, motion direction, and rotation counts.

4.1 Experiments

4.1.1 Linear Mover Design

4.1.1.1 Locomotion
Figure 4.1: Plots Showing Motion Detection Using Eigen Vector and Classification Using Angle Estimation and Rotation Count for Locomotion in Front Radar

4.1.1.2 Fidgeting
Figure 4.2: Plots Showing Motion Detection Using Eigen Vector and Classification Using Angle Estimation and Rotation Count for Fidgeting in Front Radar

4.1.1.3 Locomotion at 45°
Figure 4.3: Plots Showing Motion Detection Using Eigen Vector and Classification Using Angle Estimation and Rotation Count for Locomotion at an Angle of Approximately 45° in Front Radar
4.1.2 Linear Mover Measurement Results & Discussion

In Figure 4.1, it shows the linear servo performing locomotion in front of the front radar module. Two or more complete rotations were classified as locomotion. For 24 GHz, a motion of approximately 1.2cm should result in two rotations. From Table 4.1, we can observe four to five rotations in each time segment where motion was detected.
One graph is shown because the algorithm assumed that one of the radar modules was dominate in receiving more motion signals compared to the other module. Based on the assumption, the algorithm concludes that the radar was the front module. The plot is distinguish by two different colors, red and blue. The red line is the motion pattern, which was determined by the eigenvalue demodulation. The blue line is the rotation pattern, which classify the motion type based on the number of rotation counts. Along with motion and rotation pattern, individual IQ plots are shown for each motion performed. Each IQ plots were produce by using the time segments when both the blue and red lines are changing amplitude or performing motion. In the motion pattern, amplitude of 1 is classified as motion. On the other hand, amplitude of 0 is classified as no motion. For the rotation pattern, amplitude of 2 is classified as moving forward and amplitude of -2 is moving backward.

After testing for locomotion, the linear mover was placed facing straight towards the front radar to simulate fidgeting or swaying the body. The resulting analysis is shown in Figure 4.2. As can be seen in Table 4.2, there are less than 2 complete rotations transcribed. One graph is shown because the algorithm assumed that one of the radar modules was dominate in receiving more motion signals compared to the other module. Based on the assumption, the algorithm concludes that the radar was the front module. The color specification and parameters of amplitude are the same as locomotion. In the motion pattern, amplitude of 1 is classified as motion. On the other hand, amplitude of 0 is classified as no motion. For the rotation pattern, amplitude of 1 is classified as fidgeting forward and amplitude of -1 is fidgeting backward.
Another important aspect to be considered for this system is to observe is the effect of motion at an angle towards both the radars. In such a situation, the motion content along their respective axes will be seen by the front and side radar. However, the motion content seen will be a function of the target’s angle to both radars and it shape that will determine the effective cross-section presented to the radars. In order to observe the effect of such a motion, the linear mover was moved with locomotion pattern at approximately 45 degrees to both radars. The results are shown in Figure 4.3. For motion classification, a value of 1 corresponds to fidgeting and a value of 2 corresponds to locomotion. The motion pattern detected from changes in eigenvector was the same in both radars. Due to the position of the plate, the motion component detected by the front radar is less for I and IV and hence it detects the motion as fidgeting. As the plate moves closer to II and III, more motion content is visible to the front radar and hence it can detect locomotion. However, information from front and side radars can be analyzed to classify motion in board terms of energy expenditure.

Table 4.1: Linear Mover Performing Locomotion Results

<table>
<thead>
<tr>
<th>Motion Title</th>
<th>Radar Location</th>
<th>Start Time</th>
<th>End Time</th>
<th>Direction</th>
<th>Rotation Count</th>
</tr>
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<tbody>
<tr>
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</table>

Table 4.2: Linear Mover Performing Fidgeting Results

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<thead>
<tr>
<th>Motion Title</th>
<th>Radar Location</th>
<th>Start Time</th>
<th>End Time</th>
<th>Direction</th>
<th>Rotation Count</th>
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<td>22349</td>
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</table>
Table 4.3: Linear Mover Performing Locomotion at 45° Results

<table>
<thead>
<tr>
<th>Motion Title</th>
<th>Radar Location</th>
<th>Start Time</th>
<th>End Time</th>
<th>Direction</th>
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<td>21770</td>
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</table>

4.1.3 Toy Car

4.1.3.1 Locomotion & Fidgeting at 45°

![Time Segment I](image1.png)

![Time Segment II](image2.png)

![Time Segment III](image3.png)

![Time Segment IV](image4.png)
Figure 4.5: Plots Showing Motion Detection Using Eigen Vector and Classification Using Angle Estimation and Rotation Count for Locomotion & Fidgeting at an Angle of Approximately 45° in Front Radar
4.1.4 Toy Car Measurement Results & Discussion

The toy car experiments were performed to determine whether or not the motion classification algorithm can distinguish the difference when both motions (locomotion & fidgeting) are being performed one after the other. For this experiment, the toy car was placed at an angle of 45° away from both radars and performed six motions. From the results shown in Table 4.4, the motion classification algorithm determine that the motion performed by the toy car was between both radars, since both radar’s information were listed in the table. However, the target location was placed at an angle and performing motion close to the front radar since the rotation count in the front radar is greater than the side radar. In the front radar, we can observe three to four rotations in each time segment where motion was detected. On the other hand, two to three rotations were seen in the side radar in each time segment.
Table 4.4: Toy Car Performing Fidgeting & Locomotion at 45° Results

<table>
<thead>
<tr>
<th>Motion Title</th>
<th>Radar Location</th>
<th>Start Time</th>
<th>End Time</th>
<th>Direction</th>
<th>Rotation Count</th>
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</table>

4.2 Live Animal Experiments

4.2.1 Chameleon Figures

Figure 4.7: Raw Data From Front and Side Radar Showing Changes in Amplitude due to Motion.
Figure 4.8: Result of the Detection Algorithm for Front and Side Radar
4.2.2 Chameleon Results & Discussion

In Figure 4.7, it shows the raw data from the front and side radar showing the changes in amplitude due to motion. The raw data produced by the front radar was offset by 1 for clarity. The raw data are classified as lines with different colors. The red and blue lines are baseband outputs of the front radar. On the other hand, the green and purple lines are the baseband outputs of the side radar. Based on Figure 4.7, we can see some motion occurring from 0 sec to 45 sec; however, we can’t conclude the motion for the remaining time period. Therefore, the motion classification algorithm was performed to analyze the raw data and shown in Figure 4.8. The classification algorithm determines the motion as fidgeting, since both radars had a rotation count of less than 2. From 0 to 45 sec, the chameleon was swaying the body and some form of fidgeting at 75 to 79 sec, 165 to 170 sec, and 190 to 195 sec. These results shown was verified with a video reference and proved accurate at these times when the chameleon was moving. From this
short experiment for 5 sec, the motion classification algorithm was able to distinguish the variation in body movement and walking path. Therefore, longer experiments were conducted to see whether the algorithm can retain and store massive information being captured by the chameleon movements. In Figure 4.10, it shows the motion pattern of the chameleon moving under an experiment for 30 min. In this figure, the blue line represents motion being captured by the front radar module, whereas the red line represents motion captured by the side radar module. From the data showed, the chameleon moved for 5 min straight and stops to rest for the remainder of the experiment. At the resting point, the chameleon performed some fidgeting movements, which were indicated as tick marks (change in amplitude of 1 or -1) at 11 to 15 min on Figure 4.10(a). In Table C.5 and Table C.6, it contains the time interval the target is moving, the direction, and the distance traveled. Since both motion patterns are hard to distinguish, the motion patterns are combined to determine the exact motion pattern based on the logic shown in Table 4.5. After the combination of the radar data, a single output classifying the chameleon motion pattern is color-coded in Figure 4.10 (c).
Figure 4.10: Chameleon Experiment for 30 Minutes using 10.587 GHz Radar Modules (A) Information from Both Radars, (B) Combined Information, (C) Motion Classify, (D) Pie Chart for (C)

Based on the chameleon motion pattern in Table 10.3(c), the chameleon was inactive 90% of the time during the 30 minute experiment, while performing locomotion for 3% and fidgeting for 7%. Using pie charts can give a better indication on when the chameleon is performing for a researcher or even a new user.
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this experiment, the motion activity of a chameleon was performed using Doppler radars. A motion classification algorithm was written to distinguish the two motions commonly performed by small reptiles, which are locomotion and fidgeting. To simulate these motions, mechanical targets were used to mimic these motions and observe with Doppler radars to make conditions for the classification algorithm. Chameleons and other reptiles require natural light, since they are cold-blooded and do barely any activities without light. During the experiment, a natural habitat was created for the chameleon to move and noticed that chameleon loves to climb to the highest point and stay at that location. Different locations were tested for each motion performed to notice any variations in the baseband output for each radar module. If a moving target was located in front of one radar module, the baseband output would capture more signals compared to the other radar. If the moving target was placed at 45 degrees between both radars, the time pattern would be identical. If the moving target was placed 45 degrees away from both radar, the time pattern would be identical however the rotation counts would only count half of the given motion performed. This is because the target might have been out of the range between the two radar modules to detect. In conclusion, the motion classification algorithm works.

5.2 Recommendations

The motion classification algorithm was able to distinguish the motions we were set to accomplish, which were locomotion and fidgeting. However, fidgeting can be classified as various motions performed by a small reptile, for example, tail wag, head
movement, etc. These motions might have been performing up and down and not orthogonal to either radar. Therefore, further experiments can be done by integrating a three-radar module into the setup; this would give a three-dimensional perspective of how a target performs a given motion. In addition, this would give more information to classify the motions of fidgeting individually. More experiments would have to be accomplished to see the variation when adding a new radar module to the setup and change the conditions in the algorithm. By advancing the system for three-dimensional, other animals can be tested for activity monitoring like humans or larger animals. Another decision step could be added in future where an algorithm will combine the two decisions of both radars to yield a single plot specifying the nature of activity.
Appendix A
Motion Pattern Plots
Experiment 1: Linear Mover (Locomotion, 10.587GHz)

(A) Motion Pattern (Locomotion, Front, 10.587GHz)

(B) Motion Pattern (Locomotion, Side, 10.587GHz)
Figure A.1: Linear Mover Performing Locomotion Motion Pattern for each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away from Both Radar Modules at 45°
Experiment 2: Linear Mover (Fidgeting, 10.587GHz)

(A)

Motion Pattern (Fidgeting, Front, 10.587GHz)

(B)

Motion Pattern (Fidgeting, Side, 10.587GHz)
Figure A.2: Linear Mover Performing Fidgeting Motion Pattern for each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away from Both Radar Modules at 45°
Experiment 3: Linear Mover (Locomotion, 24GHz)

![Motion Pattern (Locomotion, Front, 24GHz)](image)

- Information from Front Radar
- Information from Side Radar

(A)

![Motion Pattern (Locomotion, Side, 24GHz)](image)

- Information from Side Radar

(B)
Figure A.3: Linear Mover Performing Locomotion Motion Pattern for each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away from Both Radar Modules at 45°
Experiment 4: Linear Mover (Fidgeting, 24 GHz)

![Motion Pattern (Fidgeting, Front, 24 GHz)](image1)

(A)

![Motion Pattern (Fidgeting, Side, 24 GHz)](image2)

(B)
Figure A.4: Linear Mover Performing Fidgeting Motion Pattern for each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away from Both Radar Modules at 45°
Appendix B
Rotation Pattern Plots
Experiment 1: Linear Mover (Locomotion, 24 GHz)

(A)

(B)
Figure B.1: Linear Mover Performing Locomotion Rotation Pattern for Each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away Both Radar Modules at 45°.
Experiment 2: Linear Mover (Fidgeting, 24 GHz)

(A)

(B)
Figure B.2: Linear Mover Performing Fidgeting Rotation Pattern for Each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away Both Radar Modules at 45°
Experiment 3: Linear Mover (Locomotion, 10.587 GHz)

(A)

(B)
Figure B.3: Linear Mover Performing Locomotion Rotation Pattern for Each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at $45^\circ$, and (d) Place Away Both Radar Modules at $45^\circ$
Experiment 4: Linear Mover (Fidgeting, 10.587 GHz)

(A)

(B)
Figure B.4: Linear Mover Performing Fidgeting Rotation Pattern for Each Experiment (a) Place in Front of Front Radar Module, (b) Place in Front of Side Radar Module, (c) Place Toward Both Radar Modules at 45°, and (d) Place Away Both Radar Modules at 45°
Appendix C
Results Produced by the Motion Classification Algorithm
**Experiment 1: Linear Mover (Locomotion, 24 GHz)**

Table C.1: Linear Mover Performing Locomotion Results: (A) Place in Front of Front Radar (Front View), (B) Place in Front of Front Radar (Side View), (C) Place in Front of Side Radar (Front View), (D) Place in Front of Side Radar (Side View), (E) Toward Both Radar Modules at 45° (Front View), (F) Place Toward Both Radar Modules at 45° (Side View), (G) Place Away from Both Radar Modules at 45° (Front View), (H) Place Away from Both Radar Modules at 45° (Side View)

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Experiment 2: Linear Mover (Fidgeting, 24 GHz)

Table C.2: Linear Mover Performing Fidgeting Results: (A) Place in Front of Front Radar (Front View), (B) Place in Front of Front Radar (Side View), (C) Place in Front of Side Radar (Front View), (D) Place in Front of Side Radar (Side View), (E) Toward Both Radar Modules at 45° (Front View), (F) Place Toward Both Radar Modules at 45° (Side View), (G) Place Away from Both Radar Modules at 45° (Front View), (H) Place Away from Both Radar Modules at 45° (Side View)

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### Experiment 3: Linear Mover (Locomotion, 10.587 GHz)

Table C.3: Linear Mover Performing Locomotion Results: (A) Place in Front of Front Radar (Front View), (B) Place in Front of Front Radar (Side View), (C) Place in Front of Side Radar (Front View), (D) Place in Front of Side Radar (Side View), (E) Toward Both Radar Modules at 45° (Front View), (F) Place Toward Both Radar Modules at 45° (Side View), (G) Place Away from Both Radar Modules at 45° (Front View), (H) Place Away from Both Radar Modules at 45° (Side View)

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(G)
### Experiment 4: Linear Mover (Fidgeting, 10.587 GHz)

Table C.4: Linear Mover Performing Fidgeting Results: (A) Place in Front of Front Radar (Front View), (B) Place in Front of Front Radar (Side View), (C) Place in Front of Side Radar (Front View), (D) Place in Front of Side Radar (Side View), (E) Toward Both Radar Modules at 45° (Front View), (F) Place Toward Both Radar Modules at 45° (Side View), (G) Place Away from Both Radar Modules at 45° (Front View), (H) Place Away from Both Radar Modules at 45° (Side View)

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**Experiment 5: Chameleon (5 min) (10.587GHz, Chameleon Movement)**

**Table C.5 Information for Chameleon Motion Pattern in Figure 4.8**

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Experiment 6: Chameleon (30 min) (10.587GHz, Chameleon Movement)

Table C.6: Information for Chameleon Motion Pattern in Figure 4.10: (A) Front Radar Module & (B) Side Radar Module

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Appendix D
Motion Classification Algorithm
%% (1) Steps to Run Program

%% File Name
input2=data2file;

%% Front Radar  % Deactivate Front Radar When Using Side Radar
b=[input2(:,1),input2(:,2)];

%% Side Radar
b=[input2(:,3),input2(:,4)];

m=eigdemod(b);

[time1,low,high,time2,time2r,time3,time3r,time4,time5]=collect(input2,m);

[infot,infot1,newtime,newtime1]=gather(time5,m)

printm(newtime1,input2)

[pangle1,n,time1,tans1,ta1,mot,nangle1,ang1a,ang1b,rmot,rmot1,rmot2,rotnode,ang1,motimefs,motimefe,motdir,motdiff]=radarlinear(newtime1,input2);

%% Print Results

[motcount,rotime,rotime1,rotime2,rotime3,rotime3a,rotime3b,lizmot]=printrot(motimefs,motimefe,motdir,motdiff,input2);

%% (2) Eigenvalue Demodulation

function [m]=eigdemod(b)%b is 2 column vector [col1: I col2:Q]

[v,d]=eig(cov(b));
ml=b*v(:,1);
m2=b*v(:,2);
m=m2;
vl=v(:,2);
d1=d(:,2);
if (var(ml)>var(m2))
    m=ml;
    vl=v(:,1);
    d1=d(:,1);
end

figure;
plot(m,'LineWidth',2);
xlabel('Time')
ylabel('Amplitude')
title('Motion Signal')

%% (3) Collect Local Maximum and Minimum Points

function[time1,low,high,time2,time2r,time3,time3r,time4,time5]=collect(inputfile,m)
count=0;
count1=0;
count2=20;

for i=1:length(inputfile)
count=count+1;
if count==1
    time1(i,1)=1;
    time1(i,2)=count2;
elseif count==2
    count2=count2+10;
    count1=count1+11;
    time1(i,1)=count1;
    time1(i,2)=count2;
else
    count2=count2+10;
    count1=count1+10;
    time1(i,1)=count1;
    time1(i,2)=count2;
end

if time1(i,2)==length(inputfile)
    break;
end
end

count3=0;
for i=1:length(time1)
    sp(i,1)=time1(i,1);
    sp(i,2)=time1(i,2);
    for j=sp(i,1):sp(i,2)
        count3=count3+1;
        n(count3,1)=m(j,1);
    end
    [low(1,i),low(2,i)]=min(n(:,1));
    [high(1,i),high(2,i)]=max(n(:,1));
count3=0;
end

count4=0;
count4r=0;
for i=1:length(low)
    if (low(2,i)==1 && high(2,i)==20)
        count4=count4+1;
        time2(count4,1)=timel(i,1);
        time2(count4,2)=timel(i,2);
        time2(count4,3)=1;
    elseif (low(2,i)==20 && high(2,i)==1)
        count4=count4+1;
        time2(count4,1)=timel(i,1);
        time2(count4,2)=timel(i,2);
        time2(count4,3)=-1;
    else
        count4r=count4r+1;
        time2r(count4r,1)=timel(i,1);
        time2r(count4r,2)=timel(i,2);
    end
end
time2r(count4r,3)=low(2,i)+time1(i,1)-1;
end
end
for i=2:length(time2)
time2(i,4)=time2(i,2)-time2(i-1,2);
end
count5=0;
for i=1:length(time2)
if time2(i,4)<=10
count5=count5+1;
time2(i,5)=count5;
else
count5=1;
time2(i,5)=count5;
end
end
for i=1:length(time2r)
if time2r(i,3)<time2r(i,4)
time2r(i,7)=1;
else
time2r(i,7)=-1;
end
end
count6=1;
time2r(1,6)=count6;
count7=1;
for i=2:length(time2r)
if time2r(i,5)>20 && time2r(i-1,5)>20
count6=1;
time2r(i,6)=count6;
elseif time2r(i,5)>20 && time2r(i-1,5)\leq 20
count6=1;
time2r(i,6)=count6;
elseif time2r(i-1,5)>20 && time2r(i,5)\leq 20
if time2r(i,7)==1;
count7=0;
count6=count6+1;
time2r(i,6)=count6;
else
count6=0;
count7=count7+1;
time2r(i,6)=count7;
end
elseif time2r(i,5)\leq 20 && time2r(i-1,5)\leq 20
if time2r(i,7)==1;
count7=0;
count6=count6+1;
time2r(i,6)=count6;
end
```matlab
count6 = count6 + 1;
time2r(i, 6) = count6;
else
count6 = 0;
count7 = count7 + 1;
time2r(i, 6) = count7;
end
end
end
count7 = 0;
for i = 1:length(time2)
    if time2(i, 5) == 1
        count7 = count7 + 1;
time3(count7, 1) = time2(i, 1);
time3(count7, 2) = time2(i, 2);
time3(count7, 3) = time2(i, 3);
    else
        time3(count7, 2) = time2(i, 2);
time3(count7, 3) = time2(i, 3);
    end
end

count8 = 0;
for i = 1:length(time2r)
    if time2r(i, 6) == 1
        count8 = count8 + 1;
time3r(count8, 1) = time2r(i, 3);
time3r(count8, 2) = time2r(i, 4);
time3r(count8, 3) = time2r(i, 7);
    else
        if time2r(i, 3) < time2r(i, 4)
            time3r(count8, 2) = time2r(i, 4);
        else
            time3r(count8, 1) = time2r(i, 3);
        end
    end
end

for i = 1:length(time3)
    for j = 1:length(time3r)
        if time3(i, 1) > time3r(j, 1) && time3(i, 1) < time3r(j, 2) && time3(i, 3) == 1
            time4(i, 1) = time3r(j, 1);
time4(i, 3) = time3r(j, 3);
        end
        if time3(i, 1) < time3r(j, 1) && time3(i, 1) > time3r(j, 2) && time3(i, 3) == -1
            time4(i, 1) = time3r(j, 2);
        end
        if time3(i, 2) > time3r(j, 1) && time3(i, 2) < time3r(j, 2) && time3(i, 3) == 1
            time4(i, 2) = time3r(j, 2);
        end
        if time3(i, 2) < time3r(j, 1) && time3(i, 2) > time3r(j, 2) && time3(i, 3) == -1
```

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time4(i,2)=time3r(j,1);
time4(i,3)=time3r(j,3);
end
end

for i=1:length(time4)
    if time4(i,1)==0
        time4(i,1)=time3(i,1);
        time4(i,3)=time3(i,3);
    end
    if time4(i,2)==0
        time4(i,2)=time3(i,2);
        time4(i,3)=time3(i,3);
    end
end

count9=0;
count10=0;
for i=1:length(time4)
    if time4(i,3)==1
        count10=0;
        count9=count9+1;
        time4(i,4)=count9;
    else
        count9=0;
        count10=count10+1;
        time4(i,4)=count10;
    end
end

count11=0;
for i=1:length(time4)
    if time4(i,4)==1
        count11=count11+1;
        time5(count11,1)=time4(i,1);
        time5(count11,2)=time4(i,2);
        time5(count11,3)=time4(i,3);
    else
        time5(count11,2)=time4(i,2);
    end
end

%% (4) Gather Activity Periods

function [infot,infot1,newtime,newtime1]=gather(time5,m)

    count=0;
count1=1;
countz=0;
for i=1:length(time5)
    if i>1
        clear infot
        clear infot1
        clear infot2
        count1=1;

end
sp(i,1)=time5(i,1);
sp(i,2)=time5(i,2);
for j=sp(i,1):sp(i,2)
    count=count+1;
    infot(1,1)=sp(i,1);
    infot(1,3)=m(sp(i,1),1);
    if count==20
        count=0;
        count1=count1+1;
        infot(count1,1)=j;
        infot(count1,3)=m(j,1);
    elseif count<20
        infot(count1,2)=j;
        infot(count1,4)=m(j,1);
    end
end
[a1,b1]=size(infot);
for i1=1:a1
    infot(i1,5)=abs(infot(i1,4)-infot(i1,3));
end
count2=0;
count3=0;
for i1=1:a1
    if infot(i1,5)>0.0175
        Lizard: 0.02
        count3=0;
        count2=0;
        infot(i1,6)=count2;
        infot(i1,7)=1;
    else
        count2=0;
        count3=0;
        count3=count3+1;
        infot(i1,6)=count3;
        infot(i1,7)=0;
    end
end
count4=0;
for i1=1:a1
    if infot(i1,6)==1
        count4=count4+1;
        infot1(count4,1)=infot(i1,1);
        infot1(count4,2)=infot(i1,2);
        infot1(count4,3)=infot(i1,7);
    else
        infot1(count4,2)=infot(i1,2);
        infot1(count4,3)=infot(i1,7);
        if infot1(count4,2)==0
            infot1(count4,2)=infot(i1,1);
        end
    end
end
count5=0;
[a2,b2]=size(infot1);
for i1=1:a2
    if infot1(i1,3)==1
\[ \text{infot1}(i1, 4) = \text{infot1}(i1, 2) - \text{infot1}(i1, 1); \]

\begin{verbatim}
else
    \text{infot1}(i1, 4) = 0;
end

for i1 = 1:a2
    if \text{infot1}(i1, 4) > 25 && \text{infot1}(i1, 3) == 1
        \text{count5} = \text{count5} + 1;
        \text{infot1}(i1, 5) = \text{count5};
    elseif \text{infot1}(i1, 4) <= 25 && \text{infot1}(i1, 3) == 1
        \text{count6} = 0;
        \text{infot1}(i1, 5) = \text{count6};
        \text{count5} = 0;
    else
        \text{infot1}(i1, 5) = 0;
    end
end

for i1 = 1:a2
    if \text{infot1}(i1, 5) > 0
        \text{countz} = \text{countz} + 1;
        \text{newtime}(\text{countz}, 1) = \text{infot1}(i1, 1);
        \text{newtime}(\text{countz}, 2) = \text{infot1}(i1, 2);
    end
end

for i1 = 1:countz
    if \text{newtime}(i1, 1) >= \text{time5}(i, 1) && \text{newtime}(i1, 2) <= \text{time5}(i, 2)
        \text{newtime}(i1, 3) = \text{time5}(i, 3);
    end
end

[a3, b3] = \text{size}(\text{newtime});

for i = 2:a3
    \text{newtime}(i, 4) = \text{newtime}(i, 1) - \text{newtime}(i-1, 2);
end

\text{count7} = 0;

for i = 1:a3
    if \text{newtime}(i, 4) <= 125 \text{ \text{\textpercent \text{125}}}
        \text{count7} = \text{count7} + 1;
        \text{newtime}(i, 5) = \text{count7};
    else
        \text{count7} = 1;
        \text{newtime}(i, 5) = \text{count7};
    end
end

\text{count8} = 0;

for i = 1:a3
    if \text{newtime}(i, 5) == 1
        \text{count8} = \text{count8} + 1;
        \text{newtimel}(\text{count8}, 1) = \text{newtime}(i, 1);
        \text{newtimel}(\text{count8}, 2) = \text{newtime}(i, 2);
    else
        \text{newtimel}(\text{count8}, 2) = \text{newtime}(i, 2);
    end
end
\end{verbatim}
(5) Print Motion Pattern

```matlab
function [lizmot]=printm(input,motion)

[a1,b1]=size(input);

for i=1:a1
    sp(i,1)=input(i,1);
    ep(i,1)=input(i,2);
    for j=1:length(motion)
        for k=sp(i,1):ep(i,1)
            if j==k
                lizmot(j,1)=1;
            end
        end
        if j>max(ep)
            lizmot(j,1)=0;
        end
    end
end

figure()
plot(lizmot)
ylim([-2 2])
title('Motion Pattern for Front Radar/Side Radar (Motion Type, File Name)')
xlabel('Samples')
ylabel('Motion Detection')
```

(6) Collect Arc or Circle Information

```matlab
function [pangle1,n,time1,tans1,ta1,mot,nangle1,angl1a,angl1b,rmot,rmot1,rmot2,rot
move,angl1,motimefs,motimefe,motdir,motdiff]=radarlinear(timeinput,input)

[o,p]=size(timeinput);

for i=1:o
    % Starting Time
    sp(i,1)=timeinput(i,1);
    % Ending Time
    ep(i,1)=timeinput(i,2);
    % Counter Constants
    rcounta=0;
    for j=sp(i,1):ep(i,1)
        % Counter
        rcounta=rcounta+1;
```
%% Time
movtime(rcounta,1)=j;

%% I Channel
IC1(rcounta,1)=input(j,2);

%% Q Channel
QC1(rcounta,1)=input(j,1);

%% Complex Equation
csig1(rcounta,1)=IC1(rcounta,1)+(1i*QC1(rcounta,1));

%% Calculate Mean
if j==ep(i,1)
    mx=mean(csig1);
end
end

%% Centering to Origin
ncsig1=csig1-mx;

%% Calculate Phase Angle
phasea1=radtodeg(unwrap(angle(ncsig1)));

%% Modify Phase Angle From 0 to 2pi
[pangle1]=mphase(phasea1,movtime);

%% Summary: In this expression, it reads the first 10 points of data from
%% input(the data were observing). The data is categorized into two
%% sections, n (first column) & n (second column). In n (first column), it
%% determines how much times the data points rotates in a counterclockwise
%% direction, whereas n(second column) determines the amounts of rotations
the data points move in the clockwise direction. In addition, this expression determine the starting and ending points (time period) when it counts up to 50 datapoints of information.

```matlab
for i1=1:length(pangle1)
    count=count+1;
    if count==5
        count3=count3+1;
        n(count3,1)=count1;
        n(count3,2)=count2;
        n(count3,3)=count4;
        n(count3,5)=movtime(i1,1);
        count=0;
        count1=0;
        count2=0;
        count4=0;
    else
        % Determine if angle1 is CCW or CW
        if pangle1(i1,4)==1
            count1=count1+1;
        elseif pangle1(i1,4)==-1
            count2=count2+1;
        elseif pangle1(i1,4)==0
            count4=count4+1;
        end
    end
end
```

% Summary: In this expression, it takes the information from n and determines the exact rotation (CCW or CW). This is determine by taking % greatest amount of datapoints produce by both rotations. The exact % rotation is placed in n (Column 3).

```matlab
[an,bn]=size(n);
for i2=1:an
    if n(i2,1)>n(i2,2) && n(i2,1)>n(i2,3)
        n(i2,4)=1;
    elseif n(i2,1)<n(i2,2) && n(i2,3)<n(i2,2)
        n(i2,4)=-1;
    elseif n(i2,1)<n(i2,3) && n(i2,2)<n(i2,3)
        n(i2,4)=0;
    end
end
```
%% Time Counters
tcount1=0;
tcount3=0;

%% Summary: In this expression, it determines the change in rotations by taking the information (column 3 and column 4 of n).

The new information is placed in a variable called timel.

The first if statement is needed to stop the counting of the for statement from existing its main ending point (length(n)).

for i3=1:an
  %% This statement works only for the last datapoint.
  if i3==an
    %% Time
    timel(i3,2)=n(i3,5);
    %% Rotation
    timel(i3,3)=n(i3,4);
    %% Stop the for statement
    break
  end
end

%% This statement works all other datapoint except the last datapoint.
if n(i3+1,4)>n(i3,4) || n(i3+1,4)<n(i3,4)
  %% Time
  timel(i3,2)=n(i3,5);
  %% Rotation
  timel(i3,3)=n(i3,4);
end
end

%% Summary: In this expression, it places the information from timel in a better format, column1 (starting time), column2 (closing time), and column3 (rotation). In addition, it makes the last expression to be all zeros in every columns in tans1.

for i4=1:an
  if timel(i4,1)==timel(i4,2)
    %% Counter
    tcount1=tcount1+1;
tans1(tcount1,2)=timel(i4,2);
tans1(tcount1,3)=timel(i4,3);
    %% This statement was change (%% Scott)
tans1(tcount1+1,1)=(timel(i4,2)+1);
  end
end
tans1(1,1)=movtime(1,1);
tans1(tcount1+1,1)=0;

% Summary: In this expression, it relocates the 
% datapoints and remove the 
% lines containing all zeros in each column. In 
% addition, it calculates 
% the amount of rotations by taking the difference 
% between the ending time 
% minus the starting points. This difference is 
% located in column 4 of 
% t1 (new variable).

[q,r]=size(tans1);
for i5=1:q
    if tans1(i5,1)~=tans1(i5,2)
        tcount3=tcount3+1;
        ta1(tcount3,3)=tans1(i5,3);
        ta1(tcount3,2)=tans1(i5,2);
        ta1(tcount3,1)=tans1(i5,1);
        ta1(tcount3,4)=tans1(i5,2)-tans1(i5,1);
    end
end

% Summary: In this expression, it takes all the 
% datapoints that are tag 
% with the number 1. These datapoints are then placed 
in a new variable 
% (mot).

% Time Counter
[g,h]=size(ta1);
for i6=1:g
    mot(i6,1)=ta1(i6,1);
    mot(i6,2)=ta1(i6,2);
end

[c,d]=size(mot);
bcount=0;

for i7=1:c
    stp(i7,1)=mot(i7,1);
    if stp(1,1)==0
        stp(1,1)=1;
    end
    edp(i7,1)=mot(i7,2);
    for j=stp(i7,1):edp(i7,1)
        bcount=bcount+1;
        nangle1(j,1)=pangle1(bcount,1);
        nangle1(j,2)=pangle1(bcount,2);
        nangle1(j,3)=pangle1(bcount,3);
        nangle1(j,4)=pangle1(bcount,4);
    end
nangle1(j,5)=pangle1(bcount,5);
end

%% Summary: In this expression, it gathers the starting and ending time and corrects the rotation in angle1.

for i8=1:c
  %% Starting Time
  sl(i8,1)=mot(i8,1);
  if sl(1,1)==0
    sl(1,1)=1;
  end
  %% Ending Time
  el(i8,1)=mot(i8,2);
  for j=sl(i8,1):el(i8,1)
    if mot(i8,3)==-1
      nangle1(j,6)=-1;
    elseif mot(i8,3)==1
      nangle1(j,6)=1;
    end
  end
end

%% Angle Counters
acount=2;
acount1=2;

%% Summary: In this expression, it organized the datapoints of mot and determine if there are multiple rotations in each time interv

for i9=1:c
  %% Starting Time
  ls(i9,1)=mot(i9,1);
  if ls(1,1)==0
    ls(1,1)=1;
  end
  %% Ending Time
  le(i9,1)=mot(i9,2);
  for j=ls(i9,1):le(i9,1)
    if nangle1(j,5)>0
      acount=acount+1;
      acount1=acount1+1;
      ang1a(acount1,i9)=nangle1(j,2);
      ang1b(acount,i9)=j;
    end
  end
%% Add the datapoints for each ending point
angla(acount1+1,i9)=nangle1(le(i9,1),2);
anglb(acount1+1,i9)=le(i9,1);

angla(acount1+2,i9)=0;
anglb(acount1+2,i9)=0;

angla(acount1+3,i9)=0;
anglb(acount1+3,i9)=0;
end

%% Add zeros to the first line of code
angla(1,i9)=0;
anglb(1,i9)=0;

%% Add the datapoint for each starting point
angla(2,i9)=nangle1(ls(i9,1),2);
anglb(2,i9)=ls(i9,1);

%% Reset Counters
acount=2;
acount1=2;
end

%% Summary: In this expression, it placed all the information in anglb into
%% a single column.

%% Angle Counter
acount2=0;

[e, f]=size(anglb);
[r, q]=size(mot);
for i10=1:r
    for j=1:e
        if anglb(j,i10)>-1
            acount2=acount2+1;
            rmot(acount2,1)=anglb(j,i10);
        end
    end
end

%% Summary: In this expression, it takes the difference using the present
%% datapoint minus the previous datapoint.

for i11=2:length(rmot)
    rmot(i11,2)=abs(rmot(i11,1)-rmot(i11-1,1));
end

%% Summary: In this expression, it takes the datapoints from rmot and
%% organized it.

%% Angle Counter
acount3=0;

for i12=1:length(rmot)
if (rmot(i12,1) >=0) && (rmot(i12,2)>0) %20
    acount3=acount3+1;
    rmot1(acount3,1)=rmot(i12,1);
end
end

%% Summary: In this expression, it adds another columns, so that it can
%% show the user the starting and ending points when rotations occurs. In
%% addition, the last line on both columns will be both zeros.

for i13=2:length(rmot1)
    rmot1(i13-1,2)=rmot1(i13,1);
end

rmot1(length(rmot1),1)=0;

%% Summary: In this expression, it fixs the errors i created and make the
%% result more accurate.

for i14=1:length(rmot1)
    if rmot1(i14,1)>0 && rmot1(i14,2)==0
        rmot1(i14,1)=0;
    elseif rmot1(i14,1)==0 && rmot1(i14,2)>0
        rmot1(i14,2)=0;
    end
end

%% Summary: In this expression, it remove all of the
%% zeros and place the
%% remaining datapoints into a new variable called
rmot2.

%% Angle Counter
acount4=0;

for i15=1:length(rmot1)
    if (rmot1(i15,1) ~= rmot1(i15,2))
        acount4=acount4+1;
        rmot2(acount4,1)=rmot1(i15,1);
        rmot2(acount4,2)=rmot1(i15,2);
        rmot2(acount4,3)=nangle1(rmot1(i15,1),6);
        rmot2(acount4,4)=nangle1(rmot1(i15,1),2);
        rmot2(acount4,5)=nangle1(rmot1(i15,2)-1,2);
    end
end

[a1,b1]=size(rmot2);

for i15a=1:a1
    if i15a==al
        break
end

end
end
if rmot2(i15a+1,1)==rmot2(i15a,2)
    rmot2(i15a,2)=rmot2(i15a,2)-1;
end
end

for i16=1:a1
    if rmot2(i16,4)<rmot2(i16,5)
        rmot2(i16,6)=1;
    elseif rmot2(i16,4)>rmot2(i16,5)
        rmot2(i16,6)=-1;
    end
end

[an,am]=size(rmot2);

if an==1
    rmot2(1,7)=0;
elseif an==2
    rmot2(1,7)=0;
    rmot2(2,7)=abs(rmot2(2,4)-rmot2(1,5));
elseif an>2
    for i18=2:a1
        rmot2(i18,7)=abs(rmot2(i18,4)-rmot2(i18-1,5));
    end
end

rotcount1=0;
rotcount2=0;
for i17=1:a1
    if rmot2(i17,6)==1
        rotcount2=0;
        rotcount1=rotcount1+1;
        if rmot2(i17,7)>300
            rotcount1=1;
        else
            if i17==1
                rotcount1=1;
            else
                rotcount1=rotcount1;
            end
        end
        rmot2(i17,8)=rotcount1;
    else
        rotcount1=0;
        rotcount2=rotcount2+1;
        if rmot2(i17,7)>300
            rotcount2=1;
        else
            if i17==1
                rotcount2=1;
            else
                rotcount2=rotcount2;
            end
        end
        rmot2(i17,8)=rotcount2;
    end
end

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rotcount3=0;
for i19=1:a1
    if rmot2(i19,8)==1
        rotcount3=rotcount3+1;
        rotmove(rotcount3,1)=rmot2(i19,1);
        rotmove(rotcount3,2)=rmot2(i19,2);
        rotmove(rotcount3,3)=rmot2(i19,4);
        rotmove(rotcount3,4)=rmot2(i19,5);
        if rmot2(i19,7)>300
            rotmove(rotcount3,6)=0;
        else
            rotmove(rotcount3,6)=1;
        end
    else
        rotmove(rotcount3,2)=rmot2(i19,2);
        rotmove(rotcount3,4)=rmot2(i19,5);
    end
end
[a2 b2]=size(rotmove);
for i20=1:a2
    if rotmove(i20,6)==1
        rangle1=rotmove(i20,3);
        ang1(i20,1)=rangle1;
    else
        ang1(i20,1)=rangle1;
    end
end
for i20d=1:a2
    if rotmove(i20d,5)==0
        if rotmove(i20d,3)>rotmove(i20d,4)
            rotmove(i20d,5)=-1;
        else
            rotmove(i20d,5)=1;
        end
    end
end
[a2z b2z]=size(ang1);
countz=1;
ang1(1,2)=countz;
for i20a=2:a2z
    if ang1(i20a,1)==ang1(i20a-1,1)
        countz=countz+1;
        ang1(i20a,2)=countz;
    else
        countz=1;
        ang1(i20a,2)=countz;
    end
end
for i20b=1:a2z
    if i20b==a2z
        break
    end
    if ang1(i20b,2)==1 && ang1(i20b+1,1)==ang1(i20b,1)
        ang1(i20b,3)=1;
    else
        ang1(i20b,3)=0;
    end
end

for i20c=1:a2z
    if ang1(i20c,2)>1
        ang1(i20c,3)=1;
    else
        ang1(i20c,3)=0;
    end
end

%% Summary: In this expression, it adds a new columns and tags it if the first datapoint located in ang1 are within the limits stated in rmot2 ( % column 4 and 5).

for i21=1:a2
    if ang1(i21,3)==1
        if rotmove(i21,5)==1 && rotmove(i21,3)<rotmove(i21,4)
            rotmove(i21,7)=((abs(rotmove(i21,3)-rotmove(i21,4)))/360);
        elseif rotmove(i21,5)==1 && rotmove(i21,3)>rotmove(i21,4)
            if abs(rotmove(i21,4)-rotmove(i21,3))>15
                diff(i21,1)=((abs(rotmove(i21,3)-rotmove(i21,4)))/360);
            else
                diff(i21,1)=(((360-rotmove(i21,3))+(rotmove(i21,4)))/360);
            end
        elseif rotmove(i21,5)==-1 && rotmove(i21,3)>rotmove(i21,4)
            rotmove(i21,7)=((abs(rotmove(i21,3)-rotmove(i21,4)))/360);
        elseif rotmove(i21,5)==-1 && rotmove(i21,3)<rotmove(i21,4)
            if abs(rotmove(i21,4)-rotmove(i21,3))>15
                diff(i21,1)=((abs(rotmove(i21,3)-rotmove(i21,4)))/360);
            else
                diff(i21,1)=(((rotmove(i21,3))+(360-rotmove(i21,4)))/360);
            end
        end
    end
end
if rotmove(i21,5)==1 &&
rotmove(i21,3)<rotmove(i21,4)
    diff(i21,1)=((abs(rotmove(i21,3)-
rotmove(i21,4)))/360);
elseif rotmove(i21,5)==1 &&
rotmove(i21,3)>rotmove(i21,4)
    if abs(rotmove(i21,4)-rotmove(i21,3)>15
       diff(i21,1)=(((360-
rotmove(i21,3))+(rotmove(i21,4)))/360);
    else
       diff(i21,1)=((abs(rotmove(i21,3)-
rotmove(i21,4)))/360);
    end
else if rotmove(i21,5)==-1 &&
rotmove(i21,3)>rotmove(i21,4)
    diff(i21,1)=((abs(rotmove(i21,3)-
rotmove(i21,4)))/360);
elseif rotmove(i21,5)==-1 &&
rotmove(i21,3)<rotmove(i21,4)
    if abs(rotmove(i21,4)-rotmove(i21,3)>15
       diff(i21,1)=(((rotmove(i21,3))+(360-
rotmove(i21,4)))/360);
    else
       diff(i21,1)=((abs(rotmove(i21,3)-
rotmove(i21,4)))/360);
    end
else
    diff(i21,1)=0;
end

if diff(i21,1)>(5/360) % 5 degrees
    rotmove(i21,7)=diff(i21,1);
else
    rotmove(i21,7)=0;
end

count1z=0;
count2z=0;
for i21b=1:a2
    if rotmove(i21b,5)==-1 && rotmove(i21b,7)>0
        count2z=0;
count1z=count1z+1;
rotmove(i21b,8)=count1z;
elseif rotmove(i21b,5)==1 && rotmove(i21b,7)>0
        count2z=0;
count2z=count2z+1;
rotmove(i21b,8)=count2z;
else if rotmove(i21b,5)==1 && rotmove(i21b,7)==0
    || rotmove(i21b,5)==-1 && rotmove(i21b,7)==0
        count1z=0;
end
count2z=0;
end
end

for i21c=1:a2
  if i21c>1 && i21c<a2
    if rotmove(i21c,8)==1 && rotmove(i21c-1,8)==0
      && rotmove(i21c+1,8)==0 && rotmove(i21c,7)>(350/360)
      rotmove(i21c,7)=0;
    end
  end
end

end

%% Summary: In this expression, it determines how much forward movement occurs.
[a3 b3]=size(rotmove);
rcount2=0;
rcount3=0;
for i22=1:a3
  if rotmove(i22,7)>0 && rotmove(i22,5)==1
    rcount2=rcount2+rotmove(i22,7);
    forward1(1,i)=rcount2;
    motimefs(i22,i)=rotmove(i22,1);
    motimefe(i22,i)=rotmove(i22,2);
    motdir(i22,i)=rotmove(i22,5);
    motdiff(i22,i)=rotmove(i22,7);
  elseif rotmove(i22,7)==0 && rotmove(i22,5)==1 ||
    rotmove(i22,7)==0
    forward1(1,i)=rcount2;
  end
end

%% Summary: In this expression, it determine how much backward movement occurs.
for i23=1:a3
  if rotmove(i23,7)>0 && rotmove(i23,5)==-1
    rcount3=rcount3+rotmove(i23,7);
    backward1(1,i)=rcount3;
    motimefs(i23,i)=rotmove(i23,1);
    motimefe(i23,i)=rotmove(i23,2);
    motdir(i23,i)=rotmove(i23,5);
    motdiff(i23,i)=rotmove(i23,7);
  elseif rotmove(i23,7)==0 && rotmove(i23,5)==-1 ||
    rotmove(i23,7)==0
    backward1(1,i)=rcount3;
  end
if i~=o
  clear movtime
  clear csg1
  clear n
  clear timel
  clear tansl
  clear tal
  clear mot
clear ang1a
clear ang1b
clear rmot
clear rмот1
clear rмот2
clear rotmove
clear ang1
end
end

%% (6a) Calculate Phase Angle

function [angle]=mphase(input,input1)

%% Output Variables
%% 1) angle = phase angle

%% Angle Columns
%% (1) Original Phase Angle
%% (2) Modify Phase Angle
%% (3) Round Phase Angle

%% In this expression, it takes the phase angle and placed it in a column.

for j=1:length(input)
    angle(j,1)=input(j,1);
    angle(j,6)=input1(j,1);
end

%% After unwrapping, there are phase angles that excess the limits of a full rotation (360 or -360 degrees). To fix this problem, an expression was created to find these errors, so that the angles are within the parameters of 0 to [(2*pi) or 360 degrees]. The corrected angles are placed in the second column of angle.

for j=1:length(input)
    % Excess the limits of a full rotation
    if angle(j,1)> 360 || angle(j,1) < -360
        % rot: Amounts of Rotations
        rot(j,1)=fix(angle(j,1)/360);
        % Phase Angle Modify
        angle(j,2)=angle(j,1)-(rot(j,1)*360);
        % Round Phase Angle
        angle(j,3)=fix(angle(j,2));
    % No Change
    else
        % Copy Original to the Modify
        angle(j,2)=angle(j,1);
        % Round Phase Angle
        angle(j,3)=round(angle(j,2));
    end
end
%% Summary: In this expression, it locates all of the negative angles within the second column of 'angle' and converts them to a positive angle. This conversion will make analyzing easier by allowing the user to distinguish counterclockwise (CCW) and clockwise (CW) rotations.

for j=1:length(input)
    %% Negative Angles
    if angle(j,2)<0
        angle(j,2)=360+angle(j,2);
        angle(j,3)=round(angle(j,2));
        if angle(j,3)==360
            angle(j,3)=0;
        end
    end
end

%% Counter
count1=0;

%% Summary: In this expression, it calculates the difference between the previous/ present phase angle and the present/next phase angle. If this scenario occurs, the phase angle will equal to zero if the phase angle difference is greater than 300 degrees.

for j=1:length(input)
    count1=count1+1;
    if count1>1 && count1<length(input)
        diff1(j,1)=abs(angle(j,3)-angle(j-1,3));
        diff1(j,2)=abs(angle(j+1,3)-angle(j,3));
    else
        diff1(j,1)=0;
        diff1(j,2)=0;
    end
end

for j=1:length(input)
    if diff1(j,1)>300 && diff1(j,2)>300 && angle(j,3)>300
        angle(j,3)=0;
        angle(j,2)=0;
    elseif diff1(j,1)>300 && diff1(j,2)>300 && angle(j,3)<10
        angle(j,3)=360;
        angle(j,2)=360;
    else
        angle(j,3)=angle(j,3);
    end
end

%% Counter
count0=0;
%% Summary: In this expression, it separated the phase angle of Signal 1 into two variables (a & b) to determine whether it is rotating in a clockwise direction or in a counterclockwise direction. In the variable a, it contains the present values while b contains the previous values. A difference of these two variables is calculated to give a precise answer. When the target is moving in a counterclockwise direction, it is indicated as 1, while clockwise direction is indicated as -1. These tags are placed in the third column of 'angle'. If the difference between the variables (a & b) exceed 300 degrees, the phase angle will be tagged with a number. The difference means when it completed a full rotation in any direction (CCW or CW).

```plaintext
for j=2:length(input)
    a1(j,1)=angle(j,3);
    b1(j,1)=angle(j-1,3);
    diff(j,1)=abs(a1(j,1)-b1(j,1));
    if b1(j,1) < a1(j,1)
        angle(j,4)=1;
    elseif b1(j,1) > a1(j,1)
        angle(j,4)=-1;
    end

    if diff(j,1) > 260
        count0=count0+1;
        angle(j,5)=count0;
    else
        angle(j,5)=0;
    end
end
```

%% (7) Print Final Information

```plaintext
function [motcount,rotime,rotime1,rotime2,rotime3,rotime3a,rotime3b,lizmot,graph1]=printrot(input1,input2,input3,input4,motion) total

[a1,b1]=size(input1);

counta=0;
countb=0;
for j=1:b1
    if j>1
        countb=0;
        counta=0;
```
for k=1:a1
    if input3(k,j)==1
        countb=0;
        counta=counta+1;
        motcount(k,j)=counta;
    elseif input3(k,j)==-1
        counta=0;
        countb=countb+1;
        motcount(k,j)=countb;
    elseif input3(k,j)==0
        countb=0;
        counta=0;
    end
end
end
count=0;
i=1;
for j=1:(a1*b1)
    count=count+1;
    if count==a1
        rotime(j,1)=input1(count,i);
        rotime(j,2)=input2(count,i);
        rotime(j,3)=input3(count,i);
        rotime(j,4)=input4(count,i);
        rotime(j,5)=motcount(count,i);
        count=0;
        i=i+1;
    else
        rotime(j,1)=input1(count,i);
        rotime(j,2)=input2(count,i);
        rotime(j,3)=input3(count,i);
        rotime(j,4)=input4(count,i);
        rotime(j,5)=motcount(count,i);
    end
end
[a2,b2]=size(rotime);
count1=0;
for j=1:a2
    if rotime(j,1)>0 && rotime(j,2)>0
        count1=count1+1;
        rotime1(count1,1)=rotime(j,1);
        rotime1(count1,2)=rotime(j,2);
        rotime1(count1,3)=rotime(j,3);
        rotime1(count1,4)=rotime(j,4);
        rotime1(count1,5)=rotime(j,5);
    end
end
[a3,b3]=size(rotime1);
count4=0;
for j=1:a3
    if rotime1(j,5)==1
        count4=count4+1;
        rotime2(count4,1)=rotime1(j,1);
        rotime2(count4,2)=rotime1(j,2);
        rotime2(count4,3)=rotime1(j,3);
        rotime2(count4,4)=rotime1(j,4);
        rotime2(count4,5)=rotime1(j,5);
    end
end
[a4,b4]=size(rotime2);
count4=count4+1;
rotime2(count4,1)=rotimel(j,1);
rotime2(count4,2)=rotimel(j,2);
rotime2(count4,3)=rotimel(j,3);
rotime2(count4,4)=rotimel(j,4);
else
    rotime2(count4,2)=rotimel(j,2);
    rotime2(count4,3)=rotimel(j,3);
    rotime2(count4,4)=rotime2(count4,4)+rotimel(j,4);
end
end

[a4,b4]=size(rotime2);

count5=0;
count6=0;
for i=1:a4
    if rotime2(i,3)==-1
        count6=0;
        count5=count5+1;
        rotime2(i,5)=count5;
    elseif rotime2(i,3)==1
        count5=0;
        count6=count6+1;
        rotime2(i,5)=count6;
    end
end

for i=2:a4
    rotime2(i,6)=rotime2(i,1)-rotime2(i-1,2);
end

count7=0;
for j=1:a4
    if rotime2(j,5)==1
        count7=count7+1;
        rotime3(count7,1)=rotime2(j,1);
        rotime3(count7,2)=rotime2(j,2);
        rotime3(count7,3)=rotime2(j,3);
        rotime3(count7,4)=rotime2(j,4);
    elseif rotime2(j,6)<=50
        rotime3(count7,2)=rotime2(j,2);
        rotime3(count7,3)=rotime2(j,3);
        rotime3(count7,4)=rotime3(count7,4)+rotime2(j,4);
    else
        count7=count7+1;
        rotime3(count7,1)=rotime2(j,1);
        rotime3(count7,2)=rotime2(j,2);
        rotime3(count7,3)=rotime2(j,3);
        rotime3(count7,4)=rotime2(j,4);
    end
end

[a5,b5]=size(rotime3);
maxx1 = max(rotim3(:,4));

count8 = 0;
for j = 1:a5
    if rotime3(j,4) >= (0.16*maxx1) \% 15 percent
        count8 = count8 + 1;
        rotime3a(count8,1) = rotime3(j,1);
        rotime3a(count8,2) = rotime3(j,2);
        rotime3a(count8,3) = rotime3(j,3);
        rotime3a(count8,4) = rotime3(j,4);
    end
end

[a6,b6] = size(rotim3a);

count9 = 0;
count10 = 0;
for i = 1:a6
    if rotime3a(i,3) == 1
        count10 = 0;
        count9 = count9 + 1;
        rotime3a(i,5) = count9;
    elseif rotime3a(i,3) == -1
        count9 = 0;
        count10 = count10 + 1;
        rotime3a(i,5) = count10;
    end
end

for i = 2:a6
    rotime3a(i,6) = rotime3a(i,1) - rotime3a(i-1,2);
end

count11 = 0;
for j = 1:a6
    if rotime3a(j,5) == 1
        count11 = count11 + 1;
        rotime3b(count11,1) = rotime3a(j,1);
        rotime3b(count11,2) = rotime3a(j,2);
        rotime3b(count11,3) = rotime3a(j,3);
        rotime3b(count11,4) = rotime3a(j,4);
    else
        if rotime3a(j,6) <= 100
            rotime3b(count11,2) = rotime3a(j,2);
            rotime3b(count11,3) = rotime3a(j,3);
            rotime3b(count11,4) = rotime3b(count11,4) + rotime3a(j,4);
        else
            count11 = count11 + 1;
            rotime3b(count11,1) = rotime3a(j,1);
            rotime3b(count11,2) = rotime3a(j,2);
            rotime3b(count11,3) = rotime3a(j,3);
            rotime3b(count11,4) = rotime3a(j,4);
        end
    end
end
[a7, b7] = size(rotim3b);

for i = 1:a7
    sp(i, 1) = rotim3b(i, 1);
    ep(i, 1) = rotim3b(i, 2);
    for j = 1:length(motion)
        for k = sp(i, 1):ep(i, 1)
            if j == k && rotim3b(i, 4) >= 0.68 && rotim3b(i, 3) == -1
                lizmot(j, 1) = 2;
            elseif j == k && rotim3b(i, 4) >= 0.68 && rotim3b(i, 3) == 1
                lizmot(j, 1) = -2;
            elseif j == k && rotim3b(i, 4) < 0.68 && rotim3b(i, 4) > 0 &&
                rotim3b(i, 3) == 1
                lizmot(j, 1) = 1;
            elseif j == k && rotim3b(i, 4) < 0.68 && rotim3b(i, 4) > 0 &&
                rotim3b(i, 3) == -1
                lizmot(j, 1) = 1;
        end
    end
    if j > max(ep)
        lizmot(j, 1) = 0;
    end
end

figure()
plot(lizmot)
ylim([-3 3])
title('Rotation Pattern for Front Radar (Motion Type, Motion Title)')
xlabel('Samples')
ylabel('Motion Detection')

for i = 1:length(lizmot)
    if lizmot(i, 1) == 1
        graph1(i, 1) = 1;
    elseif lizmot(i, 1) == -1
        graph2(i, 1) = 1;
    elseif lizmot(i, 1) == 2
        graph3(i, 1) = 2;
    elseif lizmot(i, 1) == -2
        graph4(i, 1) = 2;
    else
        graph1(i, 1) = 0;
        graph2(i, 1) = 0;
        graph3(i, 1) = 0;
        graph4(i, 1) = 0;
    end
end

for i = 1:length(lizmot)
    if lizmot(i, 1) == 0
        graph5(i, 1) = 0;
end
figure()
p0=plot(graph1)
set(p0,'Color','green')
hold on
p1=plot(graph2)
set(p1,'Color','green')
hold on
p2=plot(graph3)
set(p2,'Color','magenta')
hold on
p3=plot(graph4)
set(p3,'Color','magenta')
p4=plot(graph5)
set(p4,'Color','black')
ylim([-3 3])
title('Rotation Pattern for Front Radar (Motion Type,Motion Title)')
xlabel('Samples')
ylabel('Motion Detection')
References


