MIDDLE EAST TECHNICAL UNIVERSITY

# ELECTRICAL & ELECTRONICS ENGINEERING DEPARTMENT

# EE-400

# SUMMER PRACTICE REPORT


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**Name:** ASELSAN

**Department:** Radar & Electronics Warfare Systems

**SP Date:** 26.08.2021 – 20.09.2021

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# 1. INTRODUCTION

I have performed my second compulsory summer practice in ASELSAN, which is Turkey's largest multi-product electronics industry. ASELSAN creates advanced electronic equipment for both military and commercial customers. ASELSAN has lots of different facilities located in various parts of Ankara such as Gölbaşı, Macunköy, Akyurt, Teknokent facilities.

My internship lasted 20 days, starting from 26.07.2021 to 20.08.2021. The first week of the internship was organized to learn and internalize occupational safety and health. This week was online, and the interns had to conclude 12 hours of online interactive videos in that period. They brought us to our predetermined facilities at the end of the week with absolutely no chance of changing them. I was in the Gölbaşı Facility, which is the newest facility of ASELSAN. The operation mainly focuses on the radar and electronic warfare systems in that facility. So my internship was on the topic of electronic warfare.


*Figure 1: ASELSAN Gölbaşı Facilities*

A thorough explanation of the things I did and observed throughout the summer practice is provided in this report. It begins with a company description, which explains the firm's address, contact, general description, brief history, organizational structure, mission, vision, employers, affiliates, and company shareholders. The description section of the report is followed by the project, which covers the efforts connected to the "Passive Geolocation For Electronic Support Systems". Finally, a conclusion section is included as well as the references and the appendices. In the references part, the sources of the information covered in this report will be included. The appendices part will include the complete MATLAB source code that I wrote for my duty in the internship. All of the code will not be shared in this report since it will occupy lots of space. So, while some parts will be shown, the rest can be found in the link shared in the appendices.

# 2. ABOUT THE COMPANY

## 2.1. COMPANY NAME

- ASELSAN Electronic Industries Inc.

## 2.2. COMPANY LOCATION

ASELSAN has four big facilities which are Gölbaşı, Macunköy, Akyurt and Teknokent Facilities.

### Gölbaşı Facilities

**Adress:** Konya Yolu 8. Km, Oğulbey Mah. 3051. Sok. No:3, 06830 Ankara, Türkiye

**Phone:** +90 (312) 592 60 00

**Fax:** +90 (312) 592 60 06

**Mail:** aselsan@hs02.kep.tr

**Macunköy Facilities**

**Adress:** Mehmet Akif Ersoy Mahallesi İstiklal Marşı Caddesi No: 16, 06200 Yenimahalle-Ankara, Türkiye

**Phone:** +90 (312) 592 60 00

**Fax:** +90 (312) 354 26 69 / +90 (312) 354 13 02

**Mail:** aselsan@hs02.kep.tr

**Akyurt Facilities**

**Adress:** Balıkhisar Mahallesi Koca Seyit Onbaşı Caddesi No: 1 Akyurt-Ankara P.K. 20 Akyurt, 06750 Ankara, Türkiye

**Phone:** +90 (312) 847 53 00

**Fax:** +90 (312) 847 53 20

**Mail:** aselsan@hs02.kep.tr

**Teknokent Facilities**

**Adress:** Üniversiteler Mahallesi İhsan Doğramacı Bulvarı No:23/A Teknokent ODTÜ, 06800

**Phone:** +90 (0312) 592 13 20

**Mail:** aselsan@hs02.kep.tr

## 2.3. GENERAL DESCRIPTION OF THE COMPANY

### ASELSAN

ASELSAN is a Turkish Armed Forces Foundation organization founded in 1975 to serve the Turkish Armed Forces' communication demands using national methods. The Foundation now owns 74,20 percent of the shares, with the remaining 25,8 percent trading on the Istanbul Borsa stock exchange.

Radar and electronic warfare, communication and information technologies, electro-optics, avionics, unmanned systems, naval, land, and air defense and missile systems, command and control systems, weapon systems, traffic, automation, transportation, security, and medical systems are all part of ASELSAN's capability/product portfolio.

ASELSAN has set a goal to be a firm that maintains its long-term growth by producing value in the global market; preferred for its competitiveness, trusted as a strategic partner, and concerned about the environment and people. The firm invests 7% of its yearly profits for self-financed research and development operations, in addition to the highly skilled engineering personnel among the company's more than 8.500 workers, who are the primary driving power behind the success of the company.

## 2.4. ORGANİZATIONAL STRUCTURE

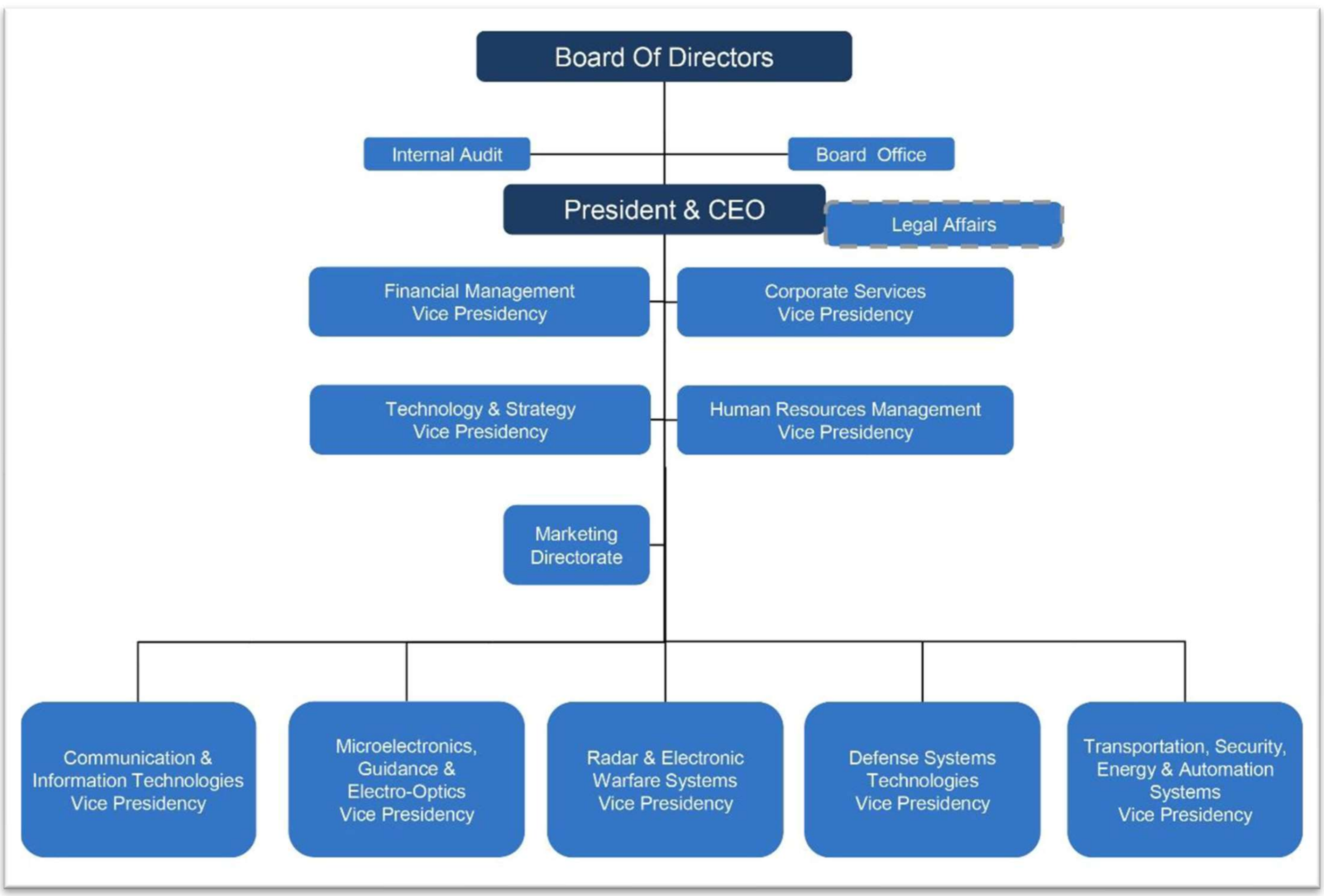


*Figure 2: Organizational structure of ASELSAN*

## 2.5. MISSION & VISION

### Mission

By focusing on the needs of the Turkish Armed Forces; providing high-value-added, innovative, and dependable solutions and products to global customers in the fields of system integration and electronic technologies; continuing activities in line with global targets; and contributing to Turkey's technological independence.

### Vision

To be a trustworthy, competitively favored, environmentally responsible, and socially conscious technological company that maintains its long-term growth in the global market by creating value for stakeholders and meeting its founding goals.

## 2.6. NUMBER AND DUTIES OF ENGINEERS EMPLOYED

The total number of people in the ASELSAN is 8979, of which 5,387 are engineers and 2,693 are technicians. The rest workers consist of administrative personals and servants. Also, 79% of employers are male, and 21% of employers are female.

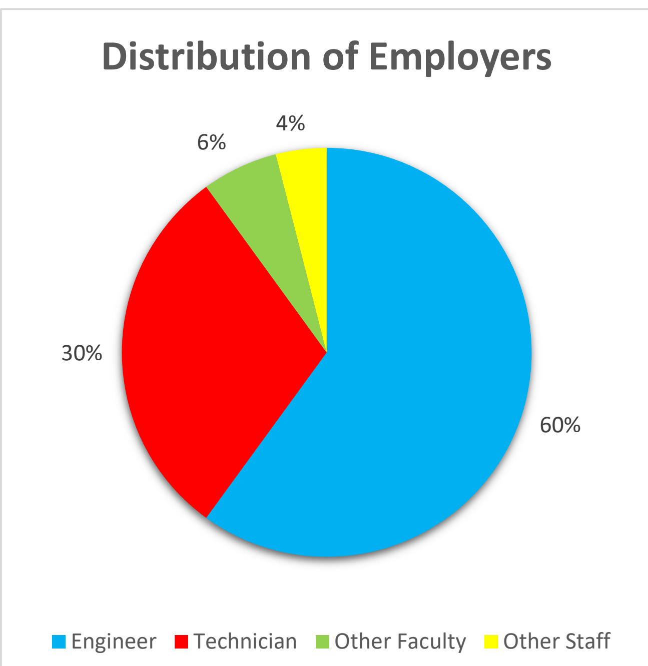


*Figure 3: Distribution of Employers in ASELSAN*

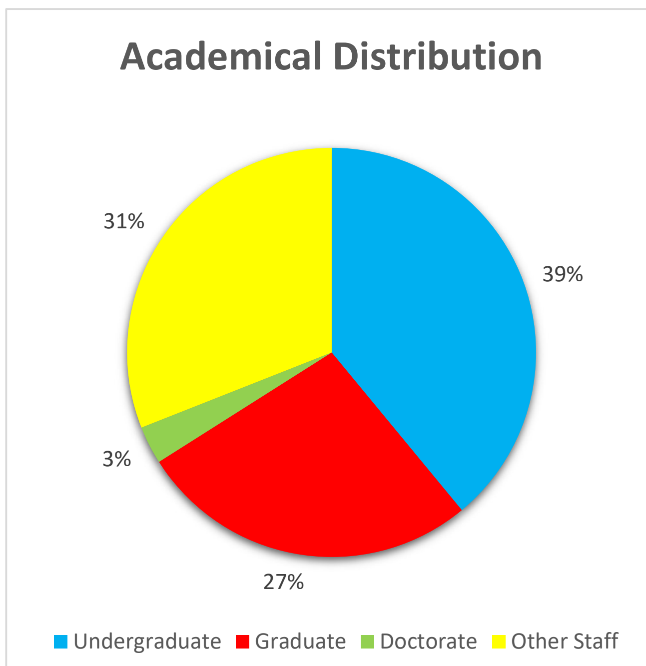


*Figure 4: Academical Distribution of Employers in ASELSAN*

## 2.7. SHAREHOLDERS OF THE COMPANY

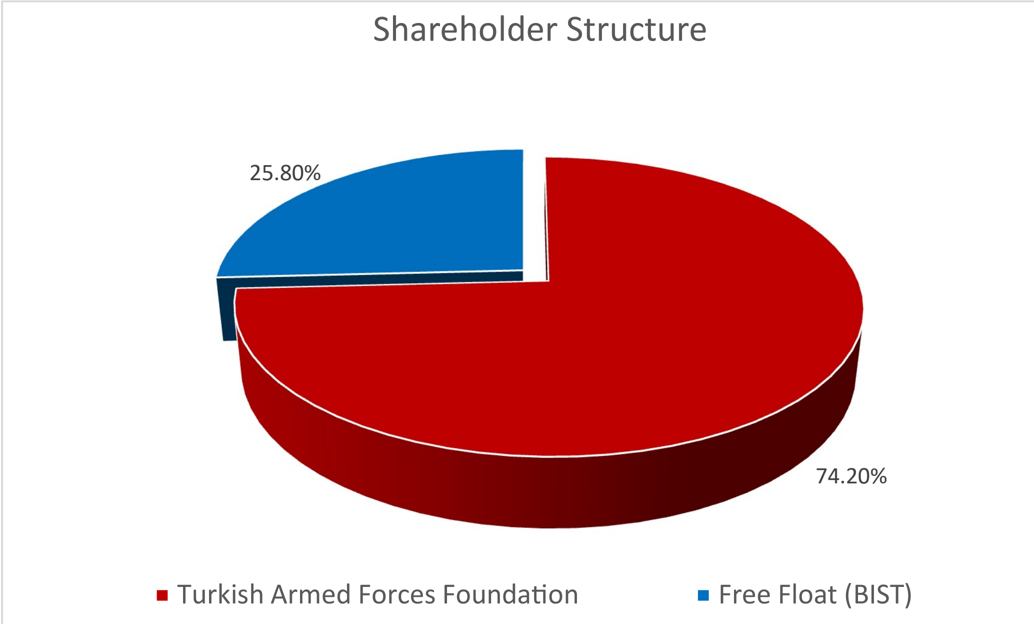


*Figure 5: Shareholders of ASELSAN*

## 2.8. AFFILIATES OF THE COMPANY

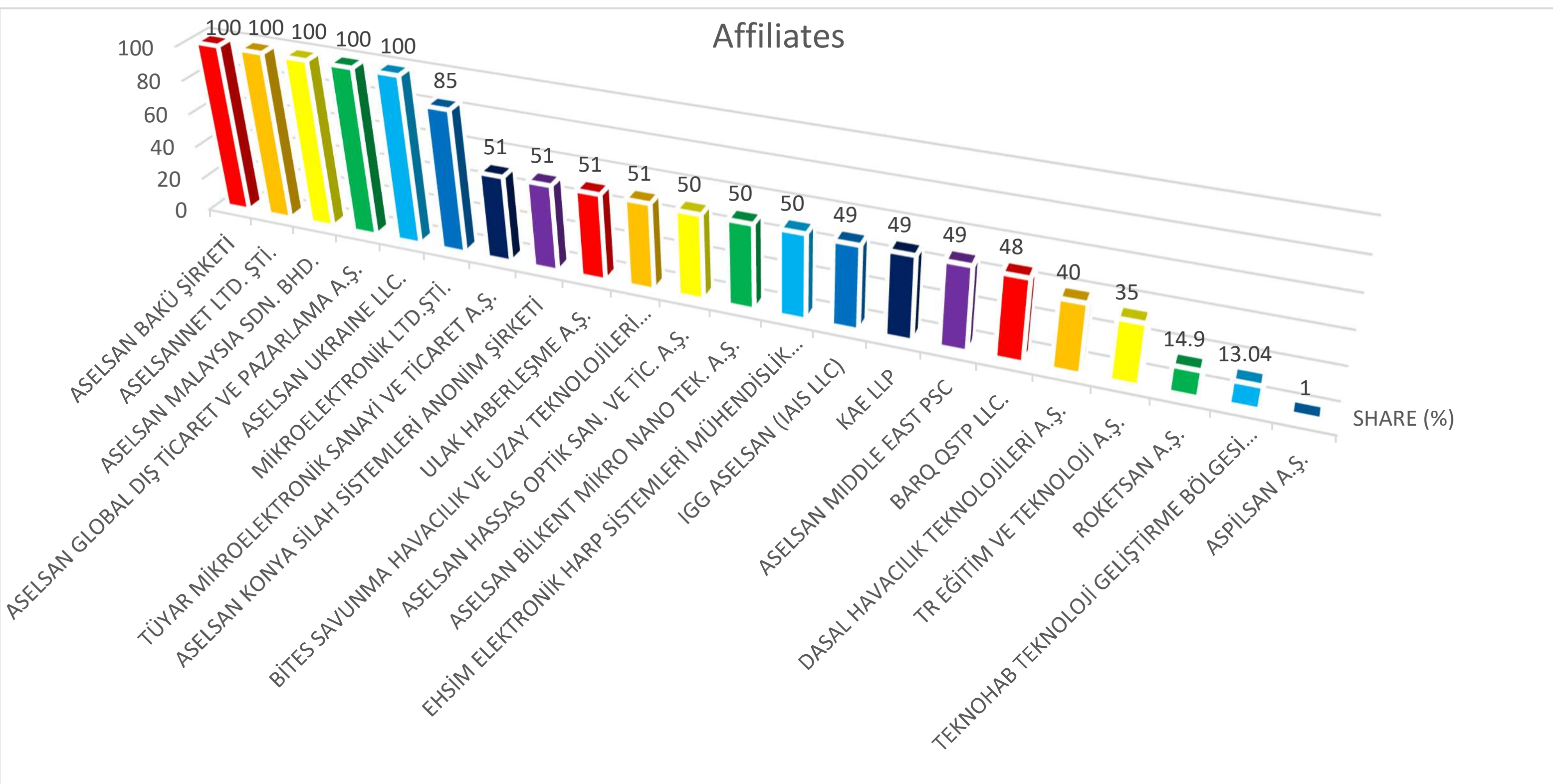


*Figure 6: Affiliates of ASELSAN*

# 3. PASSIVE GEOLOCATION FOR ELECTRONIC SUPPORT SYSTEMS

As I mentioned before, I developed a MATLAB code to simulate passive geolocation according to two technics namely the Weighted Instrumental Variables (WIV) Method and the Phase Difference Rate (PDR) Method. These technics were obtained from two articles shared in the references part. After applying the methods mentioned in the articles, I compared the performance results to see whose performance was better. Before going into details of the simulation and these two methods, I want to explain some simple concepts.

- Electronic Warfare

  Electronic warfare (EW) is the capability to sense, protect, and communicate via electromagnetic signals like radio, infrared, or radar. Also, it may be utilized to prevent attackers from disrupting or exploiting these signals.

  - Electronic Attack

    The offensive use of electromagnetic energy to attack enemy personnel, facilities, or equipment with the intent of degrading, neutralizing, or eliminating enemy combat capability, including human life, is known as Electronic attack (EA). This activity is most frequently referred to as "jamming" in the case of EM energy and can be conducted on communications systems or radar systems. Anti-radiation weapons frequently comprise missiles or bombs that can lock in on a single signal and follow that path directly to strike, destroying the system broadcasting.

  - Electronic Protection

    Electronic protection (EP) refers to actions taken to protect friendly forces such as personnel, facilities, and equipment from the effects of electromagnetic spectrum use that degrade, neutralize, or destroy friendly combat capability (EA). EP refers to a player's ability to beat EA.

  - Electronic Support

    Electronic Support (ES) or electronic support measures (ESM) are terms used in military telecommunications to describe a branch of electronic warfare that involves actions taken under the direct control of an operational commander to detect, intercept, identify, locate, record, and analyze sources of radiated electromagnetic energy for the purposes of immediate threat recognition.

    - What is Passive Listening?

      Passive listening is the use of electromagnetic spectrum to identify the locations, movements, velocities, fire powers, and the communications of the friendly and enemy units.

- What is Geolocation?

  Geolocation, also known as geopositioning and geotracking, is the technique of finding or estimating an object's geographic position.

In the military, passive listening systems are designed to find the location of the signal emitter (radar), and it's named "Passive Geolocation". Traditionally, the "Triangulation Method" is used for passive geolocation. In this method, the listener platform needs to listen to the electromagnetic spectrum for a while. Because the system can determine the emitter's direction with a single received signal; however, the range cannot be determined. Therefore, the system listens for a while and collects the direction information. Some time later, the system will detect the exact position by combining the found direction vectors.

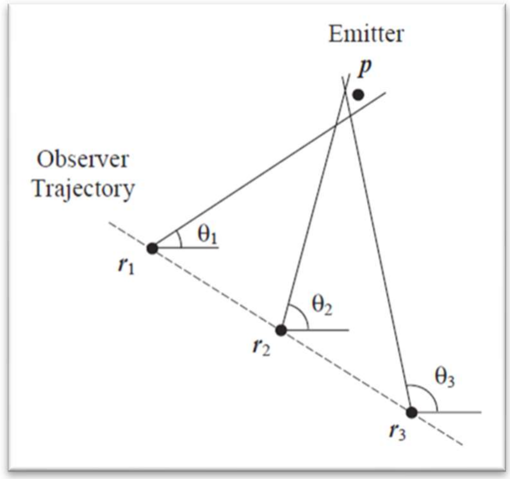


*Figure 7: Simple demonstration of triangulation method*

In the simulation scenario, a friendly fighter jet tries to estimate the position of an enemy radar emitter. It is assumed that the (vertical and horizontal) angles between them and the frequency of the received signal are known already. Proper noises are added to angles and frequency for calculations to be more realistic in which they are used. I assumed they are known and ready for calculations because, similarly, the vertical-horizontal angles and frequency can be easily found by analyzing the received radar signal.

So, the critical point for the friendly jet is to find the range to radar emitter. Because the received signal does not contain any information about the range. Let me explain the simulation before going into the details of the project.

## 3.1. SCENARIO & SIMULATION ENVIRONMENT

In the simulation, three of the MATLAB toolboxes are utilized:

- **Simulink 3D Animation Toolbox**

  Simulink 3D Animation connects Simulink models and MATLAB algorithms to virtual reality 3D graphics objects. During a desktop or real-time simulation, one may animate a virtual environment by altering its scale, location, rotation, and other object attributes. Collisions and other events in the virtual environment may also be detected and sent back into MATLAB and Simulink algorithms. Therefore, this toolbox is used to create our objects and animate them in the simulation.

- **Phase Array System Toolbox**

  Phased Array System Toolbox provides necessary tools such as apps and algorithms to develop and model sensor array and beamforming systems In medical imaging applications, radar, sonar, acoustic, and wireless communication. Active arrays, passive arrays, subarrays, and arbitrary shapes may all be modeled and analyzed. For beamforming and signal processing algorithm development, these arrays may broadcast and receive simulated signals. Therefore, this toolbox is used enemy radar to detect our friendly fighter jet's position.

```
%% Create a Virtual World from the Template

% CREATION OF WORLD
% bring up template
copyfile terrain.wrl terrain_copy.wrl;
myworld = vrworld('terrain_copy.wrl');
% open the virtual world
open(myworld); view(myworld);

%% Enemy Radar

% CREATION OF RADAR
% create a new Transform node, called "radar"
radar = vrnode(myworld, 'radar', 'Transform');
radar_inline = vrnode(radar, 'children',...
'radar_Inline', 'Inline');
radar_inline.url='Patriot.wrl';
% the model is appointed

% RADAR'S SPECIFICATIONS
xradar = 4000;
yradar = 230;
zradar = 10500;
    radar.scale = [25 25 25];
    radar.translation = [xradar yradar
```

*Figure 8: Creation of the world and the enemy radar using simulink 3d animation toolbox in matlab*

- **Communication Toolbox**

  Communications Toolbox includes methods and applications for communications system analysis, end-to-end simulation, design, and verification. Compose and simulate a physical layer model of a standard-based or custom-designed wireless communications system using toolbox methods like channel coding, modulation, MIMO, and OFDM. So, this toolbox is used for radar to analyze the returned signal.

  The last two toolboxes are only used for the radar application. Our objective is more close to analyzing the fighter jet's behavior with discussed two methods. So, for the electronic warfare part of the project, no toolbox is utilized.

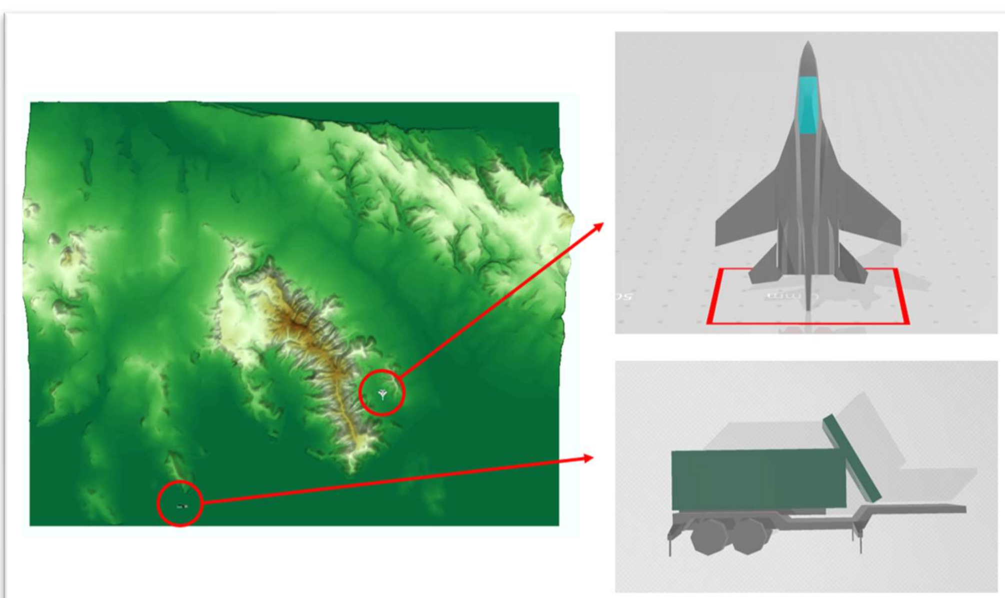

*Figure 9: The simulation world with the friendly fighter jet and the enemy radar*

As it can be understood from Figure 10, the friendly fighter jet follows the path in the direction of the z-axis. Its speed is adjusted to a constant 500km/hr. Also, both the jet and radar receive and send signals every one second, respectively. That is to say, the graphics, which will be shown in the following pages, are plotted with the data collected every one second.

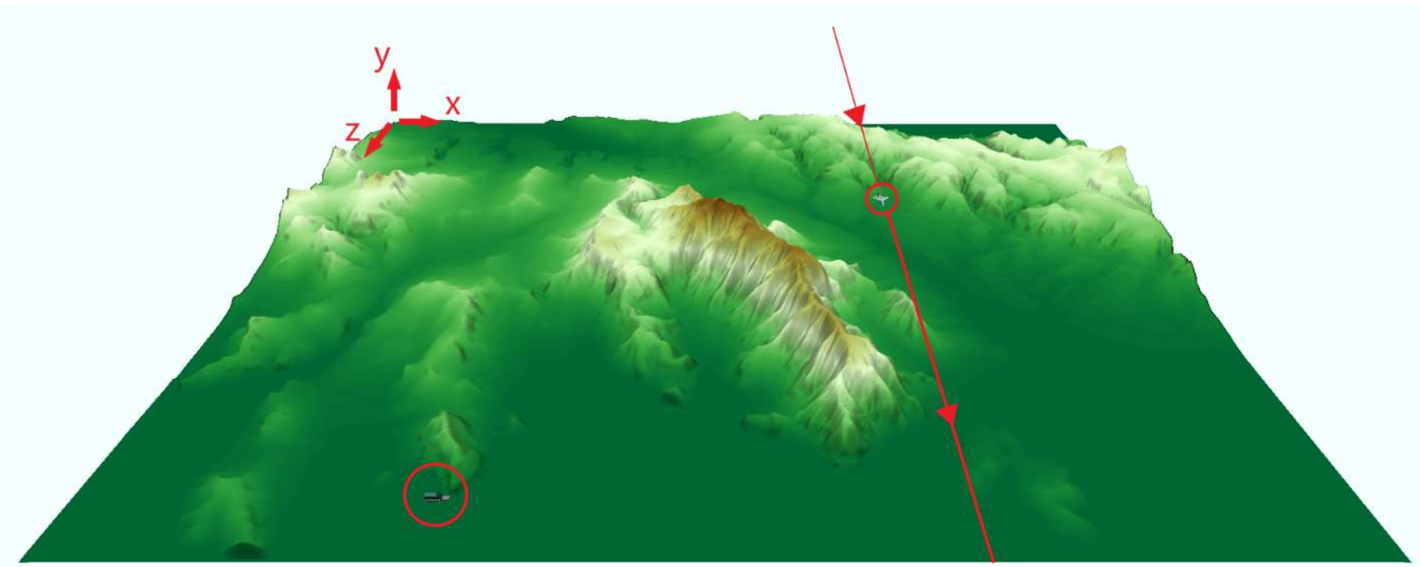


*Figure 10: A scene from the simulation shows; the axes of the simulation world, the enemy radar, the friendly fighter jet, and the path it follows.*

Also, the more detailed explanation of the scenario given in Figure 11 and Table 1. "$R_{first}$", "$R_{deviation}$" and "$R_{final}$" are first range, final range, and the distance of the emitter to the flight direction of the fighter jet, respectively. "$V_{platform}$" and "$h_{platform}$" are the speed and the altitude of the platform (fighter jet). Finally, "$h_{emitter}$" indicates the altitude of the signal emitter.

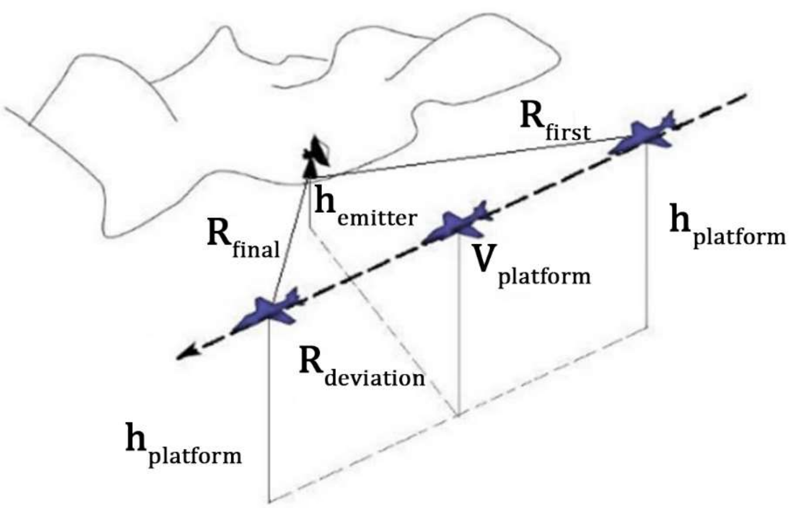


*Figure 11: Demonstration of the simulation with the necessary parameters signified*

| Parameter | Value |
|---|---|
| $R_{first}$ | 75 km |
| $R_{deviation}$ | 5 km |
| $R_{final}$ | 85 km |
| $V_{platform}$ | 500 km/h |
| $h_{platform}$ | 800 m |
| $h_{emitter}$ | 0 m |

*Table 1: The initialvalues of the necessary parameters*

## 3.2. PHASE DIFFERENCE RATE METHOD

The first method applied in the simulation for localization of emitter is the phase difference rate method. This method depends on the interferometry technic widely used in electronic support systems to extract direction information. In the stationary emitter and non-stationary passive listener platform scenario, the changing phase difference rate created by the incoming electromagnetic wave sent from the emitter includes the range information.

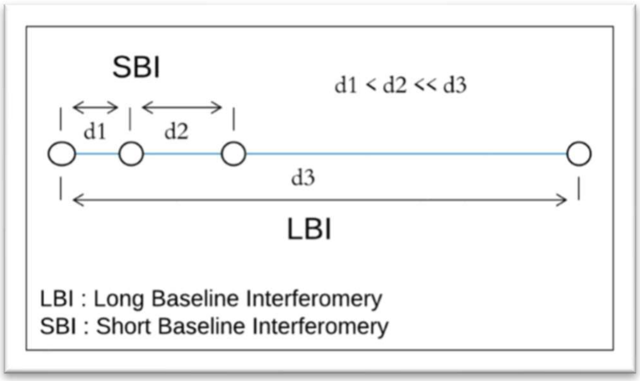


*Figure 12: Positioning of the antennas (LBI is the important one for our simulation)*

*Figure 13: Demonstration of the orientation of two antennas on a fighter jet*

Unlike the classical methods, there need to be two antennas to catch this phase difference rate and analyze it to extract range information. These antennas are generally placed around 3 meters apart on the wing of a fighter jet, as shown in Figure 13. The distance between two antennas has to be between the interval 100-500 wavelength; so that the method works properly and the results have the necessary sensitivity.

### 3.2.1. TECHNICAL DETAILS

Expressions of the method and variables used in these expressions have shown in Figure 14. "$\theta$" and "$\varphi$" are the horizontal and vertical angles between the signal emitter and the antennas, respectively. "$d$" and "$\theta_{ant}$" are distance and the angle between the antennas, "$r$" is the difference of the distances between antennas and signal emitter, "$b$" is the projection of this difference to the x-y axis, and "$a$" is the other side of the triangle that is created by this projection. With some mathematical manipulations, the phase difference rate "$\dot{\phi}$" and the range "$R$" can be found as follows:

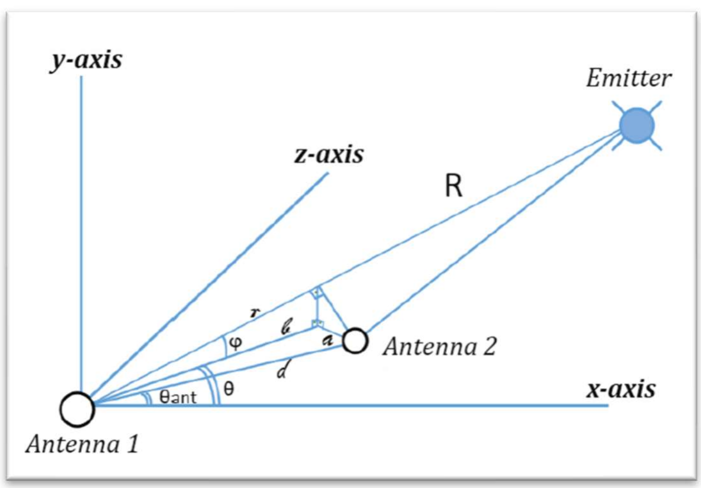


*Figure 14: The necessary variables with respect to the geometry of positioning of antennas and emitter*

$$\dot{\phi} = \frac{-2\pi f d}{c} \sin(\theta - \theta_{ant}) \cos\varphi\, \dot{\theta} + \frac{-2\pi f d}{c} \cos(\theta - \theta_{ant}) \sin\varphi\, \dot{\varphi}$$

```
%% PHASE DIFFERENCE RATE METHOD

    if i>1 %derivative of plane's position (velocity)
    v_xplane_dot(i) = K*(v_xplane(i)-v_xplane(i-1));
    v_yplane_dot(i) = K*(v_yplane(i)-v_yplane(i-1));
    v_zplane_dot(i) = K*(v_zplane(i)-v_zplane(i-1));
    end

    if i>1 %derivative of angles
    v_theta_w_n_dot(i) = K*(v_theta_w_n(i)-v_theta_w_n(i-1));
    v_theta_ant_dot(i) = K*(v_theta_ant(i)-v_theta_ant(i-1));
    v_alpha_w_n_dot(i) = K*(v_alpha_w_n(i)-v_alpha_w_n(i-1));
    end

    v_t_minus_tant(i) = v_theta_w_n(i)-v_theta_ant(i);
    v_phase_dif(i) = 2*pi*freq(i)*d*cosd(v_t_minus_tant(i))*cosd(v_alpha_w_n(i))/c ;
    if i>1 %derivative of PHASE DIFFERENCE
         v_phase_dif_dot(i) = K*(v_phase_dif(i)-v_phase_dif(i-1));
    end
```

*Figure 15: Application of the Phase Difference Rate Method in MATLAB*

As shown in Figure 15, necessary parameters have been found, such as derivatives of the positions (velocities), derivatives of angles, phase difference, and most importantly, its derivative (phase difference rate), by implementing a simple MATLAB code.

$$R = \left[\frac{-2\pi f d}{c\dot{\phi}} \sin(\theta - \theta_{ant})\, (-\dot{y})\cos\theta\right] - \left[\frac{-2\pi f d}{c\dot{\phi}} \sin(\theta - \theta_{ant})\, (-\dot{x})\sin\theta\right] + \left[\frac{-2\pi f d}{c\dot{\phi}} \cos(\theta - \theta_{ant})\, \sin\varphi\, (-\dot{z})\cos\right]$$
$$- \left[\frac{-2\pi f d}{c\dot{\phi}} \cos(\theta - \theta_{ant})\, \sin^2\varphi(-\dot{x})\cos\theta\right] - \left[\frac{-2\pi f d}{c\dot{\phi}} \cos(\theta - \theta_{ant})\, \sin^2\varphi(-\dot{y})\sin\theta\right]$$

```
%% Range Detected By Phase Difference Method

% The antennas estimate the radar positionusing phase difference method
    v_r_phase_dif = abs( (-2*pi*freq*d./(c*(v_phase_dif_dot))).*...
        (sind(v_t_minus_tant) .* (-v_zplane_dot ).*cosd(v_theta_w_n)...
        -sind(v_t_minus_tant) .* (-v_xplane_dot ).*sind(v_theta_w_n)...
        +cosd(v_t_minus_tant) .* sind(v_alpha_w_n) .* (-v_yplane_dot ).*cosd(v_alpha_w_n)...
        -cosd(v_t_minus_tant) .* sind(v_alpha_w_n).^2 .* (-v_xplane_dot ).*cosd(v_theta_w_n)...
        -cosd(v_t_minus_tant) .* sind(v_alpha_w_n).^2 .* (-v_zplane_dot ).*sind(v_theta_w_n)...
        ))  ;
```

*Figure 16: Range formula implementation to MATLAB*

Also, in Figure 16, the range formula given in the related article and shown above is implemented to MATLAB code.

### 3.2.2. PROCEDURE

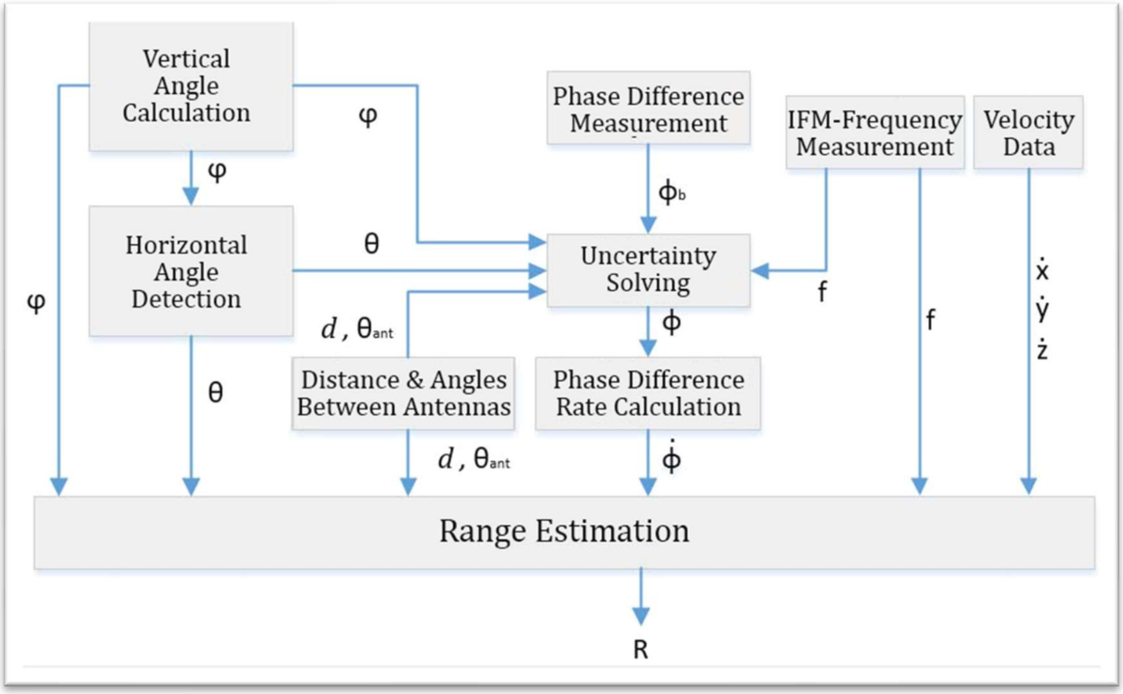


*Figure 17: The procedure table that is needed to be followed in PDR Method*

The necessary steps to apply this method is shown in Figure 17. So, to use this method efficiently, the following variables need to be known:

- The angles “$\theta$” and “$\varphi$” between the emitter and the antennas
- The distance “*d*” and the angle “$\theta_{ant}$” between antennas
- The phase difference rate “$\dot{\phi}$” between the signals arrived at antennas
- The frequency “*f*” of the received signal comes from the emitter.
- The velocity data “$\dot{x}, \dot{y}, \dot{z}$” of the platform on which antennas placed

Also, as mentioned before, real-like noises added in the estimation of angles and the frequency. These noises are created using Gaussian Distribution by the standard deviation expressions are as follows:

$$\sigma_{angle} = \frac{\lambda}{d|\cos{(angle)}|\pi\sqrt{10^{\frac{SNR}{10}}}} \qquad \sigma_{frequency} = \sqrt{\frac{6{f_s}^2}{4\pi^2(N^3 - N)10^{\frac{SNR}{10}}}}$$

The variables “*d*”, “SNR”, “$f_s$” and “N” are the distance between antennas, signal to noise ratio (which is a measure of comparison of the level of a signal to the level of undesired noise.), signal sampling frequency and the number of samples.

### 3.2.3. RESULT

The scenario has simulated for 800 seconds, and the result has shown in Figure 18.

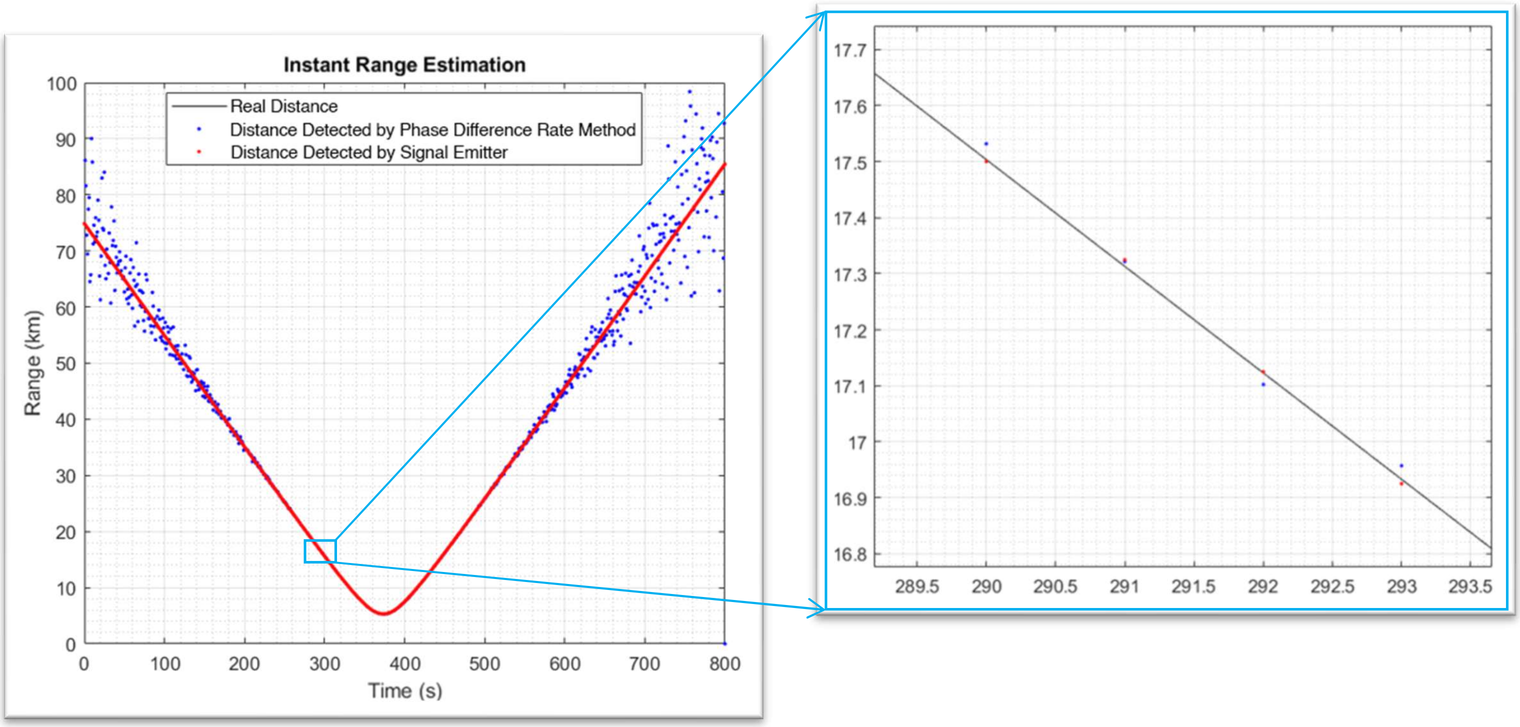


*Figure 18: The result of the simulation in which applied PDR Method*

In Figure 18, the black line is the actual distance between the fighter jet and the signal emitter. The red points are the distance detected by the enemy radar (signal emitter), and the blue points are the distance detected by fighter jet using the Phase Difference Rate Method. This graph shows that the fighter jet can detect the range with under 5 meters error when the distance is around 17 kilometers. It can be said that the method does not work correctly if the distance is higher than 17-18 kilometers, <u>as long as a filter is not used</u>. <u>Since no (Kalman or any other) filter is used in this simulation, it is hard to say if the method works correctly at higher distances.</u>

Also, unlike the classical triangulation method or the Weighted Instrumental Method, which will be discussed as the second method, the Phase Difference Rate Method has no memory. That is to say, a system (in this case, the fighter jet) that uses this method does not need to spend time on listening. At the moment the system starts to listen to the electromagnetic spectrum, the most accurate outcome has been obtained.

## 3.3. WEIGHTED INSTRUMENTAL VARIABLES METHOD

As discussed before, the triangulation technic is often used for passive geolocation. However, the classical methods based on triangulation technic need significant listening time to give accurate results. Since every second counts on the battlefield, the required time has to be decreased as much as possible. This situation is the reason for the development of the Weighted Instrumental Variables Method. This method also depends on the triangulation technic and has quite similar parts to the classical methods.

This method uses the predictions of the present parameters from past measurements to achieve uncorrelation between the measurements and the present bearing noise under the assumption of independent bearing noise. Neither of the classical algorithms has a closed-form solution because they rely on an iterative calculation of the instrumental variable matrix. Their convergence is also known to be very sensitive to initialization and the stepsize.

### 3.3.1. TECHNICAL DETAILS

As shown in Figure 19, some vectors are defined to be used in the WIV method's algorithm. The vector “p” indicates the position vector of the emitter (in our case, enemy radar), and the vector “r” shows the position vector of the platform performing passive listening (fighter jet).

As discussed above, the methods, which use triangulation have quite similar procedures. In this method, the system listens to the received signals for a while when changing its position. Then, the measurements are combined, and the position of the emitter estimated

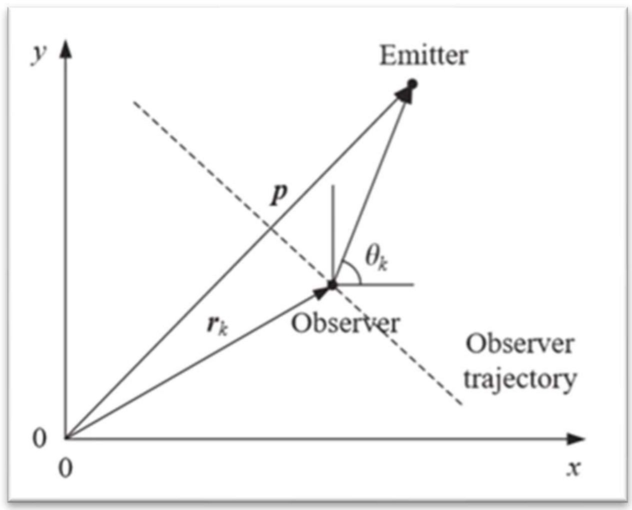


*Figure 19: Demonstration of necessary parameters for WIV Method*

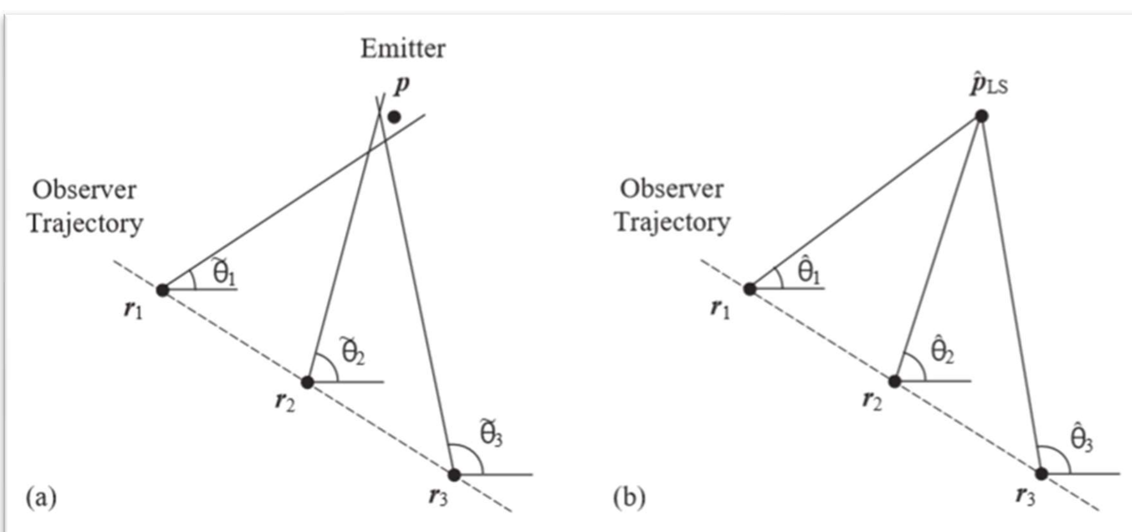


*Figure 20: Non-filtered and filtered results of the triangulation method*

```
%% WEIGHTED INSTRUMENTAL VARIABLES METHOD

%Necessary definitons and assignments
n_wiv(i) = v_theta_w_n(i) - v_theta(i);
r_wiv(i,1) = ant1.translation_abs(1);
r_wiv(i,2) = ant1.translation_abs(3);
a_wiv(1,i) = sind(v_theta_w_n(i));
a_wiv(2,i) = -cosd(v_theta_w_n(i));
s_wiv(i,1) = (xradar-ant1.translation_abs(1));
s_wiv(i,2) = (zradar-ant1.translation_abs(3));
d_wiv_old(i) = sqrt(s_wiv(i,1)^2 + s_wiv(i,2)^2);
e_wiv(i,:) = d_wiv_old(i)*sind(n_wiv(i)*a_wiv(:,i));

nn(i) = d_wiv_old(i)*sind(n_wiv(i));

if i==1
A_N = [(a_wiv(:,i).')];
b_N = [(a_wiv(:,i).')*r_wiv(i,:).'];
else
A_N = [A_N; (a_wiv(:,i).')];
b_N = [b_N; (a_wiv(:,i).')*r_wiv(i,:).'];
end

p_LS(:,i) = inv((A_N.')*A_N)*(A_N.')*b_N;
% v_theta_w_n(i) = atand(( p_LS(i,2) - planetranslation3 )/( p_LS(i,1) - planetranslation1 ));
d_wiv(i) = sqrt((p_LS(1,i)- r_wiv(i,1) )^2 + (p_LS(2,i)- r_wiv(i,2) )^2);

if i==1
G_N = [sind(v_theta_w_n(i)),cosd(v_theta_w_n(i))];
else
G_N = [G_N;sind(v_theta_w_n(i)),cosd(v_theta_w_n(i))];
end

W(i,i) = d_wiv(i)^2*s_d_angle2(i)^2;
p_wiv(:,i) = inv((G_N.')*inv(W)*A_N) * (G_N.') * inv(W)*b_N;

    if N+1>i
% distance calculation by least square method
v_r_ls(i+1) =sqrt((p_LS(1,i)-ant1.translation_abs(1))^2+(p_LS(2,i)-
ant1.translation_abs(3))^2+(yradar-ant1.translation_abs(2))^2);
% distance calculation by least weighted instrumental variables
v_r_wiv(i+1) = sqrt((p_wiv(1,i)-ant1.translation_abs(1))^2+(p_wiv(2,i)-
ant1.translation_abs(3))^2+(yradar-ant1.translation_abs(2))^2);
     end
```

Figure 21: Application of the Weighted Insturmental Variables Method in MATLAB

### 3.3.2. PROCEDURE

As simulation proceeds, it can be observed that the matrixes and the variables used in the method expand. The system stores new measurements in growing matrixes in every step and uses all that stored data in the following calculation.

The necessary expressions and the final formula of the step are given below:

$$\boldsymbol{a}_k = \begin{bmatrix} \sin\tilde{\theta}_k \\ -\cos\tilde{\theta}_k \end{bmatrix}$$

$$\boldsymbol{A}_N = \begin{bmatrix} \boldsymbol{a}_1^{\mathrm{T}} \\ \boldsymbol{a}_2^{\mathrm{T}} \\ \vdots \\ \boldsymbol{a}_N^{\mathrm{T}} \end{bmatrix}, \quad \boldsymbol{b}_N = \begin{bmatrix} \boldsymbol{a}_1^{\mathrm{T}}\boldsymbol{r}_1 \\ \boldsymbol{a}_2^{\mathrm{T}}\boldsymbol{r}_2 \\ \vdots \\ \boldsymbol{a}_N^{\mathrm{T}}\boldsymbol{r}_N \end{bmatrix}, \quad \boldsymbol{\eta}_N = \begin{bmatrix} \eta_1 \\ \eta_2 \\ \vdots \\ \eta_N \end{bmatrix}$$

$$\boldsymbol{G}_N = \begin{bmatrix} \boldsymbol{g}_1^{\mathrm{T}} \\ \boldsymbol{g}_2^{\mathrm{T}} \\ \vdots \\ \boldsymbol{g}_N^{\mathrm{T}} \end{bmatrix} = \begin{bmatrix} \sin\hat{\theta}_1 & -\cos\hat{\theta}_1 \\ \sin\hat{\theta}_2 & -\cos\hat{\theta}_2 \\ \vdots & \vdots \\ \sin\hat{\theta}_N & -\cos\hat{\theta}_N \end{bmatrix}$$

$$\boldsymbol{W} = \operatorname{diag}(\hat{d}_1^2\sigma_{n_1}^2, \ldots, \hat{d}_N^2\sigma_{n_N}^2),$$

$$\boxed{\hat{\boldsymbol{p}}_{\mathrm{WIV}} = (\boldsymbol{G}_N^{\mathrm{T}}\boldsymbol{W}^{-1}\boldsymbol{A}_N)^{-1}\boldsymbol{G}_N^{\mathrm{T}}\boldsymbol{W}^{-1}\boldsymbol{b}_N.}$$

Here is the definition of the variables:

- “$\theta$” is the ideal bearing angle. (In navigation, the horizontal angle between the direction of an object and another object is bearing.)
- “$\tilde{\theta}$” is the noise added bearing angle. (Necessary noises are explained on page 13)
- “$n$” is the bearing noise.
- “$\sigma^2$” is the variance used to create bearing noise. (Similarly, related expressions are on page 13)
- “$\eta$” is defined as “$\eta_k = d_k * \sin(n_k)$” and “$d_k$” is defined as “$d_k = ||s_k||_2$”. Finally, “$s_k$” is shown in Figure 22.

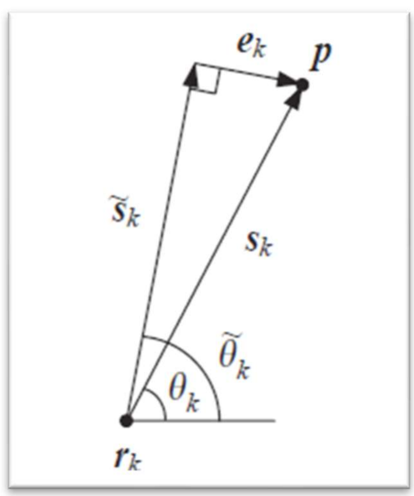


*Figure 22: The necessary variables’ definition*

### 3.3.3. RESULT

The results of the WIV Method simulation is shown on Figure 23.

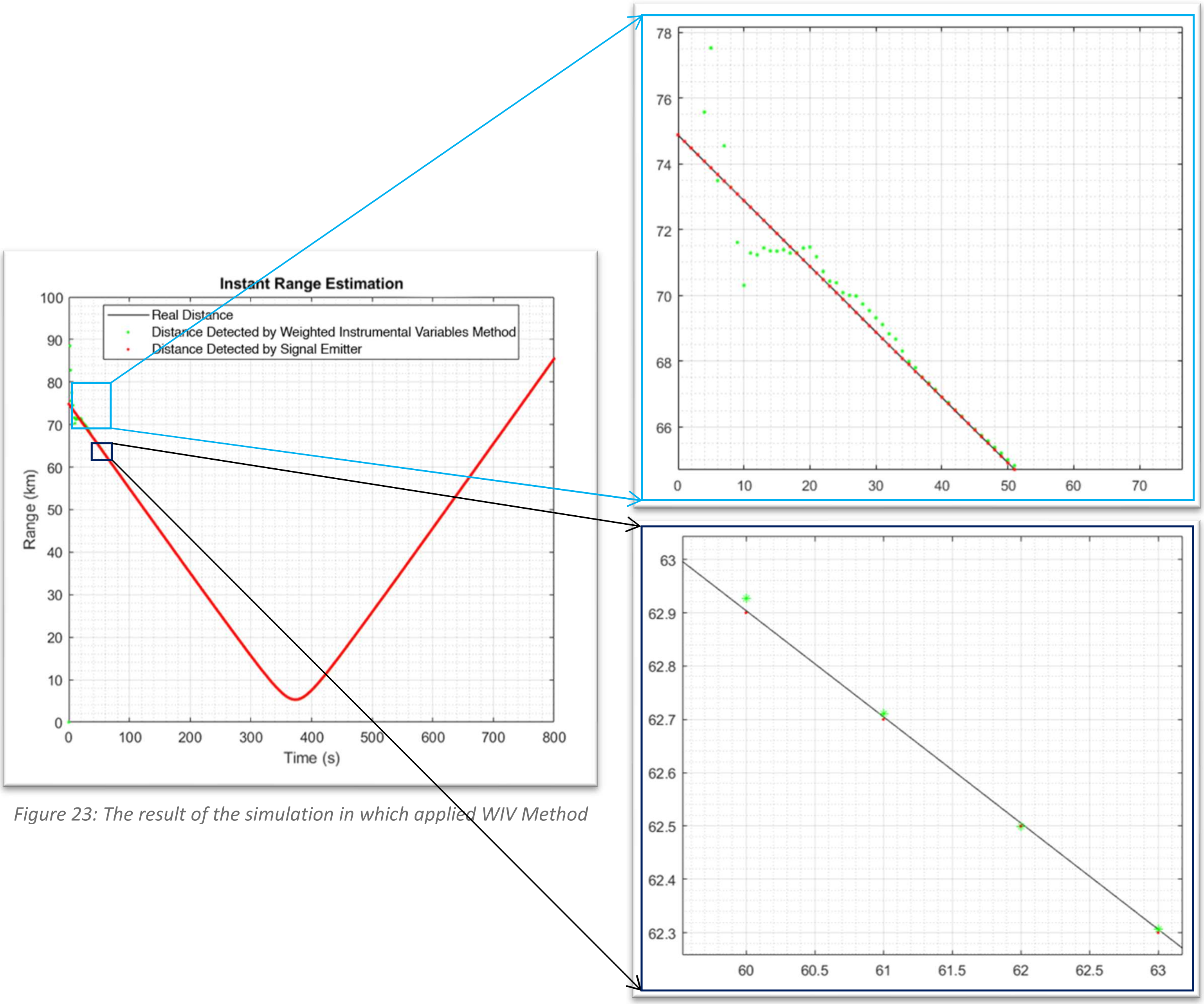


*Figure 23: The result of the simulation in which applied WIV Method*

As shown in the figure, the range estimation error drops under 20 meters in 60 seconds, even if the total time of the simulation is 800 seconds. This error is not directly related to the distance between the emitter and the listener because no extraordinary error is observed at the final moments of the simulation. Actually, the error is directly related to listening time. In the graph, many high errors are observed at the very beginning moments. However, as time passes and the listener platform gets enough data to localize emitter accurately; so, the estimated range converges to actual distance.

In reality, 60 seconds is significantly valuable time for military actions, and there exist much better applications that require a much lower amount of time. The simulation results in that amount of time because the sampling time is 1 second in simulation. As the sampling time decreases, the performance will increase obviously.

## 3.4. FINAL COMPARISON

For the comparison of tho methods, the combination of the Figures 18 and 23 is shown below as Figure 24.

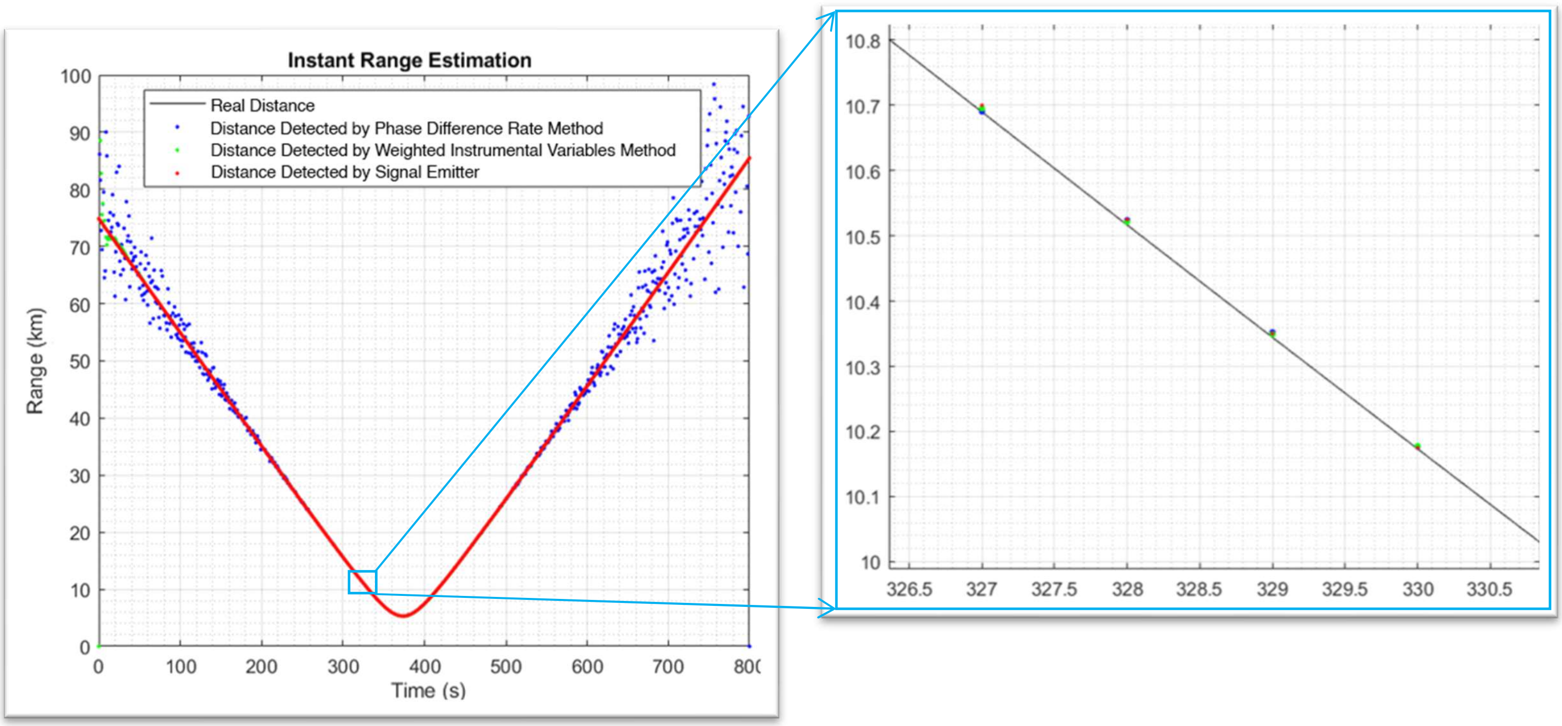


*Figure 24: The combination of the results of both PDR and WIV Methods*

Under certain conditions, both of the methods work correctly and give similar, accurate results. For the Phase Difference Rate Method, the listener platform needs to be close enough to the emitter, and for the Weighted Instrumental Variables Method, the listener platform needs enough listening time apart from the distance to give accurate results. That is to say; if the fighter jet has enough time to listen and is not close to enemy radar, the WIV method should be used; if the jet does not have enough time and it is too close to enemy radar, the PDR method should be used.

Finally, I need to re-express the absence of any filter. Since there is no filter applied to the resultant measurements, the above explanations may change in the existence of a filter. Especially in the PDR method, there are lots of noises for bigger distances to be suppressed with a Kalman filter preferably.

# 4. REFERENCES


- aselsan.com.tr/en
- en.wikipedia.org/wiki/Aselsan
- G. G. Gungor, A. Orduyilmaz, and M. Serin, "Passive geolocation using phase difference rate for electronic support systems, « presented at the 2018 26th Signal Processing and Communications Applications Conference (SIU), May 2018.
- K. Doğançay, "Passive emitter localization using weighted instrumental variables,« Signal Processing, vol. 84, no. 3, pp. 487-497, Mar. 2004.


# 5. APPENDICES

- The whole documentation of the project including the complete MATLAB code:
  - https://github.com/MB-Emektar/Comparison-of-Two-Passive-Geolocation-Methods