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EXPERIMENTAL INVESTIGATION OF RANGE MEASUREMENT ERROR FOR RADAR UNDER DIFFERENT WEATHER CONDITIONS

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Abstract

In this paper, the effect of different weather conditions on radar distance measurements was investigated experimentally. In current radar applications, the speed of the EM wave in the environment is accepted as the speed of light for distance measurements by radar. However, this speed varies in different weather conditions and is essential for sensitive radar applications. A radar system followed the target at a fixed distance to examine the changes in the speed of the EM wave due to the changes in the dielectric constant and conductivity parameters in different weather conditions. While measuring the distance, temperature, apparent temperature, relative humidity, and pressure were also recorded. Thus, erroneous distance measurements caused by air change could be detected. MLR, SVM, ANN, KNN and ANFIS models were used to estimate erroneous distance measurements caused by weather change. The results showed that the error in distance measurements could be estimated with great accuracy.

Key words: radar measurement, EM wave velocity, measurement error, error estimation, MLR, SVM, ANN, KNN, ANFIS

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Introduction. The electrical properties of the environment variables in different weather conditions are studied. The EM wave is affected by atmospheric gases, rain, clouds, fog, and free electrons [1]. For this reason, different velocity values can be observed while the EM wave propagates. In rainy weather, the EM wave propagating in the environment is absorbed and dispersed [2]. Absorption of the EM wave will cause attenuation and reduce the range in radar operations. It is known that the range drops by as much as 45% due to attenuation in rainy conditions [3]. In radar measurements, the raindrops' size also changes the EM wave's attenuation rate and thus the radar range [4]. Similarly, it is known that snowfall affects attenuation [5]. It is also known that the atmosphere affects the propagation of the EM wave. With the effect of the atmosphere, the wave's amplitude and speed decrease, and the wave is refracted [6]. The EM wave's propagation speed in the atmosphere is always lower than in a vacuum. Depending on the changing properties of temperature, atmospheric pressure, and relative humidity in the atmosphere, the EM wave travels slower while propagating. This effect also causes errors in radar distance measurements [7]. Atmospheric delays of the EM wave in different weather conditions can also cause malfunctions of GPS systems [8]. It is known that heavy snowfall causes high propagation delay in GPS systems [9]. The effects of precipitation are also present in the SAR images taken over the satellite, and these effects can be predicted and corrected [10]. EM waves propagating in the atmosphere are affected by the gases in the environment. Even a refractive index slightly greater than one causes a decrease in the speed of the wave. This increases the time it takes for the signal to reach the receiving antenna, increasing the equivalent path length [11]. For EM waves, the increase in the refractive property of the atmosphere leads to a decrease in the propagation velocity and the occurrence of distance measurement errors [12]. The propagation delay of EM waves is affected by meteorological changes. In addition to the temperature change, the variation of water vapour density and cloud amount with height also critically affects the propagation delay [13]. These effects cause a decrease in the propagation speed of the signal. Atmospheric refractive index, atmospheric temperature, atmospheric humidity, and pressure should be considered when calculating the EM wave's propagation delay [14].

Errors in radar distance measurements have great importance, especially for sensitive applications. In this study, the effect of weather conditions on radar distance measurements was investigated experimentally. Along with the distance data obtained from the radar, the temperature, apparent temperature, relative humidity, and pressure data were taken and recorded in the database. Weather change causes a change in the velocity of the EM wave, and a change in the velocity of the EM wave also changes the radar distance measurement. Thus, it is possible to predict the changes in radar distance measurement caused by weather changes via some techniques [15, 16]. Multilayer mesh structures for many different applications are widely used for artificial neural teaching. In this study MLR, SVM, ANN, KNN and ANFIS models were used to estimate error in radar distance measurement with respect to weather data. Weather parameters were used as inputs and radar measurement error was used as output in these techniques [17].

Materials and methods. According to the changes in the weather conditions, distance deviations occur in the radar measurement of the target at the fixed point. This is due to the variation of the velocity of the EM wave in different weather conditions. EM waves propagate at different velocities in environments with different electrical properties. In order to reveal how the distance deviations in radar measurements are affected by different weather conditions, an experimental setup was created with a radar system that performs continuous measurements. In radar distance calculations, the speed of the EM wave is taken as approximately 2.99792458×10^8 m/s, which is accepted as its speed in space. However, the speed of EM waves is theoretically expressed by the following equations in 3 different situations, lossless environment, low loss environment, and good conductors, according to the loss status of the environment.

For lossless environment ($\sigma = 0$):

$$u = \frac{1}{\sqrt{\mu \cdot \varepsilon}}. \tag{1}$$

For low loss environment $\left(\dfrac{\sigma}{\omega \cdot \varepsilon} \ll 1\right)$:

$$u = \frac{1}{\sqrt{\mu \cdot \varepsilon}} \left[1 - \frac{1}{8} \cdot \left(\frac{\sigma}{\omega \cdot \varepsilon}\right)^2\right]. \tag{2}$$

For good conductor environment $\left(\dfrac{\sigma}{\omega \cdot \varepsilon} \gg 1\right)$:

$$u = \sqrt{\frac{2 \cdot \omega}{\mu \cdot \sigma}}. \tag{3}$$

As can be seen from equations (1–3) the EM wave's speed depends on the environment's electrical properties. It is seen that the dielectric constant (ε_r) and intrinsic conductivity (σ) will affect the velocity (u) of the EM wave as parameters of the environment in the equations given by assuming that the magnetic permeability (μ) of the environment does not change. Accordingly, it is seen that the EM wave velocity, which must be used in radar distance measurements, changes according to the environmental conditions. Since the speed value used is kept constant in the radar systems in use while determining the position of the detected targets, measurement errors may occur, especially in adverse weather conditions. In order to investigate this problem, a radar system has been established that continuously records the measurement results taken from the fixed position target. The aim is to establish a relationship between the obtained measurement data and the weather data.

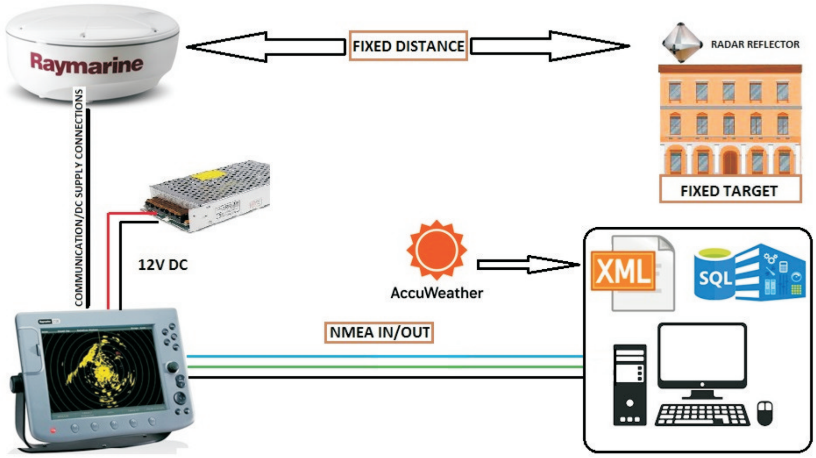

Fig. 1. Diagram of the experimental setup

Experimental setup. Experimental studies consist of two parts. In the first part, it is aimed to track a fixed target with radar. The distance values measured on the radar were obtained over the serial port via a developed PC application. The second part obtained weather data through the application developed with XML over AccuWeather. AccuWeather is an open-source XML application. Radar distance measurement values and weather data obtained simultaneously were saved on SQL server with the application developed on the C# program. The diagram of the performed experimental setup is shown in Fig. 1. In order to obtain a precise result, the system was operated so that the measurements were repeated every 2 minutes. As regards the installation of radar on roof of a building some measurement screenshots are given in Fig. 2.

(a) (b)

Fig. 2. Radar assembly and radar measurement screenshots. (a) Installation of the radar system; (b) Radar scan image of the tracked target and Marpa List created via TTM

Radar and computer connection was made with RS232 connection located on the back of the C120 display unit, which can send the desired data in NMEA format. The radar used has Target Tracking Mode (TTM) feature. With this feature, it was provided that the radar follows the target in a fixed position. Necessary adjustments were made on the C120 display unit, and the location information of the tracked target was sent to the computer in NMEA format. A USB-RS232 converter was used on the computer side to receive measured distance data. Thus, the data in NMEA format was obtained through a USB port on the computer. In the developed application, an interrupt was created on the COM port and the data was read.

The technical specifications of the radar (Raymarine RD218) used in the experimental setup are given in Table 1.

Table 1

Technical specifications of the radar used in the experimental setup

Transmitter	
Transmitter Frequency	9410 +/– 30 MHz Peak
Transmitter	Solid-state modulator driving Magnetron
Peak Power Output	4.0 kW (nominal)
Antenna	
Antenna Type	Patch array
Beam Width	4.5° horizontal, 25° vertical
Polarization	Horizontal
Rotation Rate	24 rpm (nominal)
Receiver	
IF Frequency	60 MHz (nominal)
Receiver Characteristic	Logarithmic
Receiver Noise Figure	Less than 5 dB
Receiver Bandwidth	12/3/0.7/0.5 MHz

Analyzing the recorded data. Distance measurement values made with radar and the weather data taken at the moment of measurement were recorded on the database. The measurements were taken on different days, and a total of dataset with 11223 instances was created. These data were taken from the database for analysis. Since the distance of the fixed position target to the radar (5440 m) is known, the error value was obtained by subtracting the actual value from the measured values. By using MLR, SVM, ANFIS, KNN and ANN models, they were provided to correlate the error values with the weather data. In order to make a more accurate analysis, the data was mixed before splitting. In order to make comparisons for the models, the same test data set used for all models were used.

Results and discussion. In this study, distance data were obtained from the radar on different days and examined. Weather data were also received simultaneously as each radar data was received. In the study, it was tried to estimate the errors in the distance measurements made with the radar over the weather data using MLR, SVM, ANFIS, KNN and ANN models. Temperature, relative humidity, apparent temperature, and pressure were used as weather data. 7900 out of 11223 data were used for training, and the remaining 3323 data were used as test data to complete for the all models. Error data was calculated by subtracting the actual distance from the radar range measurement of the target. While selecting the data set, attention was paid to take radar data, and weather data were wide enough to cover almost all seasons. The MAE, MAPE, RMSE and MSE values as a result of the analyses made with each method are shown in Table 2.

Table 2

Statistical result of SVM, MLR, ANFIS, KNN, ANN models

Parameter	MAE	MAPE (%)	RMSE	MSE
SVM	3.67	29.66	4.74	22.52
MLR	3.67	27.14	4.56	20.80
ANFIS	2.34	17.35	3.29	10.85
KNN7	1.22	7.80	2.22	4.93
KNN9	1.15	7.37	2.16	4.67
KNN11	1.26	7.97	2.33	5.44
KNN13	1.24	7.90	2.27	5.15
ANN	1.06	7.15	1.67	2.81

Comparing MLR, SVM, ANFIS, KNN, and ANN results. In this study, statistical calculations were carried out for MLR, SVM, ANFIS, KNN, and ANN models, and the results were revealed. When the RMSE and MAPE values are examined in Table 2, it is seen that SVM, MLR and ANFIS methods are much weaker than other methods. In the KNN method, it is seen that the KNN_9 method, which is calculated using 9 neighbourhoods, gives the most accurate result among the KNN calculations. However, it is clearly seen that ANN is the model that estimates the error most accurately, with a MAPE value of 7.15% among all methods.

In order to clearly see that the efficiency of the ANN model makes better error estimation than other models, the error estimation results and actual error values of each model for 50 randomly selected data are shown in the graphs given in Fig. 3.

Conclusion. In this study, experimental studies were carried out to accurately detect the target's position with radar even in adverse weather conditions. In this regard, the effects of weather conditions on distance measurement with radar were investigated. In the experimental setup, a target with a fixed position was continuously monitored by radar. At the same time, weather data (temperature, relative humidity, apparent temperature, and pressure) were recorded through an application developed. An error value was calculated by subtracting

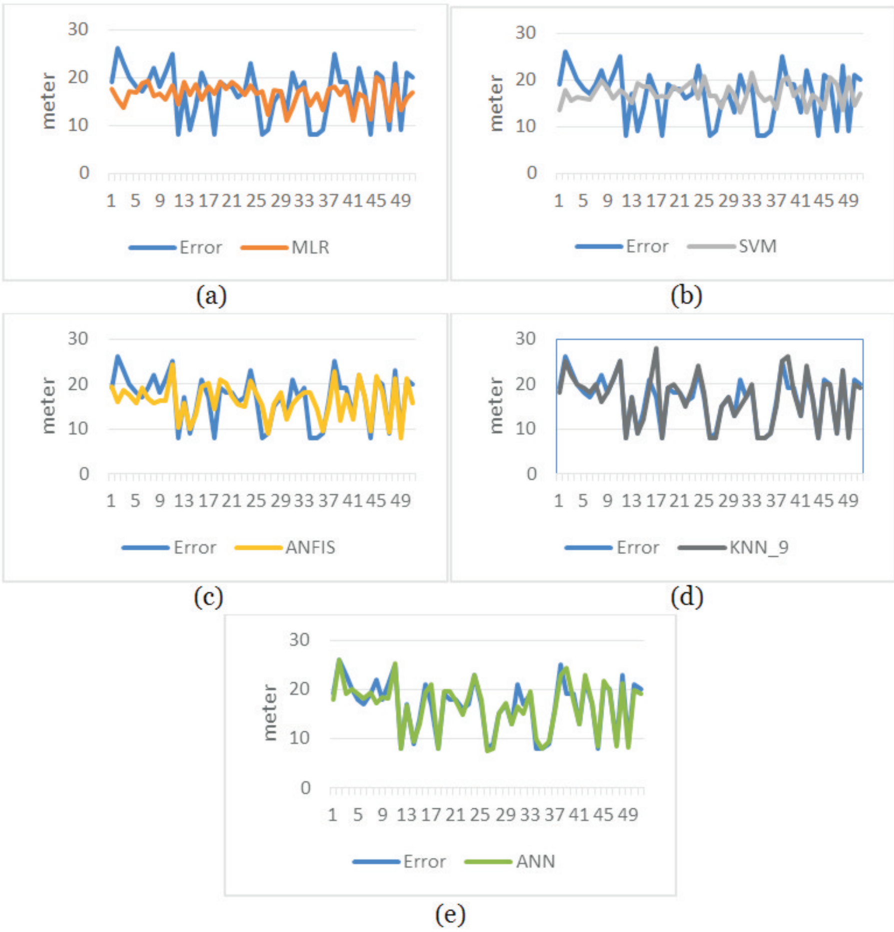

Fig. 3. Comparison of 50 randomly selected data with the results calculated with (a) MLR, (b) SVM, (c) ANFIS, (d) KNN_9, (e) ANN models, and actual error data

the actual distance value from the distance measurements made with the radar. Weather data was defined to MLR, SVM, ANFIS, KNN and ANN as input and actual error data as output. For all models 70% of the dataset are reserved for training and the remaining 30% for testing. Then, the error value was tried to be estimated according to the weather parameters. When the statistical results of the models are compared, it is seen that the ANN and KNN models give more accurate results than other models. For the KNN_9 (k value 9) model, MAE was calculated as 1.15 and MAPE as 7.37. For the ANN model, MAE was calculated as 1.06 and MAPE as 7.15. When the results are analyzed, the results of the ANN method and the KNN_9 method are very close to each other. However, with the ANN model, slightly more sensitive results are obtained than the KNN_9 model. It has been observed that error values can be mainly estimated with high accuracy with ANN. Thus, a method has been put forward to eliminate measurement errors that may occur due to weather conditions in radar applications. Thus, with this innovative approach, a method has been developed to obtain more accurate distance measurements for sensitive applications such as air defense systems and autonomous driving.

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