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Line of sight visibility analysis for foreign object debris detection system

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Line of sight visibility analysis for foreign object debris detection system

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Abstract. It is challenging to monitor busy airports' runway through visual inspection to precisely detect foreign object debris. Currently, many technologies for the detection of foreign object debris are available. It has been investigated that millimeter-wave radar technology's detection capability can be one of the most effective techniques for detecting foreign object debris as it is weather-resilient. However, the positioning and height of a millimeter-wave radar pole covering the runway area, considering the existing runway infrastructure, are challenging. The task involves finding the appropriate placement and optimum height. This paper presents a novel method of line of sight visibility for placement and height of radar pole using human factor research to ensure that each point on the runway is visible from various heights of the millimeter-wave radar pole to the runway locations. Kuala Lumpur International Airport, Malaysia runway 32L/14R, has used a case study to test the visibility analysis. The visual analytic test's successful results for different millimeter-wave radar pole locations and viewing heights under a visible and invisible line of sight conditions on the runway have been verified in the field experiment.

1.Introduction

Aviation accidents are a severe problem for the aviation industry due to increase in air traffic. According to International Civil Aviation Organization (ICAO), aviation accidents increased from 50 to 514 during 2017 to 2018. Based on accident data statistics, runway safety is in high-risk categories in the ICAO Global Flight Safety Plan [1-2] where one of its significant challenges is the detection and classification of runway debris or foreign object debris (FOD). FOD is defined as any debris or damage that can lead to aircraft accidents [3].

FOD costs aeronautics industry millions of dollars annually, including engine failures or airframes and indirect revenue costs (e.g., flight delay, cancellations, and additional work by employees). For safe airport operations, the runway must remain in a constant operation state. Regular inspection is an essential part of an aerodrome preventive and corrective maintenance program, intending to avoid any loose object or debris [4]. FOD risks can reduce by prevention, detection, and removal methods. Thus, an efficient system is required to ensure aircraft safety during landing and takeoff procedures [5].

Examples of existing FOD detection systems are Tarsier millimeter-wave radar, hybrid electro-optical millimeter-wave radar with video camera, intelligent high-resolution camera, and mobile vehicle-mounted millimeter-wave radar. These four FOD detection systems have tested and approved by the Federal Aviation Administration (FAA) [6]. These systems reported are capable of improved runway safety but require high investments. However, to resolve the cost problem, the millimeter-wave radar over fiber technique proposed by the researchers is a cost-effective solution to detect foreign object debris [7]. Millimetre-wave radar over fiber FOD detection system is currently under field trial. Runway closure isn't necessary during installation and maintainance of millimeter-wave radar over fiber system[8-9]. Location and height of radar poles are very important while placing milimeter-wave radar. According to the International Civil Aviation Organization (ICAO), human factor research and engineering encompass the ability of human vision and taking into account limitations, when the location and height of the tower is decided. For that, Federal Aviation Administration (FAA) has released the order 6480.4A for the control tower siting process. Visibility is an essential criterion to address the clear view of runways, taxiways, landing areas, and air traffic in the vicinity of airports [10]. An essential requirement for the visibility test is a line of sight (LOS) analysis from the tower height to the desired location.

One of the parameters for radar planning and propagation is line of sight (LOS) visibility to any FOD on the runway [11]. LOS visibility provides point-to-point information on visibility. Perfect visibility achieved when all the observation points can be seen from the viewpoint, as shown in figure 1. A LOS is a line between two points that shows parts of the surface along the visible path or hidden from an observer. The LOS test gives insight into whether a given location is visible from the observation point. Figure 1 illustrates the LOS experiment setup, which shows the viewpoint and the observation point. Note that the viewpoint can be set on the height of radar pole [12, 13]. The line of sight between viewpoint (P) and observation points(L) needs to test for obstructions, which might break the LOS.

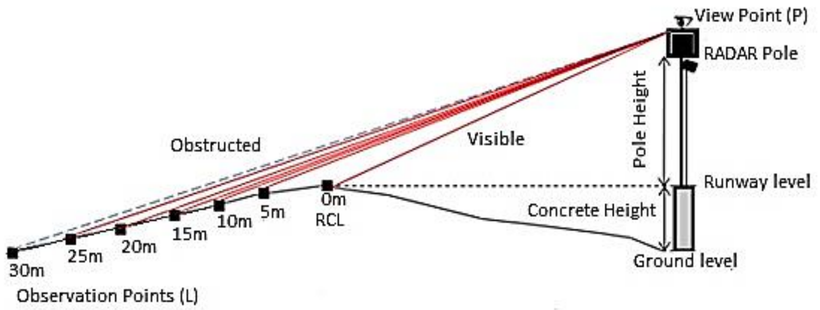


Figure 1: Line of sight visibility

It is substantial to evaluate the terrain data for radar over fiber network deployment. Therefore, site preparation is a necessary prerequisite before the installation of radar. This paper introduces a technique involving the human factor in checking the millimeter-wave radar pole visibility on the runway area to maximize the visible coverage area since it is a cost-saving process. The technique helps deploy the radar over the fiber network and develop the runway propagation model. This paper further divided into three sections. The visibility test method using the human component covered in Section 2. Section 3 analyzes the runway's experimental findings at Kuala Lumpur International Airport (KLIA) while paper concluded in section 4.

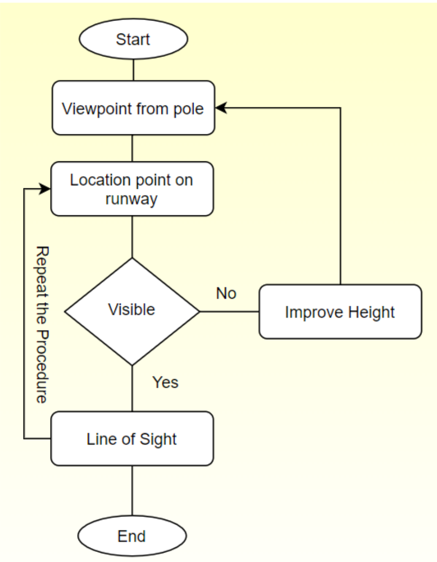
2. Experimental Method

Observers reported observations with healthy vision for the line of sight visibility test. To view the line of sight vision from the height of the millimeter-wave radar pole to the location points on the runway, the observer's eye is at the height of the millimeter-wave radar pole. The RAU (Remote Antenna Unit) is the name of the millimeter-wave radar pole. The millimetre wave's radar pole's height and location precalculated, as shown in Table 1 below. The height of the millimeter-wave radar pole in Table 1 is the maximum altitude, while in the experiment, Three positions are chosen with a 1m decrement in the height of the observer's eye.

Table 1: Millimeter-wave radar pole details

S. No	Millimeter-wave radar pole name	Longitude	Latitude	Height(m) (Maximum)	Runway Distance(m)
01	RAU 1-1	101.717772°	2.713078°	7.38	185
02	RAU 1-2	101.715242°	2.716817°	8.82	185
03	RAU 1-4	101.710186°	2.724300°	10.32	259.150
04	RAU 1-5	101.707661°	2.728042°	9.94	185
05	RAU 2-1	101.698089°	2.741208°	8.85	243.650
06	RAU 2-3	101.700130°	2.739319°	8.20	240.850
07	RAU 1-6	101.705269°	2.731872°	9.49	253.781

In this paper, the proposed approach discussed is composed of two parts.First establish viewpoints on the radar pole, and second plan the location points on the runway. Furthermore, figure 2 explains overall approach of case study. The first step involves setting the observer's eye height while the next phase is to set a precise location by placing flashlights on each location point on the runway. The visibility is observed if the observer eye on height can see a flashlight on location points. Initially, the minimum height of observer's eye is selected. The process is repeated with an increased height of 1 m until it reaches the maximum height of the observing eye on the radar pole.The detailed discussion of height and locations are described in following sections.



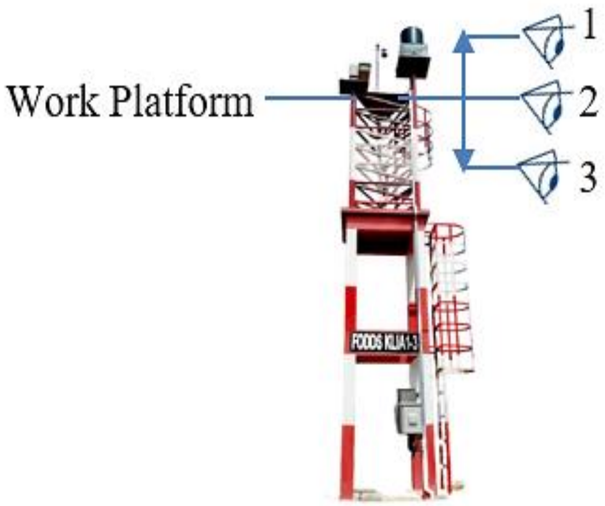


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Figure 2: Methodology of the experiment

Figure 3: View Points from different heights

2.1 Creation of viewpoints on radar pole

For millimeter-wave radar pole measurements, three positions were selected for the observer's eye. The reference point of these positions is the platform. Position one set to be 1 meter above the reference point, which is the maximum height, position two located on the reference point itself, and position three is 1 meter below the reference point, which is the minimum height, as shown in Figure 3.

2.2 Creation of Location points

Three main directions are labelled as Left (L), Centre (C), and Right (R), as shown in figure 4, selected for each radar pole. On these locations, seven different visibility observations with a difference of five meters have made to cover the runway from the centreline as shown in figure 5a and figure 5b. There are seven location points to be observed from a millimeter-wave radar pole to L, C, and R directions.

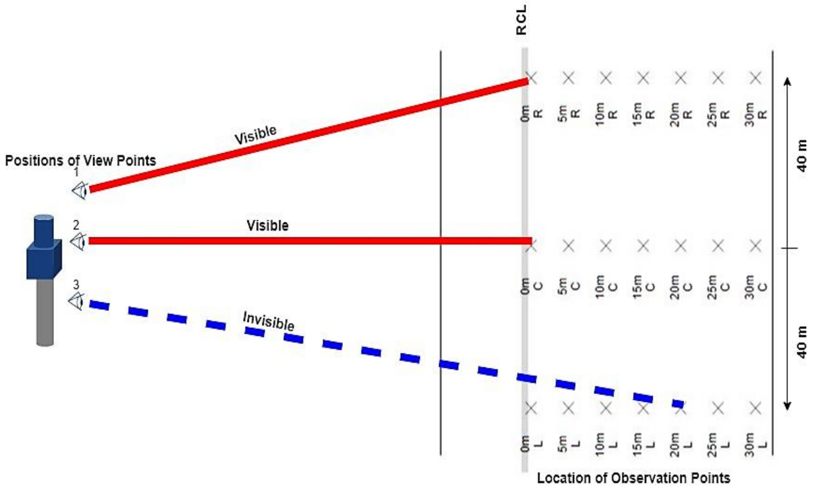


Figure 4: Location points on runway

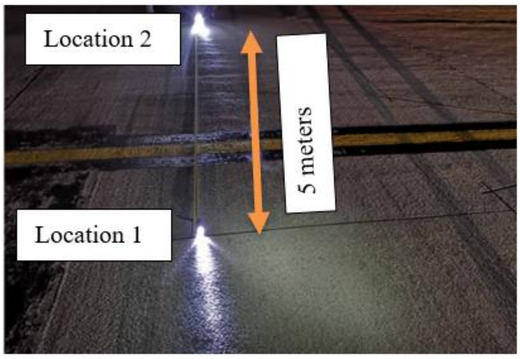


Figure 5a: Distance between two points

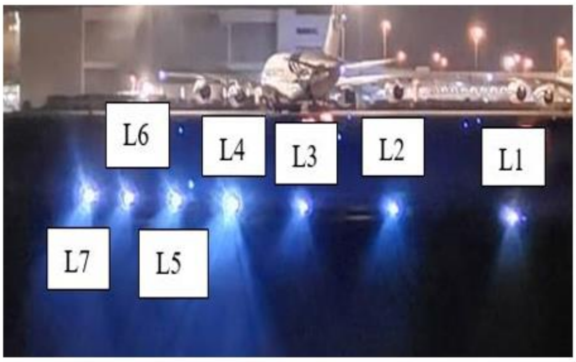


Figure 5b: Seven location points set on runway

Each direction has seven location points and three directions (L, C and R) that mean that a total of twenty-one observations have recorded for one millimeter-wave radar pole. A total of sixty-three (21 observations*3 observer eye heights) views can be recorded from the whole experiment during night time to check the visibility. The distance between the left and right directions is forty meters. It should note that LOS visibility may affect night time due to several factors that include the runway lights, illumination of surroundings, airport infrastructure, and dazzling effects.

3. Results and Discussion

This section presents a real-time visual study performed by a group of researchers at Kuala Lumpur International Airport (KLIA) runway 32L/14R. Seven millimeter-wave radar poles were chosen for visibility analysis. After data collection, the results are plotted using the Matlab 2020a software, and the descriptive statistics used to analyze the experimental visibility test data using IBM SPSS Statistics Software 26 to validate the method.

3.1. Visibility analysis of field experiment data

The purpose of the experiment is to examine visibility from the radar pole's height to the runway. As shown in the following figure 6, the overall observations were obtained from the different millimeter-wave radar pole heights to the location points on the runway plotted in Matlab 2020a. Three variables location points (x-axis), height (y-axis) and visibility (z-axis) are used to evaluate the experimental results. Observations were recorded against each point, starting from the runway centerline (L1=0 m) to the end, considering the width of runway (L7=30 m). For the state of visibility, '1' indicates the visible, and '0' indicates the invisible. At distinct location points, the colors of circles and asterisks represent the responses. The symbol "o" is the visible symbol, and "*" is the invisible symbol for the observed field data. The observed data from the experiment plotted as shown in figures 6a, 6b, and 6c.It has been notified from the following Figure 6a that all directions and all heights on the left side of millimeter-wave radar poles have 100% visibility.

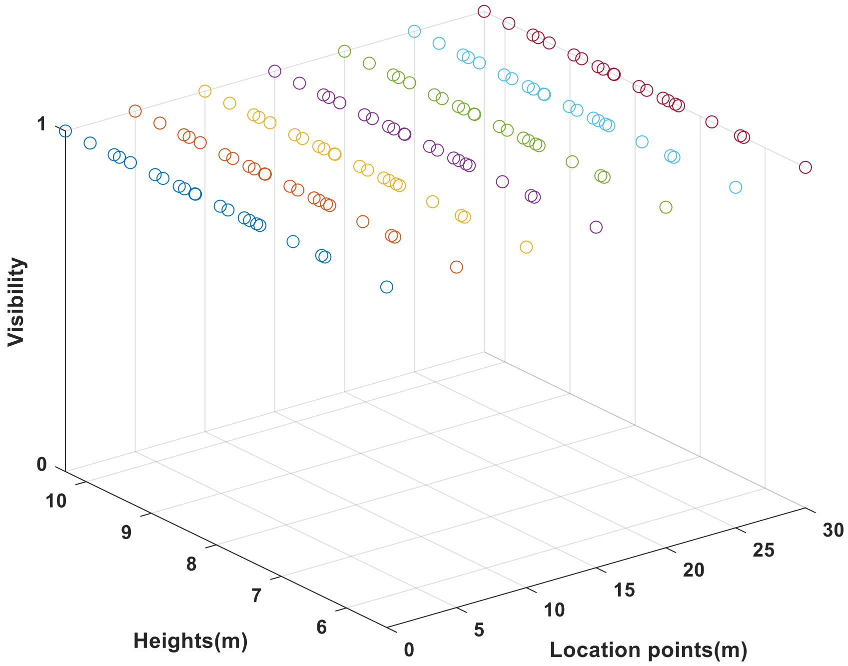
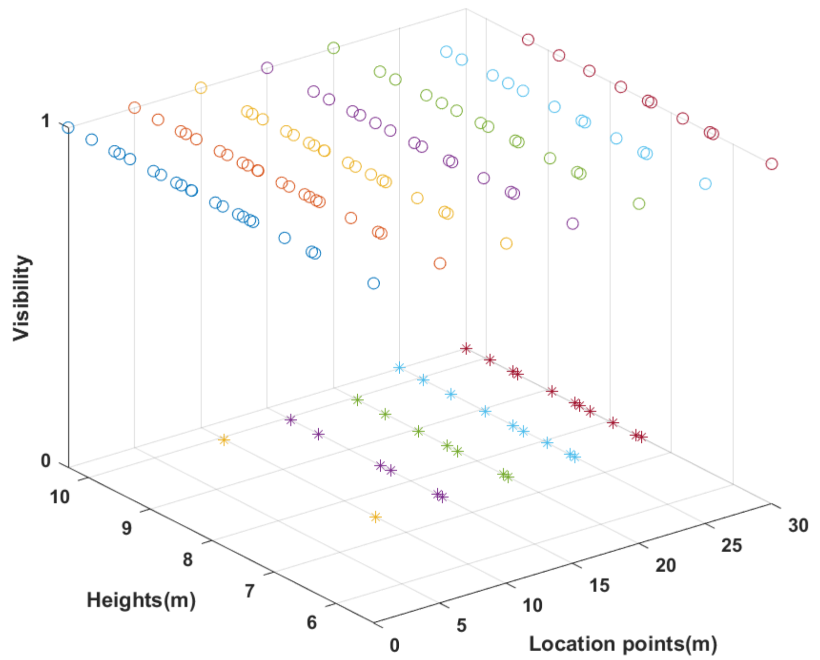


Figure 6a: Visibility for left directions of poles

In comparison, as shown in Figure 6b, visibility on the center direction of the millimeter-wave radar pole has begun to decrease from 10 m to 30 m (see Table 3 for Marginal Percentage). Nonetheless, Figure 6c, for the right direction, analyzed the maximum visibility only on location 0m, whereas on 5m,10m and 15m and 20 m have achieved a marginal percentage of 67%,38%,24%, and 14%, but 0% visibility on location 25m and 30m. In contrast with the left and center directions, millimeter-wave radar poles' right direction has more invisible points. It was discovered from the centre and right direction that visibility starts to decrease as distance increases. The findings of this study indicate that many factors affect visibility. One of them is the runway lighting system in which runway lights have different intensities, airport infrastructure is another significant reason, and 4^0 runway slope i These are the factors that may affect visibility condition.



Figur6b: Visibility for center directions of poles

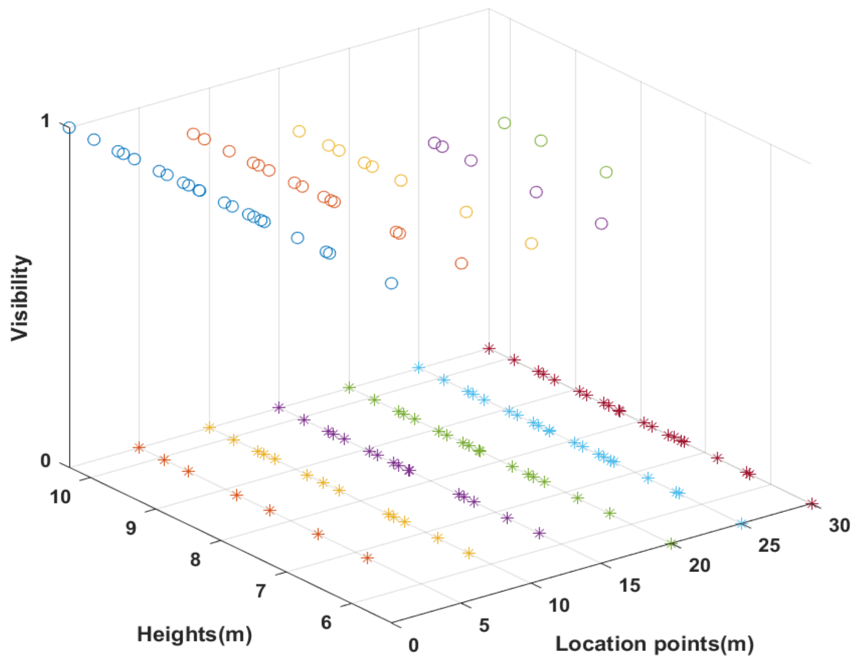


Figure 6c: Visibility for right directions of poles

3.2 Statistical analysis of experimental data

In the field of data analysis, descriptive statistics (mean, standard deviation, variance, and standard error) play a crucial role in interpreting and representing collected data in a meaningful manner[15]. There are 21 observations of the collected data from the LOS visibility test and three positions at the heights of seven millimeter-wave radar poles, tested on IBM SPSS software, and stated in the following tables. The visibility test's primary objective is to ensure the millimeter-wave radar pole's proper placement by observing the error at each point for each direction. The mean, variance, and standard deviation are required to calculate the standard error to perform the estimate for visibility analysis over the locations. An interpretation of descriptive statistics is given in Table 2; it is evident from Table 2 that 100% visibility on all location points was achieved. This ground-breaking finding implies that there is no standard error in each millimeter-wave radar pole's left direction.

Table 2: Descriptive Statistics for left direction

Location Points	Observations	Marginal Percentage	Minimum Statistic	Maximum Statistic	Sum Statistic(LOS)	Mean		Std. Deviation	Variance
						Statistic	Std. Error		
L1=0m	21	100%	1	1	21	1	0	0	0
L2=5m	21	100%	1	1	21	1	0	0	0
L3=10m	21	100%	1	1	21	1	0	0	0
L4=15m	21	100%	1	1	21	1	0	0	0
L5=20m	21	100%	1	1	21	1	0	0	0
L6=25m	21	100%	1	1	21	1	0	0	0
L7=30m	21	100%	1	1	21	1	0	0	0

The second set of analyses is the impact of the error in the center direction in Table 3. It shows that the standard error observed from location L3 (Std Error=0.066) to L7 (Std Error=0.112) affects visibility. Table 4 shows the outcome of the right directions, considering the locations. LOS has been disturbed from Location L2 (Std Error = 0.105) to L5 (Std Error = 0.078). Further statistical tests revealed that 0% of visibility was observed in Location L6 and L7. Therefore, the descriptive statistics for these locations did not show any LOS visibility values. Overall, these results indicate that experimental observations and descriptive statistical tests have been verified. The results can be improved by achieving 100% visibility in the center and right direction of the millimeter-wave radar pole. It may be possible to increase the radar pole's height or place the radar pole on either side of the runway.

Table 3: Descriptive Statistics for center direction

Location Points	Observation	Marginal Percentage	Minimum Statistic	Maximum Statistic	Sum Statistic(LOS	Mean		Std. Deviation	Variance
						Statistic	Std.		
L1=0m	21	100%	1	1	21	1	0	0	0
L2=5m	21	100%	1	1	21	1	0	0	0
L3=10m	21	90%	0	1	19	0.90	0.066	0.301	0.090
L4=15m	21	71%	0	1	15	0.71	0.101	0.463	0.214
L5=20m	21	67%	0	1	14	0.67	0.105	0.483	0.233
L6=25m	21	57%	0	1	12	0.57	0.111	0.507	0.257
L7=30m	21	52%	0	1	11	0.52	0.112	0.512	0.262

Table 4: Descriptive Statistics for right direction

Location Points	Observations	Marginal Percentage	Minimum Statistic	Maximum Statistic	Sum Statistic(LOS)	Mean		Std. Deviation	Variance
						Statistic	Std. Error		
L1=0m	21	100%	1	1	21	1.000	0	0	0.000
L2=5m	21	67%	0	1	14	0.67	0.105	0.483	0.233
L3=10m	21	38%	0	1	8	0.38	0.109	0.498	0.248
L4=15m	21	24%	0	1	5	0.24	0.095	0.436	0.190
L5=20m	21	14%	0	1	3	0.14	0.078	0.359	0.129
L6=25m	21	0%	0	0	0	0	0	0	0
L7=30m	21	0%	0	0	0	0	0	0	0

Conclusion

This study aims to determine the millimeter-wave radar pole's optimum height and location~~,~~ subject to the visibility and obstruction. A method for testing LOS visibility has been used in this paper. The method applied to Kuala Lumpur International Airport (KLIA) on its 32L/14R runway. An experienced team of experts carried out a visual analysis test at night for seven-millimeter radar poles. It has been shown that visibility determines the best possible location from the center of the runway ranging from 185 m to 260 m and the optimum height range from 7 m to 11 m. The method presented in this research plays an important role in determining the radar, antenna, camera, or watchtower's best location and height. This work can be further extended to a complex runway system to analyze the pole's height and exact location using airport surveillance and safety visibility test.

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