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Optimal Sensor Suite Selection for Helicopter Enhanced Vision in All-Weather-All-Environment Operation Using Multi Criteria Decision Making Techniques

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Abstract

Optimum sensor selection for helicopter enhanced vision in all-weather operations is a strategic issue and has a significant impact on safety, efficiency and utility of military and Emergency Service Helicopters. On the other hand, selecting the optimal sensor among many alternatives is a multi-criteria decision-making (MCDM) problem. The sensor selection task in this paper is modelled as a stepwise Analytic Hierarchy Process (AHP) to guide the selection process, based on criteria relating to environmental conditions (fog, rain, dust) and sensor characteristics (detection range, update rate, resolution). Result of this study reveals that a combination of millimeter wave radar, passive millimeter wave camera and infrared camera is the optimal suite having the highest value among all the alternatives considered. This result will guide decision makers at the Headquarters of the Nigerian Air force and indeed other helicopter operators in their quest to equip helicopters for operation in adverse weather conditions.

Keywords: Enhanced Vision, Helicopter, All weather operation, multicriteria decision making, Analytical Hierarchical Process, Sensors

1.0 INTRODUCTION

Hazardous weather and environmental conditions can significantly limit the operational capability of helicopters. Poor visibility creates service delays, which could be costly especially for helicopter Emergency Medical Services (EMS), military operations in complex environment as well as search and rescue operations. For example, Shuford and Anderson [1] examined the number of missed EMS flights due to weather for a six year period using Vanderbilt Life Flight, an EMS company, as a case study. They found that 24% of flight request were missed due to low clouds and poor visibility. They also estimated that another 10% might have been missed as a result of the failure by contacting agencies to request services under the assumption that the weather was too poor for flight.

Poor visibility also affects safe operations of helicopters as pilots usually use visual reference to determines control strategy during approach and touchdown. Thus, when visual reference is lost, the pilot may become unaware of the local terrain contour thus making it difficult to execute safe and stabilized wheel settling to the ground. Loss of visual reference also leads to spatial disorientation with a possibility of Controlled Flight into Terrain (CFIT) and obstacle. Consequently, realizing extended roles for helicopters in the future requires that helicopters operate in all-weather and in different operating conditions.

For efficient helicopter operation, knowledge of obstacle's presence, its position and likely future positions relative to the helicopter is imperative for timely avoidance action. Under clear weather conditions, it is possible for the pilot to extract this knowledge visually from the scene ahead of him. Alternatively, sensor information could be processed to determine the presence and location of the obstacles. However, under low visibility due to darkness or poor weather, the pilot's ability to perform this task unaided is degraded and the type of sensors that could be used is limited. Several sensors have been proposed to aid the pilot operate in poor visibility conditions. The selection of suitable sensors to fulfill the requirements of a given

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mission is a very crucial part of the design of any surveillance and enhanced vision system. A proper sensor selection for helicopter enhanced vision is a very important issue for air forces around the world as well as EMS as lack of enhanced vision system or improper selection could negatively affect overall performance and productivity of helicopter crew. Indeed, the Nigerian Airforce is desirous of equipping its helicopters with technology for day, night all weather operations. Considering the advantages and drawbacks of different sensor technologies, a suite of sensors, is needed for All-Weather-All-Environment (AWAE) operations. Sensor suite can simply be selected based on one’s experience and intuition. However, since this method is devoid of rigorous and robust analysis, it is highly subjective yielding invalid result in the face of complexity [2]. To overcome this drawback, researchers have resorted to the use of quantitative methods to evaluate the effectiveness of sensor systems against specified requirements. This may involve a study of the performance of individual sensors, as well as combinations of sensors [2].

Several methods have been developed for the selection of a suitable option from a list of alternatives. One method widely used by both researchers and practitioners in different areas of endeavor is the Multiple Criteria Decision Making (MCDM) approach. In a situation where several possible combinations of sensors are available, the application of MCDM approach provides a valuable tool to prioritize these combinations and select the most suitable solutions under a multidimensional framework. Several methods exist within the MCDM framework and as noted in [3], there is no better or worst method with methods depending on the task at hand. Some of the most popular methods include Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Organization, Rangement Et Synthese De Donnees Relationnelles (ORESTE) as well as Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE).

To illustrate, AHP technique was used to select suitable industrial wireless sensor network (IWSN) for manufacturing [4]. Similarly, selection of the best temperature sensor from among several alternatives for industrial application using the AHP was reported in [5]. In [6,7], an ANP based MCDM system was applied to the problem of selecting optimum cluster head for wireless sensor application. Their result show that the ANP method performs better than existing energy efficient method with respect to optimum cluster selection and reselection process minimization. The utilization of TOPSIS for cluster head selection in a wireless senor network was proposed in [8] while a combination of AHP and TOPSIS for the selection of the most suitable machine for industrial production is reported in [9]. De Leeneer and Pastijn [10] applied MCDM outranking approach based on ORESTE and PROMETHEE to the selection of best sensor combination for land mine detection. Sensors were characterized by the way their operation was altered in the presence of unfavorable environmental condition. Experiments using different electro-optics and radar sensors show that the MCDM approach could be used to select the best sensor for land mine detection. Dagdeviren et al; [11] proposed a weapon selection strategy using the AHP and the fuzzy TOPSIS methods. The authors reported that the combined AHP-Fuzzy TOPSIS MCDM approach led to a significant increase in the efficiency of decision making process in weapon selection. The ELECTRE III Method was used in [12] to select the best sensor for helicopter borne anti-submarine system for the Indonesian Air Force. A tool that enables customers determine the best digital cameras to meet their need based on certain criterial was reported in [13]. The tool uses a combination of AHP and TOPSIS to rank different options and select the most suitable option.

The MCDM approach is a well-known and implemented approach to decision making. While the literature reveals several uses of MCDM in sensor selection, to the best of our knowledge, its application to the domain of helicopter enhanced vision especially for AWAE operations is lacking. The main objective of this study therefore is to propose a systematic evaluation model to help the Nigerian Air Force and indeed other air forces as well as EMS helicopter operators in the selection of optimal sensor suite among a set of available alternatives. Optimum sensor selection is a MCDM problem where many criteria should be considered in decision-making. Consequently, the sensor selection task in this paper is modelled as a MCDM problem using the AHP framework. The rest of the paper is organized as follows. In Section 2 the helicopter enhanced vision environment and technologies are described. A brief description of the AHP based MCDM principles is given in Section 3. In Section 4, the application of the AHP method to helicopter AWAE sensor suite selection is presented and discussed while Section 5 concludes the study.

1.1 Helicopter Safe Flight Requirements

Part 135, section 135.205 (b) of the Federal Aviation Regulation states that “no person may operate a helicopter under Visual Flight rule (VFR) in Class G (uncontrolled) airspace at an altitude of 1,200 feet or less above the surface unless the visibility is at least 1/2 miles (about 800m) during daytime and 1 mile (about 1.6km) at night" [14, 15]. Furthermore, Section 135.207 states that "No person may operate a helicopter under VFR unless that person has visual surface reference or, at night, visual surface light reference, sufficient to safely control the helicopter". Therefore, operation under VFR requires adequate visibility and appropriate surface reference such as ground, ground light or horizon. Weather and operating environment reduces visibility which in turn affects the safety of helicopter operation. Poor visibilities due to weather conditions (e.g. fog, rain and snow) as well as poor visibility due to dust (brown-out) and snow (white-out) conditions adversely affect helicopter operation. Table 1 gives a definition of the various weather conditions and how they affect visibility.

Table 1: Various Weather Conditions and Their Effect on Visibility [16,17]

Effect	Description	Rate	Visibility (m)
Fog	Light fog	0.032 g/m^3	400 - 1000
	Moderate fog	0.05 g/m^3	200 - 400
	Thick fog	0.32 g/m^3	40 - 200
	Dense fog	2.8 g/m^3	< 40
Dust	Dust Storm	3.9 g/m^3	< 3
Snow	Light snow	0 – 1 mm/hr	> 1000
	Moderate snow	1 – 2.5 mm/hr	400 - 1000
	Heavy snow	> 2.5 mm/hr	0 - 400
Rain	Drizzle	0.25 mm/hr	
	Light rain	1 mm/hr	
	Moderate rain	4 mm/hr	
	Heavy rain	16 mm/hr	

Table 1 shows that fog, snow and dust significantly reduce visibility to the point where helicopter operation is prohibited. These conditions are further illustrated with Figure 1 which shows helicopter pilots degraded vision due to snow, fog and dust conditions.

Operating helicopter under reduced visibility occasioned by weather and operating environment requires sensors that would enhance the vision of the pilot in these conditions. These sensors would enable helicopters achieve AWAE capability. Consequently, AWAE capability connotes helicopters' ability to operate in different operating environment despite poor visibility due to weather (e.g. fog, rain and snow) as well as poor visibility due to dust (brown-out) and snow (white-out) conditions using sensor technologies.

(a) (b) (c)

Figure 1: Helicopter visibility in poor weather conditions (a) Whiteout due to snow (b) Foggy condition and (c) Brownout condition due to dust [18]

1.2 Candidate Sensor Technologies for Enhanced Vision in AWAE Operations

There are several kinds of active and passive sensors that operate in different bands of the Electromagnetic (EM) spectrum. Sensors in the visible, infrared and millimeter wave regions of the EM spectrum are affected by attenuation as shown in Figure 2.

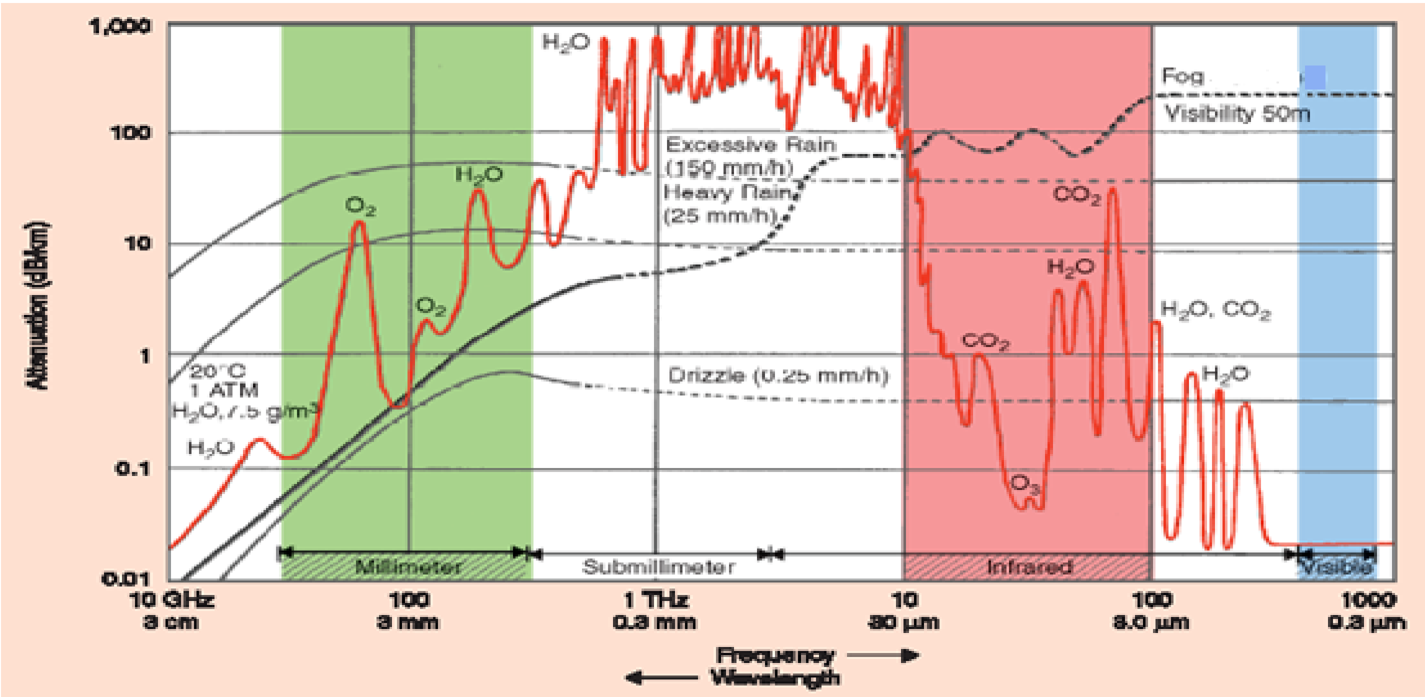

Figure 2: Attenuation in the EM spectrum at Different Weather Conditions [19]

These sensors, though available for helicopter AWAE operation has inherent drawbacks. For example, IR camera has excellent angular resolution but very poor weather penetrating capability, whereas mmW radar can operate in complex weather conditions but has low angular resolution and update rates. Characteristics of various sensors stating their advantages and disadvantages are summarized at Table 2.

Table 2: Summary of Sensor Characteristics [20- 23]

Sensor	Advantages	Disadvantages
Visible Camera	• Low cost and light weight • Best resolution imager • colour, texture and shape information available • Excellent revisit rate	• Daylight or artificial illumination required • no direct range information • Adversely affected by clouds, rain, fog, haze, dust, smoke and any other atmospheric obscurants
Infrared Camera	• Excellent revisit rate • Can operate both day and night • Can be processed to detect wires at any angle of incidence • Can determine object size and shape • Fine spatial and spectral resolution imagery	• Lower resolution and texture compared to visible camera • Do not provide range data directly • Degraded by atmospheric obscurants such as rain, fog, haze, dust and smoke • Suffer blooming effect • Poor foliage and cloud penetration
Laser	• Can operate both day and night • Fine spatial and spectral resolution imagery • Capable of wire detection at any angle of	• Bad at penetrating obscurants such as fog, dust and rain • Blinding in bright sunlight

Sensor	Advantages	Disadvantages
	incidence • Direct range and reflectance data available	• Poor foliage and cloud penetration • Poor revisit rate
MMW Radar	• Can operate both day and night • Range and image data available • High range resolution • Can penetrate obscurants such as fog, smoke, dust, snow and rain • Can penetrate foliage	• Poor angular resolution • difficult to detect thin wires at high AOA • Clutter variability is higher in comparison to the IR and visible cameras • Detection range is significantly reduced by rain greater than 16mm/hr
PMMW Camera	• Can operate both day and night • Clutter variability is much less in PMMW images than in other sensor images • Minimally affected by obscurants such as dust, fog, smoke and cloud • Can penetrate foliage	• Lower resolution compared with the IR camera • Range data not available directly • Detection range is reduced in the presence of heavy rain

2.0 METHOD

2.1 Analytic Hierarchy Process Principles

Five major principles define the AHP; hierarchy framework, Pair Wise Comparisons (PWC), relative weights derivation, consistency checking and synthesizing results [24].

Step 1 Hierarchy Construction: The first step in using the AHP is therefore to formulate the decision problem in the form of the hierarchy framework where the top level represents the goal or objective to be achieved, the criteria to use at the middle level, and the lowest level representing the alternatives.

Step 2 Pair Wise Comparison: Next is to determine the relative importance of two elements (pairs) using a scale that represents the values of a quantified judgement. This PWC of the criteria and alternative is a vital step and considered as a backbone of the AHP process. To achieve this, a nine-point scale as shown in Table 3 is utilized.

Table 3: Pair Wise comparison Scale [24]

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

The PWC judgments are recorded in a decision matrix in the form shown at Figure 3.

$$\mathbf{A} = \begin{bmatrix} \mathbf{a}_{11} & \mathbf{a}_{12} & \cdots & \mathbf{a}_{1n} \\ \mathbf{a}_{21} & \mathbf{a}_{22} & \cdots & \mathbf{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \mathbf{a}_{n1} & \mathbf{a}_{n2} & \cdots & \mathbf{a}_{nn} \end{bmatrix}.$$

Figure 3: *Pair Wise Comparison Matrix*

Where a_{ij} are the relative judgments between the two alternatives or criteria

$$a_{ij} = 1 \Leftrightarrow i = j \quad (1)$$

$$a_{ij} = \frac{1}{a_{ji}} \tag{2}$$

Step 3. Relative Weights Computation: In this step, the relative weights for each of the criteria/ sub criteria and alternatives are estimation. Approaches to estimate the relative weights abound in literature, this study however uses the Eigen values and eigenvectors method which provides a natural measure of consistency. A matrix shown in Figure 4 is therefore constructed using the following relationship

$$a_{ij} = \frac{w_i}{w_j} \tag{3}$$

C	A_1	A_2	A_3	.....	A_n
A_1	w_1/w_1	w_1/w_2	w_1/w_3	.....	w_1/w_n
A_2	w_2/w_1	w_2/w_2	w_2/w_3	.....	w_2/w_n
A_3	w_3/w_1	w_3/w_2	w_3/w_3	.....	w_3/w_n
,					,
A_n	w_n/w_1	w_n/w_2	w_n/w_3	.....	w_n/w_n

Figure 4: *Relative Weights Matrix*

The above matrix is normalized by dividing each individual column value by the column sum. Eigen vector (EV) is computed from equation (4), which represents the average value of each row.

$$EV_i = \frac{1}{n}\sum_{j=1}^{n} a_{ij} \quad where\ i = 1,2,3,\ldots\ldots,n \tag{4}$$

Step 4. Consistency Check: Consistency check involve calculating Consistency Measure (CM), Consistency Index (CI) and Consistency Ratio (CR). Figure (5) illustrates the steps in calculating the CM.
The CI is a measure of the degree or deviation of consistency is given by

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{5}$$

where $\lambda_{\max}$ is the maximum eigenvalue and n is the number of factors in the judgement matrix. Accordingly, the consistency ratio is defined as

$$CR = \frac{CI}{RI} \tag{6}$$

where RI denote the average consistency index over numerous random entries of same order reciprocal matrix. The PWC matrix and its associated eigenvector are considered acceptable if $CR \leq 0.1$ otherwise the judgement is revised until $CR \leq 0.1$.

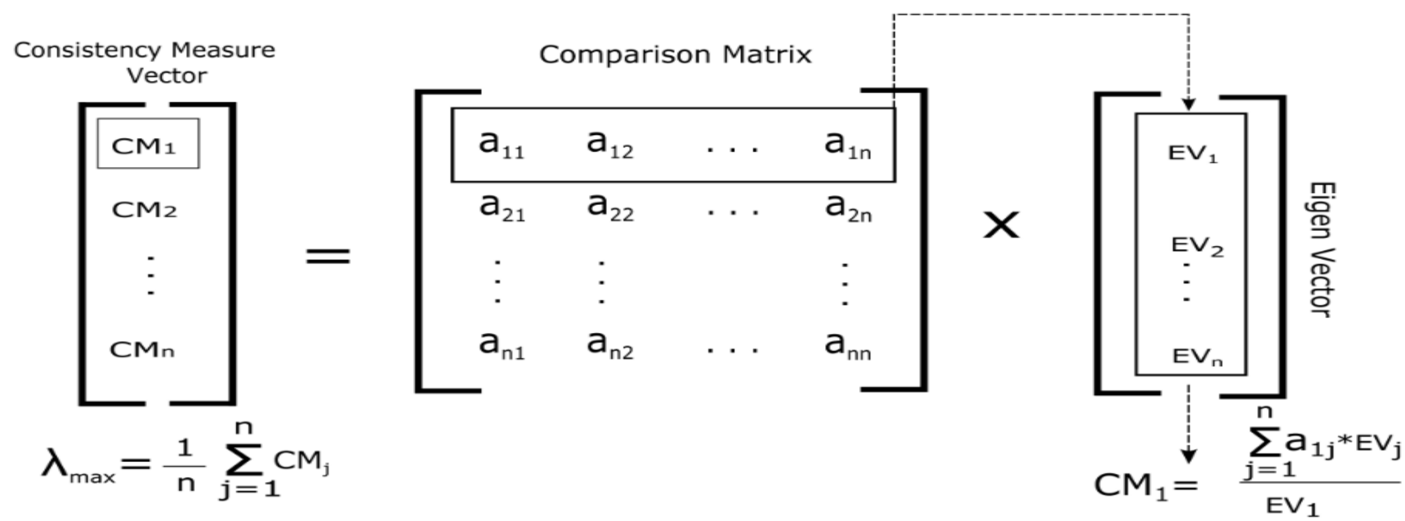

Figure 5: Consistency Measure Calculation [25]

Step 5. Result Synthesis: The relative values for each set of alternatives are summed to establish the overall score or criteria weight of each alternative. The normalized local Priority Vectors (PV) are obtained for both the criteria and alternatives. The PV from the normalized PWC of the selection criteria is multiplied by the PV obtained from normalized PWC of the alternatives with respect to the corresponding criteria. The same procedure is repeated for all the criteria and alternatives. The alternative with the highest value is chosen as the most suitable alternative.

3.0 RESULTS AND DISCUSSION

A case study is presented here to describe the AHP based sensor selection procedure. The purpose of this case study is to assess possible alternative sensor solutions for helicopter enhanced vision in AWAE conditions to help the decision-makers at the Nigerian Air force Headquarter in their desire to improve helicopter safety and efficiency in obstacle prone and complex environment. The AHP is applied to the selection of the optimum sensor suite for helicopter enhanced vision in AWAE operation. The flow chart of the sensor suite selection methodology is presented at Figure 6.

For this study, an expert team made up of researchers from the Air Force Research and Development Centre and the authors of this paper was formed. The expert team was then tasked with determining criteria that are considered crucial for an objective and unbiased decision on the subject matter. At the same time, the various options that need to be considered are also defined. The criteria are related to the weather and environmental conditions as well as sensor characteristics while the options relate to the assessed sensors either in standalone configuration or in combination. Additional to the environmental constraints already identified, additional requirements were identified to drive the correct selection of sensory hardware. Some of these requirements include minimum detection range, revisit rate and sensor resolution. Based on regulatory requirement, the expert team identified additional requirements shown in Table 4

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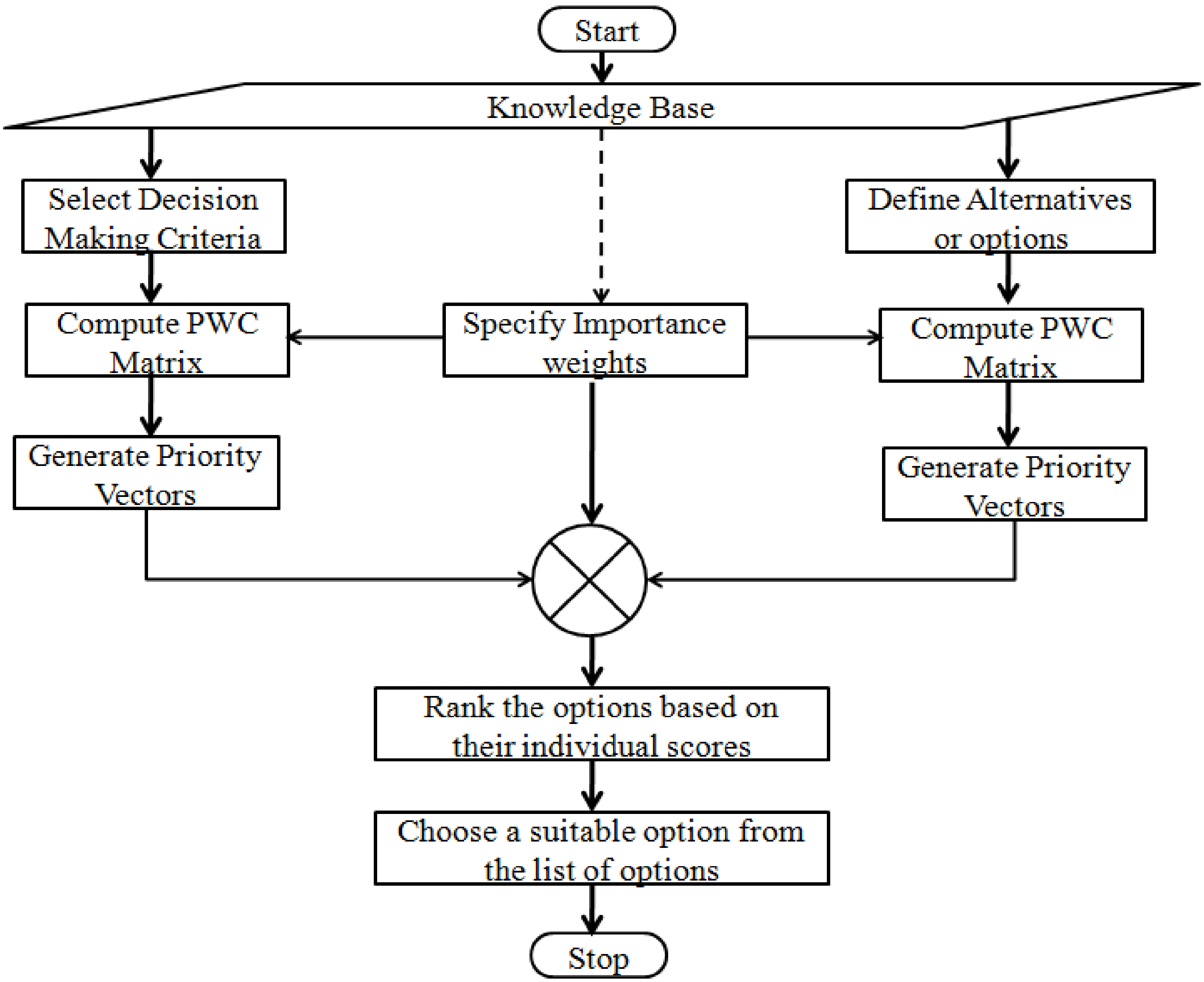

Figure 6: *Sensor Suite Selection Methodology*

Table 4: Additional requirement for Sensor Suite Selection

Parameters	***Values***
Minimum Detection Range	800 meters
Azimuth Angular Resolution	0.86 degrees
Elevation Angular Resolution	0.36 degrees
Revisit Rate	10 Hertz

The minimum range at which an obstacle should be detected in order to ensure safe avoidance crucial in defining the type of sensor and the sensor resolution needed for detection. Sensor update rate is necessary as sufficient number of observation is required before any decision is made to start obstacle avoidance maneuvers. Consequently, the criteria identified for the sensor suite selection problem are listed in Table 5.

Table 5: Sensor Suite Selection Criteria

Criteria	**Code**	**Attributes**
Day and night	DN	Basic criteria to be met by all sensors
Fog, smoke and Dust	FSD	Important criteria
Rain and snow	RS	Important criteria
Minimum Detection range	MDR	Very Important criteria
Resolution for hover and landing	R	Important criteria
Update Rate	UR	Important criteria
Cost, weight and volume	CWV	Important criteria

PCW is carried out with the Eigen values and eigenvectors calculated. The PWC matrix and its associated eigenvector are considered acceptable if $CR \leq 0.1$ otherwise the judgement is revised. Table 6 shows the pair-wise comparison matrix for the chosen criteria. A normalized pair-wise matrix is calculated by dividing each value by its column sum. For each pair-wise comparison, a priority vector is calculated. Priority vector is the normalized principal Eigen vectors obtained by averaging across the row of the matrix. Table 7 shows normalize PWC matrix for the chosen criteria together with the computed priority vector.

Table 6: Pair Wise Comparison of Selection Criteria

	DN	FSD	RS	MDR	R	UR	CWV
DN	1	1/3	1/3	1/5	1/4	3	3
FSD	3	1	1	1/3	1/3	4	4
RS	3	1	1	1/3	1/3	4	4
MDR	5	3	3	1	2	5	5
R	4	3	3	1/2	1	5	5
UR	1/3	1/4	1/4	1/5	1/5	1	1
CWV	1/3	1/4	1/4	1/5	1/5	1	1
Col Sum	16.67	8.83	8.83	2.77	4.35	23	23

$\lambda_{max} = 7.35$, RI = 1.32, CI = 0.044, CR = CI/RI = 0.033 < 0.1

Table 7: Normalized Pair-wise Comparison and priority vector

	DN	FSD	RS	MDR	R	UR	CWV	Priority Vector
DN	0.06	0.04	0.038	0.072	0.058	0.130	0.130	0.075
FSD	0.18	0.11	0.113	0.120	0.077	0.174	0.174	0.136
RS	0.18	0.11	0.113	0.120	0.077	0.174	0.174	0.136
MDR	0.30	0.34	0.34	0.361	0.463	0.217	0.217	0.320
R	0.24	0.34	0.34	0.181	0.232	0.217	0.217	0.252
UR	0.02	0.03	0.028	0.072	0.046	0.043	0.043	0.120
CWV	0.02	0.03	0.028	0.072	0.046	0.043	0.043	0.041
Col sum	1	1	1	1	1	1	1	1

Table 7 shows that minimum detection range (MDR) is the criteria with the highest importance (weight). Cost, volume and weight had the least weight of all the criteria. The PWC of the alternatives were carried out with respect to each of the criteria. Table 8 shows an example result with respect to day and night criteria.

Table 8: PWC of alternatives with respect to Day and Night Criteria

Day & Night	IR	LR	MM WR	PM MW	LR/IR	MMW R/IR	PMMW /MMW	MMW R/LR	MMWR /LR/IR	MMWR /LR/IR	MMWR /IR/PMMW	PMMW/ LR/IR
IR	1	3	1/3	1	1	1/3	1/3	1/3	1/3	1/3	1/3	1
LR	1/3	1	1/4	1/2	1/2	1/4	1/4	1/4	1/4	1/4	1/4	1/3
MMWR	3	4	1	2	3	1	1	1	1	1	1	2
PMMWR	1	2	0.5	1	2	1/4	1/4	1/2	½	1/2	1/2	1
LR/IR	1	2	1/3	1/2	1	1/3	1/4	1/3	1/3	1/3	1/3	1
MMWR/IR	3	4	1	2	3	1	1	1	1	1	1	2
PMMW/MMW	3	4	1	2	3	1	1	1	1	1	1	2
MMWR/LR	3	4	1	2	3	1	1	1	1	1	1	2
MMWR/LR/IR	3	4	1	2	3	1	1	1	1	1	1	2
MMWR/ IR/ PMMW	3	4	1	2	3	1	1	1	1	1	1	2
PMMW/LR/IR	2	3	0.5	1	1	0.5	0.5	0.5	5	0.5	0.5	1
Column sum	23.3	35	7.92	16	23.5	7.92	7.92	7.92	12.42	7.92	7.92	16.33

$\lambda_{max} = 11.8515$, RI = 1.49, CI = 0.057, CR = CI/RI = 0.038 < 0.1

Similarly, the normalised PWC matrix and PV of the alternatives with respect to Day and Night is shown in Table 9. The priority vector from the normalised pair wise comparison of the selection criteria is multiplied by the priority vector obtained from normalised pair wise comparison of the alternatives with respect to the corresponding criteria.

Table 9: Normalised Pair-wise Comparison and priority vector (Day and Night)

Day &Night	**IR**	**LR**	**MMWR**	**PMMW**	**LR/IR**	**MMWR /IR**	**PMMW /MMW**	**MWR /LR**	**MMWR/LR/IR**	**MMWR/ IR/ PMMW**	**PMMW/LR/IR**	**Priority Vector**
IR	0.043	0.086	0.042	0.063	0.043	0.042	0.042	0.027	0.042	0.042	0.061	0.048
LR	0.014	0.029	0.031	0.031	0.021	0.032	0.032	0.020	0.032	0.032	0.020	0.027
MMWR	0.129	0.114	0.126	0.125	0.128	0.126	0.126	0.081	0.126	0.126	0.122	0.121
PMMWR	0.0429	0.057	0.063	0.063	0.085	0.063	0.063	0.040	0.063	0.063	0.061	0.060
LR/IR	0.0429	0.057	0.042	0.031	0.043	0.042	0.042	0.027	0.042	0.042	0.061	0.043
MMWR/IR	0.129	0.114	0.126	0.125	0.128	0.126	0.126	0.081	0.126	0.126	0.122	0.121
PMMW /MMW	0.129	0.114	0.126	0.125	0.128	0.126	0.126	0.081	0.126	0.126	0.122	0.121
MMW/LR	0.129	0.114	0.126	0.125	0.128	0.126	0.126	0.081	0.126	0.126	0.122	0.121
MMWR/L R/IR	0.129	0.114	0.126	0.125	0.128	0.126	0.126	0.081	0.126	0.126	0.122	0.121
MMWR/ IR/PMMW	0.129	0.114	0.126	0.125	0.128	0.126	0.126	0.081	0.126	0.126	0.122	0.121
PMMW/LR /IR	0.086	0.086	0.063	0.063	0.043	0.063	0.063	0.0403	0.063	0.063	0.061	0.096
Column sum	1	1	1	1	1	1	1	1	1	1	1	1

For example, From Table 7, the priority vector for Day /Night is 0.075 and from Table 9, the priority vector for IR sensor is 0.048. Hence the IR score with respect to day and night criteria is

$$IR(DN) = 0.075 \times 0.048 = 0.0036$$

The same procedure is repeated for all the criteria and alternatives. The result obtained is summarized in Table 10

Table 10: Summary of Sensor Suite Selection Result

	Day Night	Fog Smoke Dust	Rain Snow	Min Detection Range	Resolution	Update Rate	Cost Weight and Volume	Total
IR	0.0036	0.0036	0.0038	0.0051	0.0119	0.0127	0.1121	0.1528
LR	0.0020	0.0026	0.0024	0.0453	0.0333	0.0041	0.0316	0.1214
MMWR	0.0091	0.0190	0.0179	0.0126	0.0069	0.0059	0.0544	0.1258
PMMWR	0.0045	0.0063	0.0092	0.0051	0.0119	0.0024	0.0127	0.0521
LR/IR	0.0032	0.0036	0.0038	0.0453	0.0333	0.0033	0.0305	0.1230
MMWR/IR	0.0091	0.0019	0.0179	0.0126	0.0107	0.0055	0.0539	0.1287
PMMW /MMW	0.0091	0.0019	0.0179	0.0126	0.0107	0.0013	0.0127	0.0832
MMW/LR	0.0091	0.0019	0.0179	0.0453	0.0333	0.0017	0.0351	0.1614
MMWR/LR/IR	0.0091	0.0019	0.0179	0.0453	0.0333	0.0016	0.0351	0.1613
MMWR/ IR/PMMW	0.0091	0.021	0.021	0.0453	0.0333	0.0017	0.0351	**0.1665**
PMMW /LR/IR	0.0072	0.0063	0.0092	0.0453	0.0333	0.0007	0.0124	0.1144

The values for each alternative are summed along the row to establish the overall score. A plot of the score normalized in percentage for each of the alternative is at Figure 7.

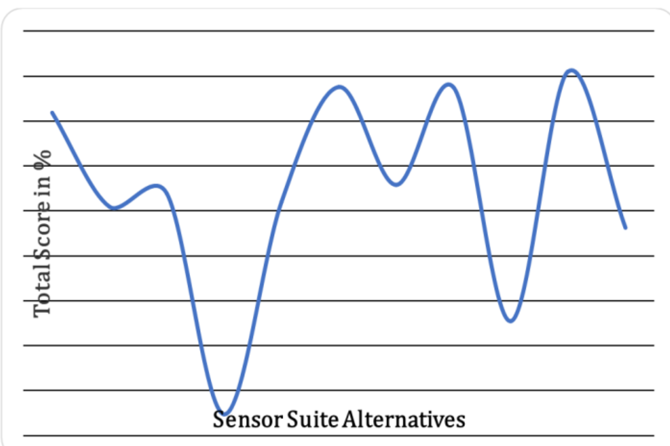

Figure 7: Sensor Suite Selection Result

The sensor suite with the highest value is considered as the optimum and most suitable alternative. The combination of mmW radar, PmmW camera and IR camera has the highest score and is therefore chosen as the most suitable alternative.

4.0 CONCLUSION

Optimum sensor selection for helicopter enhanced vision in AWAE condition is strategic issue and has significant impact on safety, operational efficiency and improved utilization of military and EMS helicopters. This paper presents a methodology for evaluating and selecting optimum sensor suite given several alternatives. The sensor selection task in this paper is modelled as a MCDM problem using the AHP framework. The result of this study reveals that a combination of mmW radar, PmmW camera and IR camera is the optimal suite having the highest value (0.1665 or 16.65%) among all the alternatives considered. Having achieved the objectives of the investigation, the study could be expanded to include effect of moisture and heat on the performance of individual sensor as helicopters operate in extreme weather environment.

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