

# Multi-Agent Information-Inferencing Fusion System for Decision Support System

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## ABSTRACT

*In this paper we address the utilization of multi-agent approach to an information-inferencing fusion system. Information-inferencing fusion is an emulation of the way human fuses information delivered by human sensing organs after observing a phenomenon in his/her environment. The fused information is used as the basis for making a decision or an action to face the current situation or anticipate the situation that can probably occur in the future. This human capability is then emulated to Multi-Agent Information-inferencing Fusion System (MAIIFS) based on A3S (Arwin-Adang-Aciek-Sembiring). From the results presented in this paper, the A3S method information-inferencing fusion method can deliver comprehensive information in a very quick manner so the decision maker can have situation awareness quicker. Therefore, he can to make the decision in accurate and quick manner.*

### Keywords:

*A3S, Decision Making Support, Information, Information-Inferencing Fusion, MAIIFS, Multi-Agent*

## 1.0 INTRODUCTION

An accurate and quick decision is a highly important matter in strategic organizations such as nation strategic industries or armed forces. An incorrect and prolonged decision especially if it relates to strategic matters, can cause loss not only materials but also personnel. Good decision can be obtained if the decision maker has good situation awareness and much knowledge regarding the matters that have to be decided. Those two things can be obtained by presenting the decision maker with comprehensive information that is collected by multiple information sources or we call it as information multi-source.

Of the ways for obtaining comprehensive information is by emulating the way human brain fuses or combines collected information delivered by human sensing organs. As we can observe in everyday life, human has many capabilities in solving complex problems. If he cannot solve the problem, he will ask other people for help. By cooperating, they can achieve the common objective in efficient and effective manner. If we treat each individual human as an agent equipped with information fusion capability, then the cooperation amongst agents to achieve a common goal creates a structure called **Multi-Agent Information-Inferencing Fusion System (MAIIFS)**. The agent's information fusion will be done by using **A3S (Arwin-Adang-Aciek-Sembiring)** information-inferencing fusion method.

The paper is started with Section I which covers the paper background and followed by Section II where we present some related theories regarding the proposed system. Section III covers the design and implementation of **MAIIFS Decision Support System (MAIIFS-DSS)** based on A3S information-inferencing fusion method. A simple example is given in Section IV. The paper converges in Section V with some concluding remarks.

## 2.0 THE CONCEPT OF INFORMATION FUSION AND MULTI-AGENT SYSTEM

### 2.1 Information Fusion Origin and Definition

The information fusion originates from the examination of how human can make a decision or an action in accurate and quick manner after having much information regarding a certain situation. Besides that, human can also predict or estimate the situation that is probably occurred in the future by combining recent information with his/her previous knowledge.

Human obtains much information from his/her sensing organs which comprises eyes, ears, nose, skin, and tongue. On the other hand, human also gains information from other information multi-source such as making communications with other people. After gathering information for multi-source, the brain does its job by fusing the information to become comprehensive information as the basis for decision making. This mechanism is called as human information fusion system and it is done continuously in human everyday life. This mechanism is depicted in Figure 1.

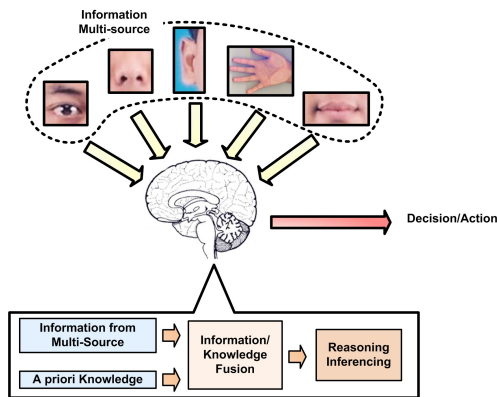


Figure 1: Human information fusion system [Sumari, 2008a]

Some early researchers prefer to use data fusion term rather than information fusion term, even though “information” word is included in the term itself. We use the definition issued by [US DoD, 2006] that defines information as (1) facts, data, or instructions in any medium or form; (2) the meaning that a human assigns to data by means of the known conventions used in their representation. By taking into consideration of how the human brain does information fusion, we define information fusion as a method of fusing multi-source information to become comprehensive information to predict or estimate an entity states. The entity in this case is the environment.

There are three matters that have to be apprehended at first place in designing and implementing an information fusion system. The three matters are selection to the most appropriate process model, selection to the most suitable architecture as well as its related method, and selection to the fusion class levels to be done in the system. Next, we will present a brief introduction to these three matters

### 2.1.1 Information Fusion Process Models

There are six process models that are commonly used for data/information fusion, namely intelligent cycle, Joint Director’s Laboratory (JDL), OODA or Boyd’s loop, waterfall, Dasarathy, Omnibus, and a new hybrid process model [Sumari & Ahmad, 2008]. Figure 2 depicts a hybrid

process model which combines the advantages of JDL and Dasarathy process models.

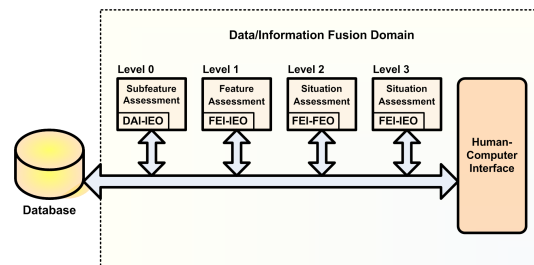


Figure 2: Hybrid process model [Sumari & Ahmad, 2008]

### 2.1.2 Information Fusion Process Models

There are three alternative architectures in information fusion applications domain with their dedicated information fusion methods, namely centralized architecture, autonomous architecture and hybrid architecture which is the combination the two previous architectures [Hall & Llinas, 2001].

### 2.1.3 Information Fusion Class Levels

Information fusion level classes are classified in [Hall & Llinas, 2001], namely pixel level fusion, feature level fusion, decision level fusion. A new fusion class level called inferencing level fusion is applied to inferencing resulted from information inference processes that are done in previous level of information fusion [Sumari, 2008a]

## 2.2 Agent and Multi-Agent System

In real life, agent is defined as a thing that causes a significant effect on a situation. In order to give this effect, agent must have capabilities. “**Capability**” in this circumstance is the ability to manage when the tasks will be carried out, knows where to move, knows how to do the tasks, knows the success level of the tasks being carried out, and the consequences of the tasks being done.

All of these capabilities are easy to be accomplished by human agent because he/she has sensing organs as the sensors and other parts of the body such as arms and legs as the effectors. The main thing that enables the agent in performing its activities is the brain, a place where the information processing is carried out. This mechanism is done autonomously. This is the main reason that an intelligent agent that emulates human agent must have an essential characteristic which is called as **self-governing**. Self-governing means the agent has capability to instruct itself to accomplish the tasks and do self-evaluation to value the success rate of the assigned tasks accomplishment for future enhancement [Ahmad & Sumari, 2008].

An agent alone has limitations in achieving the objectives. In some cases single agent is considered enough to do certain simple tasks. When the problems at hand get more complex, single agent probably can still do the tasks but there will be consequences that have to be considered such as speed and time. These two parameters are the influent factors in information processing that covers the time that is taken to deliver the information from information multi-source up to the fused inferencing is ready to be used as the basis for decision making. The capacity of single agent is limited by its knowledge, resources, and perspective. By forming a community or an agency, a solution based on a modular design can be implemented where each member of agency accomplishes one certain aspect of the problem.

### 3.0 MULTI-AGENT INFORMATION-INFERENCING FUSION SYSTEM DESIGN

#### 3.1 Information-Inferencing Fusion Part

Information-inferencing fusion method holds a very important role in an information-inferencing fusion system because it is the heart of the system. Fusion process model defines how data/information flows from one phase to another, what type of processed inputs-resulted outputs, and what is done to them. The architecture prepares the structure of the system while fusion class level defines the type of fusion will be done to the data/information.

In facing a problem, human tends to assess the problem probabilistically in finding a solution or in other words, human observes indications in his/her environment and compares them to the knowledge that he/she already has or we call it as a set of hypotheses. Information regarding the indications is delivered by his/her sensing organs to the brain and then fused to obtain comprehensive information. This mechanism is emulated by a novel information-inferencing fusion method called A3S (Arwin-Adang-Aciek-Sembiring) [Sumari, 2008a] as presented in Equation (1). This method is the enhancement of Maximum Score of the Total Sum of Joint Probabilities (MSJP) method introduced in [Sumari, 2008b].

$$P(A_i \boxplus B_j) = \frac{\prod_{i=1}^n \prod_{j=1}^m P(A_i | B_j)}{j} \quad (1)$$

$$P(A_i \boxplus B_j)_{estimated} = \max_{i=1, \dots, n} (P(A_i \boxplus B_j))$$

where  $i = 1, \dots, n$  is the number of hypothesis and  $j = 1, \dots, m$  is the number of indication. The  $P(A_i \boxplus B_j)$  notation means as “joint (fused) probabilities” of all a posteriori probabilities from the same hypothesis, while “estimated”

means the selected hypothesis is the most likely hypothesis from all available hypotheses given indications.  $P(A_i \boxplus B_j)_{estimated}$  is the largest value of  $P(A_i \boxplus B_j)$  or we call it as **Degree of Certainty (DoC)**.

The fusion mechanism is depicted in Figure 3. For the detailed explanation regarding this method, interested readers may refer to [Ahmad & Sumari, 2008].

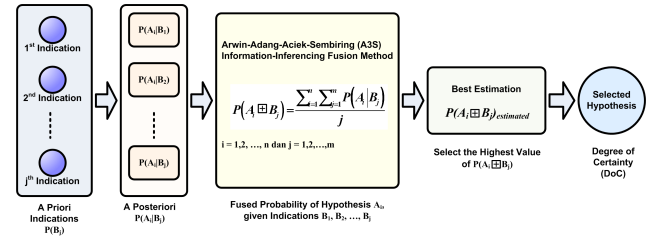


Figure 3: A3S information-inferencing fusion mechanism [Sumari, 2008a]

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In real life, agent is defined as a thing that causes a significant effect on a situation. In order to give this effect, agent must have capabilities. “Capability” in this circumstance is the ability to manage when the tasks will be carried out, knows where to move, knows how to do the tasks, knows the success level of the tasks being carried out, and the consequences of the tasks being done.

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decision making. The capacity of single agent is limited by its knowledge, resources, and perspective. By forming a community or an agency, a solution based on a modular design can be implemented where each member of agency accomplishes one certain aspect of the problem.

In information fusion perspective, there must be one agent that acts as the main agent which functions to fuse all fused information delivered by other agents to obtain final comprehensive information. This final information is used as the basis for making a decision or performing an action. So, the action done by the system is the result of a collective computation done by the multi-agent after perceiving its environment. The illustration of a multi-agent structure with information fusion capability is depicted in Figure 4.

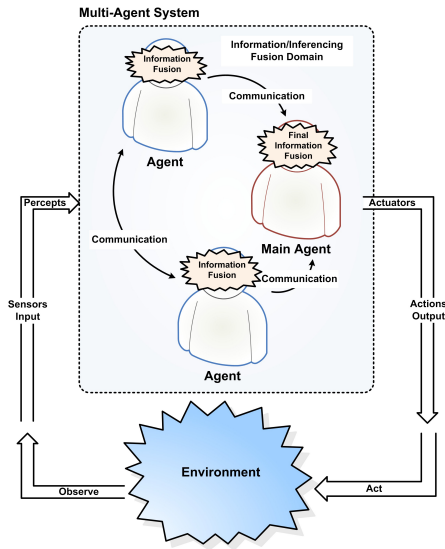


Figure 4: An architecture of a multi-agent system with information-inferencing fusion capability

We extend agent perception-action model as described by [Wooldridge, 2002] so it can be applied to information-inferencing fusion system as follows:

- observe is a function that maps environment being observed to percept

$$\text{observe} : \text{environment} \rightleftharpoons \text{percept} \quad (2)$$

- fuse is a function that maps percepts to information fusion

$$\text{fuse} : \text{percepts} \rightleftharpoons \text{information\_fusion} \quad (3)$$

- act is a function that maps fusion results to action to be performed

$$\text{act} : \text{fusion\_result} \rightleftharpoons \text{action} \quad (4)$$

### 3.3 Multi-Agent Information Fusion System

After considering Section 3.1 and 3.2, the complete architecture of a **Multi-Agent Information-inferencing Fusion System (MAIIFS)** is depicted in Figure 5.

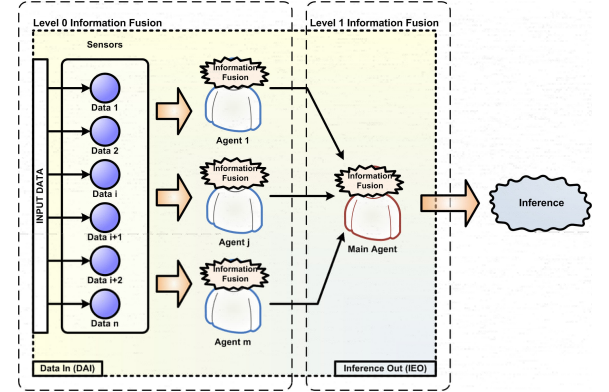


Figure 5: MAIIFS architecture

## 4.0 MAIIFS APPLICATION TO DECISION SUPPORT SYSTEM

### 4.1 A Simple Scenario

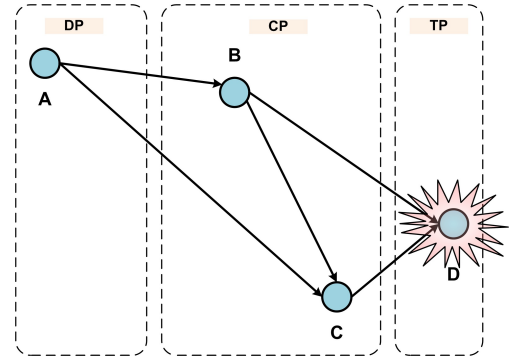


Figure 6: A simple air mission scenario

In this paper we present the design and implementation of MAIIFS for decision making support in planning an air mission. The task of the mission is to deliver logistics support to a remote base “D” from headquarter “A” via “B” and “C”. In this scenario, the system must deliver comprehensive information regarding weather conditions in each point that span from Departure Point (DP) to Target Point (TP).

Along the way from DP to TP, there are some Connecting Points (CP) which the mission executor must select so as to accomplish the mission successfully. The scenario is depicted in Figure 6. Weather condition in each point is collected by

distributed sensors. The sensors in each area are equipped with information fusion capability, so their results are fused (joint) information regarding the weather conditions in the area under their observation. In this example we only use four points, namely one TP, two CPs, and one TP.

#### 4.2 Scenario Data

For example we use data taken from [Ahmad & Sumari, 2008] as follow:

Table 1: *Weather data at A*

No.	Variable	Season			Note
		Rainy	Transition	Dry	
1.	Wind (knot)	12	8-10	12	
2.	Cloud (octave)	-	3-5	-	Morning
3.	Rain (mm)	1,500	-	1,500	Morning
4.	Air Temperature (°C)	-	28	-	
5.	Air Pressure (mb)	-	-	-	
6.	Visibility (km)	0.6	Normal	-	Morning
7.	Fog	No	No	No	After 05.00

Table 2: *Weather data at B*

No.	Variable	Season			Note
		Rainy	Transition	Dry	
1.	Wind (knot)	6	6	6	Min
2.	Cloud (octave)	3-5	3-5	3-5	Morning
3.	Rain (mm)	60-90	-	10-30	
4.	Air Temperature (°C)	27-29	-	27-29	
5.	Air Pressure (mb)	-	-	-	
6.	Visibility (km)	10-12	10-12	10-12	No storm
7.	Fog	No	No	No	After 06.30

Table 3: *Weather data at C*

No.	Variable	Season			Note
		Rainy	Transition	Dry	
1.	Wind (knot)	-	4-12	-	Morning
2.	Cloud (octave)	-	2-8	-	Morning
3.	Rain (mm)	-	No	-	Morning
4.	Air Temperature (°C)	-	-	-	
5.	Air Pressure (mb)	-	-	-	
6.	Visibility (km)	-	8	-	
7.	Fog	No	No	No	After 07.30

Table 4: *Weather data at D*

No.	Variable	Season			Note
		Rainy	Transition	Dry	
1.	Wind (knot)	Normal	12-23	Normal	
2.	Cloud (octave)	3-5	3-5	3-5	
3.	Rain (mm)	40-80	-	15-30	
4.	Air Temperature (°C)	26-30	-	27-32	
5.	Air Pressure (mb)	-	-	-	
6.	Visibility (km)	8-10	8-10	8-10	
7.	Fog	No	No	No	After 07.00

#### 4.3 MAIIFS-DSS Architecture

By referring to Section 2 and Section 3, we prefer to use hybrid process model because we want the system to produce fused information of the weather condition in each point as well the weather conditions in all points in one integrated view. Single point situation view is produced via JDL's Level 0 and integrated view is produced via Level 1. We select autonomous architecture because of its flexibility to accept any kind of input, data or feature. For fusion method and class level, we use MSJP method that has been explained in Section 2.2 and feature level fusion. Hence, the MAIIFS Decision Support System (MAIFSS-DSS) architecture is depicted in Figure 7.

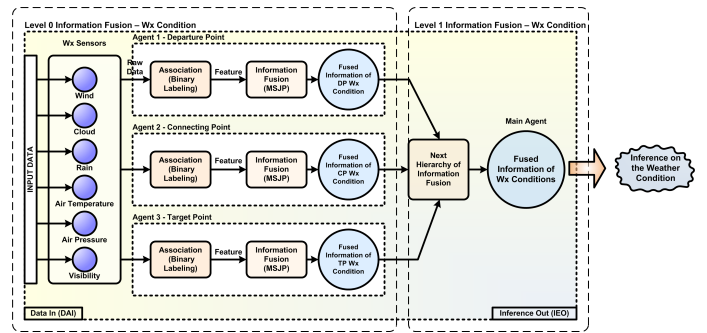


Figure 7: MAIIFS-DSS architecture

#### 4.4 MAIIFS-DSS Fusion Implementation

For implementation purpose, we define two conditional probability variables, namely  $A_i$  that represent type of season and  $B_j$  that represent weather elements which is in this case are wind, cloud, rain, air temperature, air pressure, and visibility conditions. So, the information fusion mechanism implementations at these two levels are:

- Level 0 – A3S method

$$fusion\_wx[i][j] = \frac{\prod_{i=1}^n \prod_{j=1}^m P(A_i + B_j)}{m} \quad (5)$$

- Level 1– A3S method

$$fusion\_all = \mathbb{H} ( fusion\_wx[i][j] ) \quad (6)$$

where  $\mathbb{H}$  is information fusion operator.

#### 4.5 MAIIFS-DSS Fusion Products

##### 4.5.1 Level 0 Fusion

Information fusion products at Level 0 are listed in Table 5, while one fusion product example is depicted in Figure 8.

Table 5: Season weather probabilities at all points

Area	Point	Rainy	Transition	Dry
DP	A	0.143	0.714	0.143
CP	B	0.381	0.238	0.381
	C	0.143	0.714	0.143
TP	D	0.357	0.286	0.357

Fusion products at Level 0 only provide the decision maker a single view of each point's weather condition in each season, so it will take a time to make a decision. This is the reason we need Level 1 fusion to combine all fused information into single integrated view.

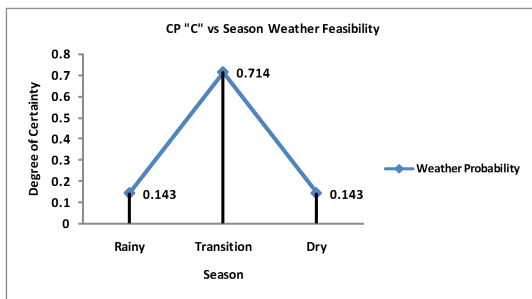


Figure 8: Level 0 information fusion product for CP "C"

#### 4.5.2 Level 1 Fusion

Information fusion product at Level 1 is depicted in Figure 9.

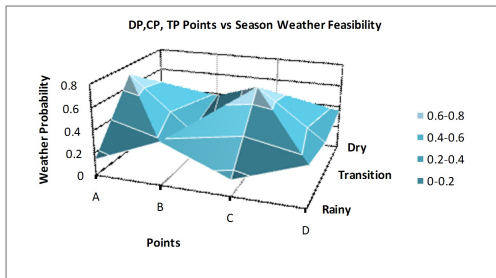


Figure 9: Level 1 information fusion product all points

#### 4.5.3 Fusion Product Inferencing

After observing the Level 1 fusion product, the mission executor will have situation awareness regarding the weather situation from DP to TP. From Figure 9, it can be inferred that the largest DoC for the mission can be accomplished successfully is if it is executed in Transition Season via CP "C". Before the decision is made, this inferencing is also used by the decision maker to prepare supporting matters for the successfulness of the mission

## 5.0 CONCLUDING REMARKS

We have presented the concept of multi-agent information fusion followed by establishing the concept to a MAIIFS-DSS based on A3S information-inferencing fusion. A simple application example has also been presented to show the system's benefits in supporting decision making. Further works will be in elaborating the information-inferencing fusion method so as to provide better results.

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