International Journal of Advance Research in Science and Engineering
Vol. No.6, Issue No. 07, July 2017
www.ijarse.com
IJARSE
ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

INFORMATION FUSION FOR MULTI-SENSORY DATA

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ABSTRACT

In present time sensory resources are used extensively to develop various autonomous applications. Multi sensory networks produce large amounts of data that needs to be processed, delivered, and assessed according to the application objectives. Some fundamental problems are how to collect the sensory data and generate the inference parameter to take intelligent decisions for autonomous systems. There are some performance parameters which ought to consider while developing such applications or system, for example, reliability, computational time, accuracy and so on. Information fusion technique compute information gathered by multiple, and eventually heterogeneous sensors to generate inference not obtainable with single sensor. This paper gives detail information about basic concepts of information fusion such as existing methodologies, Algorithms, architectures, models. In addition highlighted and described the methodology of proposed system with mathematical formation and analysis of unsupervised decision making is done by using probability and theory of computation concepts.

Index Terms- Information Fusion/ Sensor Fusion, Supervised And Unsupervised Learning, Machine Learning, Decision Making.

I. INTRODUCTION

Information Fusion is a technology which integrates the data from multiple heterogeneous or homogeneous sources and produces better result than sum of their individual results. Information Fusion or Sensor Fusion system is used to solve problems in various domains like Artificial Intelligence, Cognitive Computing, Neural Network, Machine Learning, and Soft Computing. Basically problem is divided into four sections:a)Collect the observations or data from multiple heterogeneous or homogeneous sources. b)Extract the required information (data analysis, filtering and estimation). c) Draw some logical inferences (based onsome comparisons and evaluation) andd) Make some adequate and good decisions. Information Fusion system have several applications in above specified domains ranging from home automation, military applications, health care, remote sensing, to space science. As per problem classification system should make accurate intelligent decisions for applications. To make intelligent decisions at final phase we have to take special care while fusing the data and generating inference parameter upon fusion result.

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

Several standard technique are available to fuse the information like Bayesian network, Dempster shaper theory, Kalman filter, center limit theorem, fuzzy logic, and neural network. Some of these techniques are supervised and some are semi supervised. Getting the motivation from our peripheral nervous system, human brain as central processing element, senses input from our five senses such as test, vision, hearing, smell, touch, and take the intelligent supervised or unsupervised decisions. Proposed system provides a novel unsupervised algorithm to fuse the information from various homogeneous or heterogeneous sources and make the intelligent decisions by generating inference parameter. System mainly focuses on reducing conflicts and uncertainty from real time sensory data and makes the accurate and intelligent decisions as per applications.

II. SOME BASIC FUNDAMENTAL CONCEPT OF INFORMATION FUSION

Through the years different terminologies have been used to describe the process of information fusion as per architectures, methodologies and applications namely data fusion, sensor fusion, data aggregation, multisensory integration, information integration. Fig [1] depicts the relationship among fusion these terms. Basically fusion is a process of integrate, join or combine two or more things together to form a single entity to give one reliable, robust, unbiased decision rather than many uncertain decisions. In simple mathematics we can express fusion process as average. Average reduces biased nature and provides a one compact view of bulky data. In data fusion, input to the fusion process is unprocessed data. In this combining and correlating data is done to provide single insights. Information fusion and data fusion can be used alternatively.

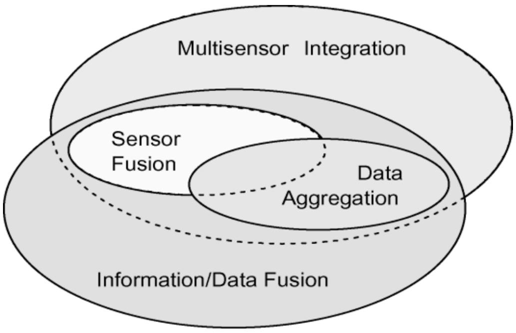

Figure 1: The relationship among the fusion terms: multisensor/sensor fusion, multisensor integration, data aggregation, data fusion, and information fusion [4].

In reference [7] author defined information fusion perfectly as it is a “supervised or semi supervised transformation of information from various sources into single parameter for effective unsupervised decision making.”The input to the information fusion process is processed data, and sources for the input could vary from sensors, images,databases to information generated by humans.Sensor fusion is a subset of information fusion and gets the data from only sensory resources. Sensor fusion provides the better results, betteranalysis, performance and better decision making because different types of sensors have different strength and weaknesses, the strength of one type can compensate for the weakness of other type. Extra sensors could work as backup if other fails [6].Data aggregation represents another subset of information fusion where the objective is to summarize or reduce the data volume [7]. Multi sensor integration deals with the application of information fusion to make inferences using sensory devices and other information. Some basic fundamental concepts of information fusion

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ISSN (O) 2319 - 8354
ISSN (P) 2319 - 8346

are depicted in fig [2]. It depicts input sources to information fusion process, why we need information fusion, benefits, applications, models of information fusion. As we have seen that input sources for information fusion can vary, it can be sensory input or images. The main objective information fusion is to improve accuracy in results and make the intelligent decisions as per application. Information fusion process takes the unprocessed data as input and converts it into knowledge; it will be useful to take intelligent decisions.

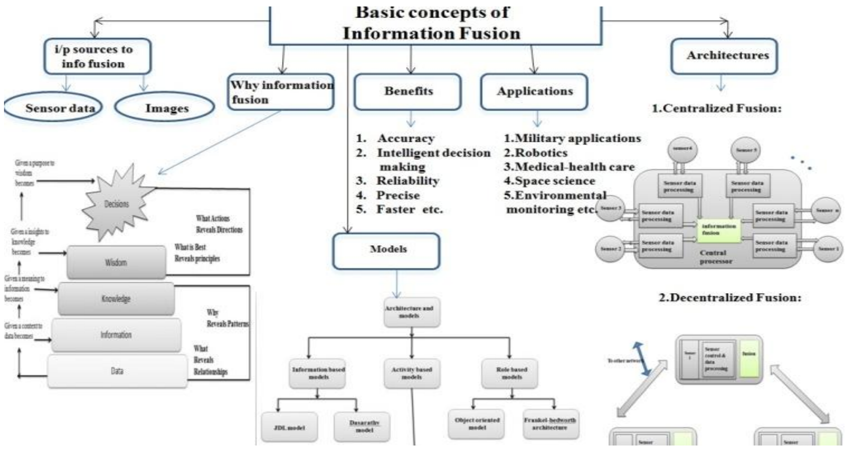

Figure 2: Basic fundamental concepts of information fusion

In current era of information, information fusion is widely used in various domains such as neural network, soft computing, artificial intelligence, machine learning to solve the domain specific problems. Informationfusion is beneficial to improve the accuracy, reliability and decision making by reducing uncertainty. Its results are more precise, faster. Additionally information fusion provides one more benefit as the strength of one type source can compensate for the weakness of another type.. Informationfusion is also important to reduce the overall communication load in the network, byavoiding the transmission of redundant messages [4]. Information fusion is commonly used in detection, classification, and object tracking and estimation tasks in different application domains. Now days it is widely used in military, space science, medical-health care and environmental monitoring applications.

Information fusion architectures are useful to understand that how to place sensor nodes in information fusion system centralized or distributed or combination of both. There are some existing popular models which guide to design information fusion system. The evolution of models and architectures for information fusion system design is described in reference [4]. Taxonomy of models depicted in figure [2]. There are several models, for our proposed system we used JDL model to fuse the data from various sources and dassarthy model for decision making. Two levels are considered as data-in –information-out and information or feature-in-decision-out for this system.

III. MOTIVATION

My motivation towards this concept is human being, peripheral nervous system of human, sensing capabilities of human and brain as central processing element. It motivates me because if we think deeply that how human beings learn things, how brain is the ultimate decision maker and ability to bring the sensory information. Fig [3]

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ISSN (O) 2319 - 8354
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depicts the sensory resources of human being and brain as central processing unit to make supervised or unsupervised decisions upon the sensory input. Fig [4] depicts the fusion process gives the estimated results by using the data from various sources.

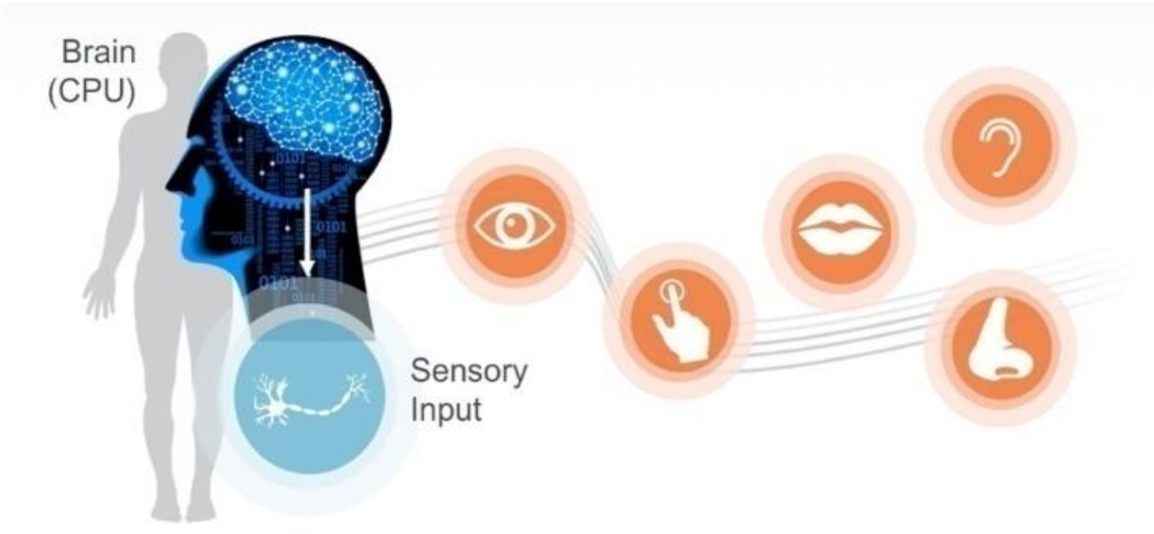

Figure 3: Sensory information (vision, hearing, smell, taste, and touch) is gathered from one's surroundings and travels through the peripheral nervous system to the brain for processing and response [10].

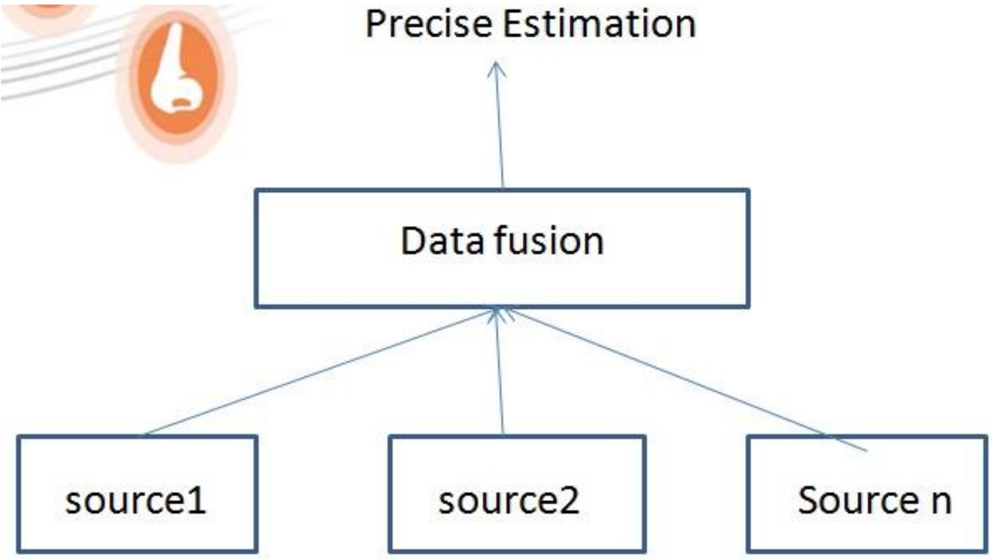

Figure 4: data fusion

IV. EXISTING ALGORITHMS AND STANDARD TECHNIQUES FOR INFORMATION FUSION

To fuse the data or information several techniques and algorithms are available such as kalman filter, dempstershafer evidence theory, center limit theorem, baysienbelif network, fuzzy logic, neural network. As per author [2] these algorithms can be classified based on some criteria, such as the data abstraction levels, purpose, parameters, type of data and mathematical foundation. According to this criterion, information fusion can be performed with different objectives such as inference, estimation, classification feature maps, abstract sensors, aggregation, and compression. Here we consider the main objective of fusion process is accurate inference generation and intelligent decision making as per application. To get the accurate inference from fusion process, we have to reduce some challenging aspects or we can say some challenging problems to fusion process such as imperfect, incomplete, inconsistent data, ambiguity, uncertainty, conflicts etc. In reference [3] author discussed these aspects in detail. Among existing algorithmsbaysien network, fuzzy logic and neural network are the best match to proposed algorithm. Proposed algorithm works on both supervised and unsupervised manner and provides greater accuracy in result within less amount of time. It is efficient to process big data. Gap analysis among existing techniques and proposed algorithm is described in table [2]

4.1 Kalman Filter

Kalman Filter originally proposed in 1960 by the Kalman. Then it became very popular fusion method. The Kalman filter is used to fuse low-level redundant data. Kalman Filter is all about finding almost accurate result between Estimated Value and Data.The kalman filter goes through an iterative process till user is satisfied withthe output.

4.2 Fuzzy Logic

Theidea of fuzzy logic was first advanced by Dr. Lolfizadeh the University of California at Berkeley in the 1960s. The modern computer is based on Boolean logic i.e true or false or 1 or 0 logic. Fuzzy logic is reasoning and computing based approach, based on degrees of truth between 1 or 0. The inventor of fuzzy logic, Lofizadeh, observed that unlike computer, the human decision making includes a range of possibilities between YES and NO. Fuzzy logic is a method of reasoning that resembles human reasoning. The approach of fuzzy logic imitates the way of decision making in humans that involves all intermediate possibilities between digital values YES and NO. Fuzzy logic may not give accurate reasoning, but acceptable reasoning. Fuzzy logic deals with uncertainty, incomplete, ambiguous, distorted or inaccurate inputs.

4.3 Neural Network

Neural network is a computer system modeled on the human brain and nervous system. It is also referred to as connectionist systems. Neural network is information processing paradigm that is inspired by the way biological nervous systems, such as the brain process information. Neural networks were originated in the early 1960s with supervised learning mechanisms. Neural network take a large number of training examples to develop a system which can learn from those training examples. It also generates the inferences or infer rules from the training examples to improve accuracy. Neural network can work without any human intervention. Neural network is a great way to develop more advanced techniques, such as deep learning.

4.4 Bayesian Theory

Table 1: Summary of related work

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Bayesian theory also referred as belief theory is based on probability theory. By using Bayesian theory in information **Standard techniques of sensor fusion**	**Characteristics of technique**	**Capabilities of technique**	**Can deal with challenging problem of multisensory data fusion**	**Resolution strategy**	**Limitations of standard technique**	**Applications**
Bayesian Theory	-Probabilistic graphical model. -Represent sensory data using probabi- lity distributions fused together within Bayesian framework. -Deals with data uncertainty. -The core of these method is Bayes Rule. -More accurate result than D-S theory.	-Well established and understood approach to treat data uncertainty.	-Imperfect data -Handles data uncertainty.	-Bayes Rule -conditional probability distribution -Random variable	-The main issue is that the probabili- ties P(B) and P(B/A)have to be estimated / guessed beforehand since they are unknown. -incapable of addressing other data imperfection aspects. -Not flexible	-In Classification task -Robotics map building -In WSN to solve localization problem
Dempster-Shafer Evidence Theory	-basedondempster Shafer belief Accumulation -it's a mathematical theory -generalizes the Bayesian theory -it deals with belifs or mass functions just as bayes' rule deals with probabilities. -fundamental concept "frame of discernment.	-it allows each source to contribute information with different levels of details -No need to assign a priori probabilities to unknown propositions	-Enables fusion of uncertain and **ambiguous data** -Belief functions theory is a popular method to deal with **uncertainty** and **imprecision**	Belief- mass function	Inefficient for fusion of highly conflicting data -Exponential complexity of computations.	-to build dynamic operational picture of battlefields for situation assessment. -Event detection and data routing -To detect routing failures -Route re-discovery when necessary
Kalman Filter	-Provides exact Analytical solution -Zero-mean Gaussian noise for a linear systems -simple -Easy to implement -Optimality in a mean-squared error sense	A kalman filter is an optimal estimator	It infers parameters of interest from indirect, inaccurate, and uncertain observations.	-if all noise is Gaussian,kf minimizes the mean square error of estimated parameters -if noise is not Gaussian then	-Very sensitive to data corrupted with outliers -not efficient for Non-linear systems. -in WSN it requires a proximate clock	-source localization and tracking -Robotics -distance estimate -Accuracy improvement

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ISSN (O) 2319 - 8354
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				Extended KF is used for Non-linear estimation	synchronization among sensor nodes	
Fuzzy logic	-Allows vague data representatn using fuzzy membership and fusion based on fuzzy rules	Intuitive approacht odealwith vague dataesp.human generated	Uncertainty	Fuzzy reasoning	Limited merely to fusion of vague data	-Position control -Localizing hazardous

Table 2: Gap analysis of related work

Standard Techniques → / Parameters↓	Bayesian Belief Network	Dempster Shafer Evidence Theory	Kalman Filter	Neural Network	Fuzzy Logic	Proposed System
Accuracy	YES	LESS	YES	YES	MODERATE	YES
Reliability	YES	YES	NO	YES	LESS	YES
Flexibility	NO	YES	NO	LESS	LESS	YES
Can Reduce Uncertainty	YES	YES	YES	YES	YES	YES
Can Reduce Imperfection, Incompleteness, Inconsistency	NO	YES	YES	YES	MODERATE	YES
Decision Making	YES	YES	YES	YES	MODERATE	YES
Multisensor data fusion	YES	YES	YES	YES	YES	YES
Computation Time	LESS	LESS	MODERATE	LESS	MODERATE	LESS
Big data processing	NO	NO	NO	YES	NO	YES
Energy Saving	YES	REDUCE ENERGY CONSUMPTION	LESS	YES	LESS	YES
Real time monitoring	YES	YES	YES	YES	YES	YES
Heterogeneity of devices	YES	YES	YES	YES	YES	YES
Supervised or Unsupervised	SUPERVISED	SUPERVISED	SUPERVISED	SUPERVISED UNSUPERVISED	SUPERVISED	UNSUPERVISED

V. PROPOSED SYSTEM -METHODOLOGY AND MATHEMATICAL MODELING WITH ALGORITHM

The critical data fusion problem is not data collection and analysis of raw sensor data using complex mathematical algorithms and parallel processors. Although these technologies are part of total solutions,the key issue for data fusion is how to convert the initially processed sensor data into information and knowledge to support the decision maker in a timely fashion.

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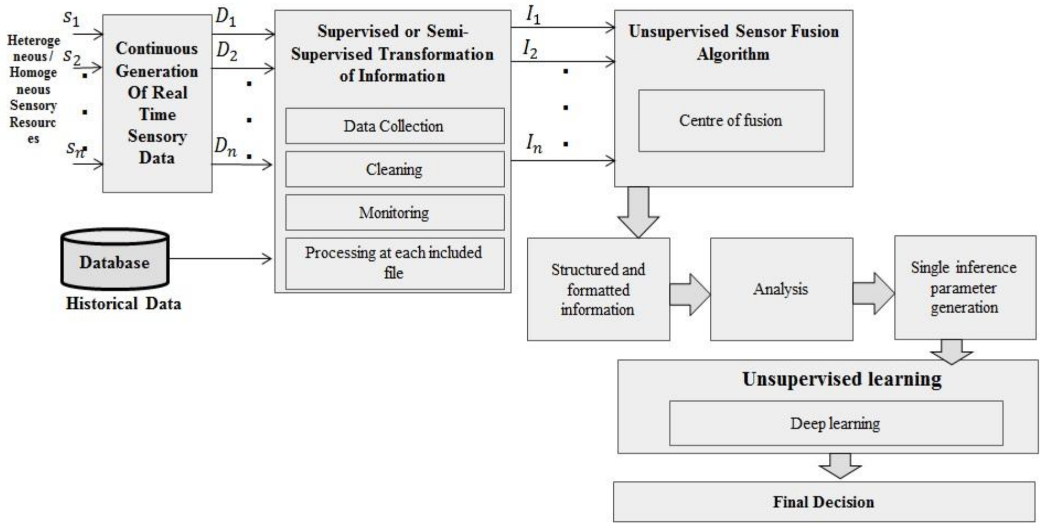

Figure 9: Methodology of proposed system

Proposedmathematical model is based on TOC [Theory of computation], Averages and Probability.To do mathematical formation I have considered one simple scenario of space application; **scenario**- suppose astronaut wants to go outside the spaceship, he or she should check the temperature, pressure, oxygen, humidity outside the spaceship. Upon that calculations and analysis he or she can take accurate decision. For information fusion part mathematical formulation is done with averages and unsupervised decision making is done with probability. Here, Decision making and fusion process are unsupervised. That is it process its current inputs at every state and it requires output at every given input. Deterministic and nondeterministic finite automata give the output or decision only in YES or NO format i.e. in Boolean logic 1 or 0 logic. We require ranges of decisions as per inputs it's just like human brain gives decisions. Because of that I consider mealy machine to frame the mathematical modeling with averages and probability.

A Mealy Machine is an FSM whose output depends on the present state as well as the present input.

It can be described by a 6 tuples (Q, ∑, O, δ, X, q_0) where −

1. Q is a finite set of states.
2. ∑ is a finite set of symbols called the input alphabet.
3. is a finite set of symbols called the output alphabet.
4. δ is the input transition function where δ: Q × ∑ → Q
5. X is the output transition function where X: Q → O
6. q_0 is the initial state from where any input is processed ($q_0 \in Q$).

1] Real time sensory data is generated from heterogeneous or homogeneous sensory resources.

- Input-

  ∑- input alphabets

  ∑= {T_S, P_S, H_S, O_S, Total-average, Probability(P)}

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ISSN (O) 2319 - 8354
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Input data may contain some conflicts, ambiguity, uncertainty, incorrectness, and noisy data. Which are denoted as -

X_n-noisy data

X_u-uncertainty

X_C-conflicts

$X_{incorrect\text{-}data}$- incorrect-data

Simply total data collected or generated from sensors as

Sensor 1

$S_{1=} \sum S_i + X_n + X_u + X_C + X_{incorrect\text{-}data}$

Sensor 2

$S_{2=} \sum S_i + X_n + X_u + X_C + X_{incorrect\text{-}data}$

in the same way for n number of sensors.

Sensor n

$S_{n=} \sum S_i + X_n + X_u + X_C + X_{incorrect\text{-}data}$

Here consider 4 sensors as Temperature, Humidity, Pressure and Oxygen.

- Q={Data, Information, Knowledge, Decisions/actions}
- q0= Data (initial state)
- O= Decisions (Final state)
- δ is the input transition function where $\delta: Q \times \sum \rightarrow Q$
- X is the output transition function where $X: Q \rightarrow O$

2] In the next phase some supervised or semi supervised processing is done on collected sensory data such as cleaning, monitoring, preprocessing etc.

3] After preprocessing and cleaning we get the information from collected sensory data. This information is input to the fusion process or algorithm. Fusion algorithm is based on deep unsupervised technique.

Total number of values to generate from temperature, humidity, pressure and oxygen sensors are = n

This can be set while generating data from sensors by using raspberry pi or aurdiuno kit.

A] Temperature sensor data-

1. $T_s = \sum^{0}_{i=1} t_{si}$

T_s = {t1, t2, t3….tn}

2. Average of temperature sensor data

$At_{si} = \sum^{0}_{i=1} t_{si} / n$

$= T_s / n$

B] Humidity sensor data-

1. $H_s = \sum^{0}_{i=1} h_{si}$

H_s = {h1, h2, h3….hn}

2. Average of Humidity sensor data

$Ah_{si} = \sum^{0}_{i=1} h_{si} / n$

$= H_s / n$

C] Pressure sensor data-

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1. $P_s = \sum^{0}_{i=1} p_{si}$

P_s = {p1, p2, p3….pn}

2. Average of Pressure sensor data

$Ap_{si} = \sum^{0}_{i=1} p_{si} / n$

$= A_s / n$

D] Oxygen sensor data-

1. $O_s = \sum^{0}_{i=1} o_{si}$

O_s = {o1, 02, o3….on}

2. Average of Pressure sensor data

$Ao_{si} = \sum^{0}_{i=1} o_{si} / n$

$= O_s / n$

Total-average = $At_{si} + Ah_{si} + Ap_{si} + Ao_{si}$

4]After fusion process we will get the structured and formatted information, by analyzing this information we can generate single inference parameter. It is denoted as Inf.

5] We can use generated inference parameter Inf to take intelligent decisions as per applications.

6] Probability is used to formulate the unsupervised decisions.

Conditional probability is used to calculate the weights [wi] as denoted in figure[] assigned to random variables-it is calculated by using bays rule-

P(A and B) = P(A) x P(B|A)

P(A) means "Probability ofEvent A"

P(B|A) means "Event B **given** Event A"

P(A) x P(B|A) = P(A and B)

P(B|A) = P(A and B) / P(A)

Weights are checked with threshold value.

Node name [random variable]	Type of variable	Value	Node creation
Temperature Sensor	Integral	Real time Sensory data	Temp sensor
Pressure Sensor	Integral	Real time Sensory data	Pressure sensor
Oxygen Sensor	Integral	Real time Sensory data	Oxygen sensor
Humidity Sensor	Integral	Real time Sensory data	Humidity sensor

Table 3: Network creation

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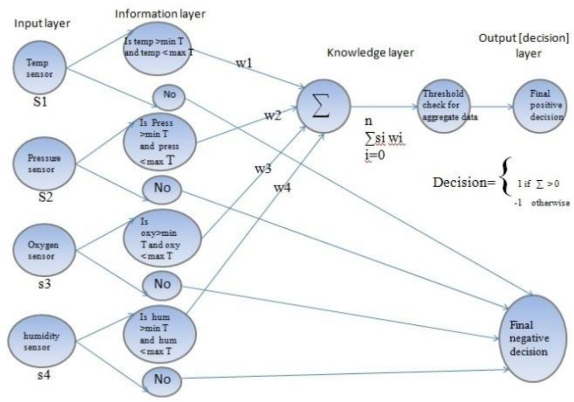

Figure 11: Mathematical Model

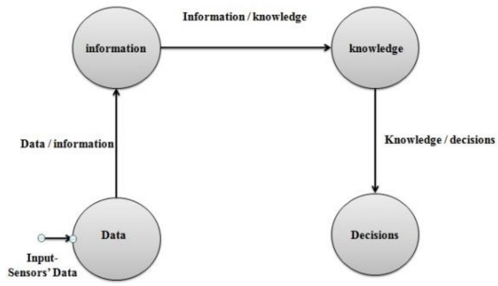

Figure 12: state transition diagram [mathematical model]

VI. CONCLUSIONS AND FUTURE OUTLOOK

This paper presented information about basic concepts of information fusion. Information fusion technique is used to solve the problems in various domains like artificial intelligence, cognitive computing, machine learning, soft computing and neural network. It provides greater accuracy in results. In this paper I have done with methodology and mathematical modeling for sensor fusion. Interesting future work will be to propose anunsupervised reliable and accurate decision making algorithmfor space science applications such as planetary explorationby using deep learning techniques.

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