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# SURVEY PAPER: MULTI SENSOR DATA FUSION FOR SENSOR VALIDATION

Subhas A.Meti Asst. Professor, BVB college of Engineering and Technology, Hubli,
V G Sangam Professor, Department of Electrical science Adama Science and Technology University, Ethiopia

## Abstract

Multi-sensor fusion of data is based on the principle that integrate data from various sensors would allow a better understanding of the circumstances. Purpose of the paper is to review the various sensor fusion performances using different techniques. This paper has reviewed various applications, technologies, models and performance when adopted sensor fusion by taking into consideration the approaches namely wavelet based methods, fuzzy logic, artificial neural network, image fusion as well as combined approaches namely multi-sensor data fusion through systematic prior review of literature. In future, this study will develop a model and implement on any algorithm based on the fuzzy logic.

**Keywords:** wavelet based methods, artificial neural network, fuzzy logic, image fusion, multi-sensor data fusion.

## Introduction

Fusion of data from various sources for achieving performances are exceeding from individual sources were identified in various areas [1] like forecasting, reliability, recognition of pattern, statistical estimation decision fusion and neural networks. In engineering systems, methods for fusion have evidence to be especially significant since they could provide capabilities of system with various sensors particularly beyond those individual systems for sensor. Multi-sensor fusions of data permits the integration of data from sensors with various physical characteristics for enhancing the perceiving of environments and give the basis for decision making, planning and control of intelligent and autonomous machines [2]. Apart from these, multi-sensor data fusion seeks for combining data from various sources and sensors for achieving inferences that are unfeasible from an individual source or sensor [3].Methods of sensor fusion integrate data from various information sources in such a way that it must provide better performance which could be reached when each and every information source is used alone. System design was on the basis methods of sensor fusion which needs the availability of complementary sensors so that drawbacks of each sensor could be overcome by the benefits of the others [4].

Fusion methods could be classified into 3 main clusters namely least square-based methods for estimation, probabilistic methods and intelligent aggregation methods. Probabilistic methods like evidence theory, Bayesian analysis of values of sensor, recursive operations and robust statistics. Least square-based methods for estimation like optimal theory, Kalman filtering, uncertainty ellipsoids and regularization. Intelligent aggregation methods like genetic algorithms, neural networks and fuzzy logic. [5]

This paper has reviewed the various applications, models, technologies and performance when adopted sensor fusion by taking into consideration the approaches namely wavelet based methods, fuzzy logic, artificial neural network, image fusion as well as combined approaches namely multi-sensor data fusion through systematic review of prior review of literature.

## Literature Review

### Wavelet based methods and Image Fusion:

Wavelet based image fusion was primarily used in [6-37] to obtain detail data from one image and pass it into another image. Detail data in image actually would present in high wavelets and frequency would possess the potential for selecting the frequencies in time and space. Outcomes of fused image would possess good characteristics relative to features from both images which enhance the imaging quality.

Improved fusion scheme was implemented in this research [38] criterion of a bilateral gradient-based sharpness-weighting in transform of dual-tree complex wavelet. Proposed techniques eliminates the ringing artifacts found in the fused image by assuming appropriate weighing schemes to pass low coefficients as well as high pass wavelet coefficients independently. It was found out normalized maximum criterion of gradient-based sharpness particularly for frequency of low coefficients improves the information of background texture and enhances the blurred regions quality in the outcome of fusion.

Reconstructing method of lower resolution image into higher resolution through interpolation of image is developed by Zhang and Wu [39]. Images are isolated on the basis of regions and pixels. Apart from these pixels are functioned by fusing the specific pixel of another image in the same image. Region and pixel method based processed is developed by Lewis et al [40]. Images with quality of multi-focal for example, capturing the image background and foreground separately are fused using non-sub sampled con-

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tour let transform was described by Zhang and Guo [41]. Fusion of image was conducted by fusion rule of variable-weight by considering fluorescent image and its subsequent phase opposite image that indicates the data clearly with its edges as mentioned by Li and Wang [42]. In addition to this shift invariant scheme for decomposition of image and multiscale directional bilateral filter was used for fusing infrared image and visible image as explained by Hu and Li [43].

Performances of super-resolution and image fusion techniques rely on representation of sparse. Such techniques neglect the human artifacts generation produced by fusion of image or super-resolution as in conventional 2 stage process. It was noted that difficulty in computing the parameters is simple and easier than computing super resolution and fusion of image separately. Hybrid image with information of high resolution is extracted by fusing low and high frequency components which in turn produces a processing image [44].

Shinde and Pathrikar [45] mentioned that image fusion is a technology for data fusion which keeps images as major contents for research. Image fusion is the techniques which combine various image of the same scene particularly from various data of image sensor or combine various images of same scene at unique times from single sensor of image. Fusion techniques in domain of medical images would be helpful in resourceful diagnosis of disease. CT (Computer tomography) for medical diagnosis gives the best data on denser or deeper tissue with minimal distortion. MRI (Magnetic Resonance Image) gives better data on soft tissue along with high distortion. Algorithm of image fusion was on the basis of discrete wavelet transform (DWT) which would be quickly developed for multi-resolution analysis fusion of image. DWT has good characteristics in time-frequency. This research studied about the method which could obtain useful data from sample images to fused images for obtaining clear images. In this research, a hardware deployment of system for image fusion is developed. After that using MATLAB we will be able to transform images into files of pixel form and for observing simulation outcomes. It was found out that input image could be recovered by integrating fused image and source image.

Sutagundar and Manvi [46] proposed CAM (Context aware multisensory) fusion of image for military networks for sensor using multi-agent system. Proposed network was developed for enhancing infrastructure for multi-sensor fusion of image for monitoring the militant activities. In this research, it was on the basis of context aware computing itadopted agents for software for fusion of image in wireless military network for sensor. In an environment, where nodes of source are near to one another, redundancy found in the sensed data and nodes of source develop a huge amount of traffic on unfixed channel, this wastes the bandwidth in scarce wireless at the same time also consumes more energy in battery. Rather than each node of source transmitting sensed images to node of sink, images from various active nodes are fused as well as transmit to the sink node with the help of mobile agent. Apart from these it was noted that use of agents provide these facilities namely asynchronous operation that does not need a continual flow between sink and source; flexibility for changing the embedded code for performing user or context driven fusion; ease of maintenance due to the code could be debugged and updated not dependent of other system agents; adaptability to differ environment and network conditions for fusion of image and reusing the code could be applied for other application with little changes and integrate in the system and enhances architecture of dynamic software.

## Fuzzy Logic:

Compromise, disjunctive and conjunctive properties of fuzzy logic was vastly used in processing of image and has witnessed to be helpful in image fusion. Methods of fuzzy logic were adopted as a decision operator or transform of feature operator for image fusion [47-69]. Information regarding techniques of fusion for reliable data fusion could be seen at [70], however fusion of sensor applications, issues and future directions were fully explained in [71-75]. Author [76] had focused on minimizing noise and redundancy and also tried to enhance failure tolerability of data created by gas turbine power plant sensors. Apart from these more industrial and practical application of sensor fusion could be seen at [77-80]. An optimal linear fusion framework was developed by [81] for solving and addressing issues in the measurement systems. Prior attempts including fuzzy rules in multisensory fusion of data were seen at [82].

In [83] it was focused on two-sensor signal improvement issue in a noisy environment. Their solution was on the basis of algorithm of expectation maximization for jointly calculating coupling system, main signal and unknown noise and signal parameters. Author in [84] proposed algorithms of two-novel neural data fusion on a LCLS (linearly constrained least square) [85] gives a systematic scheme to generate rules for optimum fusion method which would in turn greatly minimize computational than ordinary exhaustive search. Apart from using fuzzy rules, some investigators [86, 87] have attempted to introduce new operations for fuzzy logic for utilizing intuitive knowledge particularly for sensor-fusion. In addition to this, in a practical issue, for correcting faults in slow sensor drift, [88] provides a hybrid method using genetic and fuzzy logic algorithm. For exploiting benefits of Kalman-filter as an effective method for fusion and fuzzy-logic as a brilliant intelligent method [89] suggested by architectures for hybrid Kalman filter-fuzzy logic adaptive fusion of data for multisensory.

## Multisensor Data Fusion:

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Omar and Winberg [90] have proved that through efficient means of multi-sensor fusion of data it would enhance a tracking system accuracy, stability and credibility. The present study proposed 3 fusion architectures which address issue of target tracking with passive angle-only sensor and Doppler radar. This architecture's performance was compared using filter metrics and Monte Carlo simulations. It was pointed out that centralized fusion would obtain more exact and accurate filters when compared with distributed fusion. Akhoundi and Valavi [91] proposed a multi-sensor data fusion approach using sensors with unique characteristics. Focusing on bandwidth and accuracy, as two influential and significant sensor parameters, proposed research used fuzzy method for 2-sensor fusion of data. It involves 2 unique parts such as fuzzy predictor and fuzzy aggregator. Apart from these, it was noted that fuzzy aggregator utilizes benefits of fuzzy system with suitable membership functions, fuzzy inputs and fuzzy rules. System could result in acceptable outcome in many applications, whereas if the application needs extreme degree of accuracy and certainty, at that time, fuzzy predictor would be very useful. Great benefits of proposed system are indicated on simulation outcomes of control system which utilizes the system for fusion for estimating the output.

Apart from these, numerous researches were focused on multi-sensor fusion [92-94]. Some researchers focus techniques of data fusion [95-97]. Further Isermann [98] categorized some significant mathematical techniques for fusion of data particularly in multi-sensor system [99]. Betta had fault detection and isolation application methods in systems of measurements [100-102].

Kumar and Chhokar [103] stated that for designing intelligent system which works on robust applications; ability of taking numerous-choice decisions for supporting completely automated systems; then it is significant to adopt micro sensors associated with process of multi-sensor fusion. Process of multi-sensor integrates different binary decisions from single or individual sensors for supporting system to perform in a computationally effective manner and could be able to take all decisions effectively and intelligently without the intervention of human.

Sabatini and Genovese [104] developed an approach of loosely coupled filtering to estimate the height and vertical velocity of a rigid body with the help of baro-IMU (barometric altimeter integrated in the same device). Method of sensor fusion was on the basis of quaternion-based extended Kalman Filter for strap-down rotation and estimation of attitude of sensed particular force with the help of inertial sensors, subsequently by a complementary filer fed with calculated vertical acceleration of linear and result from the altimeter of barometric. For purposes of validation, method of sensor fusion was deployed in MATLAB using wearable unit for inertial measurement comprises of baro-IMU paired through Bluetooth to Android phone which was not fixed interfaced to personal computer running MATLAB through wireless fidelity. Apart from these it was noticed that successful validation was reached in various experimental conditions that encompassed free-fall motion, no-motion, squatting and forced circular motion.

Carvalho and Chang [105] presented a tool which permits a user for evaluating the performance of classification of a multi-sensor system for fusion modeled by network of Bayesian. With the help of FPM (Fusion performance model) explained in [106] and [107] proposed a study designed on a new module and combined it with open source, free and platform independent framework of probabilistic network UnBBayes. The proposed system demonstrated the tool functionalities with a model-based identification for example tracking the air target and classifying. We could be able to answer queries regarding possibility of correct classification of provided target using a particular single resource of sensor or a set of resources. In addition to this, it was also noted that it is easy to estimate the gain of marginal performance and ratio of cost/benefit of each resource of sensor. It was also noticed that proposed tool is very prominent for a decision maker for analyzing trade-offs between cost and performance and for selecting proper sensor which suites constraints and needs.

## Artificial neural network:

Neural networks are seen as significant approach of fusion for sensor data. Few researchers worked on signal evaluation, modeling and plausibility verified by architectures of artificial neural network [108]. Leger and Garland proposed integrated artificial neural networks and statistical control charts for purposes of fault detection and isolation [109] and Chen developed a probabilistic model for evaluating the sensory data [110].

Jabbari, Jedermann and Lang in the research [111] two separate artificial neural network architectures were considered for generation of measuring residual and evaluating residual. In first and foremost phase, approximation of artificial neural network was applied for generating residuals to compare measurements with approximation of temperature. In second phase, on the basis of the result of first artificial neural network architecture, PNN (probabilistic neural network) was adopted to analyze the probable failure or fault conditions and classification of failure of fault. After evaluating the residuals, situation of each and every measured signal's result was on the basis of parameters of assessment and artificial neural network approximation.

Krzysztof et al [112] presents method of data processing for AHRS (attitude heading and reference system) on the basis of artificial neural network. Proposed system involves micro-electro-mechanical systems on the basis of unit of inertial measurement which involve accelerometers, txi-axis

gyroscopes and magnetometers which provide 3 dimensional angular rates and linear accelerations. Data for training was developed by simulation fusions of inputs gathered at the time of quadcopter flight. It was found that outcomes indicate proper neural network's functioning. Apart from these, it was also noticed that proposed system would give the probability to easily incorporate other sensor for example global positioning systems for achieving better performance.

# Conclusion:

Sensor fusion in terms of various techniques and algorithms has been discussed in this particular survey. The extensive growth and developments in sensor fusion research summarized with the review of literature reveal the significant of this study in enhancing the sensor fusion in various fields. This paper has reviewed the various technologies, applications and models, performance when adopted sensor fusion by taking into consideration the approaches namely wavelet based methods, artificial neural network, fuzzy logic, image fusion as well as combined approaches namely multi-sensor data fusion through systematic review of prior review of literature. This research focused on prominent approaches namely fuzzy logic, artificial neural networks, wavelets transforms and image fusion. Apart from these, this study also focused the integrated methods seen in the multi-sensor fusion of data. In future, this study will develop a model and implement on any algorithm based on the fuzzy logic.

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# Biographies

**Subhas A. Meti** received the B.E. degree in Electronics and Communication Engineering from the Karnataka university Dharwad, Karnataka in 2000, the M.Tech degree in Instrumentation Engineering form Swami Ramanand Teerth Marathwada University of Nanded, Maharashtra in 2007. Presently pursuing the Ph.D. degree in Electrical Engineering from the Visvesvaraya Technological University Belgaum, Karnataka. Currently, He is working as an assistant Professor of Instrumentation Engineering at B V B college of Engineering and Technology, Hubli. His teaching and research areas include instrumentation, Multisensor data fusion, Soft computing.

**Dr. V G Sangam** received the B.E. degree in Instrumentation Engineering from the Mysore university, Karnataka in 1989, the M.E degree in Instrumentation Engineering form Mysore university, Karnataka in 2000, and the Ph.D. degree in Instrumentation Engineering from SwamiRamanand Teerth Marathwada University of Nanded, Maharashtra in 2007, respectively.. Currently, He is working as Professor of Electrical science at Adama science & Technology University, Ethiopia. His teaching and research areas include instrumentation, Biosensor, process instrumentation and Control system.