Research on Multi-sensor Data Fusion Technology

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Abstract. Multi-source sensor information fusion mainly collects various types of information from multiple independent decentralized sensors. Due to the different types of information, specific combinations of time and events are required to make the collected information more advanced and useful information. From the level of fusion, it will be merged from the three levels of data set, feature level and decision-making level. For different practical problems, it is necessary to use a certain level of fusion or a certain two levels of fusion according to the situation, so as to obtain the most optimal integration scheme.

Keywords: Multi-sensor; Sensor integration; Fusion algorithm.

1. Introduction
The concept of "Sensor Fusion" is actually a functional simulation of the human brain's comprehensive processing of complex problems [1]. Compared with a single sensor, which collects a certain type of specific information independently, multiple sensors collect multiple information jointly, also can improve the accuracy and robustness of the overall system. Multi-sensor fusion can improve the overall system accuracy and reduce delay. Therefore, sensor fusion technology has become a hotspot of current research.

The basic concept of sensor fusion technology was first proposed in 1973 by the US Department of Defense's independent development of the Sonax information processing system [2]. Its basic concept was mainly the technology of comprehensive processing and optimization of the acquisition of a variety of data, expressing its internal connections.

Sensors are mainly used in the Internet of Things scenes [3]. With the heavy industrial tasks and safety tasks of the plant area, the sensors required are multiplied and the data to be processed is also multiplied. At the same time, it also involves the problem of data fusion between various heterogeneous networks or multiple systems [4]. The problem of how to mine hidden information and valid data from massive data in a timely manner has brought huge challenges to sensor data processing [5]. The second part introduces algorithms for information fusion, and the third part layers of sensor fusion.

2. Sensor Data Fusion
The overall processing flow for multi-sensor fusion mainly includes bottom-end data collection, data source data processing, data analysis decision-making phase, and data fusion phase. The level of abstraction of multi-sensor data fusion in information is mainly divided into three levels: Data layer fusion, feature layer fusion, and decision layer fusion [6].

2.1. Information Fusion
Data layer fusion: Data layer fusion is also called pixel layer fusion, that is, the raw data collected by the sensor is directly processed at the data layer, the unprocessed data is comprehensively processed,
and the lower level data is concentrated. Processing, as shown in Figure 1 below it is the data layer fusion structure.

![Figure 1. Data layer fusion structure.](image)

Feature layer fusion: When extracting features from the data collected by the sensor, and then fuse according to the features, the feature extraction should be a sufficient statistic or representation of the original data [7]. Using advanced fusion methods to obtain the fusion vector, and then fusing after the vector is put into the classifier, the target is recognized. Compared with data layer fusion, feature layer fusion has less data and less calculation, so the real-time performance after data processing is higher. Feature level fusion process is shown in Figure 2.

![Figure 2. Feature layer fusion structure.](image)

Decision level integration: Decision-level fusion is the highest level of information fusion. The individual data is independently extracted to obtain the identity recognition results. The obtained results are then fused according to a suitable fusion method, and finally the final fusion result is obtained. Decision layer fusion has more fault-tolerant and more real-time. As shown in Figure 3, it shows the decision layer fusion.

![Figure 3. Decision-making level fusion structure.](image)

### 2.2. Data Fusion Algorithm

For the concept of data fusion, different algorithms could be used for different levels of fusion. Its theories include: least squares method, Bayesian criterion, D-S evidence theory, fuzzy integral theory, neural network, clustering technology, database theory, and so on. The main applications are described below.

**Bayesian criterion:** There are different prior and posterior probabilities for different problems. The prior probabilities are obtained first, then the posterior probabilities are obtained, and the sensor fusion problem is processed according to this. Bayesian processing of data requires very high requirements for the application of mathematics, and Bayes cannot distinguish between "don't know" and "uncertainty" problems, and all probabilities are independent of each other. There are certain limitations.

**D-S evidence theory:** For the expansion of the Bayesian problem, because the Bayesian network cannot determine the relationship between "unknown" and "uncertainty", a trust function is used to replace "uncertainty" and "uncertainty" for this problem. "Probability", the method of "interval estimation" is used. However, due to the complex relationship of the trust function, the determination of the index is subjective which determines the limitations of the theory to a large extent.

**Least squares method:** Find the best function match of the data by minimizing the sum of squared errors. Unknown data can be easily obtained by using the least square method, minimizing the sum of the squared errors between the resulting data and the actual data. The application of this method can eliminate the uncertainty caused by conventional methods and provide a more reliable method for experiments.

**Neural network:** This method is a large-scale distributed neural data processing system, which can process a large amount of data in real time. A neural network can perform data fusion with neural nodes,
while a neural network has numerous nodes which enables the underlying data to process a huge number of data simultaneously, in order to save time in data processing.

3. Research Status of Sensor Fusion

Many authors have put forward the following opinions on sensor fusion: Guohua Zhan\[8\] proposed a multi-source heterogeneous fusion tree architecture and fusion node design for the heterogeneity of health management information integration, which can achieve good integration of data; Zhang\[9\] proposed in medical applications and proved that the model can strengthen the fusion of multi-agents and heterogeneous information sources; Doherty\[10\] proposed that information intelligence from dynamic changes. It has the ability to fuse information from low-level to high-level, and model the agent's sensing ability under the premise of considering the context; Lin\[11\] proposed an information fusion technology based on atomic association rules for different agents based on different classification algorithms. It is proved that the closed traditional method is more accurate; Masdarolomoor\[12\] decomposed a complex system into multiple local small networks and the local networks could not interact with each other. A cohesive algorithm is proposed to make local modularity a similarity measure to collect a community with the similar nodes in the system; Castanedo\[13\] introduced multi-agent-based collaborative monitoring multi-intelligence (CS-MAS) system framework, proposed a two-layer fusion structure: a global fusion center and part of the fusion center and multiple autonomous agents, and added a new autonomous agent.

3.1. The Integration of Data Level

The integration of data layer is aimed at the processing of the underlying data of the sensor\[14\]. The current models include weighted average method, Kalman filter method, mathematical statistics method and so on. At present, many aspects of the above methods have described this aspect in detail\[15\]. Yong Sun\[16\] proposed an improved method for the parameter performance of multiple sensors and targets, weighted the data obtained by the sensors, and used the weighted data as the optimal weighting and recursion of real-time measured values of the recursive least square method. The combination of the least squares method is used to improve the fusion method of multi-sensors, and experiments have proved that the model is indeed more stable and faster than other methods.

Gan\[17\] proposed two existing multi-sensor data-level fusion methods. Based on the two current methods: simple fusion of Kalman vectors and the minimum mean square error criterion to form a multi-sensor fusion, the two fusion methods are used to simulate experiments and analysis two separate benefits.

Nale Zhao\[18\] combined the concept of vector machine in analyzing multi-source ITS data in data layer, and analysed the implementation steps from the aspects of vector machine training, training result evaluation, and vector machine test results. Support information vector machine fusion is performed on Hanshin Highway in Japan. Experiments showed that this method can improve the accuracy of data fusion.

3.2. The Integration of Feature Level

The integration of feature level algorithms mainly include Kalman filter method\[19\], fuzzy inference method, neural network method, etc. The following is a description of this aspect in the literature.

Chaib\[20\] analysed in the high-resolution remote sensing technology, the sensor data fusion feature layer used discriminative correlation analysis (DCA) as a fusion strategy to further improve the original features of the pre-trained visual geometric group network (VGG-Net) model, thereby further to reduce costs and complete effective convergence.

Bar-Itzhack\[21\] used the Kalman filter method in the feature layer to design the acceleration deviation design and used covariance analysis to identify external damage events in the process of describing engine design and navigation.

Guohui He\[22\] proposed a fusion of human face and iris features in order to improve the overall identity in multi-bio iris recognition, and combined with 2-Dimensional Fisher Linear Discriminant Analysis (2DFLD) at the feature layer fusion. Through the recognition model, a fusion recognition model of face and iris features is proposed, which overcomes the difficulty of "small sample" and achieves the feature layer fusion.
Li [23] proposed a suitable color texture analysis based on incomplete tree wavelet decomposition, and performed feature extraction and fusion on color texture images. Experiments were performed on tower wavelet decomposition, ncomplete tree wavelet decomposition, and wavelet packet decomposition. Based on the classification comparison of multi-feature fusion, it is proved that incomplete tree can have better anti-noise ability at the feature layer.

Gao [24] used face recognition and palmprint recognition technology, multi-model and multi-vision in 2-D to combine multiple visual features based on the new similarity, and applied the visual features of 3-D objects on different sensors. Research has shown that feature-level fusion provides a new way to combine multiple patterns and views for personal identification.

Kong [25] aimed to improve the recognition probability of palm prints, Gabor filters were used at the feature level to obtain phase information, and the fusion rules were used to generate fusion features. Database information experiments proved that the experiments can improve the original palmprint fusion approach.

3.3. The Integration of Decision Layer

The integration of decision layer mainly includes Bayesian reasoning [26], D-S reasoning, etc. The following is the main relevant literature.

Xukan Xu [27] proposed a trust model based on Dempster-Shaper theory based on the variability, dynamics and instability of information on the trust level of network emergencies. Experiments on the model prove that the model is feasible.

Junjun Guo [28] proposed a tracking algorithm based on multi-target tracking at the decision-making level based on Bayesian theory for the large-scale wireless sensors. The sensor was selected by the objective function for data fusion. The simulation results show the validity of the algorithm presented in this paper.

Pinheiro [29] modeled the information collected from the surroundings by multi-sensors, and realizes local fusion through Bayesian theory. Different sensors are advanced to global fusion through local fusion, and combined with the world model in the RoboCup medium league robot implementation and testing.

Huadong [30] chose the Dempster-Shafer method as the sensor fusion implementation algorithm. The context-aware sensor fusion computing project aims to construct a generalizable sensor fusion architecture in a systematic way. The relationship between the methods is compared with the probability weighted sum method, so that the advantages of D-S theory can be compared more.

4. Conclusions Remarks

The existing sensor layers are categorized into dataset fusion, feature layer integration and decision-making layer integration methods. Data fusion is performed through different fusion methods. Different scholars also obtain the advantages and disadvantages of each algorithm through experimental simulation.

The data layer, feature layer and decision-making layer make the integration level from low to high. The required data is more to less, and the real-time is from low to high. For different problems, different fusion methods can be selected. It also needs to consider. Other different related issues, such as the integrated structure of the system.

So many algorithms are existed. The focus of the next research is mainly on the integration of deep learning and algorithms. It is also the focus of research to provide suitable algorithms for practical problems.

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