Impacts of Brooks Iyengar Algorithm on PhD Dissertations

More than 28 dissertations from highly ranked universities (e.g. MIT, Carnegie Melon University, RICE University, University of Southern California, and University of Pennsylvania) have extensively inspired by the Brooks-Iyengar Algorithm or applied it in their dissertation. Here are some examples:

1. Heuven, D. W. from University of Twente, 2014 [1]

"**Brooks Iyengar Algorithm**: An algorithm to exchange data with accuracy is the Brooks-Iyengar algorithm. The Brooks-Iyengar algorithm is a hybrid algorithm that combines data fusion with Byzantine agreement to filter out-of-range values and average the accepted values. The rough steps of the algorithm are as follows:

1. First the node shares the data to aggregate with its neighbors

2. The second step is to filter out invalid (out of range) information, which results in the lower and upper bound and accuracy of the accepted values.

3. The final step is to calculate the weighted average of the accepted values, where the weights are the number of sensors whose readings intersect with each of the accepted values. An attacker can falsify the aggregated result, but it won't hurt the normal operation of the system.

The SDSN-Aggregation: The SDSN aggregation method uses a combination of methods "Brooks-Iyengar algorithm" and "Witness based approach for data fusion assurance" to achieve the aggregation. The aggregation method should work for multiple data types and for different densities of the network. The SDSN-aggregation is event-based, it is triggered on an aggregation request by another node or when new data is available. All data types have specific parameters for the freshness function which indicates if the sensor data is still fresh enough for aggregation or not. To use this implementation it is important to known the location of the sensor data and the time of the sensor data.

The aggregation is triggered when new data is available for aggregation and no recent aggregation was performed (viewpoint of the initiated node): Where the variable X is the setting indicating the number of required proofs of the aggregation, and the variable Y is the data sharing timeout indicating how long the node should wait for other nodes data sharing.

1. The node checks if there are at least X neighbors available which can perform an aggregation. When this is not the case then a node will wait until there are enough nodes available or until the data is not fresh anymore, in the last case the aggregation is aborted but the raw data is stored.

2. The initiator node broadcasts its available fresh data to its neighbors with an aggregation request and waits for period Y. During this period other nodes can broadcast their local (fresh) data) to additionally be used for aggregation.

3. The nodes filter out incorrect and non-fresh data and start the aggregation (using the Brooks-Iyengar algorithm).

4. The nodes broadcast their ’proof’ of the aggregation which consists of a message authentication code calculated on the aggregation result in addition to an indication as to which measurements where aggregated.

5. The nodes collect X proofs of their aggregation and store them with the aggregated result.”

2. Udayan Naik from Auburn University, 2005 [2]

Brooks and Iyengar give a high level view of a multi-sensor tracking system, also shown below in Figure 5.1.

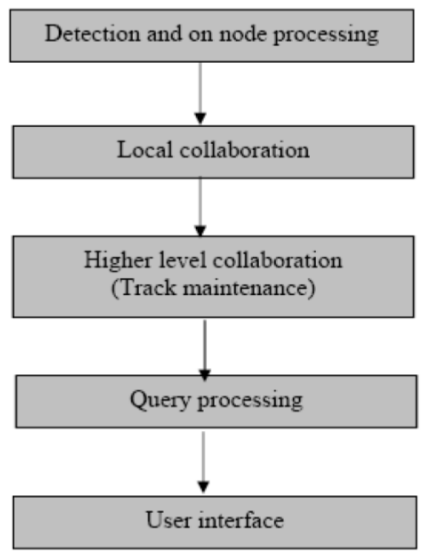

Figure 5.1 High level view of a target tracking system

Each sensor node continuously monitors its environment and tries to detect events as they occur within the sensor’s field of operation. Target information is then used by the node to create a detection event by matching it with the node’s known target type database. Local collaboration is performed to create an accurate categorization of the target, and includes only nodes within a dynamically determined geographic neighborhood and time frame. Results of this local collaboration are then used to initiate and maintain tracking of the target. Tracking information may also be stored in a distributed database which is possibly part of a complex query processing system and is tied to a user interface.

As can be deduced, detection and in-node processing is the first step for target tracking. Robustness and reliability are also important factors one must consider in this process of sensor fusion. In this context, the number of sensor failures the network can tolerate becomes crucial, as is the manner in which data from fit sensors is separated from the unfit ones. Richard Brooks, et al, give a solution that satisfies the requirements of inexact agreement problem by merging the sensor fusion algorithm with Mahaney and Schneider’s Fast Convergence algorithm. The solution assumes the self-organization of sensor nodes into clusters. The sensor fusion algorithm runs on the cluster head, which collects the processed data from the group members and inputs this into the algorithm.

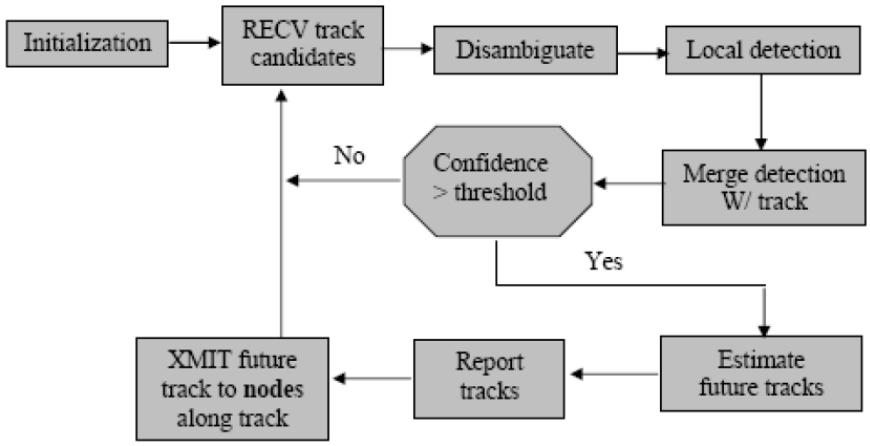

Figure 5.2 Target tracking process flow chart

A flowchart for the process of target tracking is shown in Figure 5.2. The initialization phase consists of publish-subscribe calls. Brooks-Iyengar's methodology proposes two waves of publish-subscribe calls propagated in four directions.

3. Damien Jourdan from Massachusetts Institute of Technology, 2006 [3]

Once the necessary sensors are deployed on the ground, their data is transmitted back to the base in order to provide decision makers with the necessary situational awareness. In recent years researchers have given more attention to operational issues of WSNs such as energy-efficient communication and data fusion (Brooks and Iyengar; 1998).

The only remaining piece that is needed is a routing scheme which, for each sensing cycle, describes how the data packets are directed from every sensor to the HECN. Sensors with a direct link to the HECN will obviously transmit directly to it. However when multiple hops are required to reach the HECN, the data packet may have several possible paths to get to the HECN. For example, the data of N3 in Fig. 3-1 can reach the HECN by going either through N1 or N2. The routing scheme is the set of rules whereby this path is chosen. For WSN the main challenge is to route the information so as to conserve the energy of the network, and many algorithms have been proposed and studied to that effect (Brooks and Iyengar; 1998)

4. Rodoslav Ivanov from University of Pennsylvania, 2017 [4]

"Sensor redundancy has been explored in depth in the area of sensor fusion where sensors are generally considered to measure the same variable but through different means and with different accuracies. One of the first works in this field assumes that sensors provide onedimensional intervals and shows worst-case results regarding the size of the fused interval based on the number of faulty sensors in the system. A variation of this work relaxes the worst-case guarantees in favor of obtaining more precise fused measurements through weighted majority voting (Brooks and Iyengar; 1998)."

5. Changying Li from Pennsylvania State University, 2006

In the medical area, more and more sophisticated sensors have been used in medical diagnosis. Sensors such as nuclear magnetic resonance (NMR) devices, acoustic imaging devices and fiber-optic probes, provide various ways to examine patients. If these devices and their data could be integrated, the accuracy and reliability of diagnosis would be greatly improved (Brooks and Iyengar, 1998).

In recent years, data fusion has been increasingly applied to civilian applications including: remote sensing, automated control of industrial manufacturing systems, medical diagnosis, and food quality and safety inspection (Brooks and Iyengar, 1998).

6. Zhimin Peng from Rice University, 2013

Slow increase of the performance of single-processor caused by transmission speeds, limits to miniaturization and economic limitations 2 leads to designing microprocessors in the direction of parallelism. Parallel and distributed computing not only has been used to solve difficult problems in many areas of science and engineering such as communication, computing and sensor network (Brooks and Iyengar; 1998) but also attracts people's attention from industry for its ability to process large amount of data in sophisticated ways.

7. Jennifer Mankoff from Carnegie Melon University, 2001

Fusion: Fusion involves taking input from multiple ambiguous sources about the same input event (intended action by the user) and combining them to get one set of ambiguous possible actions. Although it is rare to have redundant sensors in the GUI world, it is quite common in a robust sensing environment. Thus, a complete solution to the problem of ambiguity in the context-aware computing world would benefit from structured support for the fusion problem, a problem that has been extensively addressed in other research areas such as robotics (Brooks and Iyengar; 1997).

8. Calvin Coopmans from Utah State University, 2014

Sensor Fusion: Sensor fusion is a class of techniques of combining sensory data from disparate sources to derive more accurate or dependable information (such as shown in Chapter 6). Due to corruption from noises and disturbances, data acquired by different sensors have heterogeneous attributes and components. Sensor fusion is able to extract consensus information from distributed sensors, or derive new information based on independent measurements in a recursive sense. Sensor fusion is important for modern robotics systems (Brooks and Iyengar; 1998) Using stereo image fusion technology, robotic vision sensor is able to operate similarly as human vision, and its ability to detect and recognize objects can be significantly improved. Image fusion also allows robotic vision to abstract and identify information from multispectral or hyperspectral imagery. For mobile robots, sensor fusion allows several complementary and redundant sensors to assist the robot accurately locating itself within complex environments.

References

[1] Heuven, D. W. *Opportunistic sensing & Aggregation network Using Smartphones and Sensor nodes*. MS thesis. University of Twente, 2014.

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[4] Ivanov, Radoslav Svetlozarov. Context-Aware Sensor Fusion for Securing Cyber-Physical Systems. Diss. University of Pennsylvania, 2017.