Sensor Fusion of Intelligent Sensors using Probability Density

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ABSTRACT
The accuracy of a system is the distance of the system's results from the results desired. The precision of a system is the size of the range of values returned by the system. The algorithm will terminate with each PE Processing Element. A value that is within the given value of all the values held by the other PEs. This method is called Approximate Agreement method.

Keywords
Expected Output, Intelligent Sensor, Processing Element (PE), Fault Sensor F.

1. INTRODUCTION
In this chapter I have analyzed Dolve's algorithm and extended the same approach for Intelligent Sensors[1]. First I introduce Dolev's Approximation Algorithm for Intelligent Sensors. Then a method introduced to find expected value for intelligent sensor and produce an algorithm for getting a better result than the Approximate Agreement method.

2. PROCESSING ELEMENT
A sensor is called a processing element (PE). The number of PEs is N and F is the number of malfunctioning PEs.These algorithm is intended to return a valid value from a set of readings from N PEs given F of them are known (or supposed) to be wrong ; not to establish how many sensors are faulty.[2][5]

3. DOLEV'S ALGORITHM
Input :A set of sensors each with a value
N – Total Number of Sensors
F – Total Number of Fault Sensors
Output:A set of sensors each with a new value converging toward a common value.

Method
Step 1 : Each sensor broadcasts its value.

Step 2 : Each sensor receives the values from other Sensors and sorts the values into vector V.

Step 3 :The lowest F values and highest F values are discarded from V at each sensor [Theorem 1]

Step 4 : Each sensor forms new vector V' by taking the remaining values $V(i*F)$ Where $i = 0,1\dots$ (the smallest remaining values and every remaining F^{th} value in order).

Step 5:The new value is the mean of the values in V'.

3.1 Example
Consider a system having four sensors out of which at the most one may give false value. Therefore N = 4, F = 1. Sensor values are expressed as ranges. The Dolev's algorithm was applied to the following table:

Table 1 Sensor and Values

Sensor	Lower	Higher
S_0	**2**	**7**
S_1	**3**	**8**
S_2	**4**	**9**
S_3	**7**	**12**

Take each sensor value is the midpoint of its range. The values are stored in the following table:

Table 2 Sensor and midvalues

Sensor	Mid values
S_0	**4.5**
S_1	**5.5**
S_2	**6.5**
S_3	**9.5**

calculate the new value of V'

$$V = \{(4.5, 5.5, 6.5, 9.5)\}$$
$$V' = \{(5.5, 6.5)\}$$
$$= \{(5.5 + 6.5) / 2\}$$

The new value of **V' = 12 / 2 = 6.**

The new value of v' is present within the range of sensors S_0, S_1, S_2. The sensor S_3 range is outside the new value of V'. Therefore S_3 is the fault sensor.

4. INTELLIGENT SENSORS

In the approximate agreement problem[8] each sensor gave an output $x \pm \varepsilon$. When ε is the accuracy of the results produced by the sensor. In this section we assume *intelligent sensors* which are capable of calculating the probability density function defined over the interval $(x - \varepsilon, x + \varepsilon)$. [6][9][10].

4.1 Condition

Assume ε is a constants for all Sensors S_0, S_1, S_2 …….. S_{N-1}

Table1.3 Approximate Intelligent Sensors Readings

case	S_0	S_1	S_2	…	S_I	S_{N-1}
1	$x_0 \pm \varepsilon$	$x_1 \pm \varepsilon$	$x_2 \pm \varepsilon$	…	$x_i \pm \varepsilon$	$x_{N-1} \pm \varepsilon$
2.	$x_0 \pm \varepsilon$	$x_1 \pm \varepsilon$	$x_2 \pm \varepsilon$	…	$x_i \pm \varepsilon$	$x_{N-1} \pm \varepsilon$
3.	…	…	….	…	…	….
I	$x_0 \pm \varepsilon$	$x_1 \pm \varepsilon$	$x_2 \pm \varepsilon$	…	$x_i \pm \varepsilon$	$x_{N-1} \pm \varepsilon$
N	$x_0 \pm \varepsilon$	$x_1 \pm \varepsilon$	$x_2 \pm \varepsilon$	…	$x_i \pm \varepsilon$	$x_{N-1} \pm \varepsilon$

5. APPROXIMATE AGREEMENT FOR INTELLIGENT SENSORS

Let $S_0, S_1, S_2, \ldots S_{N-1}$ be N *intelligent sensors*. The output of S_i is given below.

S_0

x_{00}	x_{01}	x_{02}	…	x_{0j}	…	x_0n_0
p_{00}	p_{01}	P_{02}	…	p_{0j}	…	p_0n_0

S_1

x_{10}	x_{11}	x_{12}	…	x_{1j}	…	x_1n_1
p_{10}	p_{11}	P_{12}	…	p_{1j}	…	p_1n_1

S_i

x_{i0}	x_{i1}	x_{i2}	…	x_{ij}	…	x_in_I
p_{i0}	p_{i1}	P_{i2}	…	p_{ij}	…	p_in_i

S_{N-1}

$x_{N-1,0}$	$x_{N-1,1}$	$x_{N-1,2}$	…	$x_{N-1,j}$	…	x_{N-1}, n_{N-1}
$p_{N-1,0}$	$p_{N-1,1}$	$p_{N-1,2}$	…	$p_{N-1,j}$	…	p_{N-1}, n_{N-1}

6. TO FIND THE EXPECTED OUTPUT VALUE OF AN INTELLIGENT SENSOR

The expectation of the probability density function of the intelligent sensor Si is called the expected output value ei. [Bai02].

S_i

x_{i0}	x_{i1}	x_{i2}	…	x_{ij}	…	x_in_i
p_{i0}	p_{i1}	p_{i2}	…	p_{ij}	…	p_in_i

$$e_i = \sum_{i=0}^{n_i} X_i * P_i$$

7. DOLEV'S APPROXIMATION FOR INTELLIGENT SENSOR

1. Find ei for sensor.
2. Ignore F sensors having lowest ei values and F sensors having ei values.
3. Do column sum using remaining sensors.
4. *Find sum of column sum and divide each column by its sum.*
5. Output the PDF value.
6. *Output e_i value for each sensor.*

8. EXAMPLE FOR APPROXIMATE PROBABILIT

8.1 Example

A set of 5 Sensors one of them is working in a fault manner. The fault sensor broadcast different value to each of the other four sensors. The values are:

Sensor	S_0	S_1	S_2	S_3
Values	4.7 ± 0.2	1.6 ± 0.2	3.0 ± 0.2	1.8 ± 0.2
S_4 values	3.0 ± 0.2	1.0 ± 0.2	2.5 ± 0.2	0.9 ± 0.2

8.2 Approximate Agreement

S_0

4.5	4.6	4.7	4.8	4.9
0.2	0.2	0.3	0.2	0.1

Expected value of S_0 = 4.68

S_1

1.4	1.5	1.6	1.7	1.8
0.1	0.3	0.4	0.1	0.1

Expected value of S_1 = 1.58

S_2

2.8	2.9	3	3.1	3.2
0.25	0.2	0.4	0.3	0.05

Expected value of S_2 = 3.01

S_3

1.6	1.7	1.8	1.9	2
0.1	0.3	0.3	0.2	0.1

Expected value of S_3 = 1.79

S_4

2.8	2.9	3	3.1	3.2
0.15	0.1	0.5	0.2	0.05

Table 1.4 Sensors Expected Value

Sensor	e_i	Dolev's Approximation	Remark
S_0	4.68	X	Highest Value Discard (F=1)
S_1	1.58	X	Lowest value Discard (F=1)
S_2	3.01	✓	**Select**
S_3	1.79	✓	**Select**
S_4	2.99	✓	**Select**

Table 1.5 Sensors Probability Value

	1.6	1.7	1.8	1.9	2	2.8	2.9	3	3.1	3.2
S_3	0.1	0.3	0.3	0.2	0.1					
S_2						0.25	0.2	0.4	0.3	0.05
S_4						0.15	0.1	0.5	0.2	0.05
Column sum (CS)	0.1	0.3	0.3	0.2	0.1	0.4	0.3	0.9	0.5	0.1
CS/3	0.033	0.1	0.1	0.667	0.033	0.133	0.1	0.3	0.167	0.033

1.6 Result Table

X	1.6	1.7	1.8	1.9	2	2.8	2.9	3	3.1	3.2
p (x)	0.033	0.1	0.1	0.667	0.033	0.133	0.1	0.3	0.167	0.033

CONCLUSION

One iteration of Dole approximate agreement algorithm requires finding the F largest and F smallest of N values. This can be done by finding and removing the maximum and minimum of the values F times or by sorting the set in increasing order. I*ntelligent sensors* which are capable of calculating the probability density function defined over the interval (x- ε, x + ε). It is desirable not only to tolerate sensor failures but also to increase the expected accuracy of each sensors with PDF.

9. REFERENCES

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