Measure of fault isolability of diagnostic system

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Abstract
This paper concerns a problem of quantifying fault isolability of fault detection and isolation (FDI) system with different forms of notation of a fault - symptoms relation. Binary Diagnostic Matrix and Fault Isolation System are introduced and used as examples of different types of diagnostic systems. New measure is formulated and appropriate calculation algorithm is proposed. Behavior of the algorithm in basic situations is shown on examples with generalizations made. A comprehensive example is discussed.

1 Introduction
During early stages of system design it is very important to consider diagnostics requirements. On the one hand it helps to achieve required efficiency of Fault Detection and Isolation (FDI) system. On the other hand, it allows to reach demanded fault isolability level without unnecessary measurements or sensors, therefore avoiding unreasonable costs.

There are many approaches for a sensor placement optimization problem taking into account the constrain of required minimum isolability for designed system [1,2] or maximizing it [3]. Regardless of optimization method, simple qualitative statements about isolability performance of the system are not sufficient. A quantitative measure of fault isolability for diagnostic system is required.

Abovementioned works [1,2,3,4] as well as many others utilize a measure called diagnosability degree. It was proposed in [5]. It is a simple measure calculated in two steps. First, all elements of a considered fault set F are divided into pairwise disjoint subsets of unisolable (non-discriminable) faults. Those subsets are called D-classes. In second step number of D-classes denoted D is compared with total number of faults. The resulting measure is called diagnosability degree:

\[
d = \frac{D}{\text{card}(F)}
\]  

For fully isolable system, where number of D-classes is equal to a total number of faults d is equal to 1. Unfortunately, diagnosability degree has many disadvantages. Firstly, for any pair of faults in the system isolability is analyzed only in bi-valued (true or false) terms, which do not allow for more subtle distinctions. This may result in insufficient effectiveness of diagnostic system when too weak isolability condition are assumed, or too high costs of system development in opposite situation. This problem was partially addressed in [6] where fuzzy diagnosability degree is proposed. However, it requires designed diagnostic system to be Discreet Event System DES.

Another disadvantage of diagnosability degree is that it does not account for a distribution of faults among D-classes. For example if one D-class has far more faults than any other then such a system would be less useful from a practical point of view than a system with identical total number of faults uniformly distributed among identical number of D-classes. Assuming that every fault has similar frequency of occurrence in case of first system one would mostly get faults from that one D-class. Finally, diagnosability degree cannot be used in diagnostic systems with polyvalent form of notation of diagnostic relation, such as a Fault Isolation System (FIS) [7] or in approaches utilizing sequences of symptoms.

The main objective of this paper is to propose a new measure of isolability for diagnostic system that takes into account different levels of possible isolability between two faults and can be used with polyvalent forms of notation of diagnostic relation. This analysis is limited to single faults only.

The main motivation for this work is to obtain a measure that can be used while designing FDI system to estimate system performance and to be able to compare different systems. This can be used when designer is given a set of existing measurements, a set of possible new ones with prices of equipment and a budget. In most cases it is not possible for designer to buy everything he wants. In such a case proposed measure can be used as a value in modified discrete knapsack problem. It can be then efficiently solved with simple algorithm. Moreover, by dividing proposed measure of isolability by a cost of a system one gets a cost function for discrete optimization problem which can be then solved with simple, well-known methods.

The structure of this paper is as follows: In Sect. 2 theoretical background is given. Binary diagnostic matrix and Fault Isolation System are presented. Definitions of different types of fault isolability are given. In Sect. 3 new...
measure is introduced with calculation algorithm. In Sect. 4 three basic examples are discussed. Polyvalent modification of the algorithm is presented in Sect. 5. A comprehensive example is discussed in Sect. 6. Sect. 7 summarizes this paper.

2 Theoretical background

2.1 Binary diagnostic matrix

Binary diagnostic matrix (BDM, incidence matrix, fault occurrence matrix) is the most widely used form of notation of the faults-symptoms relation in FDI systems. It can be obtained by many methods, for example by modeling with fault influence, structural analysis or using expert knowledge. It was named by Gertler in [8] as a structure matrix of a residual set. It is a form of notation of a relationship specified by the Cartesian product of diagnostic signals sets \( S = \{ s_j : j = 1,2,..., J \} \) and faults \( F = \{ f_i : i = 1,2,..., n \} \). Each column \( V_j = [v_{1,j}, v_{2,j}, ..., v_{n,j}] \) of binary diagnostic matrix \( V \) can be associated with a fault \( f_i \). Often column \( V_j \) is called signature of fault \( f_i \). An example of binary diagnostic matrix is shown in Table 1.

Table 1. Binary diagnostic matrix example. 1 in j-th row and i-th column means that \( f_i \) is detectable with signal \( s_j \).

<table>
<thead>
<tr>
<th>( f_1 )</th>
<th>( f_2 )</th>
<th>( f_3 )</th>
<th>( f_4 )</th>
<th>( f_5 )</th>
<th>( f_6 )</th>
<th>( f_7 )</th>
<th>( f_8 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( s_1 )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( s_2 )</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( s_3 )</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( s_4 )</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>( s_5 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Definition 1.

Faults \( f_k, f_m \in F \) are weakly isolable if their signatures are different.

In the example from Table 1 all faults with exception of pair \((f_2, f_3)\) are weakly isolable. Weak isolability in some applications is not sufficient. It is possible that due to different sensitivity of diagnostic tests of process dynamics some signals appear earlier and match a signature of different, weakly isolated fault. In above example, appearance of only signal \( s_1 \) may be insufficient to reliably indicate fault \( f_1 \). Later signals \( s_2 \) or \( s_3 \) may appear indicating faults \( f_2, f_3 \) or \( f_5 \). Therefore a stronger property is required.

Definition 2.

Faults \( f_k, f_m \in F \) are strongly isolable if their signatures are different and, no signature can arise from other by turning “1”s into “0”s [9].

Weak isolability is necessary condition for strong isolability.

In Table 1, faults \( f_3 \) and \( f_5 \) are strongly isolable. From definition 2 following definition can be extrapolated:

Definition 3.

Signature \( V_i \) is excluding fault \( f_k \) if \( V_i \) is different than \( V_k \) and \( V_i \) cannot be obtained from \( V_k \) other by turning “1”s into “0”s.

Opposite does not have to be true. If faults are mutually excluding each other they are strongly isolable. In Table 1 signature \( V_3 \) is excluding \( f_1 \). Opposite is not true so they are not strongly isolable.

2.2 Fault Isolation System

Definitions of information system and rough information system were introduced in [10]. They are very useful in defining the faults – symptoms relation. The Fault Isolation System - FIS has been defined [7, 11] as an information system in the form of a quadruple \(<F,S,V,q>\) where:

- \( F \) – finite set of faults,
- \( S \) – finite set of diagnostic signals,
- \( V \) – a set of possible values of diagnostic signals,
- \( q \) – relation:

\[
q : F \times S \rightarrow \Phi(V) = \bigcup_{i=1}^{n} V_i
\]

assigning to each element of the Cartesian product \( F \times S \) a subset of diagnostic signals:

\[
q(f_i, s_j) \equiv V_{f_i} \subset V_j
\]

which can be taken by the signal during the occurrence of fault \( f_i \).

Following definitions for fault isolability in FIS can be given.

Definition 4.

Faults \( f_k, f_m \in F \) are conditionally isolable if and only if signatures of those faults are different and for every signal, subsets of its values corresponding to faults \( f_k \) and \( f_m \) have non-zero intersection.

Definition 5.

Faults \( f_k, f_m \in F \) are in FIS (unconditionally) weakly isolable if there is a diagnostic signal, for which subsets of values corresponding to those faults are disjoint:

\[
\exists s_j \in S \quad V_{f_k} \cap V_{f_m} = \emptyset.
\]

Definition 6.

Faults \( f_k, f_m \in F \) are (unconditionally) strongly isolable if they are weakly isolable and no signature can arise from other by turning non-zeros into “0”s.

In polyvalent systems occurrence of some fault \( f_i \) can cause different values of diagnostic signals depending on fault magnitude, set point, etc. If these signature concretizations cannot be obtained from fault \( f_i \) signatures by turning non-zeros into “0”s then this signature concretization is excluding fault \( f_i \).

In Table 2 FIS example is presented. Faults \( f_1 \) and \( f_4 \) are unconditionally weakly isolable. Pairs \((f_2, f_1)\) and \((f_2, f_3)\) are conditionally isolable.
Table 2. FIS example.

<table>
<thead>
<tr>
<th>S/F</th>
<th>f₁</th>
<th>f₂</th>
<th>f₃</th>
<th>Vᵢ</th>
</tr>
</thead>
<tbody>
<tr>
<td>s₁</td>
<td>-1</td>
<td>+1,-1</td>
<td>+1</td>
<td>{0,+1,-1}</td>
</tr>
<tr>
<td>s₂</td>
<td>0</td>
<td>0,1</td>
<td>1,2</td>
<td>{0,1,2}</td>
</tr>
<tr>
<td>s₃</td>
<td>+1</td>
<td>+1</td>
<td>+1,-1</td>
<td>{0,+1,-1}</td>
</tr>
</tbody>
</table>

3 The measure of fault isolability of diagnostic system for binary diagnostic matrix

The proposed algorithm for calculation of the measure of isolability for diagnostic system consists of two steps:
- For each fault calculate the coefficient \( d_i \) where \( d_i \) is a number of faults excluded by signature of fault \( f_i \). Then increase \( d_i \) by 1 if fault is detectable. After this step \( d_i = 0 \) if fault is not detectable and \( d_i \geq 1 \) if fault is detectable.
- Calculate measure of isolability with formula:

\[
m(V) = \frac{1}{(n+1)n} \sum_{i=1}^{n} d_i ,
\]

where \( n \) – total number of faults.

For example, when analyzing diagnostic system described by Table 1, following values are obtained: \( d_1 = 5 \), (as \( V_1 \) excludes \( f_1, f_2, f_3, f_4 \) and +1 for detectability), \( d_2 = d_3 = 6 \); \( d_4 = d_5 = 7 \); \( d_6 = d_7 = 8 \). After applying formula (6) we obtain \( m(V) = 0.75 \).

Value of this measure has a valid physical interpretation. It is an average fraction of possible single fault diagnoses that are excluded with fault signature. There are \( n+1 \) possible diagnoses: a faultless state and \( n \) single fault states.

**Lemma 1.** Maximum possible value for proposed isolability measure is 1.

**Proof:**

Maximum value of fault isolability will be obtained when every signature excludes every other fault. That situation takes place with fully, strongly isolating diagnostic system (compare with sect. 4.3). Then \( d_i = 1+ n-1 = n \) because every fault is detectable and signature exclude every other fault signature except itself. Fault isolability measure can be then calculated as:

\[
m(V) = \frac{n^2}{(n+1)n} = \frac{n}{n+1} = 1 - \frac{1}{n+1} \quad (7)
\]

Which is less than 1 for any positive and finite \( n \).

**Lemma 2.** Function defined as a isolability measure (6) satisfies properties of a measure i.e., non-negativity, null empty set and countable additivity.

**Proof:**
- Property of non-negativity means that \( m(V) \geq 0 \) for any \( V \). It is trivial to prove, as both \( d_i \geq 0 \) and \( n \geq 0 \). Therefore \( m(V) = \frac{1}{(n+1)n} \sum_{i=1}^{n} d_i > 0 \).
- Null-empty set means that \( m(Ø) = 0 \). If there is no detectable fault (matrix \( V=Ø \)), for every fault \( d_i = 0 \) and \( m(V) = 0 \) satisfying property of null empty set.
- As \( d_i \) is calculated for every fault separately then faults can be grouped into disjoin subsets \( V' \) with \( k \) and \( V'' \) with \( v \) faults, \( v+w=n \). Then

\[
m(V') = \frac{1}{(n+1)n} \sum_{i=1}^{n} d_i ,
\]

\[
m(V'') = \frac{1}{(n+1)n} \sum_{i=0}^{v} d_i ,
\]

\[
m(V') + m(V'') = m(V) .
\]

That satisfies countable additivity property.

Therefore all properties of a measure are satisfied.

Lemma 2 has a practical meaning, especially countable additivity, as it allow to use isolability measure to determine effects of changes to diagnostic system.

Fulfilling Lemma 1 and Lemma 2 proposed probability measure satisfies properties of probability measure.

This algorithm for calculating isolability can be used without modifications for any bi-valued form of notation of diagnostic relation, such as directions in residual space or a sequence of symptoms. To use this isolability measure in any system it is enough to be able to determine if signature corresponding to given fault excludes other faults.

4 Examples of basic types of diagnostic systems

4.1 The unisolable system

Table 3 presents an example of fully unisolable system with 3 faults.

Table 3. BDM for unisolable system

<table>
<thead>
<tr>
<th></th>
<th>f₁</th>
<th>f₂</th>
<th>f₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>s₁</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

In this example \( d_1 = d_2 = d_3 = 1 \) as each of these faults is detectable, but their signatures do not exclude each other.

\[
m(V) = \frac{1}{(n+1)n} \sum_{i=1}^{n} d_i = \frac{1}{4} \quad (10)
\]

Generally, for fully unisolable system \( V_u \):

\[
m(V_u) = \frac{1}{n+1} , \quad (11)
\]

and

\[
\lim_{n\to\infty}(m(V_u)) = 0 . \quad (12)
\]

4.2 The weakly isolating system

Table 4 presents example of BDM of weakly isolating system. For this system \( d_1 = 1 \) because \( f_1 \) is detectable but its signature does not exclude any other fault. \( d_2 = 2 \) because \( f_2 \) is detectable and its signature excludes \( f_1 \). Analogously, \( d_3 = 3 \).
Table 4. Example of weakly isolating diagnostic system.

<table>
<thead>
<tr>
<th>s_1</th>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
m(V) = \frac{1}{(n+1)n} \sum_{i=0}^n d_i = \frac{1}{2} \quad (13)
\]

Generally, for weakly isolating system \( V_w \):

\[
m(V_w) = \frac{1}{2} \quad (14)
\]

It is a very important property of this measure. It allows to compare performance of any FDI system to weakly isolating one.

4.3 Strongly isolating system

Strongly isolating system is presented in Table 5.

Table 5. BDM of strongly isolating system for detection of 3 faults.

<table>
<thead>
<tr>
<th>s_1</th>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this example \( d_1 = d_2 = d_3 = 3 \). Each fault is detectable and excludes other two.

\[
m(V) = \frac{1}{(n+1)n} \sum_{i=0}^n d_i = \frac{3}{4} \quad (15)
\]

Generally, for strongly isolating system \( V_s \):

\[
m(V_s) = 1 - \frac{1}{n+1} \quad (16)
\]

and

\[
\lim_{n \to \infty} (m(V_s)) = 1 \quad (17)
\]

It is worth noting that diagnosability degree (1) usually does not distinguish weakly and strongly isolating faults.

5 Algorithm modification for polyvalent forms of notation of diagnostic relation

In polyvalent systems conditional isolability is possible (Definition 4). Therefore, it is required to account for situation where due to conditional isolability some combinations of diagnostic signals exclude the other fault and some not. In such case first step of the algorithm needs to be modified.

\[
d_i = \begin{cases} 
0 & \text{if } f_i \text{ is not detectable} \\
1 + \sum_{j=0}^n w_{i,j} & \text{otherwise} 
\end{cases} \quad (18)
\]

Where:

\[
w_{i,j} = \frac{\text{card}(S_i)}{\text{card}(S_j)} \in (0;1) \quad \text{,(19)}
\]

\( S_i \) – set of all possible signatures of \( f_i \),
\( S_{ij} \) – set of all signatures excluding \( f_j \).

5.1 Example of measure of isolability calculation for FIS

Following the example presented in Table 2, \( f_1 \) is detectable and there is only one combination of signals for its signature. It is excluding \( f_3 \). Thus \( d_1 = 1 + 1 = 2 \). \( f_2 \) is detectable and has 4 possible signature concretizations. 3 of them are excluding \( f_1 \) and 3 are excluding \( f_2 \). \( d_2 = 1 + \frac{3}{4} + \frac{3}{4} = 2.5 \).

\( f_3 \) is also detectable and has 4 signature combinations. All of them exclude \( f_1 \) and 3 of them exclude \( f_2 \). \( d_3 = 1 + 1 + \frac{3}{4} = 2.75 \). Overall isolability measure \( m(V) = 0.604 \).

6 Example for two-tank system

As an example we will analyze two tank system (Fig. 1).

Fig. 1 Two tank system. \( F \) – input flow to tank 1, \( L_1 \) – water level in tank 1, \( L_2 \) - water level in tank 2

This object can be described by following equations:

\[
A_1 \frac{dL_1}{dt} = F - Q_{12} = F - \alpha_{12} S_{12} \sqrt{2g \left( L_1 - L_2 \right)}
\]

\[
A_2 \frac{dL_2}{dt} = Q_{12} - Q_2 = \alpha_{12} S_{12} \sqrt{2g \left( L_1 - L_2 \right)} - \alpha_{21} S_{21} \sqrt{2g \left( L_2 \right)} \quad (20)
\]

Following faults are considered:

Table 6. Diagnosed faults in example object.

<table>
<thead>
<tr>
<th>f_1</th>
<th>f_2</th>
<th>f_3</th>
<th>f_4</th>
<th>f_5</th>
<th>f_6</th>
<th>f_7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clog between tanks 1 and 2</td>
<td>Clog in the output of tank 2</td>
<td>Leak in the tank 1</td>
<td>Leak in the tank 2</td>
<td>Faulty measurement of F</td>
<td>Faulty measurement of L_1</td>
<td>Faulty measurement of L_2</td>
</tr>
</tbody>
</table>

We can extend equations (20) with information about faults to obtain following residuals:
\[ r_i = F + f_i - \alpha_i (S_i - f_i) \sqrt{2g (L_i + f_e - (L_e + f_i))} \]
\[ -f_3 - A^3 \frac{d(L_e + f_e)}{dt} \]
\[ r_2 = \alpha_i (S_i - f_i) \sqrt{2g (L_i + f_e - (L_e + f_i))} \]
\[ -\alpha_i (S_i - f_i) \sqrt{2g (L_i + f_e - (L_e + f_i))} - f_4 - A^2 \frac{d(L_e + f_e)}{dt} \]
\[ (21) \]

We can obtain third residual by combining \( r_1 \) and \( r_2 \).
\[ r_3 = r_1 + r_2 = F + f_3 - \alpha_i (S_i - f_i) \sqrt{2g (L_i + f_e - (L_e + f_i))} - f_3 - f_4 - A^3 \frac{d(L_e + f_e)}{dt} - A^2 \frac{d(L_e + f_e)}{dt} \]
\[ (22) \]

The binary diagnostic matrix describing is system is shown in Table 7.

Table 7. Binary diagnostic matrix for two tanks system with primary nonlinear residuals.

<table>
<thead>
<tr>
<th></th>
<th>( f_1 )</th>
<th>( f_2 )</th>
<th>( f_3 )</th>
<th>( f_4 )</th>
<th>( f_5 )</th>
<th>( f_6 )</th>
<th>( f_7 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_1 )</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( r_2 )</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( r_3 )</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Using residuals \( r_1 \), \( r_2 \) and \( r_3 \) from Table 7 and Definition 1 following sets of unisolable faults can be distinguished \( \{ f_1, \{f_6, f_7\}, \{f_2, f_4\}, \{f_3, f_5\}. \)

First step to calculate isolability measure is to calculate \( d_l \).

Using Table 7 following values can be obtained: \( d_1 = 5, d_2 = 4, d_3 = 4, d_4 = 4, d_5 = 4, d_6 = 6 \).

Then (6) can be used to calculate measure: \( m(V_g) \approx 0.59 \).

This means that this system is slightly better than fully weakly isolating.

If fault and signal dynamics is known then it is often possible to determine sequence of symptoms. Table 8 presents order of symptoms in case when time constant of tank 1 is smaller that time constant of tank 2.

Table 8. Sequences of symptoms for two tank system.

<table>
<thead>
<tr>
<th></th>
<th>( f_1 )</th>
<th>( f_2 )</th>
<th>( f_3 )</th>
<th>( f_4 )</th>
<th>( f_5 )</th>
<th>( f_6 )</th>
<th>( f_7 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_1 )</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>( r_2 )</td>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( r_3 )</td>
<td>-1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

- means that given diagnostic signal is not sensitive to that fault.

Using sequential residuals allows one to isolate faults \( f_6 \) and \( f_7 \). Measure of isolability can be then calculated. First:
\( d_1 = 6, d_2 = 4, d_3 = 4, d_4 = 5, d_5 = 7 \). Then \( m(V_g) \approx 0.71 \). This result shows that in accordance with intuition isolability of system using knowledge about sequences of symptoms is better.

This process can also be diagnosed using FIS (Table 9).

Table 9. An example of FIS for two tank system.

<table>
<thead>
<tr>
<th></th>
<th>( f_1 )</th>
<th>( f_2 )</th>
<th>( f_3 )</th>
<th>( f_4 )</th>
<th>( f_5 )</th>
<th>( f_6 )</th>
<th>( f_7 )</th>
<th>( V_{fi} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_1 )</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-1, +1</td>
<td>-1, +1</td>
<td>-1, 0, +1</td>
<td></td>
</tr>
<tr>
<td>( r_2 )</td>
<td>-1</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-1, +1</td>
<td>-1, -1, 0, +1</td>
<td></td>
</tr>
<tr>
<td>( r_3 )</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-1, +1</td>
<td>-1, +1</td>
<td>-1, +1</td>
<td></td>
</tr>
</tbody>
</table>

Following values of \( d_i \) can be calculated: \( d_1 = 5, d_2 = 5, d_3 = 4, d_4 = 5, d_5 = 4.75, d_6 = 6, d_7 = 6 \). Then: \( m(V_{fig}) \approx 0.64 \). This result means that performance of FIS based diagnostic system for two tanks is better for given set of faults and residuals than BDM based and worse than the system using symptom sequences.

7 Summary

New measure of isolability of diagnostic system for bi-valued and polyanonymous forms of notation of diagnostic relation was proposed in this paper along with the algorithm for its calculation. It was proven that it satisfies all required properties of a measure. This measure can be used for solving sensor placement optimization problem during design stage of the system.

Acknowledgments

This work was partially supported by the Mechatronics Faculty Dean’s Grant 504/01/536 and by the National Science Center under the DEC-2011/01/B/ST7/06183 project number.

References