ON THE RELIABILITY AND COMPLEXITY OF UNMANNED GROUND VEHICLE NETWORK

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ABSTRACT

There is an increasing interest in the use of unmanned ground vehicles for defense and security. Collaboration and coordination of these vehicles is very important for survivability. A set of unmanned vehicles in the battlefield have to be controlled by a commander for safety of soldiers in the battlefield. In order to achieve this objective reliability and complexity of these vehicle networks is to be ascertained at various stages of the operations in the battlefield. The objective of this paper is to suggest procedures for ascertaining the reliability and the complexity of unmanned vehicle. In this paper we suggest matrices for reliability and complexity of unmanned networks. A demonstration of the simulation of the suggested procedure would be given. The suggested procedures should be applicable to any number of vehicles in different configurations in the battlefield.

INTRODUCTION

A considerable interest has recently been shown in determining the reliability and complexity of a group of unmanned vehicle network. Both, reliabilities and complexities are important metrics for a commander to take an appropriate decision in the battle field. This paper suggests metrics for reliability and complexity of an unmanned vehicle network.

Unmanned ground vehicles play a significant role in war and nations defense-security capability. This is achieved with help of advancement of technology in sensors, architecture, robotics and standards supported by extensive research. With the advancement of the technology it is important to assure the unmanned vehicle is safe, sturdy, and efficient in all possible conditions. Thus calculation of reliability of the convoy of vehicle network, becomes a vital task. Here the reliability of the whole system of convoy, reliability of a certain path from one station to another, as well as reliability [9-14] of a certain station plays a crucial role for the safety and performance of the convoy. If the safety and reliability factors of the vehicle network are not well considered, may result in unexpected accidents. This motivates the calculation of reliability of convoy of unmanned vehicle network.

With the increasing need of unmanned ground vehicle network for combat applications, the collaboration and coordination of these vehicles have become important design considerations. Both collaboration and coordination require a large number of sensors. These sensors form a network. The complexity of such network is very important in the design stage. The objective of this paper is to give a new definition of complexity which can be used for design and implementation of sensor networks. Algorithms for predicting the complexity for sensor network are proposed. The implementation of the proposed algorithm is given.

Unmanned intelligent ground vehicles [1] are very important for the military applications as well as the commercial applications. They are critical to the combat and battlefield where the human life is in danger. The unmanned ground vehicle is used as an extension of human capability and it operates by itself using number of sensors. We suggest representing the convoy of unmanned intelligent vehicle sensor system as a communication network where the node represents the station of the unmanned ground vehicles and the branch represents the link/path between two stations. The collaboration means two or more unmanned ground vehicles working together toward a common goal in a node/station. The unmanned ground vehicles coordination is an essential process for the vehicles going from one node to another node using a path. Therefore the collaboration and coordination of unmanned ground vehicles are vital to the commander in order to complete the mission with success. We propose to represent the communication network as a graph. We suggest a combination of fuzzy and

Boolean algebra techniques to determine the complexity of the robot sensor network. Fuzzy logic is used to determine the node and branch complexities and Boolean algebra approach is utilized to determine the terminal complexity. Based on node complexity; branch complexity; and terminal complexity, we determine system complexity and network complexity. Such approaches will help in the collaboration and coordination of the convoy of unmanned ground vehicles. We also propose to simulate the robot sensor network system complexity. Algorithms for predicting the complexity for sensor network are proposed. The implementation of the proposed algorithm is given and results of fuzzy logic simulation are shown.

Complexity has been the subject of interest for engineers and scientists at least for the last five decades. Various definitions of complexity have been proposed from time to time in literature. Bryant has defined complexity of electrical network in his paper [2] in 1965. He defined electrical network complexity to be the number of the state variables which is equivalent to the dimension of the A matrix. Similarly, complexity has been defined by other research workers. The image complexity has been defined by Gavin Earnshaw in his paper [3] as the "Background homogeneity and foreground clutter, where an image with high quantity of foreground clutter is considered more complex". Gavin in his definition considers the image complexity measure as the figure-ground segmentation which contains object and count of regions.

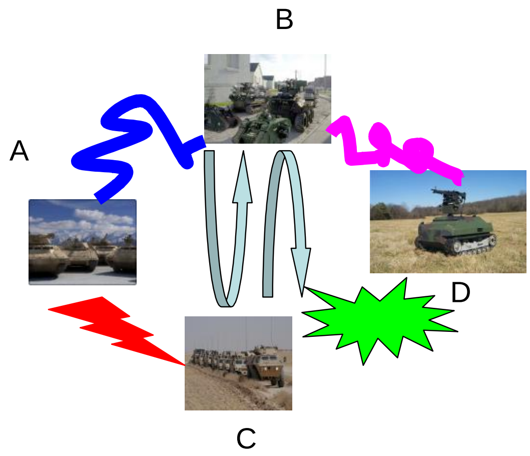
For the last three decades there has been interest in the subject of software complexity in the area of software engineering. Various definition of software complexities have been given by different authors [4-8]. Intuitively, a more complex system is more difficult to model and handle. Hence it requires more time and effort. Therefore our definition of complexity measure is the difficulty to handle the sensor network in order to achieve the desired objective during the lifecycle of system.

BASIC CONCEPTS AND DEFINITIONS [16]

- *Graph* consists of a set of nodes and branches, such that each branch from the graph is associated with an ordered pair of nodes. G = (N, B) where graph G has N nodes and B branches.

- *Tree* is special kind of a graph where there is a unique simple path from one node to another.
- *Spanning tree* of a connected graph is a sub graph of the graph such that it has all the nodes. Any graph can have multiple spanning trees. The distance between two spanning trees of a connected graph is the number of branches present in one tree but not in the other.
- *Cutset* is a set of branches of a Graph, which when removed leads to formation of a disconnected graph.
- *Vertex Cutset* is a set of nodes (vertices) of a Graph, which when removed leads to formation of a disconnected graph.
- *Node Reliability* is the reliability of a node, when the problem is expressed as a graph or a communication network.
- *Branch Reliability* is the reliability of a branch, when the problem is expressed as a graph or a communication network.
- *Terminal Reliability* refers to the reliability from a source node to the destination node.
- *System Reliability* is defined as terminal reliability of all nodes to all other nodes. In literature it is also referred as network reliability, or global reliability or overall reliability.

SYSTEM RELIABILITY OF UNMANNED GROUND VEHICLE



NETWORKS

Fig. 1 System of convoys of unmanned vehicle [1]

The convoy of unmanned vehicles is represented as a communication network in the form of a graph as seen in Fig 1 [1], where nodes represent the station of convoy of unmanned vehicles and branches represent the paths between the stations. It forms a fuzzy logic system, as it gets the values of branch and the node reliabilities from the fuzzy logic system developed using software. Thus the problem of reliability of convoy of unmanned vehicles becomes a problem of evaluation of reliability of a graph.

The algorithm for this method is as described below [16]:

a) Determine the fuzzy node reliability which has value between 0 and 1.
b) Determine the fuzzy branch reliability which has value between 0 and 1.
c) The following steps are used for drawing Binary decision Diagrams.
    a) Determine simple paths.

b) Determine the Boolean expressions which correspond to the simple paths.
c) Mark all the unique paths between the source and the destination stations.
d) Determine the non-overlapping expressions.
e) Determine a disjoint expression corresponding to the Boolean expressions to obtain terminal reliability expression.
f) Update terminal reliability expression to incorporate the fuzzy node reliabilities.
g) Substitute fuzzy branch reliability and fuzzy node reliability values in the non-overlapping expression to get terminal reliability.

d) Determine system reliabilities by obtaining reliabilities from all nodes to other nodes.

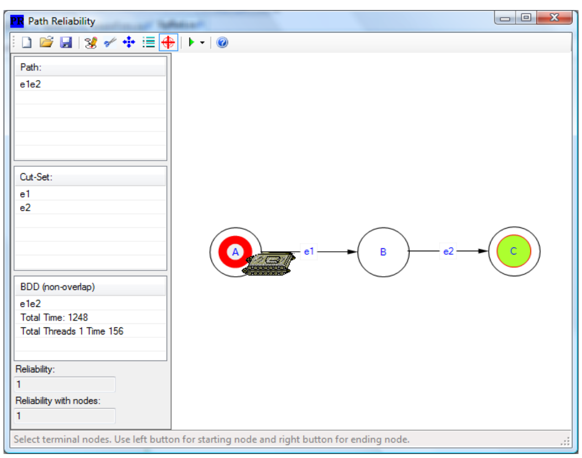


Fig. 2 Reliability Software Implementation result: series network

Fig. 2, Fig. 3, Fig. 4 and Fig. 5 shows the results of the software implementation for the reliability of series, parallel, series-parallel and non-series parallel network. Fig. 6 shows the binary decision diagram for the network in Fig. 5. The fig. 7 shows the unmanned vehicle network with multiple nodes.

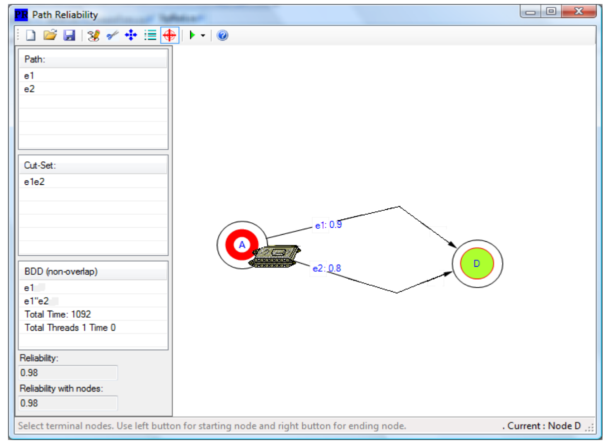


Fig. 3 Reliability Software Implementation result: parallel network

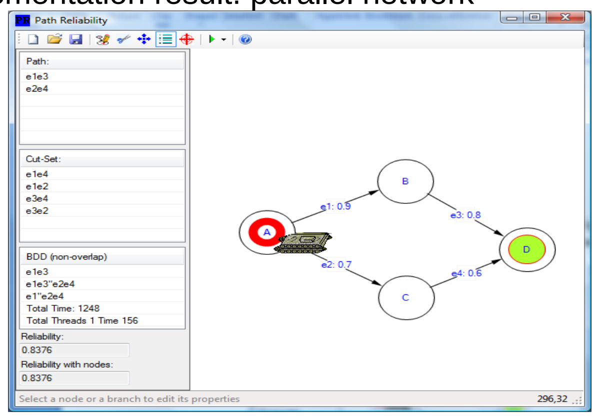


Fig. 4 Reliability Software Implementation result: series parallel network

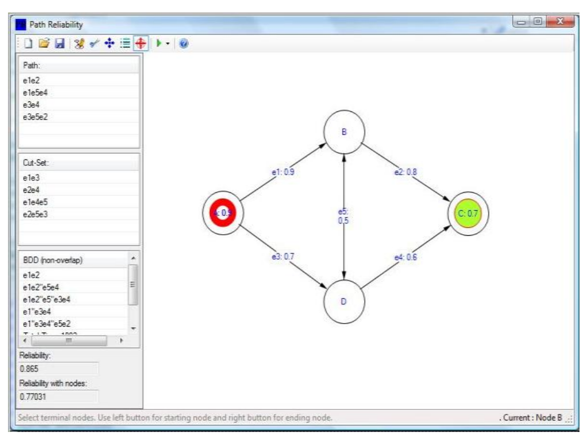


Fig. 5 Reliability Software Implementation result: non-series parallel network

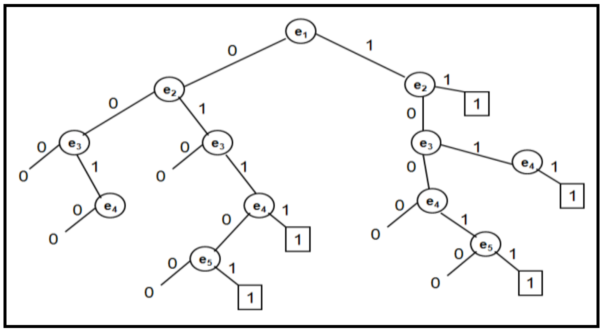


Fig. 6 Binary Decision Diagram for non-series parallel network as in Fig 5

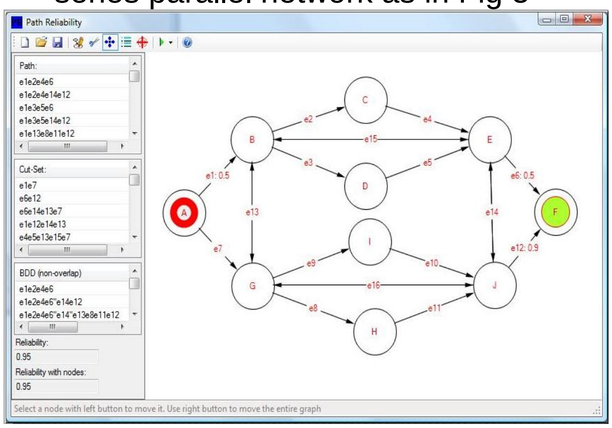
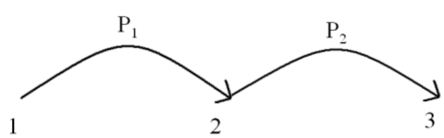


Fig. 7 Unmanned vehicle network with multiple nodes

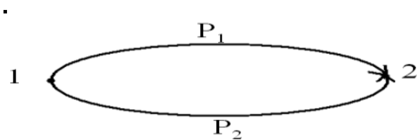
EXAMPLES

1.



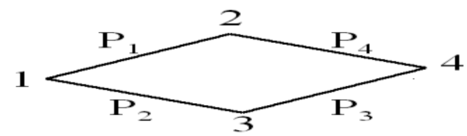
Number of node=3,
Number of node pairs=3,
Node Boolean expressions:
$N_{12} = X_1$
$N_{13} = X_1 X_2$
$N_{23} = X_2$
Srel = $X_1 X_2$
Disjoint expression, Srel = $X_1 X_2$
Arithmetic Form, Srel = $p_1 p_2$ = 0.72

2.



Number of node=2,
Number of node pairs=1,
Node Boolean expressions:
$N_{12} = X_1 + X_2$
Srel = $X_1 + X_2$
Disjoint expression, Srel = $X_1 + X_1'X_2$
Arithmetic Form, Srel = $p_1+q_1 p_2 =$ 0.98
Polynomial: $2p-p^2$

3.



Number of node=4,

Number of node pairs=6,

Node Boolean expressions:

$N_{12} = X_1 + X_2X_3X_4$, $N_{13} = X_2 + X_1X_3X_4$

$N_{14} = X_1X_4 + X_2X_3$, $N_{23} = X_1X_2 + X_3X_4$

$N_{24} = X_4 + X_1X_2 X_3$, $N_{34} = X_3 + X_1X_2X_4$

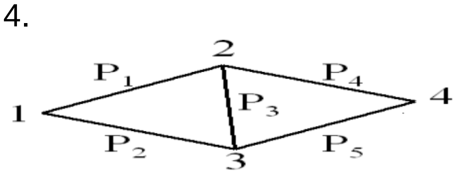
Srel = $X_1X_2X_4 + X1X_3X_4 + X_1X_2X_3 + X_2X_3X_4$

Disjoint expression: Srel = $X_1X_2 X_3 + X_1'X_2 X_3 X_4 + X_1X_2'X_3 X_4 + X_1X_2 X_3'X_4$

Arithmetic Form, Srel = $p_1p_2 p_3 + q_1p_2 p_3p_4 + p_1q_2p_3 p_4 + p_1p_2q_3p_4$ = 0.7428

Reliability Polynomial: $4p^3 - 3p^4$

4.



Number of node=4,

Polynomial: $8p^3 – 11p^4 +4p^5$
Number of node pairs=6,

Node Boolean expressions:

$N_{12} = X_1 + X_2X_3 + X_2X_5X_4$, $N_{13} = X_2 + X_1X_3 + X_1X_4X_5$

$N_{14} = X_1X_4 + X_2X_5 + X_1X_3X_5 + X_2X_3X_4$

$N_{23} = X_3 + X_1X_2 + X_4X_5$, $N_{24} = X_4 + X_3X_5 + X_1X_2X_5$

$N_{34} = X_5 + X_3X_4 + X_1X_2X_4$

$S_{rel} = X_1X_4X_5 + X_2X_4X_5 + X_2X_3X_5 + X_1X_3X_5 + X_1X_3X_4 + X_2X_3X_4 + X_1X_2X_5 + X_1X_2X_4$

Disjoint expression,

$S_{rel} = X_1X_3X_5 + X_1X_3X_4X_5' + X_1X_3'X_4X_5 + X_1'X_2X_3X_5 + X_1X_2X_3'X_4'X_5 + X_1'X_2X_3X_4X_5' + X_1'X_2X_3'X_4X_5$

Arithmetic Form,

$S_{rel} = p_1p_3p_5 + p_1p_3p_4q_5 + p_1q_3p_4p_5 + q_1p_2p_3p_5 + p_1p_2p_3q_4p_5 + q_1p_2p_3p_4q_5 + p_1p_2q_3p_4q_5 + q_1p_2q_3p_4p_5 = 0.7774$

SYSTEM COMPLEXITY OF UNMANNED GROUND VEHICLE NETWORKS

Proposed definition of system complexity of unmanned ground vehicles is "complexity of all nodes to all terminal nodes". The steps of the system complexity [17] algorithm are:

1. Represent the problem in the form of graph.
2. Determine Branch (un)complexity,
3. Determine Node (un)complexity
4. Determine the terminal complexity and uncomplexity.
5. Use the node and branches uncomplexity values to obtain the system uncomplexity.
6. System complexity of network = 1 - system uncomplexity of network.
7. Modify the system complexity of the network if imperfect nodes exist.

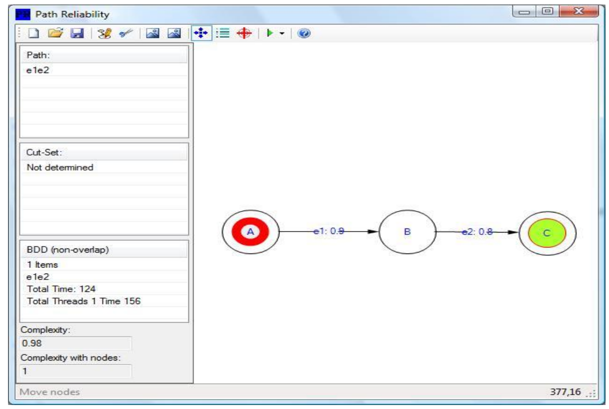


Fig.8 Complexity of series network

In the following we consider some networks and demonstrate how the terminal complexity of this network is determined. Fig. 8, Fig 9, Fig. 10 and Fig. 11 shows complexity of series, non-series parallel, ARPA and 4-D hypercube networks respectively.

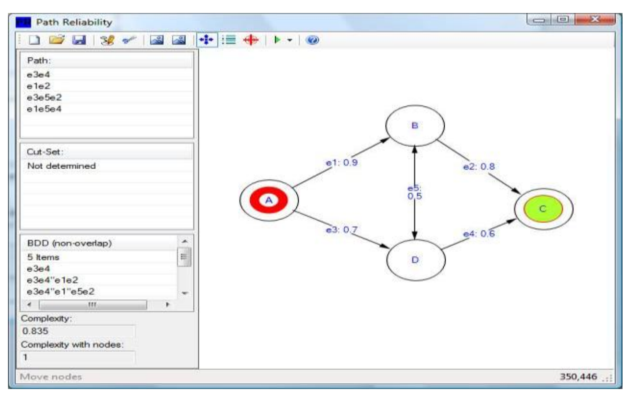


Fig.9 Complexity of non-series parallel network

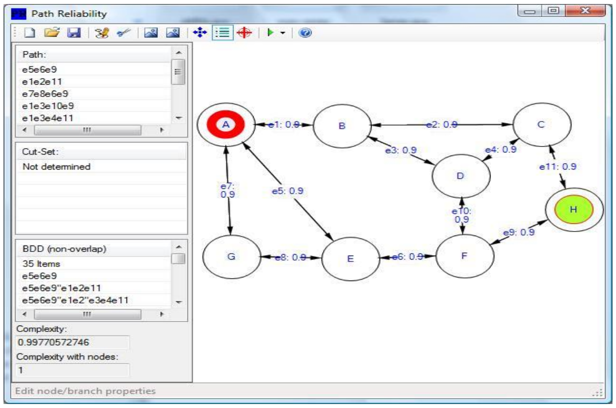


Fig.10 Complexity of ARPA network

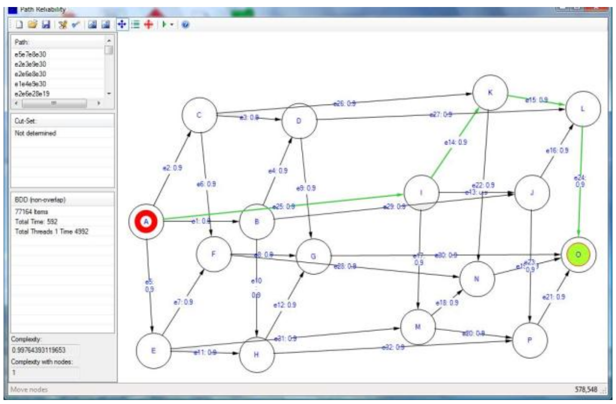


Fig.11 Complexity of 4-D hypercube [14, 15] network

CONCLUSION

This paper suggests metrics for the reliability and complexity of a group of unmanned vehicles. Both metrics are very important in taking appropriate decisions for the army commander in the battlefield. The system reliability calculation method for the convoy of unmanned vehicles is proposed with some examples. Several conditions as inputs are considered for branch reliability like obstacle, terrain, and weather. The conditions considered for the node reliability are EMC, mobility and signal strength. An algorithm is proposed for determining node reliability, branch reliability and terminal reliability.

The branch complexity is determined by three inputs: time, distance, and number of wireless connections. We used key inputs for the fuzzy model. It will be worthwhile to investigate other inputs in future work for the branch fuzzy system. Several conditions as inputs are considered for node complexity: number of robots, total number of sensors, and total number of interconnections. Fuzzy logic approach was generated based on the conditions of the stated branch and node inputs. Membership functions were generated based on the intelligence and the experience of the commander. We proposed a procedure to determine system complexity using Boolean algebra.

This paper suggests initial work in the area of developing metrics for the reliability and complexity of a group of unmanned vehicle network. It is hoped that this approach will lead to the development of more fruitful techniques which could possibly be applied in the battlefield environment of a group of unmanned vehicles possibly to be used in the future for combat operations.

ACKNOWLEDGMENT

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