Hierarchical fuzzy logic and application to Survivability

[1]Shashank Kamthan, *Member, IEEE*, [2]Harpreet Singh, *Life Senior Member, IEEE and* [3]Thomas Meitzler, *Senior Member, IEEE*

***Abstract*— Considerable interest has been shown in the last few decades in exploring the applications of fuzzy logic. The fuzzylogic approach is the basis for intelligent systems, which has become an increasing interest in complex problems. The objective of this paper is to explore the design of hierarchical systems and its applications to the survivability. Survivability has been a topic of interest for defense and security problems for over the last few decades. The interest has been increasing day-by-day because of the sophistication of the complex problems and the huge data involved with uncertain and imprecise human behavior. In intelligent systems, the classification is the main key element by which the target acquisition and identification can be achieved. Most of the key problems are tackled by classification and later determine the accuracy of the model. A number of models for the survivability of vehicles are available in literature. The most important model is the onion model given by the department of defense. This so-called onion structure is of interest to a large number of researchers. In this paper, the survivability problem is managed using multi-layer classification using hierarchical fuzzy logic. The algorithm to design the hierarchical fuzzy system for multi-layer classification is given. The given algorithm is yet to be implemented in real-life applications because no data is available due to security and nature of problems. It is hoped that this work of multi-layer classification using hierarchical fuzzy logic will go a long way in tackling the solutions of the survivability problems.**

***Index Terms*— deep learning, fuzzy logic, hierarchical fuzzy logic, classification, survivability, big data**

I. Introduction

Fuzzy logic has been of interest to various researchers for the last several decades. The work was started by the classical papers in 1960 by Lotfi Zadeh [8]. This paper has been acted as the breakthrough in the area of system and control and has been subject to researchers in all walks of life. The work by Lotfi Zadeh [8] was further extended by Mamdani in his work. It was further stretched by Sugeno. Tagaki-Sugeno further brought this work in the area of control systems and adaptive control systems. The fuzzy logic was based on rule based IF-ELSE-THEN format. As the systems become bigger and bigger, the rules become unmanageable. In order to take care of a large number of rules, some authors developed hierarchical fuzzy systems [1] [6]. Hierarchical systems, in general, reduce the number of rules as compared to conventional systems. Various authors have contributed to the development of hierarchical fuzzy systems [1] [6].

Radek [7] gave a representation of hierarchical fuzzy systems based on single input single output function. Radek's [7] procedure consists of developing non-linear data from a given equation. He then uses a fuzzy c-means clustering method to generate required clusters. Later, this number of clusters mapped to the rule base of fuzzy systems. In this paper, the Gaussian membership function is considered due to its differentiable and continuous behavior. In the paper, Radek also compared various weighted approaches to get the accuracy of the overall system. A descriptive simulation has been presented for single input single output function.

Nowadays, the classification problem has become a very important part of intelligent systems [1]. Deep learning has become one of the integral parts and created the most important aspects of the classification problem [5]. The classification problem [5] has taken a deep breakthrough in social media such as Facebook, google, amazon etc. Large datasets for social media are available in the literature with various social media websites. These data are used by different researchers and different applications.

II. Survivability model and classification of threats

Survivability has been of interest to the department of defense and security. The survivability is used for ground vehicles, UAV etc. The number of survivability models are

[1]Shashank Kamthan is a Sr. Consultant in Embedded Systems and Connected Vehicle System domain. Alongside, he is pursuing PhD (electrical engineering) in AI, Deep learning etc. from Wayne State University, MI 48202. (e-mail: shashank.kamthan@wayne.edu).

[2]Harpreet Singh is a Professor in electrical engineering at Wayne State University, MI. His area of research is AI in autonomous vehicles, modeling, simulation and visualization techniques. (e-mail: hsingh@eng.wayne.edu).

[3]Thomas Meitzler is Ground Vehicle System Survivability and Protection Senior Science Advisor at DEVCOM GVSC, Warren, MI, USA. (email: thomas.j.meitzler.civ@mail.mil)

available in the literature. The onion model of survivability describes the survivability in the best possible way.

Figure 1(a) represents the Survivability model in the form of six-layer onion structure. Each layer of onion structure provides the various assessment and the classification of threats. Figure 1(b) explains layers involved in the onion-structure survivability model and how countermeasures can be mapped based on the classification of the threat.

(a) Survivability onion model

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CLASSIFICATION OF THREAT IN REFERENCE TO LEVEL	
	Awareness of Threat
	Detection of Threat
	L1 - Low Risk
	L2 - Medium Risk
	L3 - High Risk
	L4 - Extreme Risk

(b) Classification of threats in reference to levels

Figure 1. (a) Survivability onion model (b) Classification of level

Various strategies and tactics are cited in the literature to encounter threats. It is based on what is seen in the exact moment, how we understand the situation, available actions that fit the need and the final decision made. Suggested classifications of the countermeasures have been defined in parts below. Layers in the survivability model account for:

Layer [1]. awareness of threat
Layer [2]. detection of threats
Layer [3]. tracking the movement of threats
Layer [4]. identify probable impact from threat based on future projection
Layer [5]. apply or strategize countermeasures
Layer [6]. initialization of self-protection systems.

III. MULTI-LAYER HIERARCHICAL SYSTEM DESIGN

The strategy to design a multi-layer hierarchical system is to construct a single or multiple hierarchical structure for each layer individually. From the second layer onwards, the final output from the first layer is added as one of the inputs to the next layer. While designing hierarchical systems for any layer, the idea is to create various small segments of the dataset and design fuzzy logic units for every segment separately. Later, connect all the fuzzy units in the required hierarchical structure. The reduction of rules can be achieved by using fuzzy c-mean clustering, where limited center points can be obtained and mapped to form a rule-base.

To better understand the process, let us take an example of multi-layer classification to identify dog puppies and its breed. Assuming each layer comprises its own classification that helps the next layer to filter the data to process. Consider the dataset that includes human types, sea animals, land animals etc. The classification for each layer can be described as:

Layer [1]. Classify animals from complete data
Layer [2]. Filter the animal data based on layer 1 and classify types of animals such as cats, dogs, horses etc.
Layer [3]. Filter the dog data based on layer 2 and classify type of dogs. This helps the selection of dog breed
Layer [4]. Filter the specific breed based on layer3 and classify the age of dog that helps the selection of a puppy

The above example included a four layers system. The same analogy can be extended to n-layers systems. In the first layer, the data matrix consists of only training data as inputs and outputs. Segment the data matrix in small sizes and create fuzzy units for each segment with the help of fuzzy c-mean clustering [1]. Later, connect all the fuzzy units in the required hierarchical structure. Based on the final output of the first layer, filter the data matrix, so that in the next layer only a reduced size of the data matrix needs to process. This reduces the overall performance time of the system. From the second layer onwards, the input data matrix consists of two sets: filtered data from the previous layer and hierarchical system output from the previous layer. Repeat the same process as the first layer i.e., segment the data in samples, design the fuzzy units using fuzzy c-mean clustering and connect all the fuzzy units in required hierarchical structure. The last classification layer provides the final result, which can be mapped to the desired entity. This system can be designed via any hierarchical tree structure such as: aggregated, incremental and cascaded.

The algorithm and steps to design the multi-layer hierarchical systems are given below. It is noted that the algorithm presented below includes aggregated and incremental type hierarchical tree structure [1]. There is no predefined design of cascaded tree structure, however this algorithm can easily be modified for cascaded tree structure.

I. System description: define following parameters:
   [1] Number of layers in overall system, denoted by 'C'
   [2] Number of fuzzy units for each hierarchical level, denoted by 'L'
   [3] Number of rules for every fuzzy logic unit, denoted by 'R'
   [4] Type of Hierarchical Tree Structure = {'Aggregated', 'Incremental'}

II. System Design for multi-layer classification using hierarchical systems
   [1] FOR 'Classification Layer' ranges from '1' TO 'C'
      i. Get data matrix to design hierarchical fuzzy logic units
         1. IF 'Classification Layer' equals '1'
            a. Consider the training data matrix of size $[M_C, N_C]$
            b. Where, $[M_C, N_C\text{-}1]$ defines input matrix and $[M_C$, Last column] defines output matrix for a specific classification layer
         2. ELSE
            a. Add an input column of the previous hierarchical system output to the training data. New matrix will be of size $[M_C, N_C+1]$
            b. Where, $[M_C, N_C]$ defines input matrix and $[M_C$, Last column] defines output matrix for a specific classification layer
      ii. FOR 'Total hierarchical structures in current classification layer' ranges from '1' TO 'Required Number'
         1. IF 'Hierarchical Level (H)' equals '1'
            a. Consider raw inputs from training data
            b. Group all the inputs in '2^L' segments keeping output the same
         2. ELSE
            a. consider outputs from previous levels as the inputs to the next level
            b. Group all the inputs in '2^{L-H}' segments keeping the same output label
         3. Define membership functions for every input(s) and output(s)
         4. IF 'Type of Hierarchical Tree Structure' is equal to 'Aggregated'
            a. IF 'Level of hierarchical structure' is equal to 'Lower Level'
               i. Take each input segment / sample and map with desired output
            b. ELSE
               i. Output from previous level becomes input to the next level
               ii. Create new matrix of the above inputs with desired outputs and create segments
            c. FOR 'Input Segment (I)' ranges from '1' TO 'Total input segments'
               i. Generate fuzzy inference system with 'R' number of rules
               ii. Evaluate the output and store in a buffer
            d. Connect all the fuzzy logic units in the required hierarchical structure
         5. ELSE IF 'Type of Hierarchical Tree Structure' is equal to 'Incremental'
            a. Take each input segment / sample and map with desired output
            b. IF 'Level of hierarchical structure' is equal to 'Lower Level'
               i. Generate fuzzy inference system with 'R' number of rules
               ii. Evaluate the output and store in a buffer
            c. ELSE
               i. Output from previous level becomes input to the next level
               ii. Create new matrix of the above inputs with desired outputs and create segments
               iii. FOR 'Input Segment (I)' ranges from '1' TO 'Total input segments'
                  1. Generate fuzzy inference system with 'R' number of rules
                  2. Evaluate the output and store in a buffer
            d. Connect all the fuzzy logic units in the required hierarchical structure

6. The evaluated output at the final level 'L' of hierarchical structure provides final output
7. Store the final hierarchical output in a buffer
8. IF 'Total number of hierarchical structures required in current classification layer' is equal to 'Required Number'
    a. Concatenate outputs of all the hierarchical systems in the current classification layer
    b. IF 'Classification Layer' is not equal '1', then output of the hierarchical system becomes the one of the inputs to the next classification layer.

[2] IF 'Classification Layer' equals 'C', the output of the hierarchical system at layer 'C' is the final output

The pseudo code for the above-mentioned algorithm can be summarized as follows:

Pseudo Code: Multi-layer classification using hierarchical fuzzy system for application to survivability

For I_1 = 1: 'Number of classification layer (C)'

For H = 1: 'Number of hierarchical structures required in current classification layer (C)'

If (I_1 == 1):
Consider the input-output training data matrix of size [M_C, N_C]
Else:
Add an input column of the previous hierarchical system output to the existing training data matrix.
Consider the input-output training data matrix of size [M_C, N_C+1]

For I_2 = 1: 'Number of fuzzy units for each hierarchical level (L)'

If (I_2 == 1):
Group all inputs of training data in '2^L' segments keeping the same output label
Else:
Consider outputs from previous levels as the inputs to the next level and group all the inputs in '2^{L-H}' segments keeping the same output label

For I_3 = 'Total input segments'
Generate fuzzy system with 'R' number of rules and evaluate the output
Connect all the fuzzy logic units and evaluate output at the final level 'L' of hierarchical structure provides final output

If (H == 'Number of hierarchical structures required in current classification layer (C)'):
Concatenate outputs of all the hierarchical structures of current classification layer

If (I_1 == 1):
Output of the hierarchical system becomes one of the inputs to the next classification layer.
If (I_1 == C):
Output of the hierarchical system at layer 'C' is the final output.

The multi-layer hierarchical system can be applied to the application of Survivability of manned or unmanned vehicles [2] [3]. The survivability onion model consists of six different layers. It is assumed that each layer has individual hierarchical structure. The outermost layer is considered as the first layer for classification and the innermost layer is considered as the final layer of classification, which returns the final output as the classification of the target [9] [10] of the overall system. The key factor for survivability is to protect the occupants of the vehicle.

The graphical notation of the said statements is shown in figure 2 as:

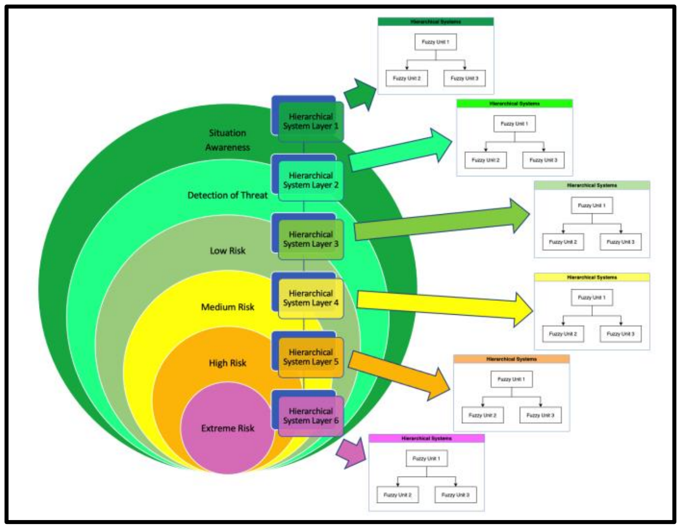


Figure 2. Graphical notation of survivability onion model

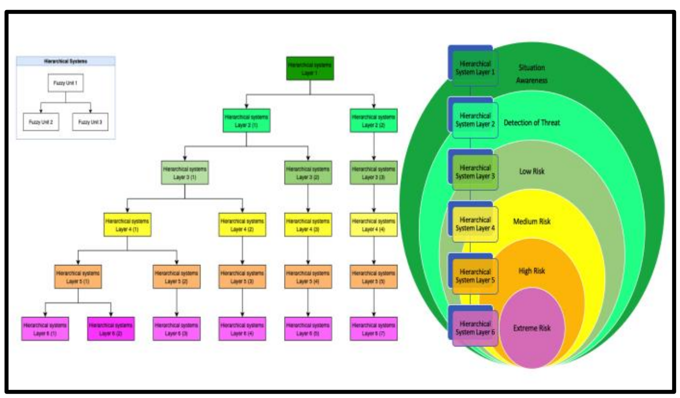


Figure 3. Graphical notation of survivability onion model using multiple hierarchical structures in each layer Flowchart of multi-layer hierarchical systems

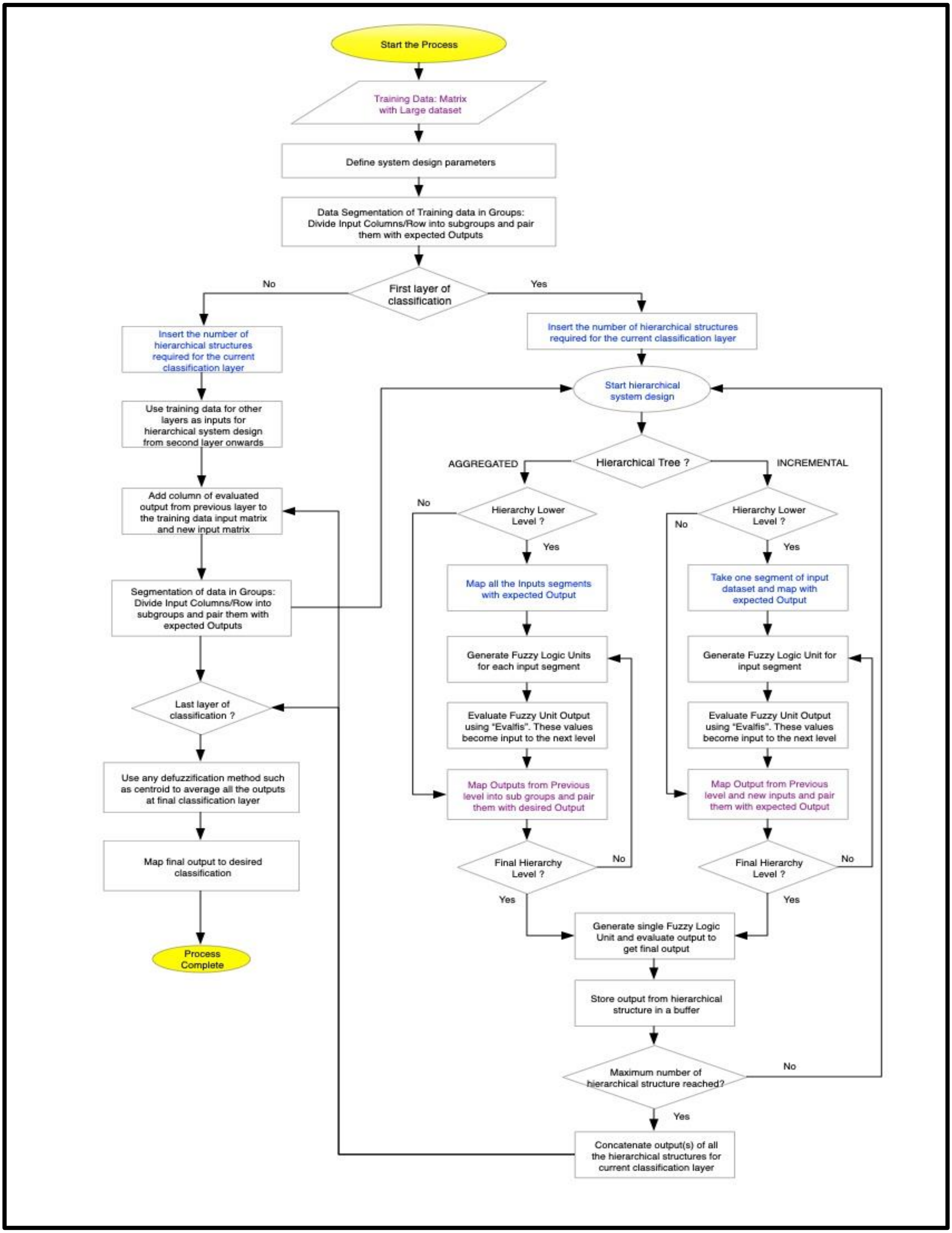


Figure 4. Flowchart representing system workflow of multi-layer classification model using hierarchical systems

In the above representation, each layer consists of a single hierarchical structure [1]. However, there is always a possibility that the classification layer may consist of multiple hierarchical structures. The graphical representation of one such example is given below in figure 3. In the example, the first layer has a single hierarchical structure, and the number of hierarchical structures increment by one for each layer compared to the number of hierarchical structures in the previous layer.

Figure 4 shows the conceptual flowchart representing the detailed multi-layer survivability onion model system design overview. This research proposes a model to identify unfriendly maneuvers, classify the threat, map the classification with survivability onion model [2] [3], identify and apply required countermeasures and later apply any damage mitigation techniques based on various mobility environments and platforms.

A multi-layer hierarchical fuzzy system has been designed as per the algorithm defined in the earlier section. The real-life data for the survivability model is not available for this paper, it is hoped that algorithms will be extended based on the availability of real data with uncertain and imprecise human behavior.

This algorithm presents an approach to design the survivability system based on the onion structure for the classification of threat with the help of multi-layer hierarchical fuzzy system [1] algorithms. Every classification layer has its own either single or multiple hierarchical systems, which narrow down the search process and help filtering the desired output. Three hierarchical tree structure algorithms [1] [6] have been discussed in this paper: aggregated, incremental and cascaded. Depending on the system complexity and behavior, the hierarchical system can be designed i.e., for aggregated tree structure, all the inputs are consumed at lower level, and next level considers output from previous level as inputs, on the other side, for incremental tree structure allows real inputs at every level along with output from previous level as inputs. The cascaded tree structure is the amalgamation of aggregated and incremental structures, so that there is no fixed process to list the steps. The cascade tree design is completely based on iteration approach. The final output of hierarchical fuzzy systems from the final hierarchy level is mapped to desired output or linguistic format. For the survivability onion model, the final outcome of the hierarchical system presents the classification of threat, which will then be mapped to the countermeasures.

For the real-life applications [4] [9] [10] [11] [12], such as survivability of unmanned vehicles [2], the data may be uncertain and imprecise because various human factors get involved. In the real world, to get imprecise and uncertain data that involve human behavior or factors are quite challenging. In this paper, the hierarchical fuzzy systems are developed using precise dataset of real images. The algorithm proposed will extend, when the data involving human perception is available.

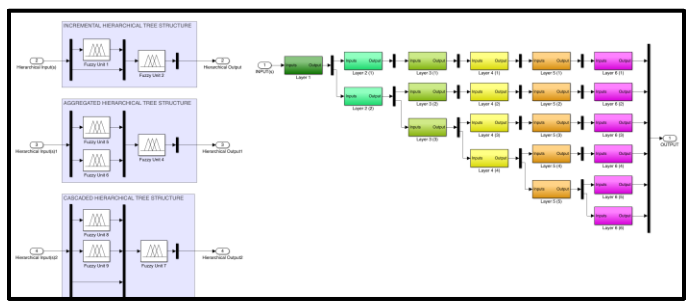
Simulink implementation

Based on the workflow and flowchart mentioned in previous sections, the prototype of Simulink implementation has been shown below in figure 5. While moving from left-to-right represents the onion layers from top to bottom. This means, the leftmost layer in Simulink represents the top layer of the onion model whereas the rightmost layer in Simulink represents the innermost layer of the onion model.

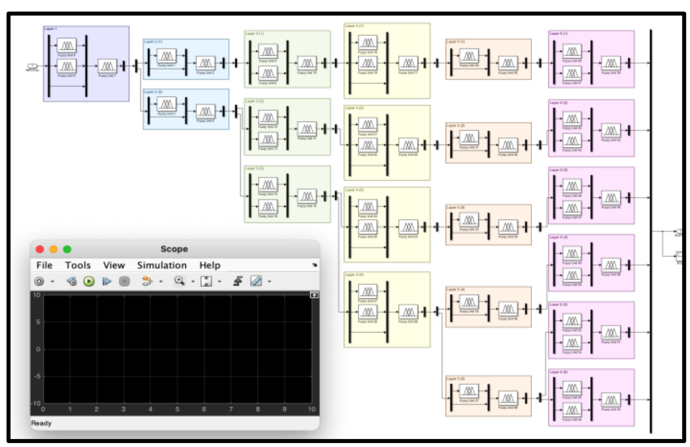
Figure 5(a) represents the six layers in reference to the survivability onion model. It is shown that while moving from left to right, the first layer has one hierarchical structure, and the next layer has the number of hierarchical structures equals one greater than the number of hierarchical structures of the previous layer and so on. The left side of the figure, three types of hierarchical tree structures are defined, such as aggregated, incremental and cascaded, which is used to design hierarchical units on each layer.

Figure 5(b) represents the extracted view of Simulink prototype implementation where, as an example, hierarchical systems at different layers are designed using various hierarchical tree structures.

The prototype of the Simulink model [11] [12] is implemented just to showcase the design approach for the multi-layer classification of a survivability onion model using hierarchical systems. Once the real data will be available including imprecise and uncertain human behavior, the complete model can be designed, and desired results in the form of classification of the threat can be obtained.



(a) Simulink representation for survivability onion model



(b) Simulink representation for survivability onion model - extracted view

Figure 5. Prototype Simulink design for the survivability onion model

IV. Conclusion

In this paper, the design algorithm for the survivability problem as a multi-layer classification is suggested. Because of the layers of onion model, the hierarchical approach is more suitable for the survivability problem. The data of the survivability model is not easily available due to security reasons. The data may be ranging from simple numeric data to complex image data. The proposed algorithm is yet to implement for real data. The future work involves the implementation of a survivability model based on human-perception i.e., imprecise and uncertain dataset. It is hoped that results obtained in this paper will open new ways of handling the problem of survivability in defense and security and also this approach will help in solving target acquisition and identification [9] [10], and for modern problems like IoTs, WSNs etc.

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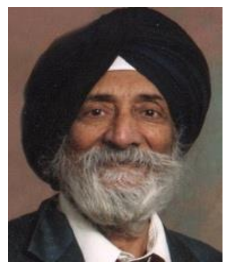
Shashank Kamthan *(M'2014)* received Bachelor of Engineering in 2007 from Rajiv Gandhi Proudyogiki Vishwavidhyalaya, India and Master of Science in Electrical Engineering in the year 2008 from Wayne State University, Detroit, MI, USA. He is currently pursuing Ph.D. from Wayne State University, MI, USA. He has more than 12 publications in international journals and conferences. On the professional front, he has over 10 years of professional experience. During his stint with the automotive industry, he has worked in the field of model-based development, AUTOSAR, connected vehicle systems (V2X), embedded software development, systems integration etc. At present, he is working full-time as Senior Embedded Systems Consultant in Automotive Domain. His current areas of interest are target detection, artificial intelligence, connected vehicles, deep learning techniques, autonomous vehicles, mobility, controls, model-based design etc.



Harpreet Singh *(M'73, SM'85, LSM'2009)* received his B.Sc. Eng. degree from Punjabi University, India, in 1963 and his M.S. and Ph.D. degrees from the University of Roorkee, India, in 1966 and 1971. He taught at the University of Roorkee from 1963 to 1981. Since 1981 he has been with Wayne State University, Detroit, MI, where he has been a professor in the Department of Electrical and Computer Engineering.

He has worked in diversified areas of systems, networks, controls, fuzzy logic, DNA Nano-digital circuits, bio-circuits and VLSI design. Dr. Singh has more than 300 publications in international journals and conferences and has received a number of awards. He has organized a number of national and international conferences and has supervised more than 25 Ph.D. theses in different areas of electrical and computer engineering. He has been awarded the distinguished Alumni Award of prestigious IIT Roorkee in 2012. He has also been awarded the distinguished alumni award from President of India in the year 1983 from Thapar Engineering College, Patiala. As a founder chair of Life Affinity Group of South Eastern Michigan section, the section received 2017 IEEE Life Member Affinity Group Achievement award.

Thomas J. Meitzler received his B.S. and M.S. in Physics from Eastern Michigan University, completed graduate coursework at the University of Michigan, and received a Ph.D. in Electrical Engineering from Wayne State University in Detroit. His doctoral dissertation in Electrical Engineering at Wayne State University was on Modern Methods for Computing the Probability of Target Detection in Cluttered Environments. He is a Fellow of the American Physical Society (APS) and Senior Member of the Institute for Electrical and Electronics Engineers (IEEE) and Society of Photo-optical Instrumentation Engineers (SPIE). He is the Ground System Survivability Senior Science Advisor. During the time from 1988 to present, Dr. Meitzler has been a research engineer at the US Army DEVCOM GVSC in Ground Vehicle Survivability and Protection. For the U.S. Army, Dr. Meitzler has been involved with the validation, verification, and development of infrared, electro-optical and human visual acquisition models. Dr. Meitzler was the principal scientist of the GVSC Visual Perception Laboratory and the principal investigator on Cooperative Research and Development Agreements (CRADA's) with GM and Ford Motor Company to apply visual target acquisition models to vehicle conspicuity and novel sensors to automobile 360-degree safety. Dr. Meitzler was the principal investigator on several Space Act Agreements with NASA's Kennedy Space Center and CRADA's with the Columbia University College of Physicians and Surgeons. He has authored/co-authored many papers in the area of Electro Optic system simulation, visual detection, sensor validation, traditional nondestructive armor evaluation and embedded piezoelectric nondestructive testing of armor materials, and spintronics. Dr. Meitzler has developed and integrated technologies for embedded armor health-monitoring, armor Non-Destructive testing, and armor embedded radio signal detection.