



Linguistic Model for Axle Fatigue

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IVHMS Project Objectives

- Develop a vehicle health management system for quick installation on vehicles without existing electronic sensor networks, e.g. CAN-Bus
- Identify a comprehensive vehicle-condition sensor array along with its wireless connection
- Develop vehicle on-board sensor data storage unit and secure sensor data transmission unit
- Develop algorithms for depot on-site diagnostics and prognostics
- Develop vehicle on-board maintenance warning capability

Long Term Benefits

- Significantly reduce maintenance cost through CBM for Army's current Light Tactical Vehicle Fleet
- Potentially save soldiers' lives by not allowing vehicles in need of maintenance to be deployed

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Presentation Outline

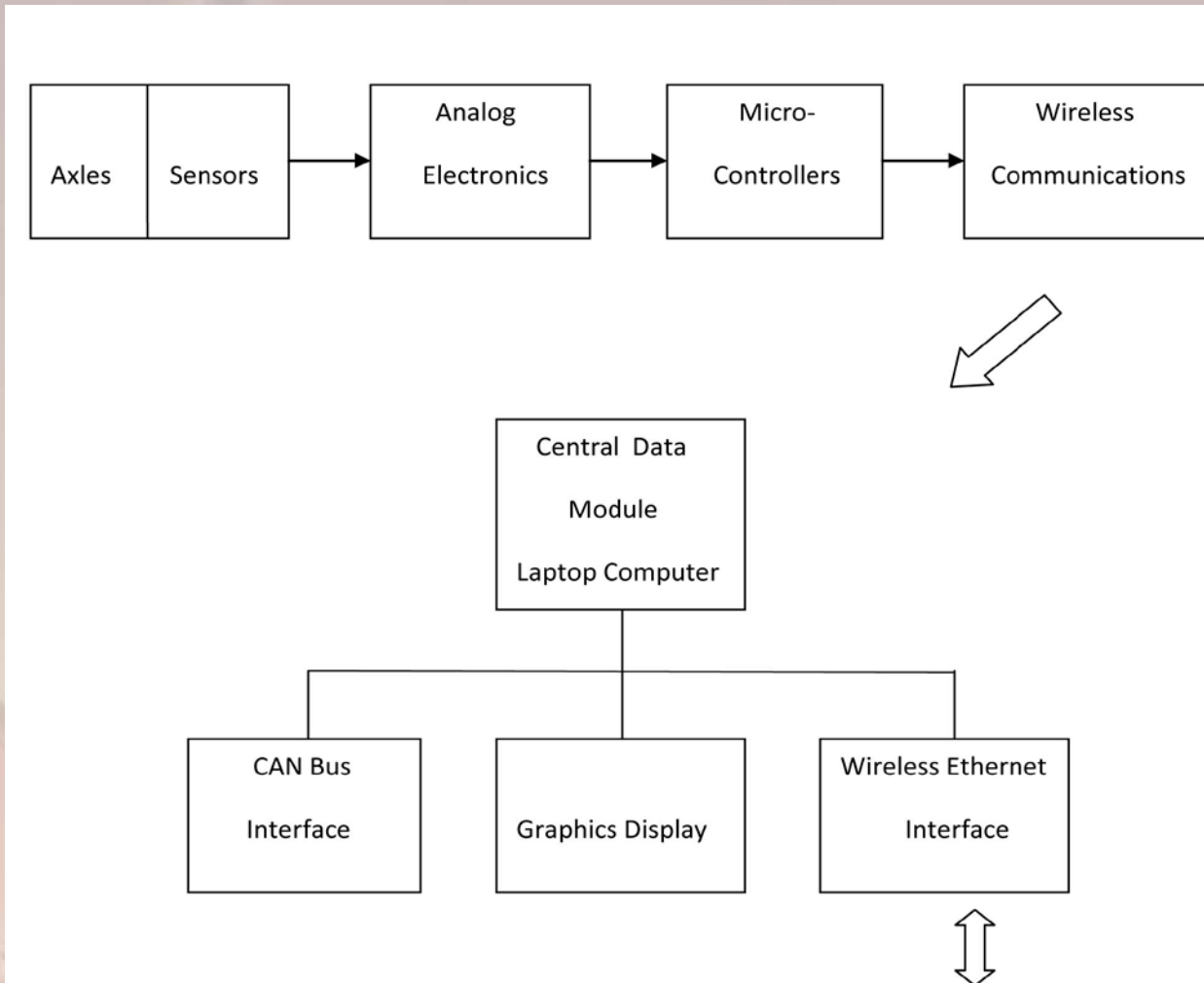
- System Architecture Overview
- Axle Sensor Board
- Axle Fatigue Damage
- Fuzzy Logic Model for Fatigue Damage
- Simulation Results
- Conclusions

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Axle Monitoring System Block Diagram of the IVHMS

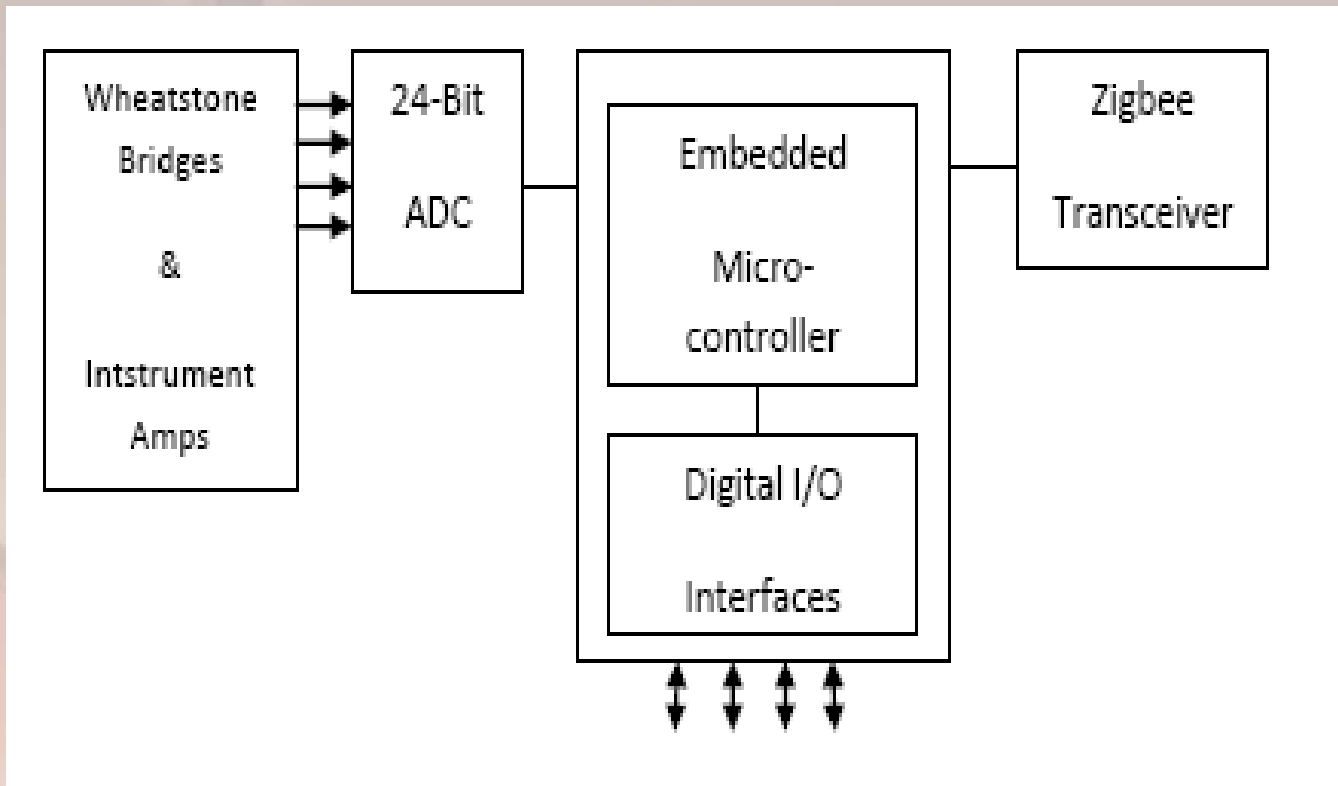
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Block Diagram of the Intelligent Axle Sensor and Wireless Communications Board

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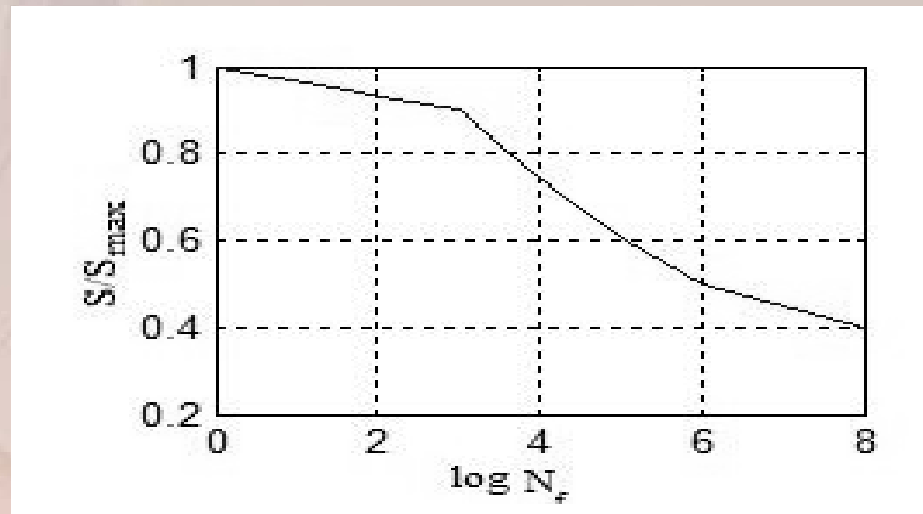


Axle Fatigue Damage

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S-N Curve

For each stress load there is maximum number of cycles that the material can stand before fatigue damage takes place. The relation between the stress S and the number of cycles to failure is usually given as the S-N curve.



S-N curve of an axle



Linear Damage Model

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The linear damage model assumes that there is a unique linear relationship between the cycle fraction $n_i/N_{f,i}$ and the material damage

$$D_c = \sum_{i=1}^n \frac{n_i}{N_{f,i}}$$

D_c : Cumulative Damage

n_i : Number of cycles of stress i

$N_{f,i}$: Number of cycles to failure of stress i

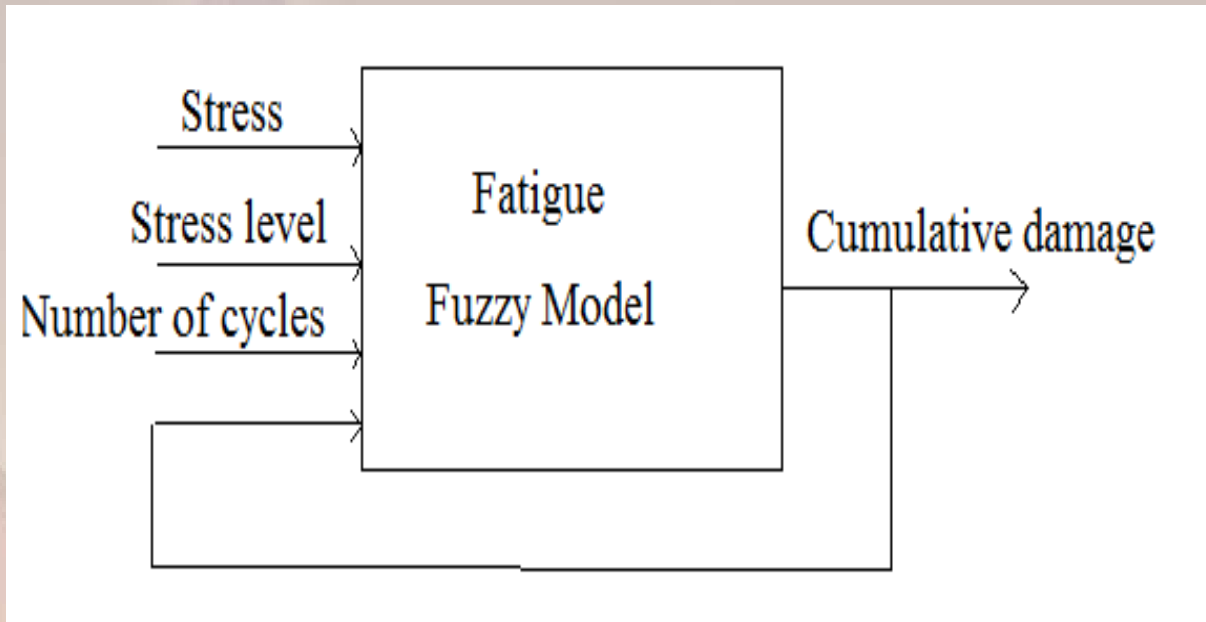
n : Total number of stress cycles that the material has had



Fuzzy Model for Axle Fatigue Damage

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- The inputs of the fuzzy model are the number of cycles, the stress, the stress level and the previous cumulative damage
- The output is the cumulative damage of the axle

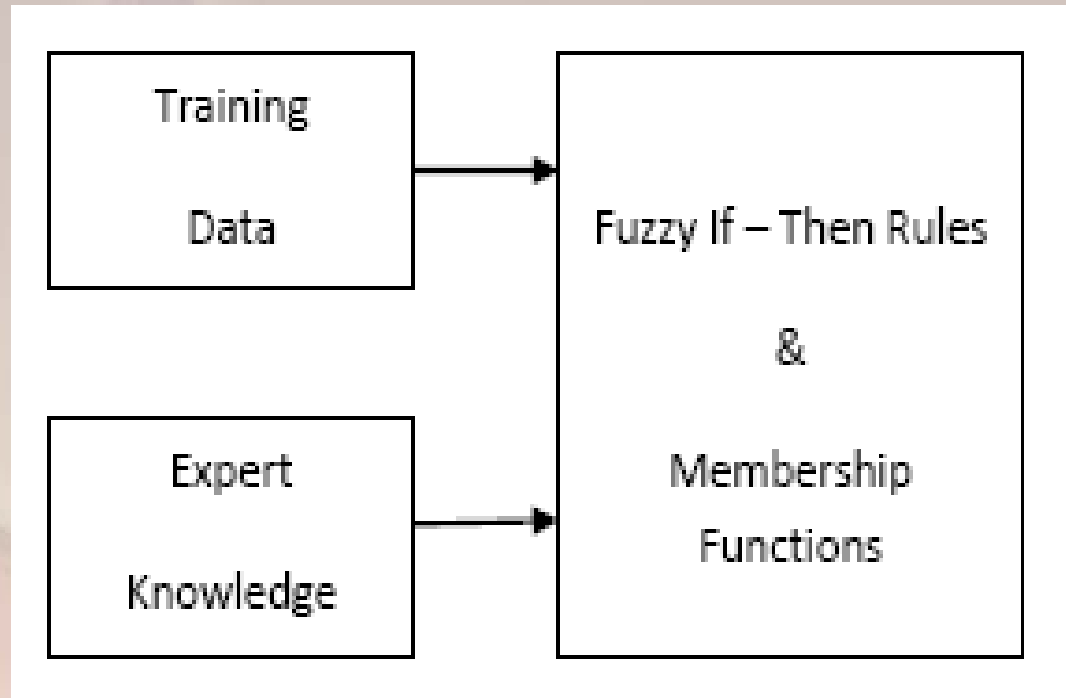




Knowledge Base of the Fuzzy Model

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The fuzzy If Then rules and the fuzzy membership functions are generated using expert knowledge and training data.





Training Data

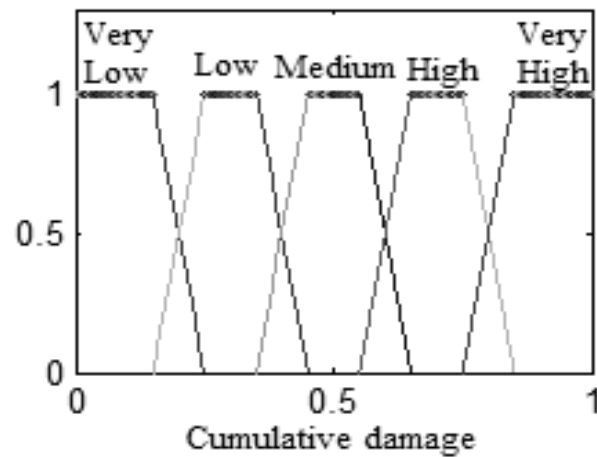
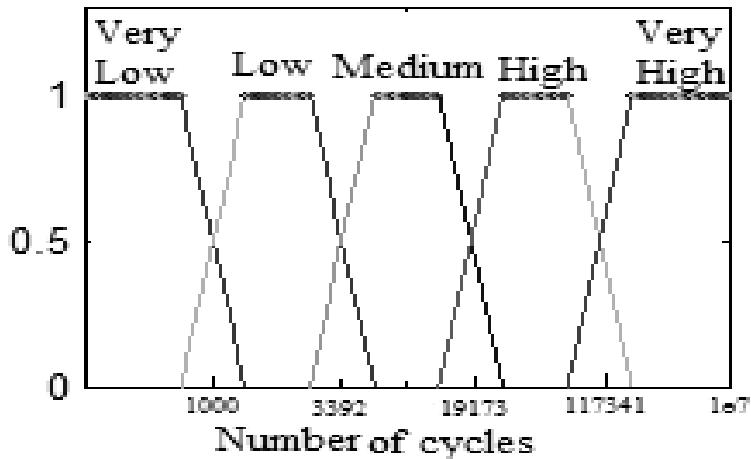
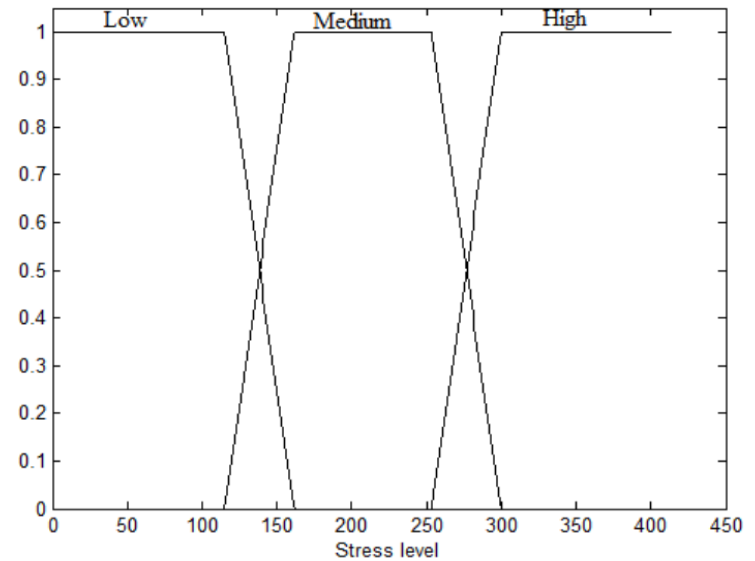
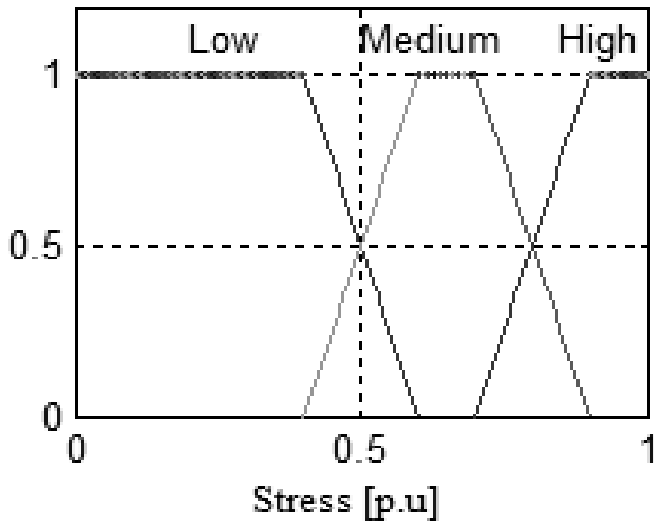
- In this stage of the research, only a limited set of sensed, experimental data were available
- The primary source of input and output data was the linear damage model
- The training data set covers all the rules, where 1000 random input data points were generated to cover the full universe of discourse
- The outputs were calculated using the linear damage model

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Membership Functions for Fuzzy Inputs and Output

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Generation of the Fuzzy Logic Rule Base

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The membership functions are initially generated using expert domain knowledge and the linear damage model. The rules are created by performing cluster extraction and re-clustering.

- Set up all possible fuzzy rules (225)
- Generate training data and calculate the outputs using the linear damage model (1000 input data for each fuzzy rule)
- The outputs of the fuzzy rules can be determined by clustering the training data and by applying the winner take-all algorithm



Generation of the Fuzzy Logic Rule Base (cont'd)

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- Minimize the number of fuzzy rules
- Update the critical parameters of the membership functions using the re-clustering operation
- Optimize the critical parameters of the membership functions by using a stochastic optimization method.



Clustering Operation

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1. Tally the number of training data points that belong to each fuzzy output

Inputs				Output (Cumulative Damage)				
S	N	<u>D_p</u>	SL	VL	L	M	H	VH
L	VL	VL	VL	900	60	40	0	0

2. Apply the winner take all algorithm to determine the output of the fuzzy rule

Inputs				Output (cumulative damage)	
<i>Stress</i>	<i>No. of cycles</i>	<i>Previous damage</i>	<i>Stress level</i>	<i>Fuzzy set</i>	<i>Support rate</i>
Low	Very Low	Very Low	Very Low	Very Low	0.9



Minimization of the Fuzzy Rules

The support rate of each rule is calculated to minimize the number of fuzzy rules necessary for the fatigue model. If there are two rules with different support rates and one of them is to be eliminated then the rule with the lower support rate will be dropped.

Inference operators and defuzzification

The max and min inference operators and the Center of Area defuzzification method are used to devise the crisp output of the fuzzy model.

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Optimization of the membership functions

- The re-clustering operation is used to make sure that the rules extracted from the clusters are effective.
- The sample data will be re-clustered to the closest cluster.
- The centers of the clusters will be measured. If the membership functions' parameters are not close enough to the clusters' centers then the membership function parameters will be modified to adopt better to the clusters' centers.

Rainflow Counting Method

- The Rainflow software is used to extract the stress, the stress level and the number of cycles from the sensory data and to convert them to appropriate inputs for the fuzzy model of the axle.

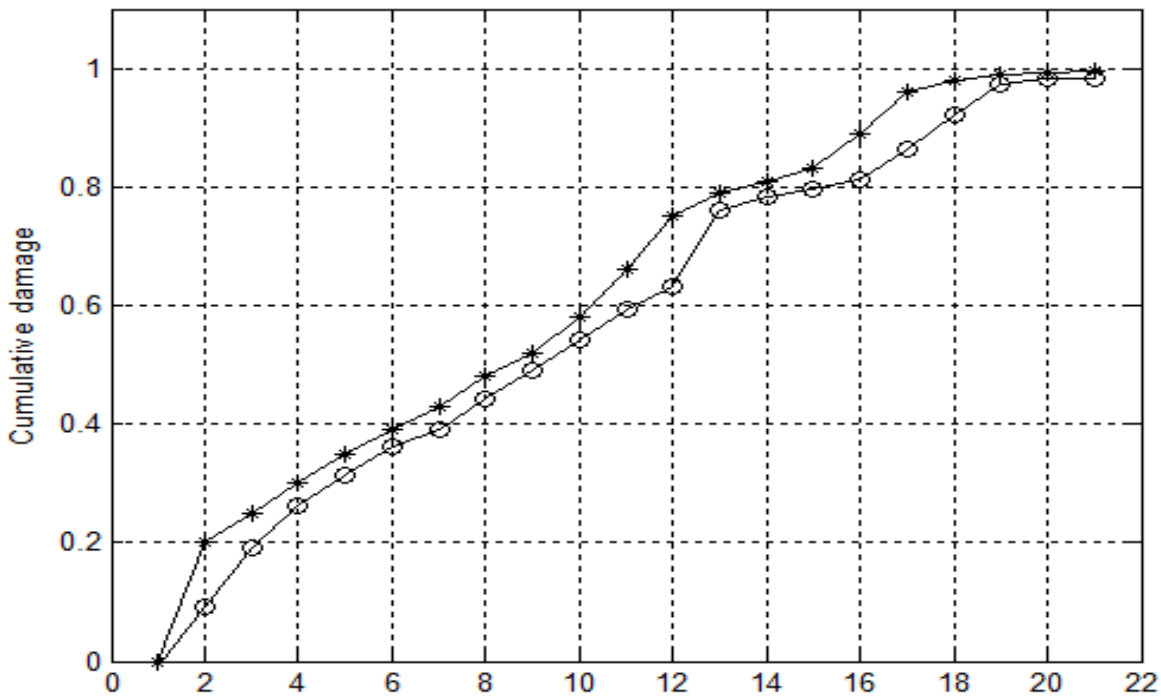
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Simulation Results

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The “o” line shows the cumulative damage using the linear damage model and the “*” line represents the cumulative damage using the fuzzy model for a sequence of input stresses.





Comments

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- The behavior of the fuzzy model looks similar to the linear damage model because the source of the training data was the linear damage model.
- There is slight difference between the outputs of the fuzzy model and the linear damage model because no optimization techniques are applied yet.
- The optimization method is not applied yet to reduce the difference between the fuzzy model and the linear damage model because:
 - the main reason for using the linear damage model as a data source is to create a reasonable initial set of fuzzy rules and membership functions.



Comments (cont'd)

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- The linear damage model predicts lower cumulative damage compared with the real damage. Due to this fact, it is a reasonable approach to let the fuzzy model output be higher than that of the linear damage model.
- The fuzzy rules and membership functions will be adjusted when we will have enough real training data. In that case an optimization method will be applied to make fuzzy model behave about the same way as the real axle system.



Conclusions

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- The architecture of the axle monitoring section of the Intelligent Vehicle Health Management System (IVHMS) for light tactical vehicles was presented
- A fuzzy model was introduced to tackle the problem of diagnosing axle fatigue
- The linear damage model was used to generate a set of training data for the fuzzy model
- The Rainflow Counting Method was used to extract the stress, the stress level and the number of cycles from the experimental sensory data
- Based on the training data, the membership functions and fuzzy rules were modified by using cluster extraction and re-clustering operations
- The critical parameters of the membership functions can be optimized to improve the performance of the fuzzy model for axle fatigue diagnostics



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The End Thank You! Any Questions?

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