FUZZY LOGIC VS. DEEP LEARNING: A COMPARATIVE STUDY FOR IMAGE-BASED POTHOLE DETECTION IN MICHIGAN

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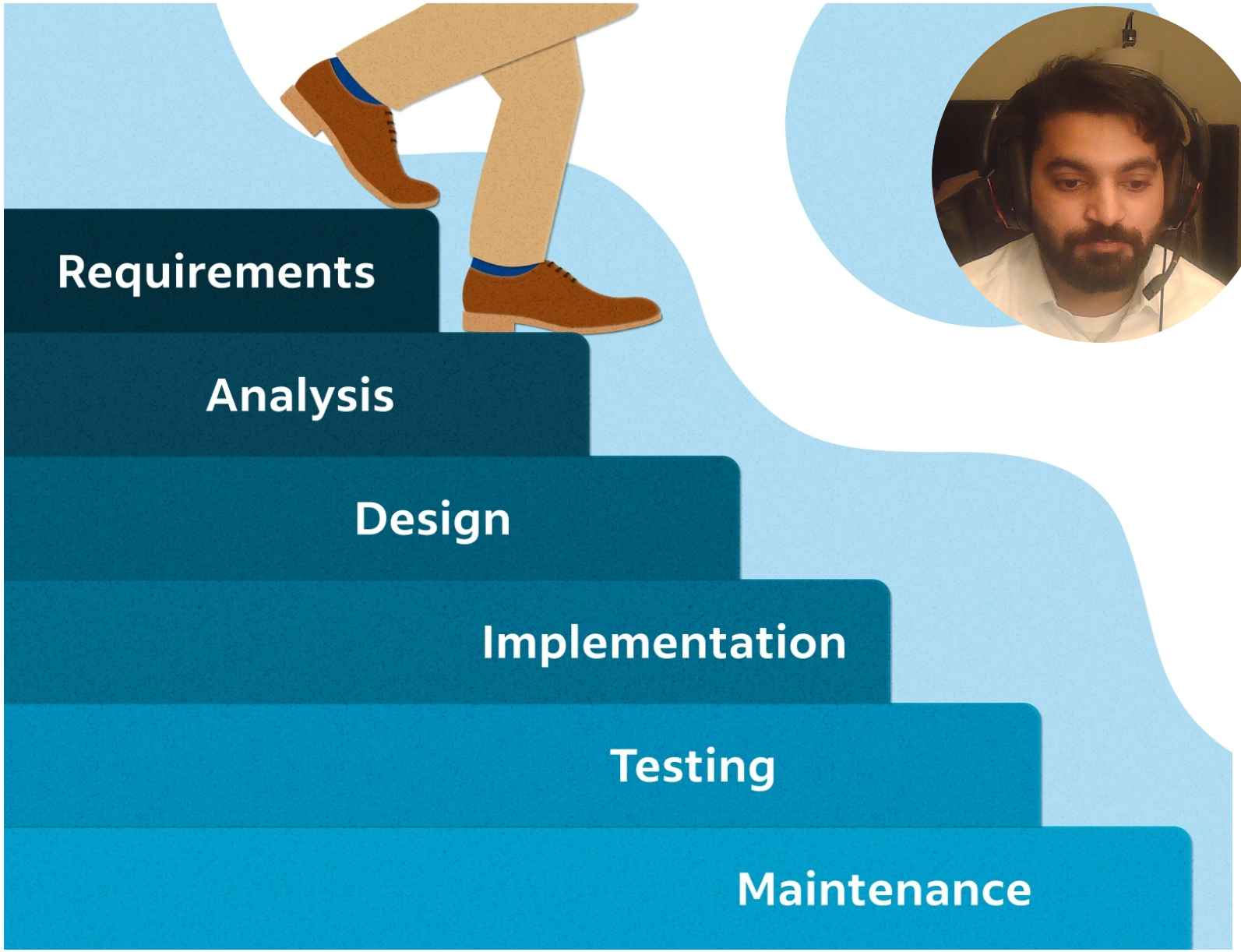
INTRODUCTION

- Michigan faces severe pothole problems due to freeze weather cycles.
  - Road surfaces expand and contract repeatedly during winter, causing cracks and potholes.
- Potholes cause millions of dollars in vehicle damage every year.
  - Michigan consistently ranks among the worst states for road quality.
- Manual road inspection is slow, expensive, and not scalable.
  - City crews must physically check thousands of miles of roadway.
- Automated pothole detection can significantly improve road maintenance.
  - Image-based detection offers fast, continuous monitoring.
- This research compares two AI approaches: Fuzzy Logic and CNN models.
  - Fuzzy Logic = explainable & rule-based
  - CNNs = high accuracy but black-box
- Goal: Determine which method performs better for Michigan road conditions while balancing interpretability and accuracy

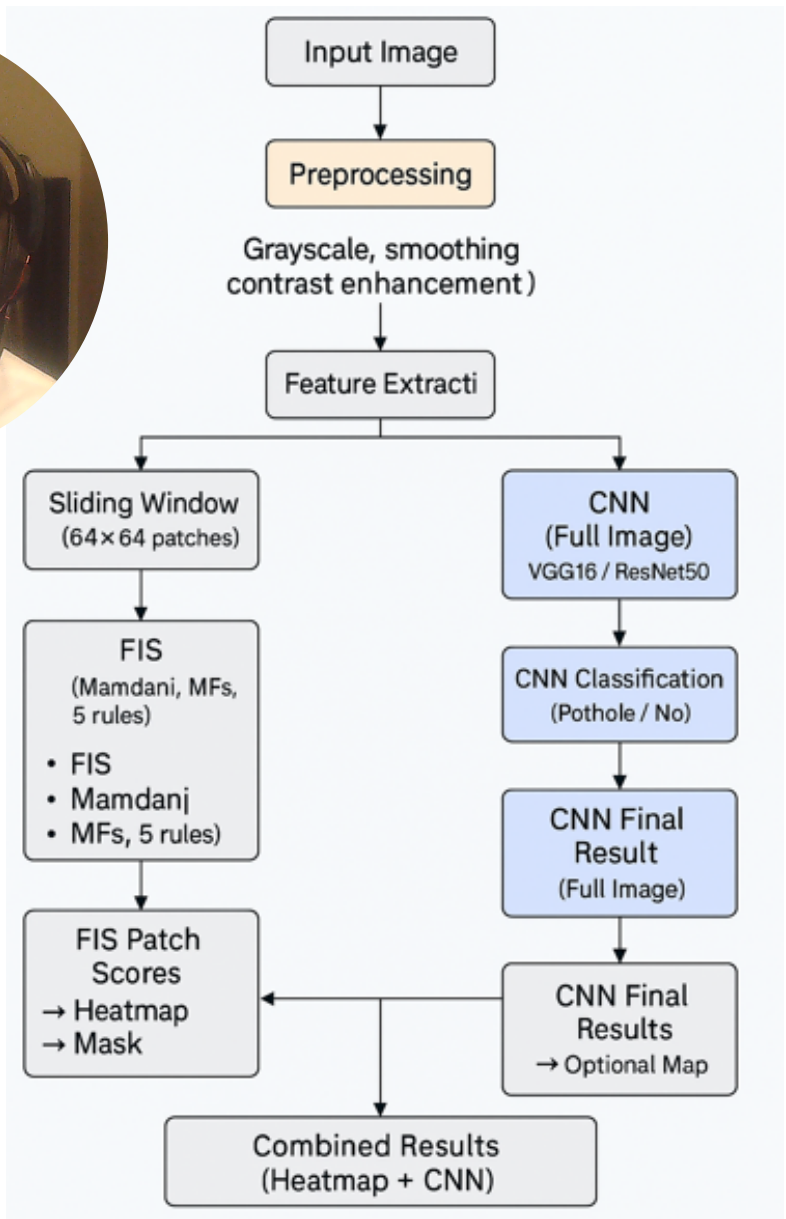
REQUIREMENTS ANALYSIS

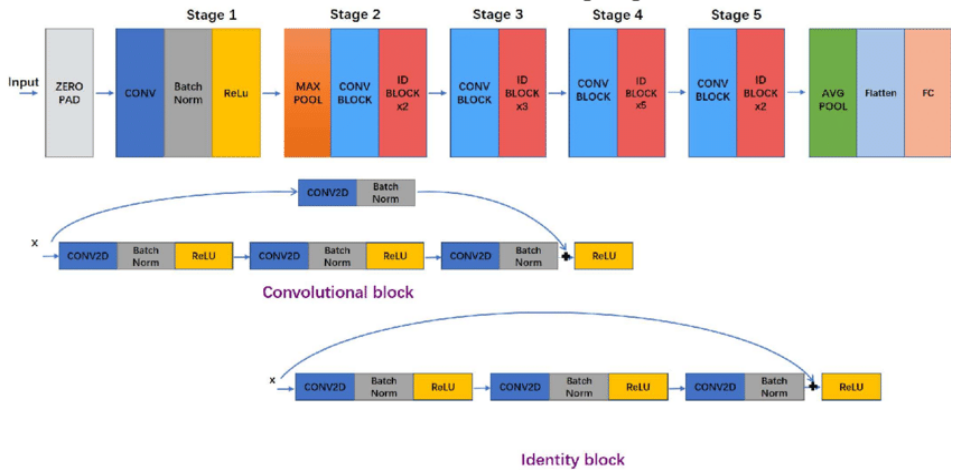
- Identify the problem: Michigan's severe pothole issue
- Need for automated, scalable pothole detection
- Requirements:
  - Detect potholes from road images
  - Compare Fuzzy Logic with CNN methods
  - Provide explainability (FIS)
  - Provide accuracy benchmarks (CNN)
- Dataset needed: Michigan road images with potholes
- Software requirements:
  - MATLAB for FIS
  - Python + TensorFlow/Pytorch/Keras for CNN models

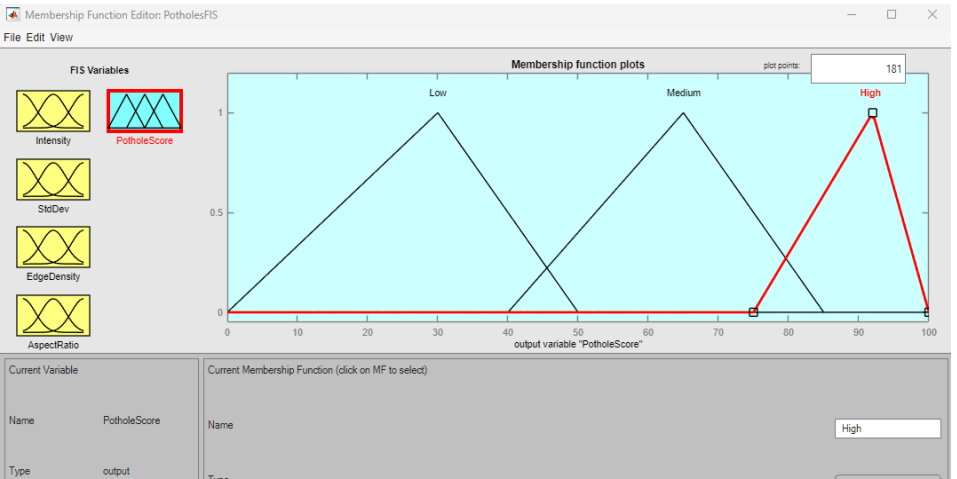


SYSTEM DESIGN

- High-level architecture with two parallel paths:
  - Fuzzy Logic Pipeline (feature extraction → FIS → score → heatmap)
  - CNN Pipeline (VGG16 / ResNet50 fine-tuning → binary classification)
- Defined features for FIS:
  - Intensity
  - StdDev (Texture)
  - Edge Density
  - Aspect Ratio
- Defined CNN architecture choices
- Determined evaluation metrics (accuracy, confusion matrix)







IMPLEMENTATION

- **Fuzzy Logic Implementation:**
  - MATLAB-based feature extraction
  - Sliding window (64×64 patches)
  - Membership functions created
  - Rule base implemented
  - Heatmap generation
- **CNN Implementation:**
  - Dataset preprocessing
  - Training VGG16/ResNet50
  - Fine-tuning and validation
  - Predicting pothole vs non-pothole

TESTING & EVALUATION

- **FIS Evaluation:**
  - Tested with various Michigan road images
  - Pothole score thresholding
  - Visual heatmaps
  - Patch-level and image-level decisions
- **CNN Evaluation:**
  - Accuracy on test set
  - Confusion matrix
  - Comparison with FIS performance

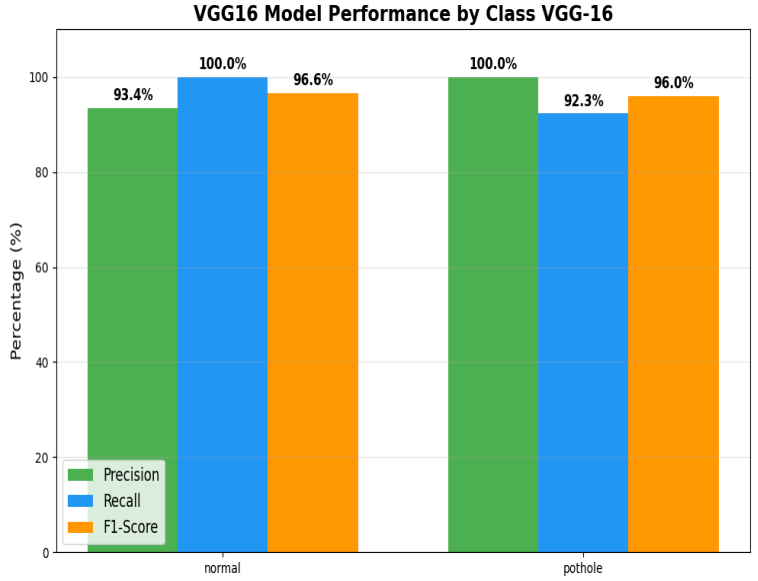
```
================================================
            VGG-16 CLASSIFICATION REPORT
================================================
              precision    recall  f1-score   support

      normal       0.93      1.00      0.97        71
     pothole       1.00      0.92      0.96        65

    accuracy                           0.96       136
   macro avg       0.97      0.96      0.96       136
weighted avg       0.97      0.96      0.96       136
```

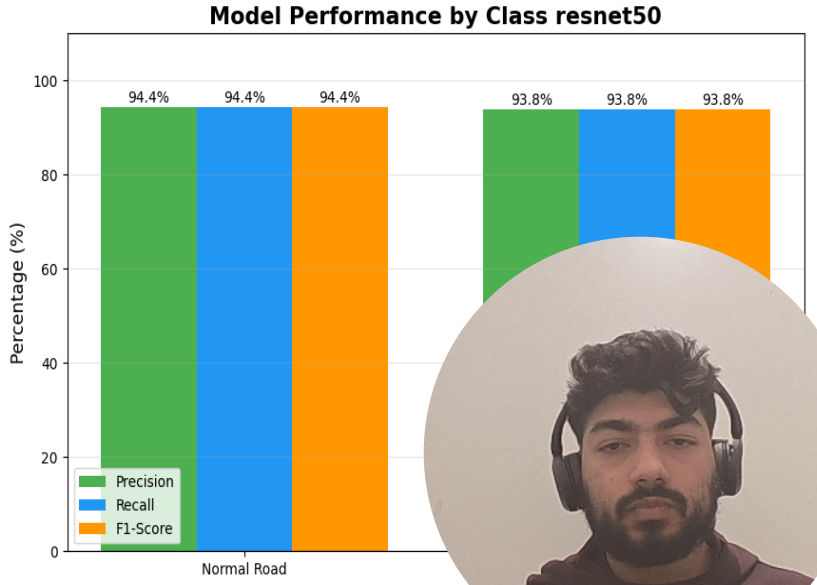
```
Accuracy: 94.12%

Resnet50 Classification Report:
              precision    recall  f1-score   support

 Normal Road       0.94      0.94      0.94       142
     Pothole       0.94      0.94      0.94       130

    accuracy                           0.94       272
   macro avg       0.94      0.94      0.94       272
weighted avg       0.94      0.94      0.94       272
```

```
POTHOLE PATCH: I=118.7, σ=39.1, E=0.196, A=0.63 → Score = 87.5 → DETECTED
CENTER PATCH:  I=118.7, σ=39.1, E=0.196, A=0.63
FIS scores: min = 87.5, max = 87.5, mean
IMAGE-LEVEL DECISION: DETECTED (max sc
```

RESULTS & COMPARISON

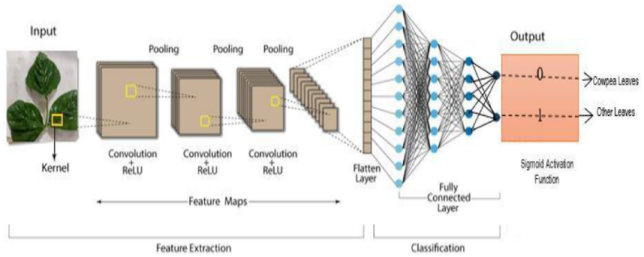
- **Fuzzy Logic:**
  - Good interpretability
  - Works well on clearly visible potholes
  - Handles ambiguity well
  - Less accurate in complex lighting
- **CNNs (VGG16 / ResNet50):**
  - High accuracy
  - Generalizes better
  - Black-box, no explainability
  - Requires more data and compute

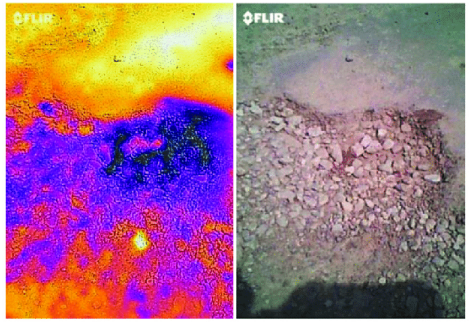




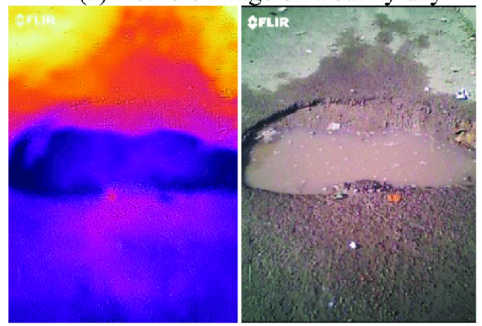
FINAL SYSTEM OUTPUT

- FIS-built heatmaps for pothole localization
- CNN binary classification
- System can be integrated into:
  - Road inspection vehicles
  - Dashcams
  - City infrastructure monitoring tools

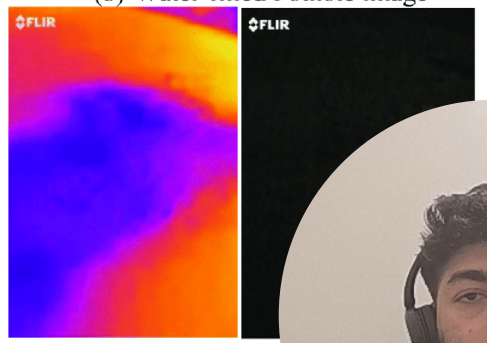




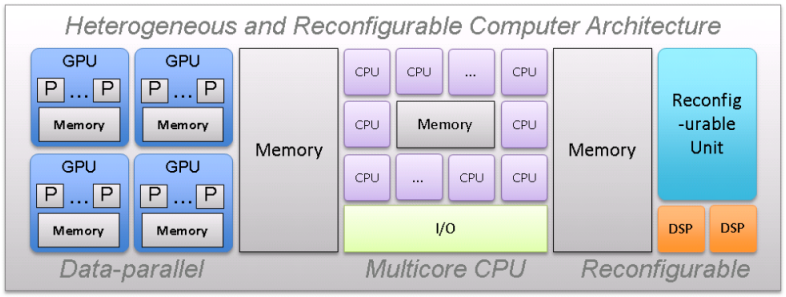
(a) Pothole image on a sunny day



(b) Water-filled Pothole image

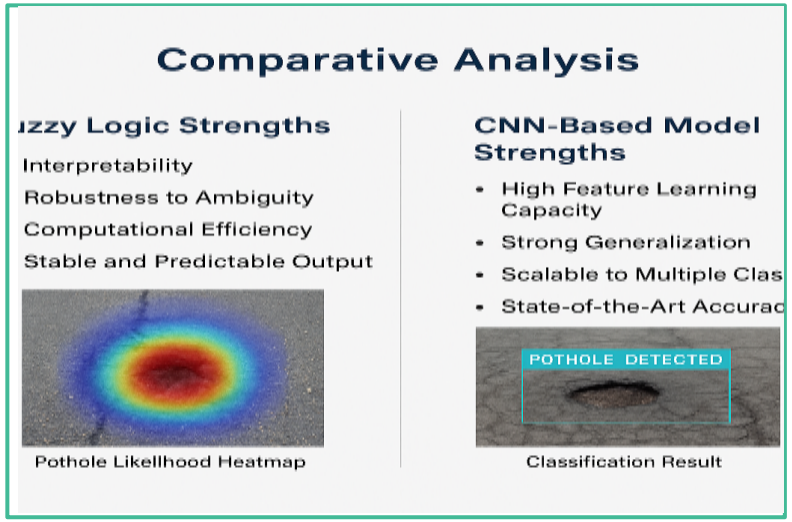


(c) Pothole ima



FUTURE WORK

- Expand dataset to more Michigan cities
- Implement Heterogenous Programming
- Add real-time video detection
- Combine Fuzzy Logic + CNN
- Use drones or smart cameras for continuous monitoring
- Improve robustness for shadows/snow



CONCLUSION

- Michigan's pothole problem motivates automated solutions
- Fuzzy Logic offers interpretability
- CNNs offer superior detection accuracy
- Both approaches are valuable