Building Early Warning Collapse System (Software)

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DUKE ENGINEERING POD DESIGN

Motivation

The recent tragedy of the condominium collapse in Miami sheds a light on the necessity of a method to detect building collapse. Our project focuses on developing a sensor system to solve this problem.

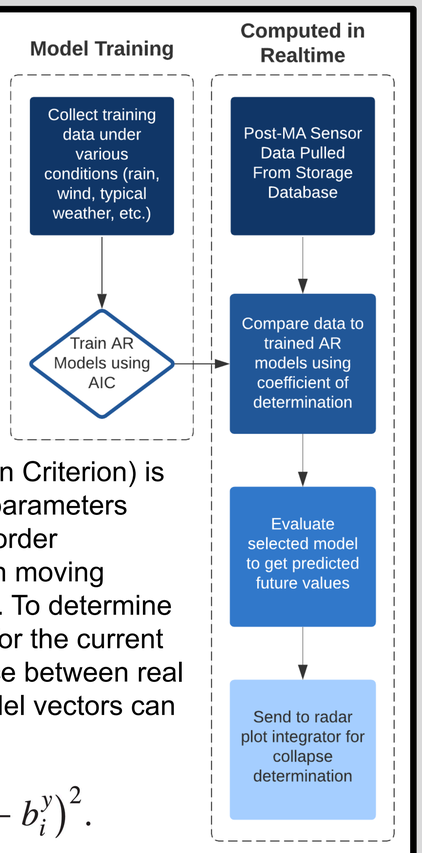
Our Project

To combat the hundreds of deaths and millions of dollars of property damage per year due to building collapse, our team has developed a software ecosystem that takes in data from a network of low-cost sensors to calculate and report a building's risk of collapse. This is done by computing regression models for various building conditions and creating risk probabilities to report results through a holistic report and real-time web interface.

Data Analysis

The core functionality of the data analysis relies on autoregressive models (ARs). These machine learning models are trained on previous univariate data to predict future outcomes.

$$y_k = \sum_{i=1}^{p} b_i^y \, y_{k-i} + r_k^y.$$

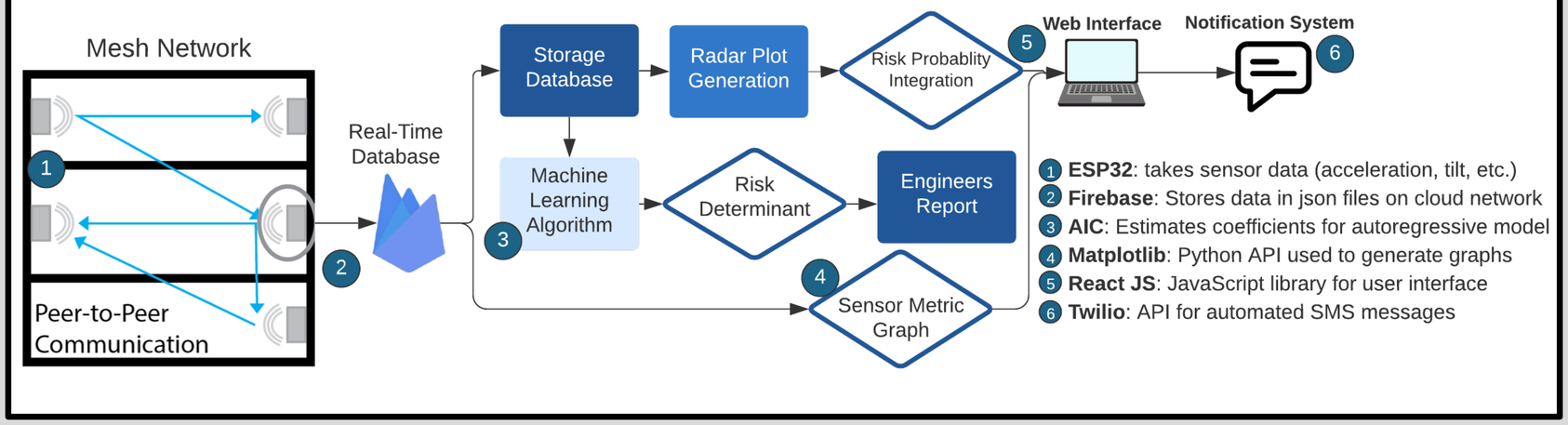


The AIC (Akaike Information Criterion) is then used to estimate the parameters (coefficients) for a second order autoregressive model given moving average (MA) training data. To determine the appropriate AR model for the current data, the Euclidean distance between real database data and AR model vectors can be found and minimized.

$$D = \sum_{i=1}^{p} \left(b_i^{\mathrm{DB}} - b_i^y \right)^2.$$

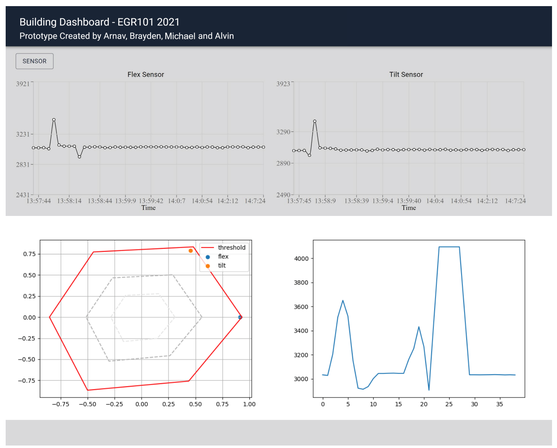
To determine the probability of collapse, an integral of the polar model of each sensor metric is taken and compared to the predicted values using z-scores. This is then passed into a parameterized sigmoid function that returns an overall probability of collapse.

Overall Design Solution

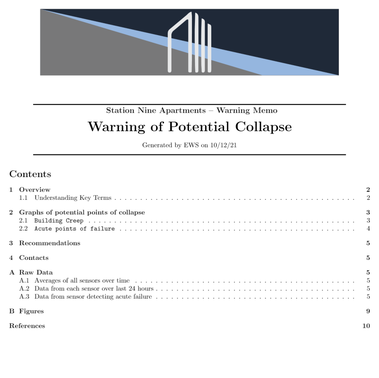


User Interface

Our client website gives easy access to real-time data and the most important graphics. It is an efficient tool for client analysis and understanding that is available 24 hours a day.



The engineer's report is a holistic tool for understanding all of the data collected by our system. It includes helpful graphics, raw data, background information, and relevant contacts (clients and structural engineers) to the severity and location of potential collapse risks.



Station Nine Apartments – Warning Memo

Warning of Potential Collapse

Generated by EWS on 10/12/21

Contents

Design Criteria and Testing

Criteria	Target Value	Test Description	Results
Reliability	0 False Positives and Negatives	Simulate 50 different scenarios (25 under normal and collapse conditions each)	TBD Need fully functional hardware
Accuracy ✓	<= 1% Error Margin	Run under constant conditions to record 1000 data points. Calculate error margins with data spread.	0.54% error margin on trained model
Urgency ✓	<= 2 min Response Time	Simulate collapse on sensor 10 times and record the time it takes to receive emergency notification	Response time of 26s on average
Ease of Use (Client) ✓	90% Approval Rating	Survey 10 laypeople using google forms to collect overall approval rating of the UI	9/10 people rated the product persuasive
Ease of Use (Analyst) ✓	90% Approval rating	Survey 30 engineers on the comprehensiveness of the data presentation	28/30 engineers rated the data helpful
Scalability ✓	>= 5000 Sensors, 100 Buildings	Calculate CPU load on computer to approximate maximum capacity.	0.3% of dual-core CPU at 2.5 gHz

Conclusion

Current Design:
- Roughly calculates the risk of collapse given sensor data using AR models
- Pushes real-time analysis and visuals using a Firebase server and web interface

Future Directions:
- Account for more factors (sensor location, differing building structures, points of load)
- Factor in how different readings affect each other
- Expand sensor base to cover entire buildings
- Accumulate a larger dataset of training models

References

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- Client: Dr. Henri Gavin
- Advisor: Dr. George Delagrammatikas
- Technical Mentor: Matt Brown
- TA: Frank Tang

Check out our Product Website