Scalable Modeling and Adaptive Real-time Trust-based Communication (SMARTc) System for Roadway Inundations in Flood-Prone Communities

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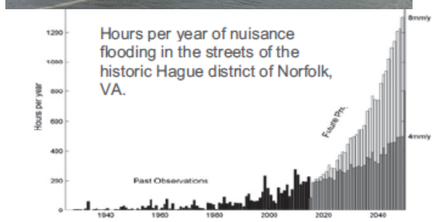
Award Type: SCC-IRG Track 2, Solicitation Year: FY2020

Problem

Recurrent nuisance flooding (RNF) expected to get worse due to sea lever rise, storm surge, and heavy rain

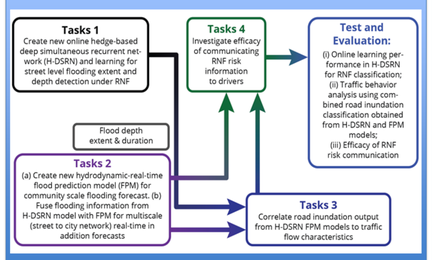


Community Partners

- City of Norfolk, VA
- RISE – non profit organization focused on community resiliency

Project Overview

Visual Schematic



Project Vision

1) **Develop a Scalable Modeling and Adaptive Real-time Trust-based communication (SMARTc) system for roadway inundation detection and monitoring**

2) **Evaluate the system for a flood-prone region in the City of Norfolk, Virginia using data from the City's cameras, tide gauges, and existing and new overland water level sensors in the field**

Project Overview

Use-Inspired Research

The project is Inspired by the needs for a system at street to community level as follows --

(i) Automatic and real-time detection of extent and depth of inundation levels and prediction of duration of RNF, and

(ii) Real time communication of the information to drivers, especially for communities affected by RNF

In collaboration with City of Norfolk, Virginia and non-profit organization RISE that are working to develop new solutions for coastal communities to adapt to SLR and RNF

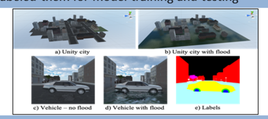
Fundamental Research Contributions

I. **Near real-time learning model for street-scale RNF extent and depth recognition;**
II. **improved community-scale road network flood prediction model for RNF extent, depth, and flood duration using City camera and other sensor data**
III. **improved microscopic car-following models for partially flooded roadway segments so that the capacities and bottlenecks may be estimated and characterized accurately in near real-time**
IV. **Effective 'risk' communication strategies for drivers using the RNF extent, depth**

Project Update

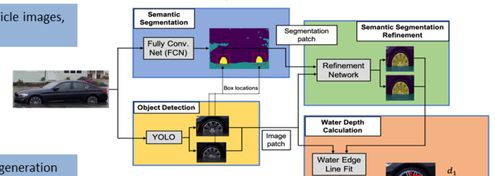
Generating Synthetic Image Data

- Generated flooding scenarios in **Unity**, extracted vehicle images, and labeled them for model training and testing

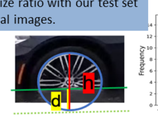


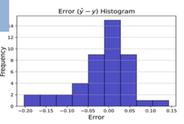
- Exploring **Blender** for more realistic synthetic image generation
  APIC (Affine Particle-in-Cell) solvers within Blender to simulate fluids, a hybrid Lagrangian/Eulerian approximation of Navier-Stokes equations

Flood Depth Prediction



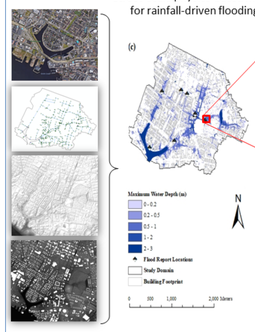
- Predict water depth in relation to wheel size
- Achieved *Mean Absolute Error (MAE)* of 0.051 in water depth to wheel size ratio with our test set of 45 real images.





Project Update

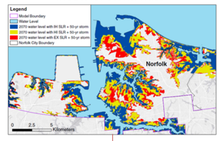
Machine Learning Surrogate Models for Coastal Urban Flooding

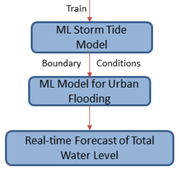


- Random Forest model: 3,000x speedup compared to physics-based rainfall-driven flood model
- Total flood level = rainfall-driven flow+tides+storm surge
- Similar speedup is expected from a ML surrogate model of the physics-based coastal hydrodynamics model, motivating the future work.
- Future work: develop a ML model for total flood level

Future work:

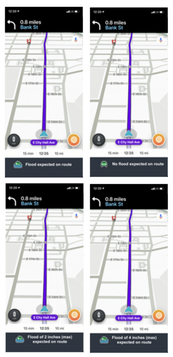
Region-Scale Physics-based Coastal Hydrodynamics Model for Storm Tides



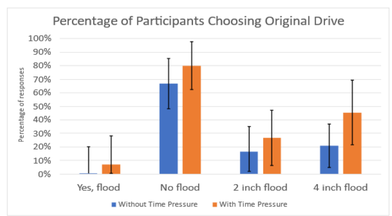


Project Update

Communicating Flood Information to Road Users



- **Purpose:** to examined the effects of time pressure and flood information type on the planned actions of road users
- **Method:** Participants were presented with a short driving scenario and a flood warning given by "Waze". They then were to decide what they would do in their situation.
- **Results:**



Intellectual Merit

- Novel machine learning (ML) algorithms for detecting floodwater extent and depth in real-time based on surveillance camera images.
- A coupled hydrologic-stormwater-coastal model to predict flood levels at city network level and real-time update of these predictions based on sensor and image data.
- Prediction of roadway capacities in real-time under partial inundations and correlation of floodwater depth and extent with driver behavior.
- Effective communication of flood risk and road inundation to the public, leveraging granularity and uncertainty of flood information.

Broader Impacts

- New solutions for predicting RNF impacts on city roads in real-time.
- Safer roads since drivers can use the information to avoid driving through flooded roads and emergency vehicles can reroute around inundated roads.
- A strong partnership with the City of Norfolk and RISE for evaluating the SMARTc system for a flood-prone region.
- Integration of research outcomes into undergraduate and graduate classes, hands on activities for visiting high school students, and interdisciplinary capstone projects.

Anticipated outcomes for next year

- Collection of vehicle trajectory data on partially inundated roadway segments, and realistic rendering of the flooding simulation for synthetic data generation.
- Validation of online experiment results through in-person driving-simulator experiments, with behavioral data and eye-tracking metrics.
- Improved ML algorithms for predicting RNF impacts
- Publish journal papers on completed work.

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