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

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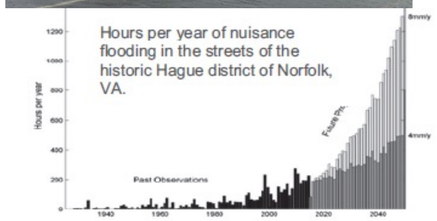
Award Type: SCC-IRG Track 2, Solicitation Year: FY2020

Problem

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

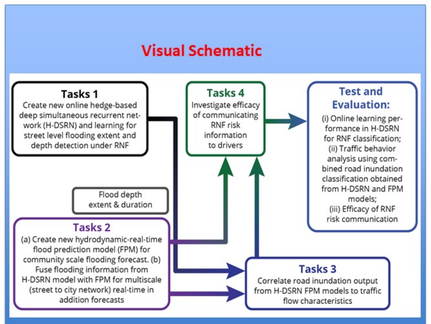


Community Partners

- 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;**

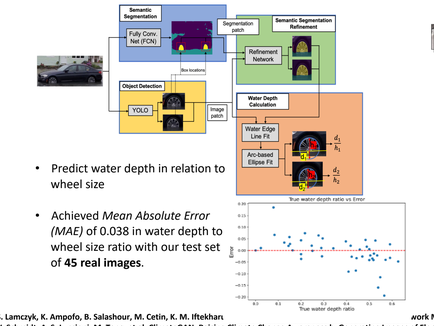
II. **improved community-scale road network flood prediction model for RNF extent, depth, and flood duration using City camera and other sensor data**

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**

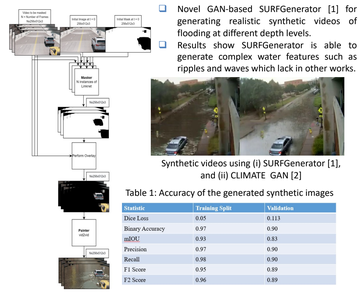
Project Update

Flood Depth Prediction



- Predict water depth in relation to wheel size
- Achieved *Mean Absolute Error (MAE)* of 0.038 in water depth to wheel size ratio with our test set of **45 real images**.

Synthetic Urban Recurrent Flooding (SURF) Generator



- Novel GAN-based SURFGenerator [1] for generating realistic synthetic videos of flooding at different depth levels.
- Results show SURFGenerator is able to generate complex water features such as ripples and waves which lack in other works.

Synthetic videos using (i) SURFGenerator [1], and (ii) CLIMATE GAN [2]

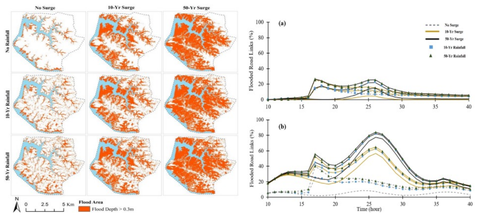
Table 1: Accuracy of the generated synthetic images

Statistic	Training Split	Validation
Dice Loss	0.05	0.113
Binary Accuracy	0.97	0.90
mIOU	0.93	0.83
Precision	0.97	0.90
Recall	0.98	0.90
F1 Score	0.95	0.89
F2 Score	0.96	0.89

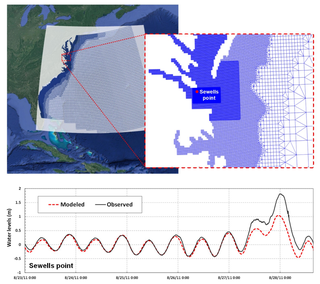
[1] S. Lamczyk, K. Ampofo, B. Salashour, M. Cetin, K. M. Iftekhar… …work Modeling for Synthetic Flooding Video Generation", IJCNN, IEEE WCCI 2022 3861.
[2] V. Schmidt, A. S. Luccioni, M. Teng, et al. ClimateGAN: Raising Climate Change Awareness byGenerating Images of Floods. 2021. arXiv: 2110 . 02871 [cs.CV].

Dynamic Modeling of Coupled Inland and Coastal Flooding

- A series of combined storm events were modeled for current (2020) and projected future (2070) climate scenarios using TUFLOW



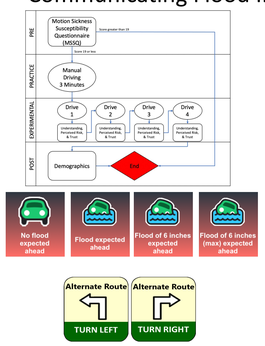
- Water level at the coastal boundary was received from the Delft3D model and fed into TUFLOW as boundary condition
- Pluvial flooding causes a larger interruption to the transportation network compared to tidal flooding under current climate conditions
- By 2070, tidal flooding will be the dominant flooding mechanism, with nuisance flooding expected to happen daily due to sea level rise



- A new integrated flow-wave model was developed in Delft3D to simulate storm surge due to major hurricanes
- The model, currently being calibrated and verified to match the data, will encompass much of the Atlantic basin to enable tracking the path of tropical cyclones

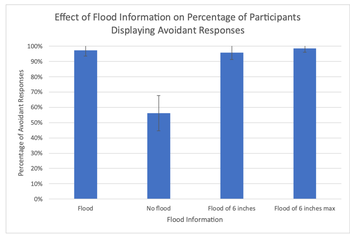
Project Update

Communicating Flood Information to Road Users



- **Purpose: T**o examine the effects of flood warning type on perceived risks, trust, and the actions taken by drivers in simulated driving
- **Method:** Participants drove through four driving scenarios in a driving simulator displaying different flood warning messages. Driving behavior and subjective reports on perceived risk of the scenario and trust in the navigation system were recorded.

- **Main Results:**
  - ✓ Flood warnings indicating possibility of flood elicited higher perceived risks and higher percentages of flood-avoidant behavior.
  - ✓ Trust was not affected by the flood warnings, although it was overall moderate (~5.5 out of 7)



ntellectual 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 for studying traffic flow behavior.
- Realistic generation of synthetic flooding with depth data.
- Effective flood risk communication through informed decision and social influence.
- Trust calibration guided by performance of SMARTc (error rate and type)
- Publish journal papers on completed work.

2022 S&CC Principal Investigators' Meeting
October 11 and 12, 2022

NSF Project ID: 1951745