UVA ENGINEERING

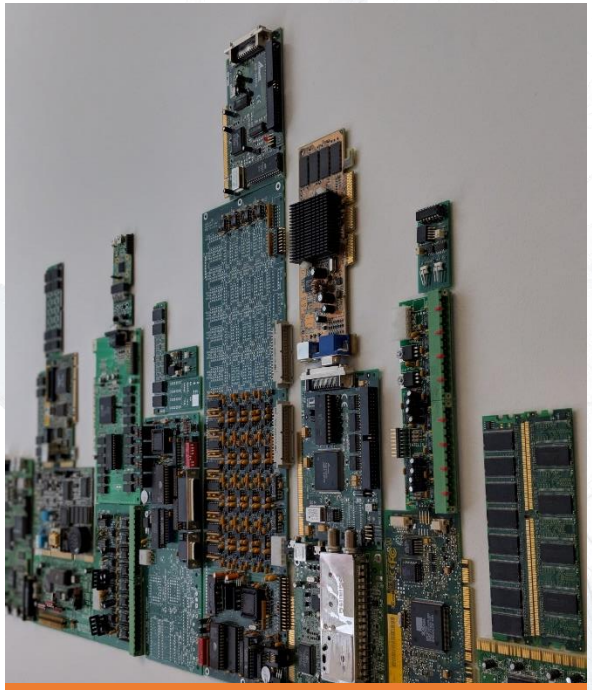
LINK LAB

UVA ENGINEERING
LINK LAB

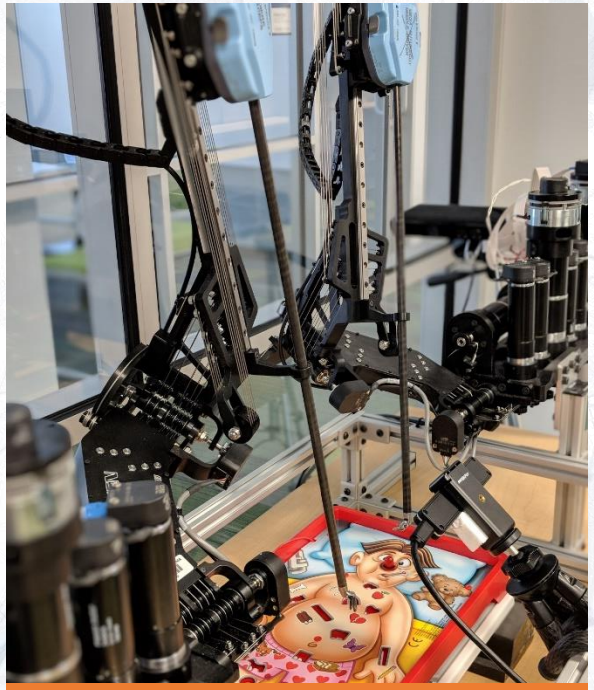
a world-class initiative in

Cyber-Physical Systems

research, education, collaboration



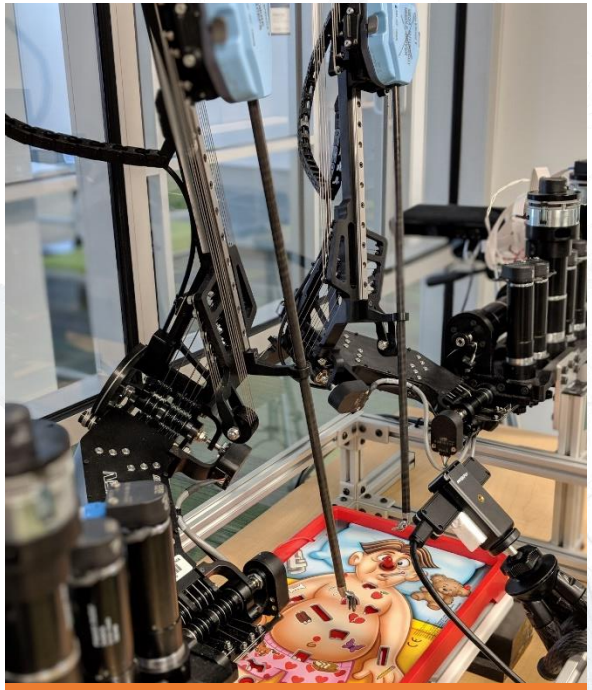
Smart Cities



Smart Health

Autonomous Systems

Smart Health



Smart Health

Treating areas such as Asthma, Dementia, Depression, Diabetes, Obesity, and Cardiac conditions, Link Lab's work builds on a growing suite of enabling technologies to advance care in the hospital, extend care and awareness throughout the everyday life of the patient, and achieve a more holistic and robust understanding of conditions.

Areas of Research:

Brain Computer Interfaces
Cognitive Assistance and Reminder Systems
Embedded Systems and Implanted Devices
Health in the Home
Human Behavior and Emotional Sensing
Human Performance and Human Factors
Robotics for Surgery and Medicine
Wireless Health via Wearables and Mobile Sensing

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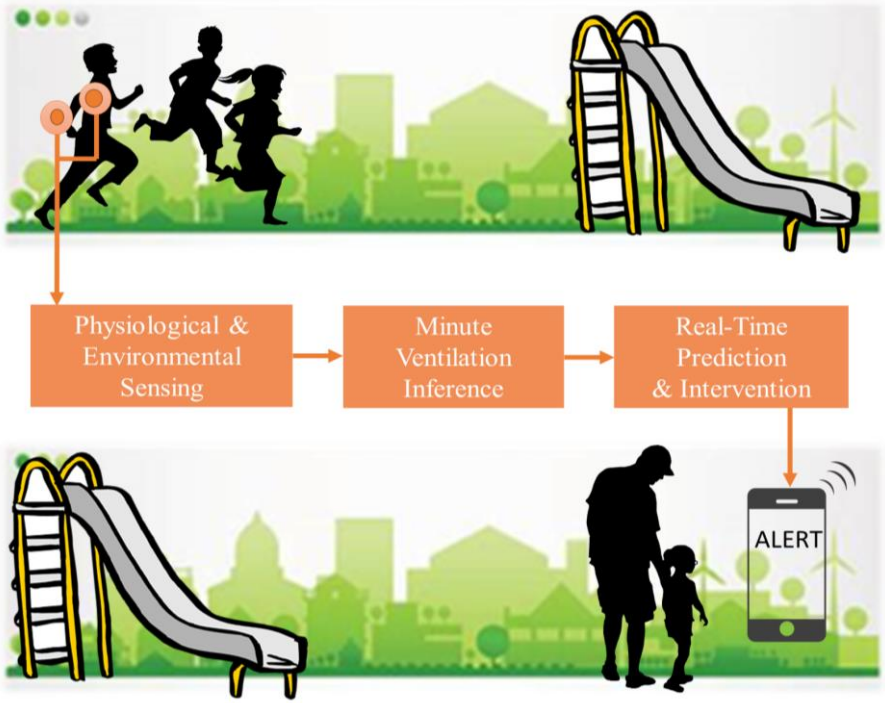
Asthma Attack Prevention

With Sensors And Predictive Models



Ridwan Alam*, Luis Lopez Ruiz, and Prof. John Lach

Link Lab, University of Virginia

Collaborators: University of North Carolina - Chapel Hill and North Carolina State University

Asthma Attack Prevention …

Environmental Sensing

Sensor Fusion → Dynamic Calibration → O_3

Motion Sensing

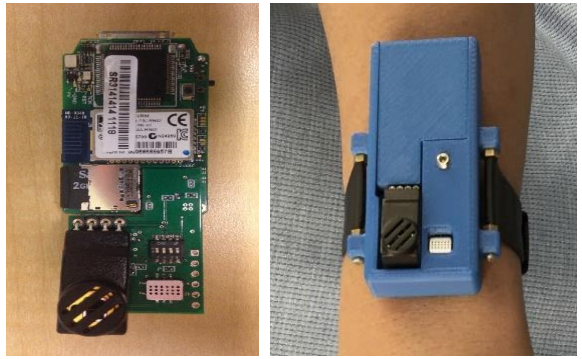
Feature Extraction → Predictive Model → V_E

O_3 := Ozone Concentration

V_E := Minute Ventilation

Pollutant Exposure Risk:

$$R_{exp} \propto O_3 * V_E$$

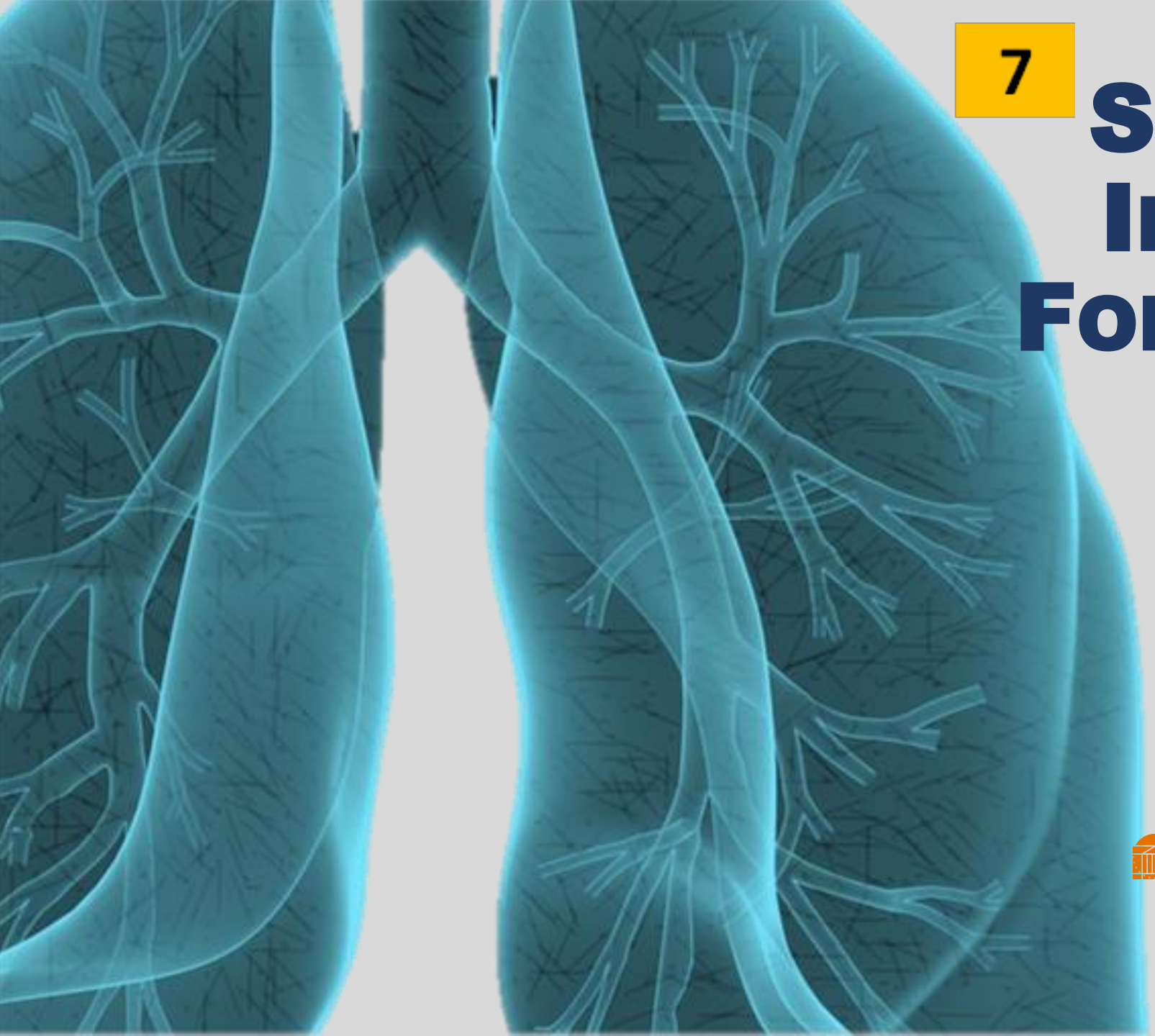


Wrist-worn Sensing Platform

Models	Training		Prediction	
	RMSE (L/min)	MAE (L/min)	RMSE (L/min)	MAE (L/min)
RT	11.75	8.01	11.76	7.97
SVM	7.56	5.44	6.62	4.76
GPR	5.81	4.11	5.19	**3.62**

Train & Test Performance

Intervention



7

Self-powered Implantables For Body Flow Sensing

Luis Lopez Ruiz
Joe Zhu

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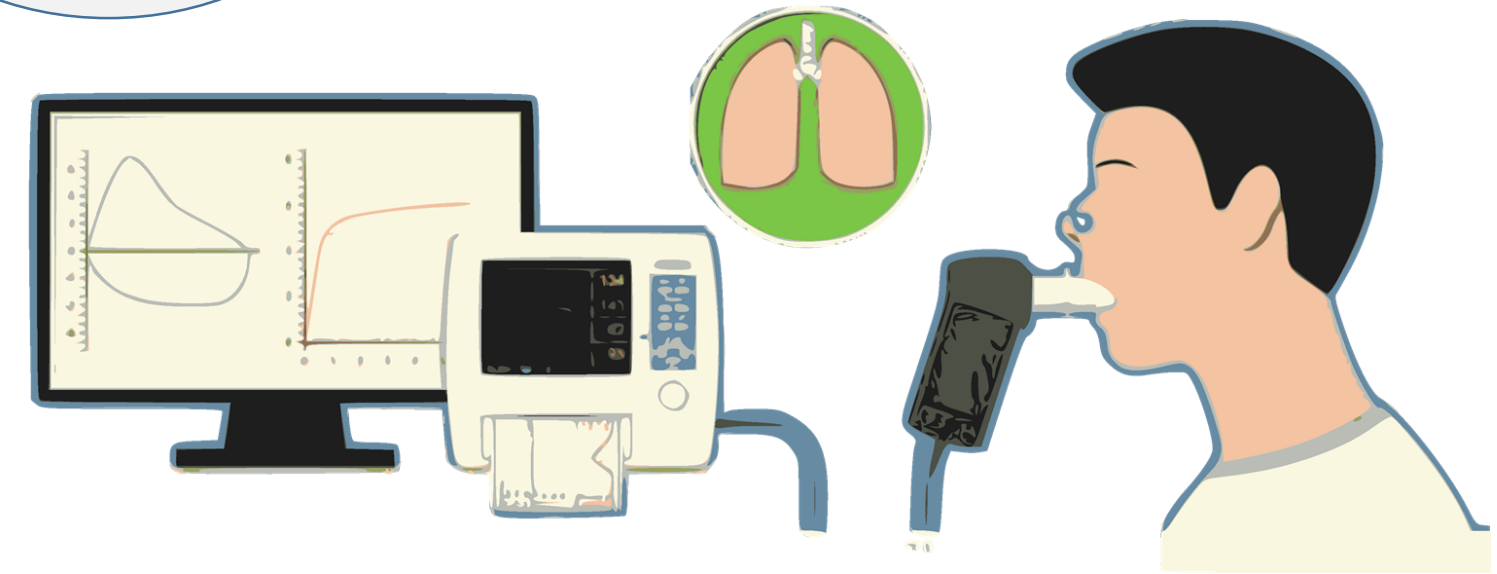
7

Can we create a *fitbit* for the lungs?

3.8% of the population diagnosed with COPD in 2016

Chronic respiratory diseases are diagnosed through **spirometry**

26 million people suffer from asthma in the U.S.



Source: COPD Foundation and World Health Organization, 2019

iAdhere: A Voice Interactive Assistant to Improve Adherence to Medical Treatments

Sirat Samyoun, Abu Sayeed Mondol, Ifat A. Emi and John A. Stankovic
Department of Computer Science
University of Virginia

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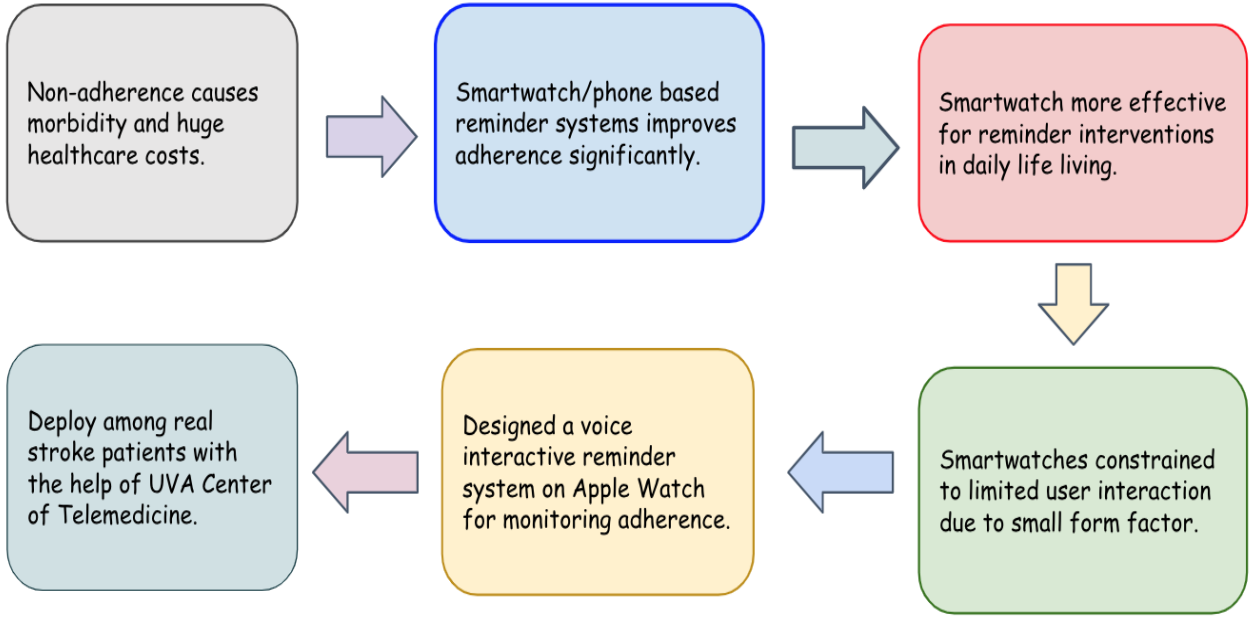
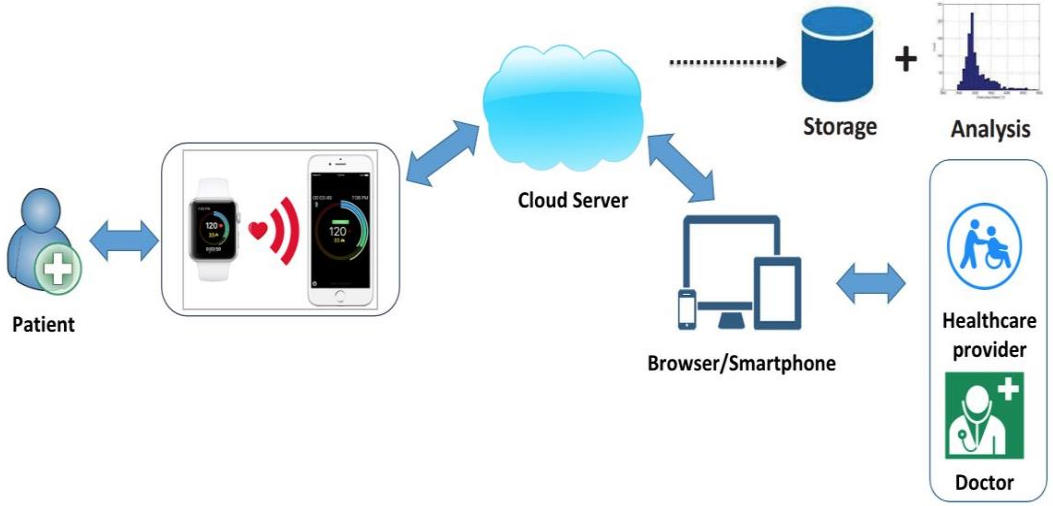
iAdhere: A Voice Interactive Assistant to Improve Adherence to Medical Treatments





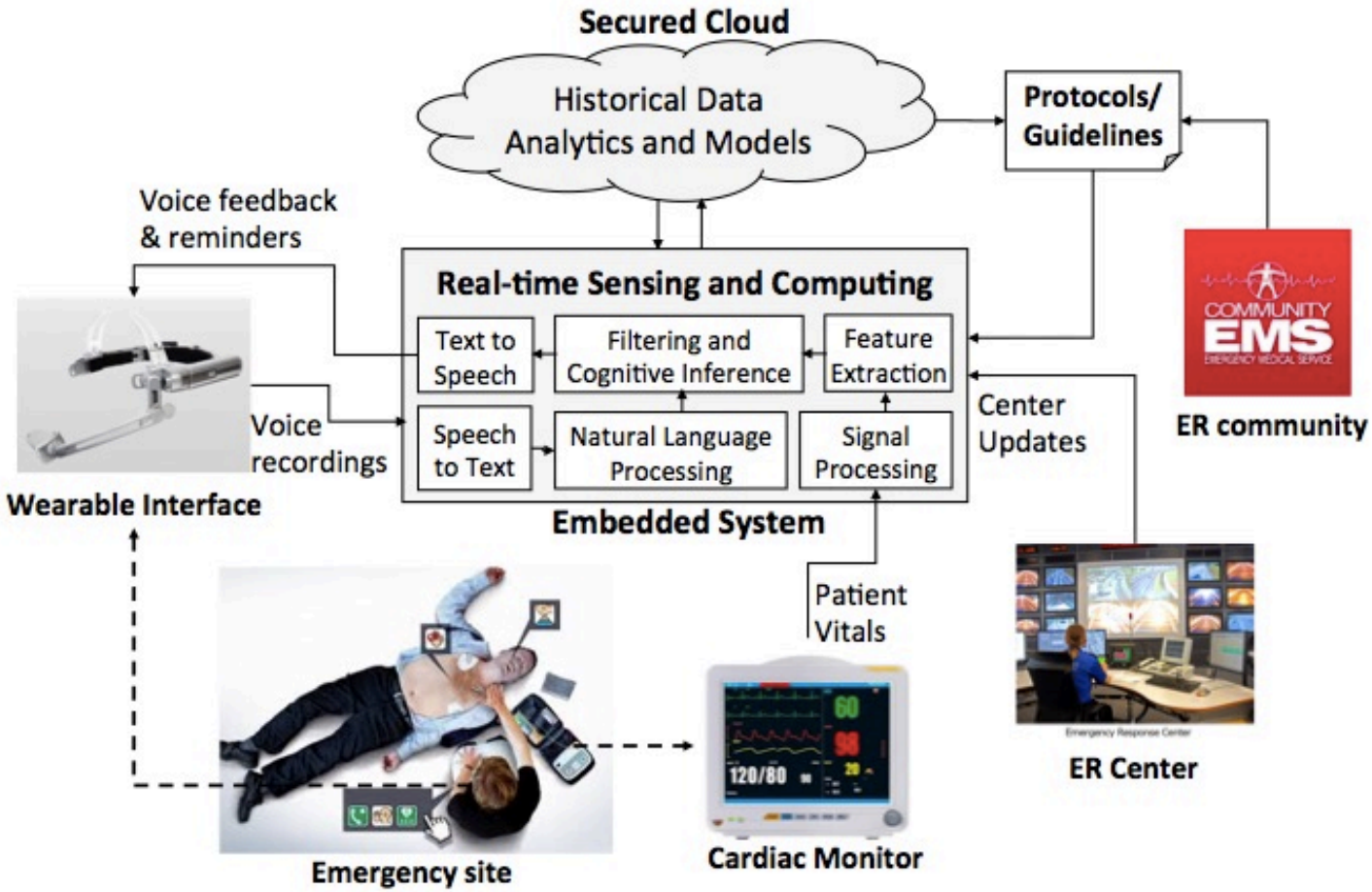
System Architecture

- Provides Daily Reminders for Prescribed Medical Treatments.
- Engages users to Voice Interactions on Apple Watch to track Adherence.
- Uploads Adherence data to cloud for Clinician Remote Monitoring.

CognitiveEMS: Cognitive Assistant System for Emergency Medical Services

Sile Shu, Sarah Preum, Haydon M. Pitchford, Ronald D. Williams, John Stankovic, Homa Alemzadeh,

University of Virginia

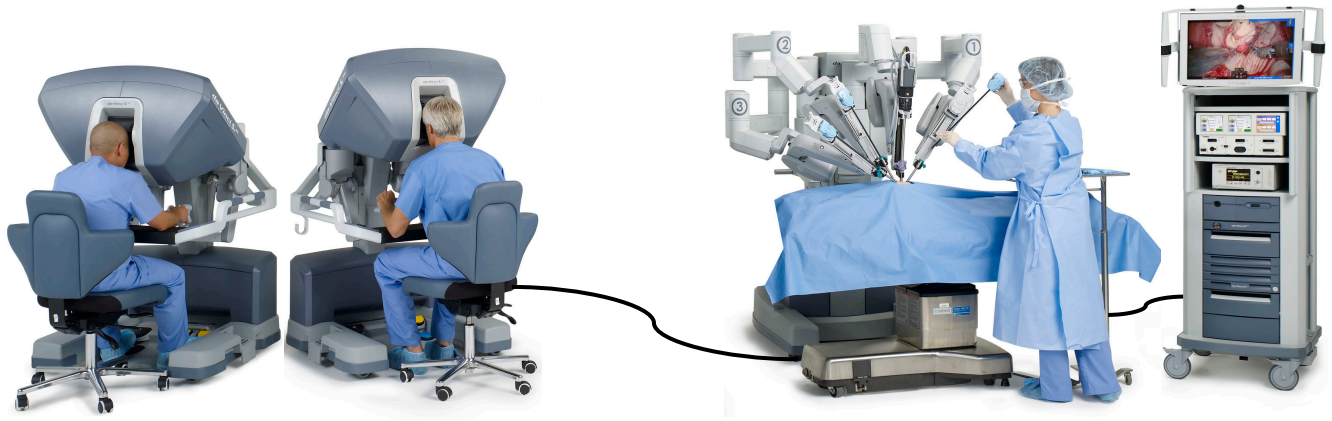


Goal: Provide dynamic and appropriate intervention suggestions to first responders in real-time

Context-Aware Monitoring System for Robotic Surgery

Mohammad Samin Yasar, David Evans, Homa Alemzadeh

Minimally Invasive Robot Assisted Surgery

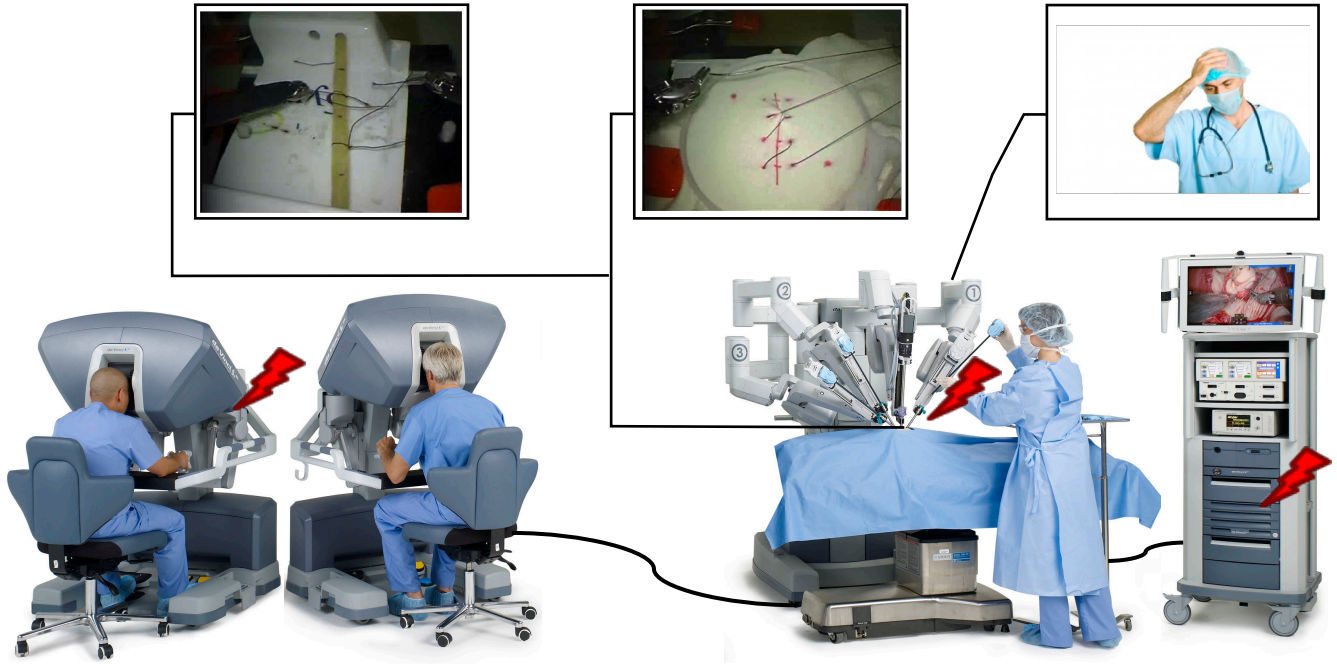


Credits: da Vinci Surgical System, Intuitive Surgical, Inc.

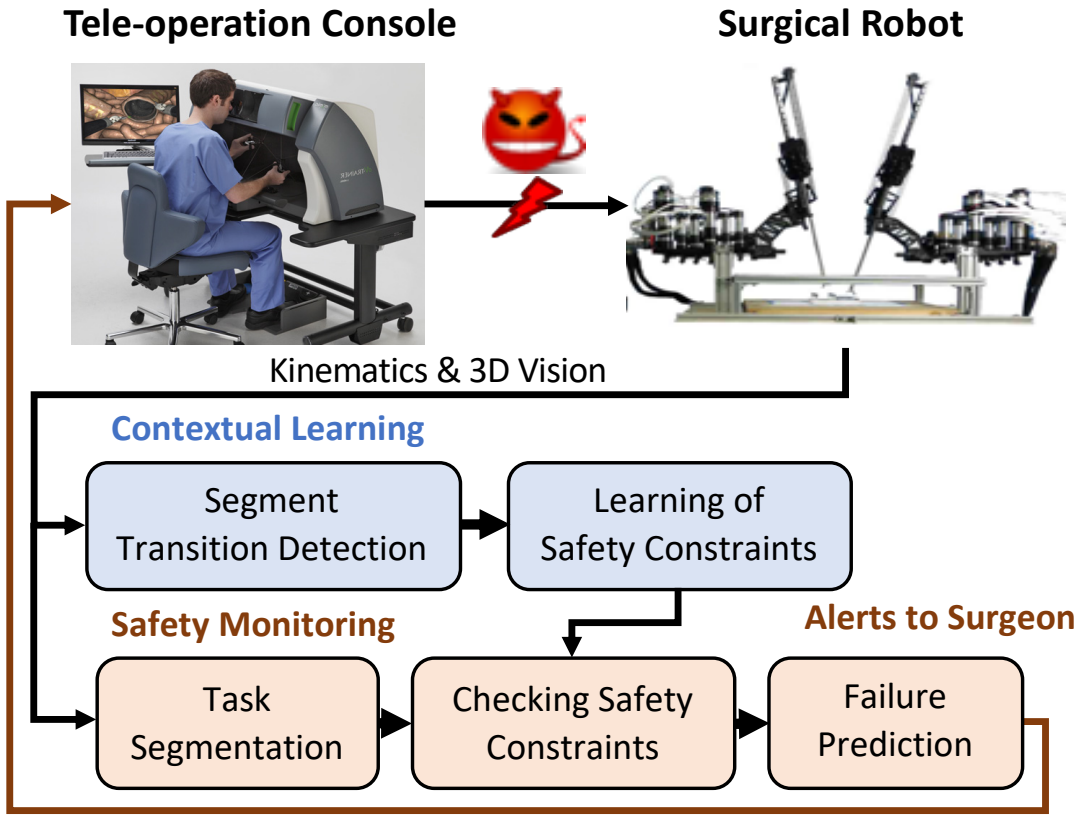
Context-Aware Monitoring System for Robotic Surgery

Mohammad Samin Yasar, David Evans, Homa Alemzadeh

Vulnerabilities in the system



Our solution



Credits: da Vinci Surgical System, Intuitive Surgical, Inc., and Price Benowitz LLP

BESI-C: Behavioral and Environmental Sensing and Intervention for Cancer

James Hayes[1], Nutta Homdee[1], Ridwan Alam[1], Katherine Gordan[2], Virginia LeBaron[2], Leslie Blackhall[3], John Lach[1]

Causes of Pain:

- Infection
- Tumor related
- Treatment related

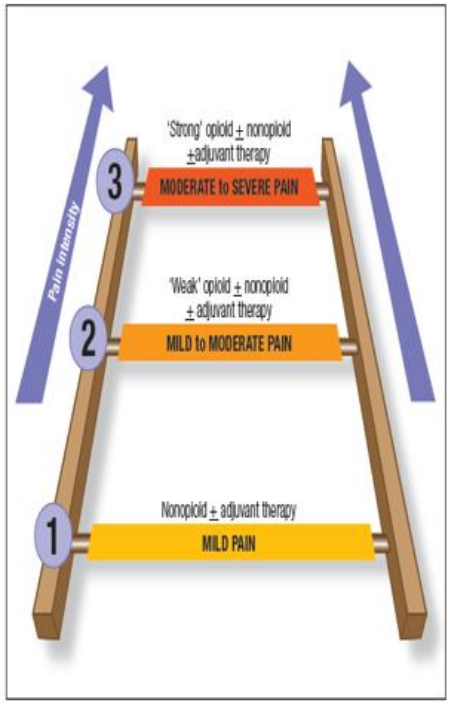


Fig: WHO 3-step pain ladder has been treatment standard most used during past 30 years.

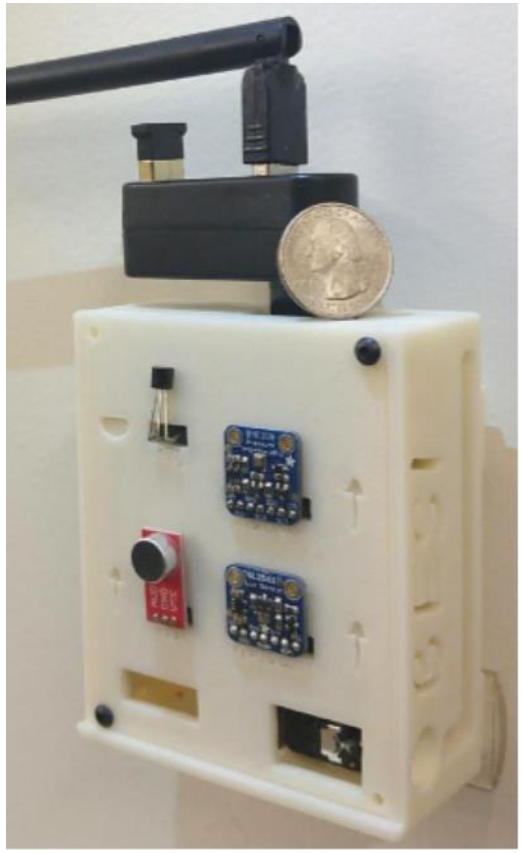
How will BESI help:

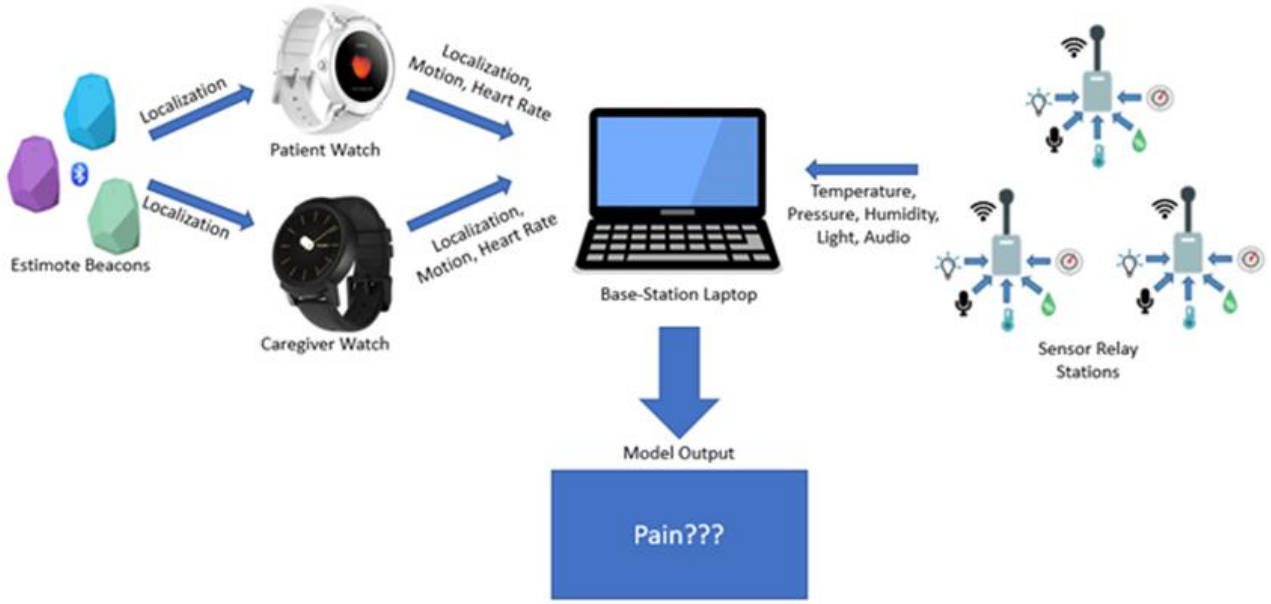
- Better assessment of pain
- Adherence vs. Addiction
- Quality of life, Vital signs
- Unreported pain
- Well-informed care

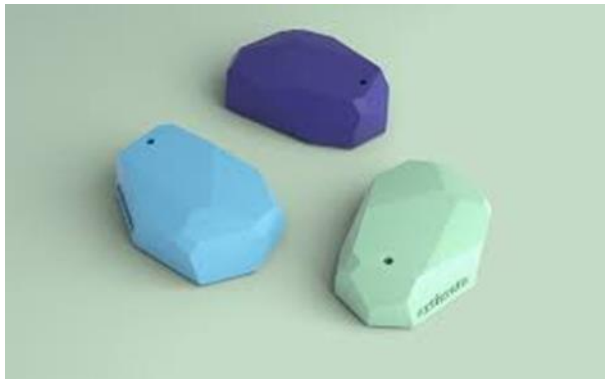
[1] Charles L. Brown Department of Electrical and Computer Engineering
[2] UVA School of Nursing
[3] UVA Cancer Center & UVA School of Medicine

Immediate Goals

- Optimize sensor system reliability
- Create machine learning model for pain prediction from collected data







Behavioral and Environmental Sensing and Intervention for Dementia Caregiver Empowerment

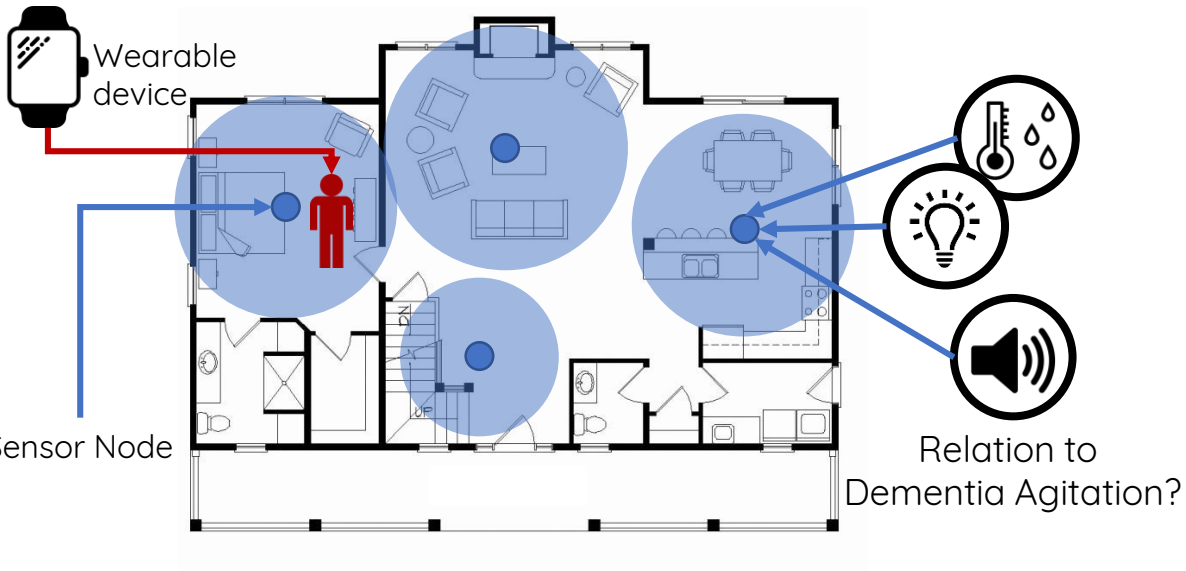
Nutta Homdee, Ridwan Alam, James Hayes, Tamanna Hamid, John Park, Sean Wolfe,
Azziza Bankole, Martha S. Anderson, Tonya Smith-Jackson, John Lach

- Dementia Caregiver Burden
  - Dementia agitation
  - Cause of institutionalization of the patient with dementia

Behavioral and Environmental Sensing and Intervention for Dementia Caregiver Empowerment

Cause of Agitation → Dementia Agitation → Agitation Escalates into Health Crisis

Prevent

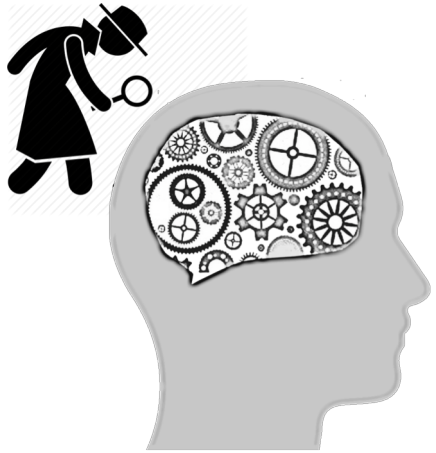


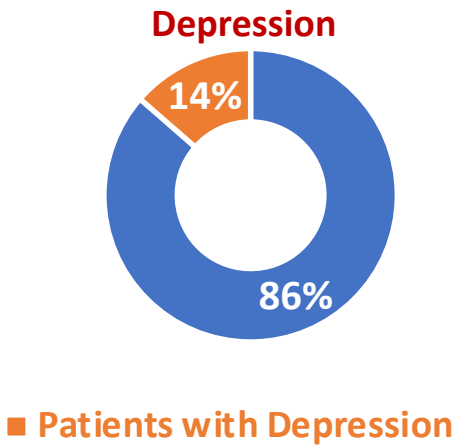
*Goals:

(1) Learn & **Detect** early stages of **agitation**

(2) Helps caregiver **Intervene**, before agitation escalates

Detecting Mental Disorder: Social Anxiety and Depression





Challenges

- Limitation of real human training data
- Strong annotation is not possible
- Resource constrained Devices
- Noisy, distant and reverberated data

General practitioners correctly identify social anxiety and depression in only **24%** and **50%** of true cases.

A. Mitchell et al. 2009

Detecting Mental Disorder: Social Anxiety and Depression

Our Solution

- Use shallow network (scalable)
- Adaptive to not having strong labeled data
- Can optimize with small training set

Mental Disorder	Previous Best Baseline approach	Improvement in F-1 score
Social Anxiety Disorder	I-vector with BLSTM	20.7%
Depression	DepAudioNet: CNN with LSTM	33%

A Corpus of Drug Usage Guidelines Annotated with Type of Advice

Arif Imtiaz

A Corpus of Drug Usage Guidelines Annotated with Type of Advice

- Prescription drug usage guidelines / patient handouts for drug safety and treatment adherence

- Patients often miss these information → adverse outcome
  - Lack of awareness in patients, information overload

- Enable automatic extraction of textual information from these documents → personalized and scalable
  - Annotation tool and corpus

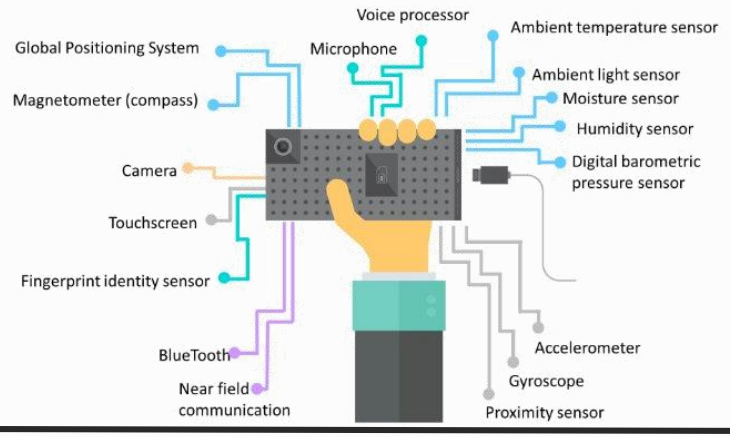
Behavioral Sensing Using Smartwatches

Mehdi Boukhechba
Research Scientist

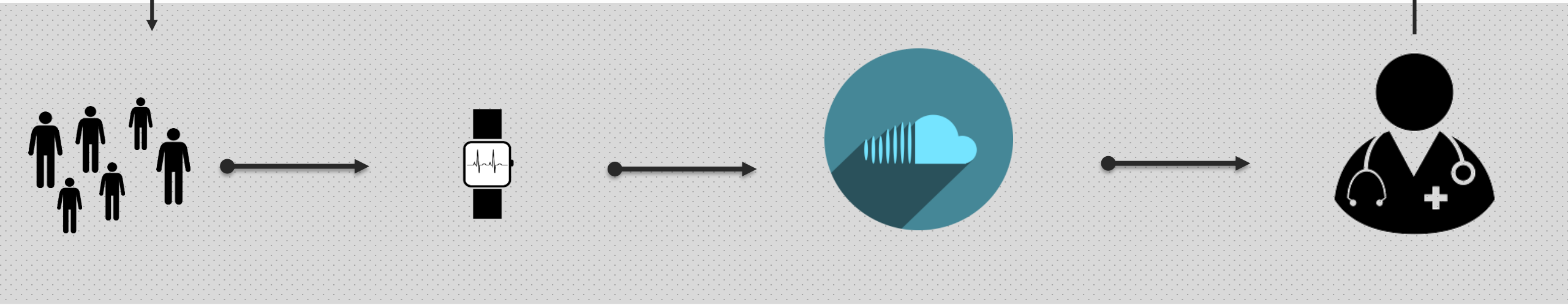
Laura Barnes
Associate Professor

03/20/2019

Behavioral Sensing



Personalized interventions



Unobtrusive sensing

Behavioral analysis

Monitoring patients remotely

UVA ENGINEERING
LINK LAB

Autonomous Systems

Autonomous Systems

Link Lab is studying autonomous science and system control regarding actions and interactions of man, machine, and environment. Our work is pushing the boundaries of machine learning and artificial intelligence applied to both individual systems and collectives. The goal of this work is to develop systems that are cognizant, task-able, adaptive, ethical, and understood across all aspects of objectives, time, resources, and security.

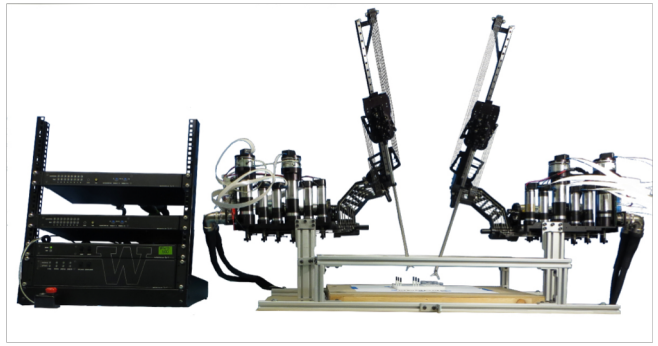
Areas of Research:

Autonomous Vehicles: Aerial, Ground, Surface, and Underwater
Bio-inspired Design for Efficient Systems
Collaboration across Homogenous and Heterogeneous Systems
Human-in-the-loop Command, Control, and Communications
Man-Machine Interactions and Interfaces
Observing and Gaming Autonomous Behaviors
Safety, Reliability, and Trust in Autonomous Systems

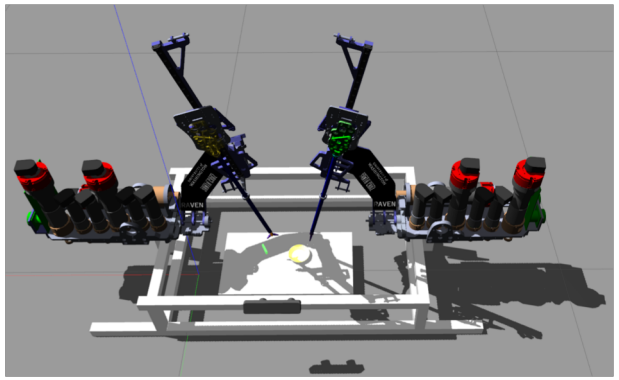
Autonomous Surgical Robots and Simulation

8

da Vinci Surgical System



Raven II Surgical System



dV Trainer and Gazebo Simulator.

1. Teleoperation of surgical robot
2. An autonomous task in the simulator
3. Robotic surgery simulation using daVinci Trainer

Yongming Qin

Advisor: Homa Alemzadeh

Electrical and Computer Engineering

Location: Link Lab 260

UVA ENGINEERING LINK LAB

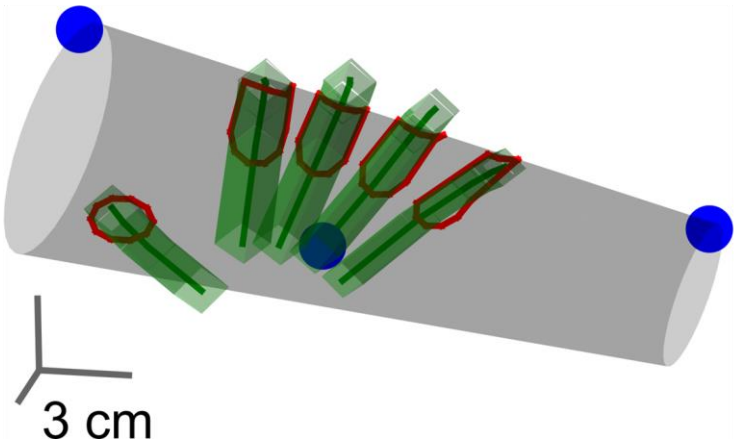
UNIVERSITY of VIRGINIA ENGINEERING

Uncovering human-to-human physical interactions that underlie the communication of emotion

9

Steven Hauser[1], Sarah McIntyre[2], Ali Israr, Håkan Olausson[2], Gregory Gerling[1]

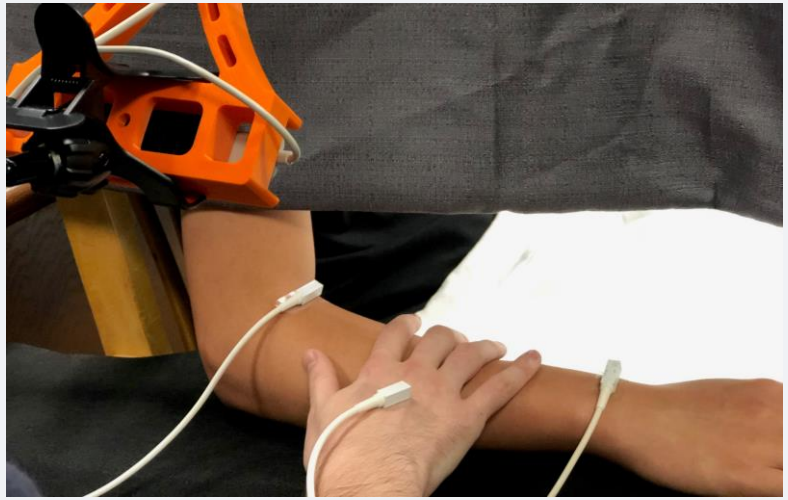
[1]University of Virginia, Charlottesville, Virgina
[2]Linköping University, Linköping, Sweden



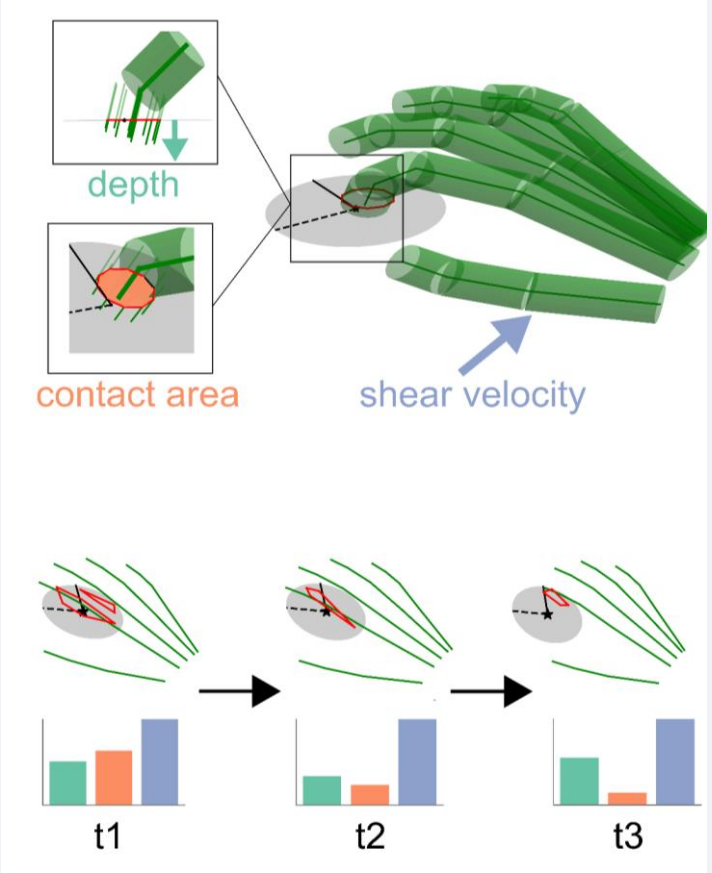
Uncovering human-to-human physical interactions that underlie the communication of emotion

Steven Hauser, Sarah McIntyre, Ali Israr, Håkan Olausson, Gregory Gerling

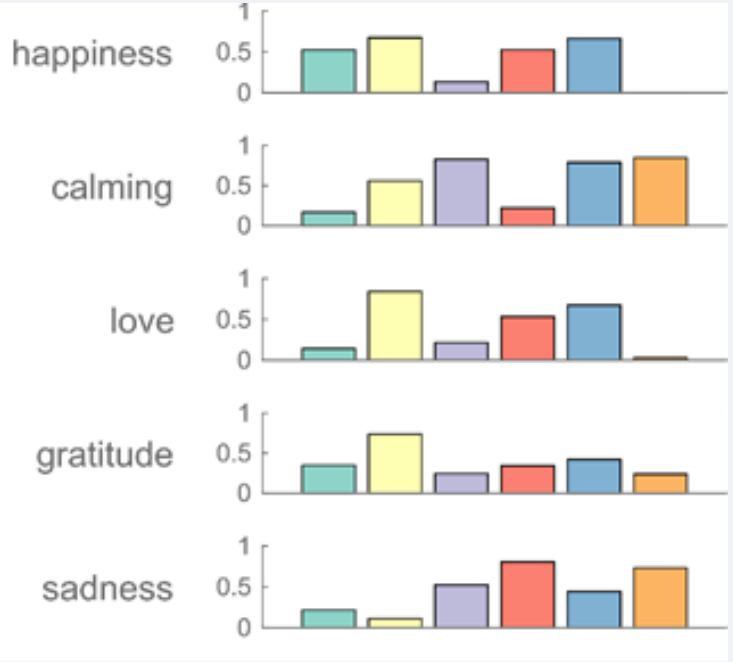
1. Naturalistic social gestures, “love,” “calming,” “sadness,” tracked with optical and electromagnetic systems.



2. Physical touch parameters quantified, e.g., contact area, shear velocity



3. Physical quantities distinguish social gestures.



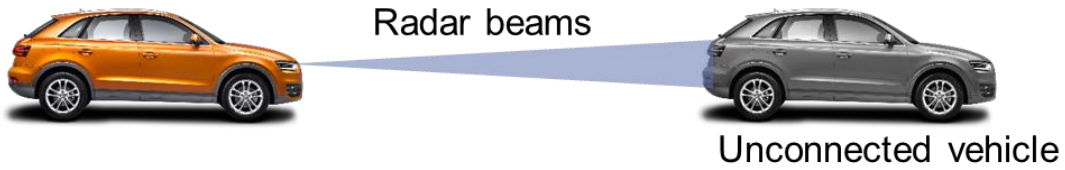
Design and Evaluation of quasi-Cooperative Adaptive Cruise Control

Zheng Chen & B. Brian Park
Department of Engineering Systems and Environment

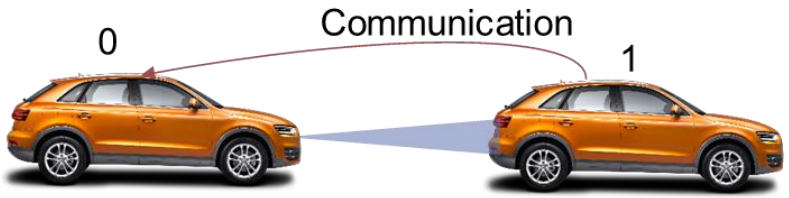
UVA ENGINEERING
LINK LAB

Design and Evaluation of Quasi-CACC

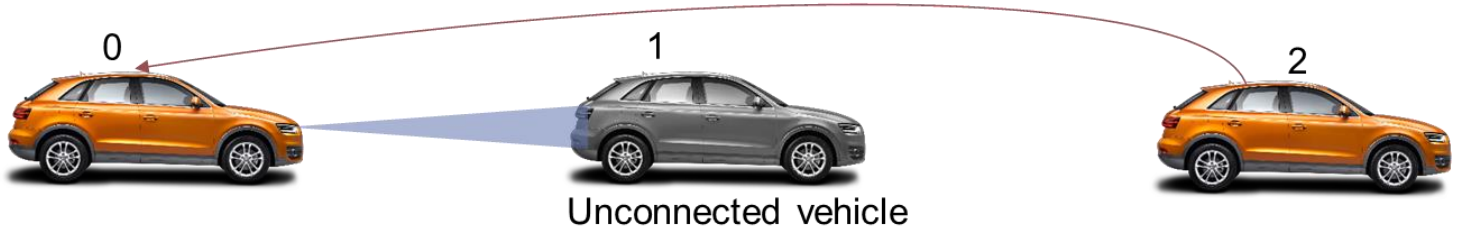
Objective: making full use of vehicular connectivity in mixed traffic



Adaptive Cruise control (ACC)

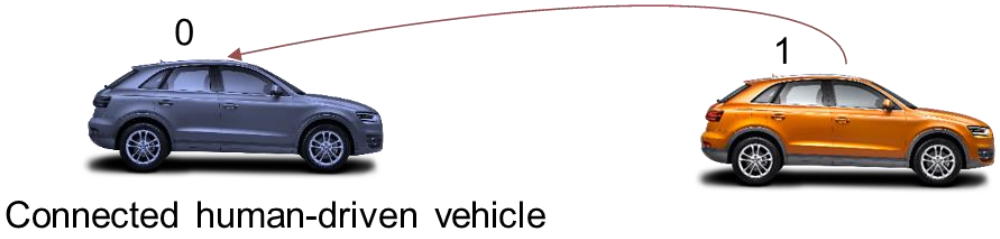


Cooperative Adaptive Cruise control (CACC)



CACC with unconnected vehicle (CACCu)

Quasi-CACC



Human-in-the-loop CACC (hCACC)

A Systems Theory of Transfer Learning

Tyler Cody, Peter Beling

Vision

Synthesis of concepts from systems theory and learning theory could inform systems analysis and design of systems of learning systems

Approach

Study the use of systems theory as a framework for transfer learning, operationalize the theory with case studies

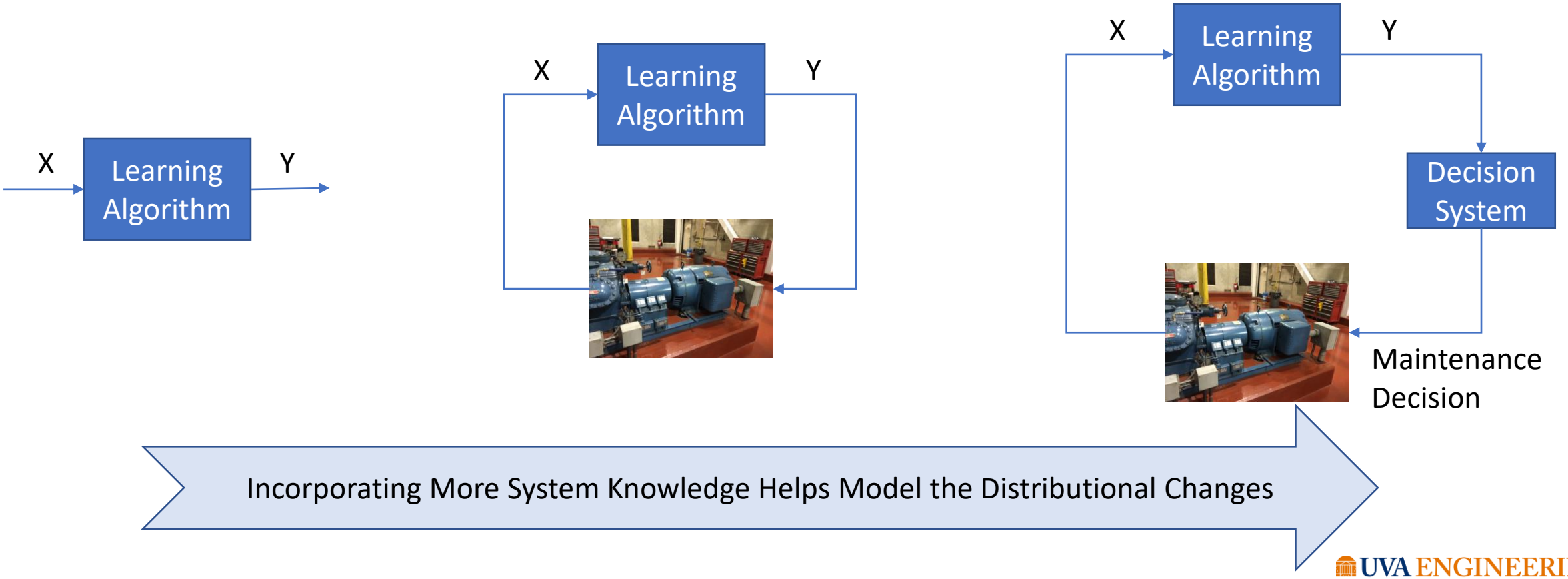
Foundations

- *Systems Theory:* Mesarovic, Takahara
- *Learning Theory*: Vapnik, Mitchell, Tikhonov

Systems Theory as Superstructure for Machine Learning

Machine Learning Perspective

Systems Theoretic Perspective



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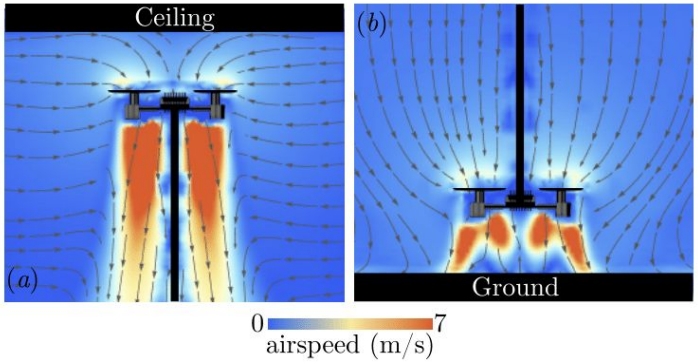
Rice 028

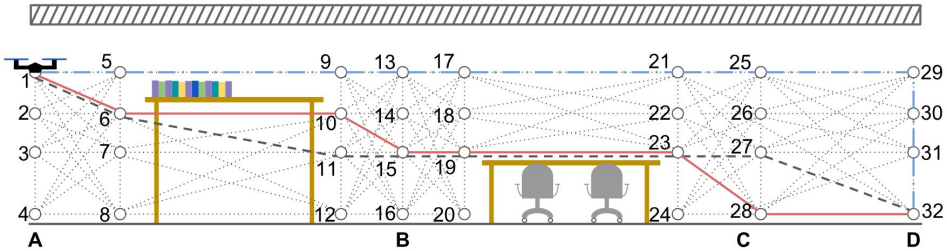
Exploiting Ground and Ceiling Effects on Autonomous UAV Motion Planning

Shijie Gao[1], Carmelo Di Franco[1], Darius Carter[2], Daniel Quinn[2], and Nicola Bezzo[1]
[1]Departments of Electrical and Computer Engineering, [2]Departments of Mechanical and Aerospace Engineering - University of Virginia

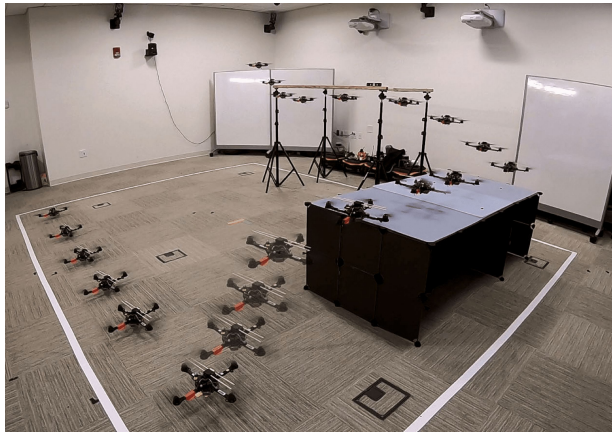


Ground/Ceiling Effects

1) **By leveraging changes in thrust a UAV can detect and estimate surfaces without the need of extra sensors**
2) **Surfaces can be leveraged at run-time to minimize energy consumption during UAV motion planning**



Energy Efficient Optimal Path Planning



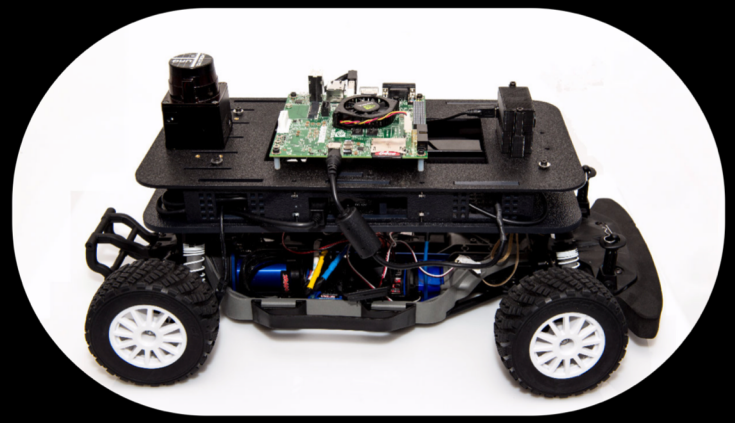
Rice 024

F1/10

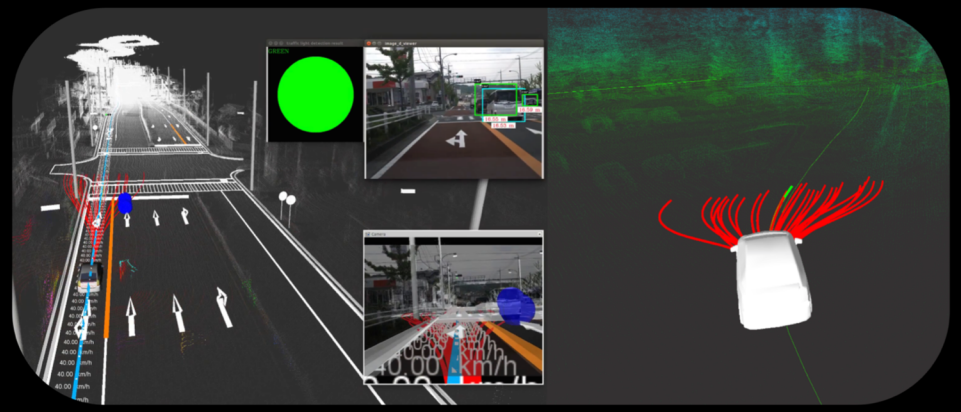
Autonomous Racing

1/10 the scale. 10 times the fun!

Build. Drive. Race.



Perception. Planning. Control



Varundev Sureshbabu, Ryan McCampbell, Hongnan Lin, and Madhur Behl

Autonomous Racing Research – UVA Link Lab

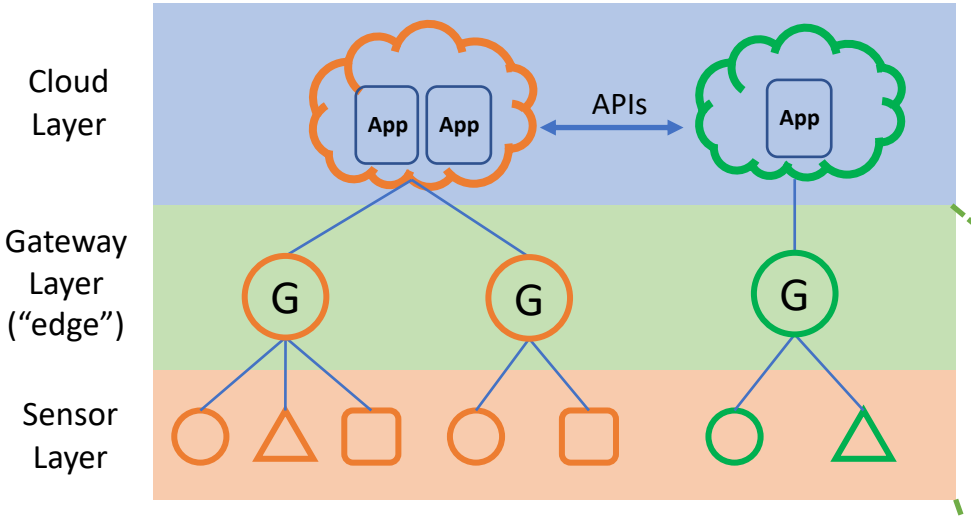
Demo in Rice Hall 024

Edge Computing Platform over Underutilized Gateways

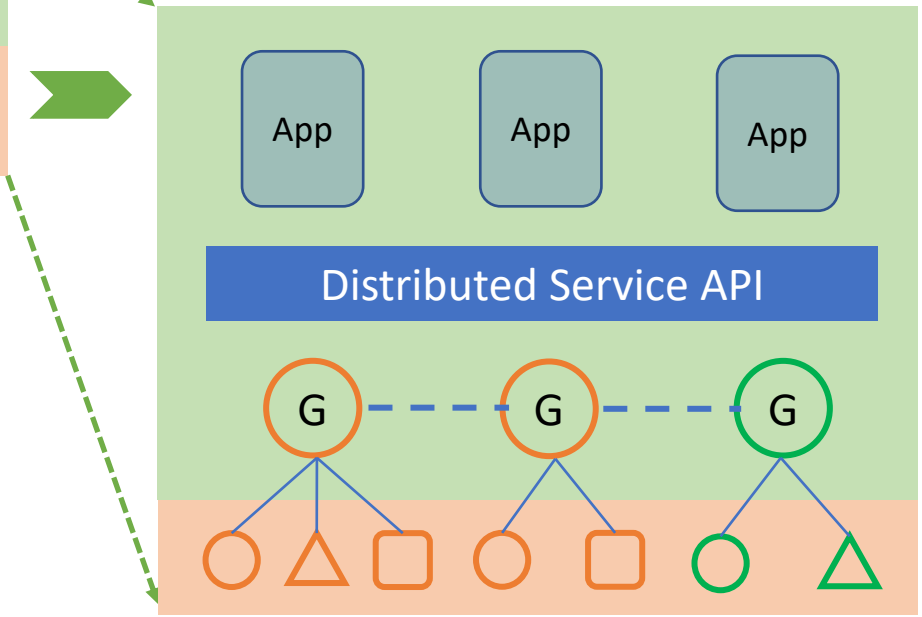
Nabeel Nasir, Brad Campbell

1

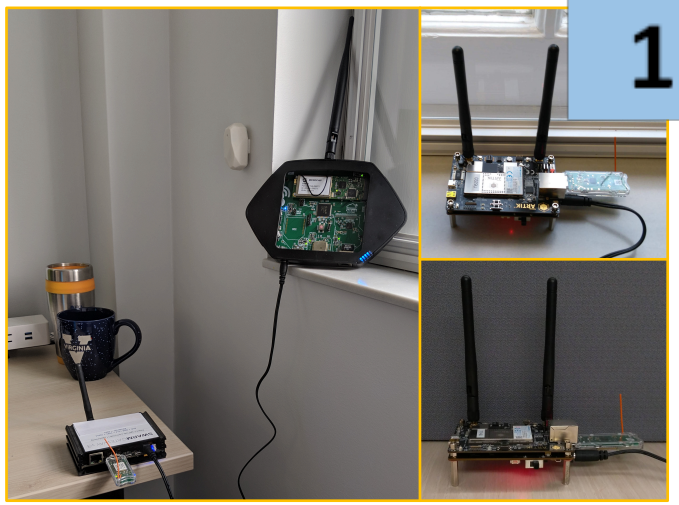
- Cloud-based IoT apps suffer from privacy issues, high latency, and need high bandwidth
- ✓ Create a network of the underutilized gateways to support distributed applications



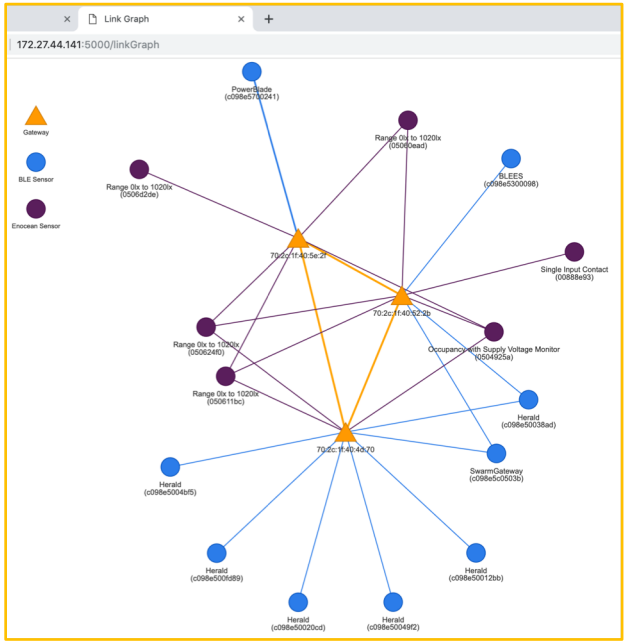
Cloud-based Internet of Things Network



Platform for distributed applications on the edge



Gateway devices deployed in the Link Lab



Live view of devices in the Link Lab

Brute Force

Drive millions of miles in simulation or in the real world; too slow; infinite situations

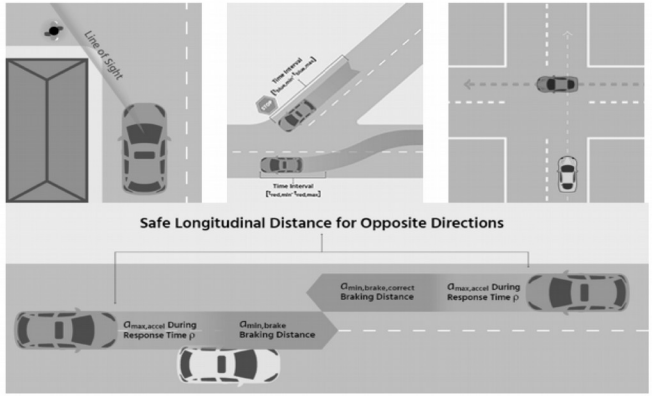
Current Attempts To Ensure Safety Of Autonomous Vehicles

16

How can we ensure that an autonomous vehicle drives safety upon encountering an unusual (edge) traffic situation ?

Formal Methods

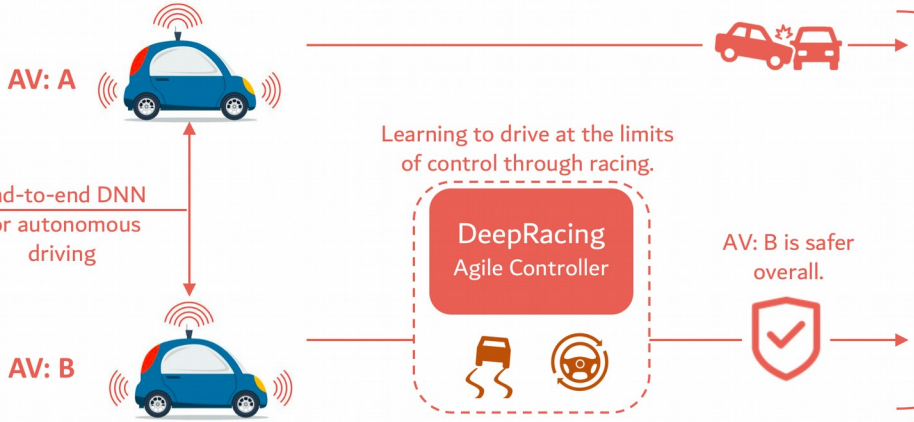
Reasoning about scenario specific safety; often too simplistic to generate guarantees



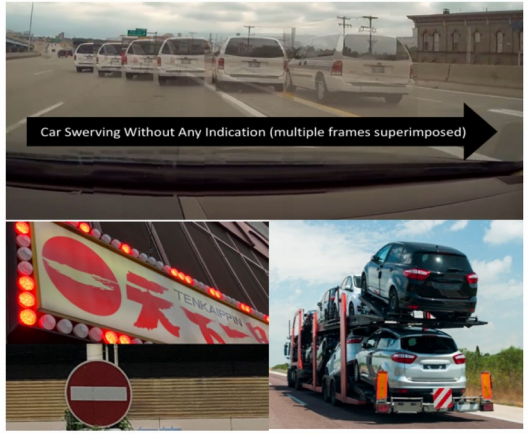
Safety Through Agility

Autonomous vehicles get trained on mostly structured traffic data-sets.

End-to-end DNN for autonomous driving



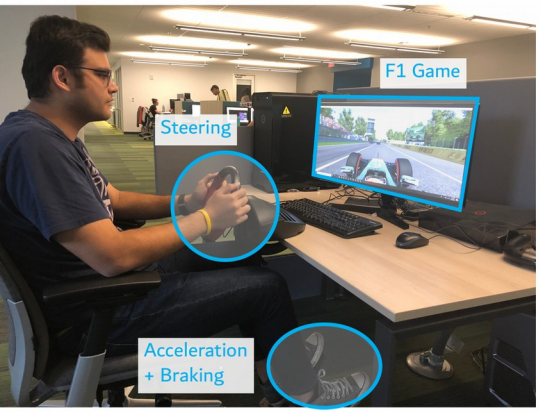
Unexpected traffic situations may occur



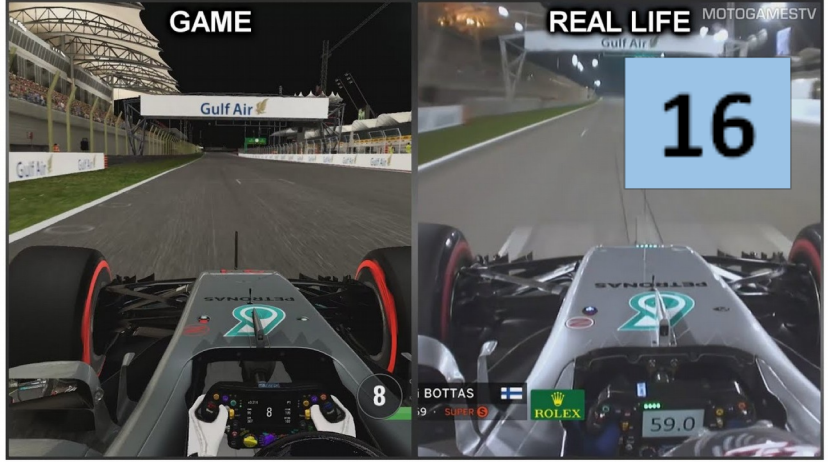
1. Consider two autonomous vehicles A & B; which are trained to drive using end-to-end deep learning on the same data-set.

2. One of the cars, has an additional agile controller integrated with the baseline DNN using our DeepRacing framework.

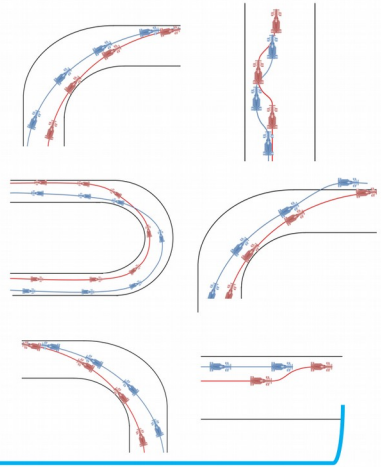
3. We hypothesize that AV: B (with the agile controller) will be safer overall and better equipped to handle edge cases.



Manual Driving Inputs



Racing creates frequent edge cases at high speeds



F1 2017 codemasters

Photorealistic + Accurate Physics

Autonomous Driving Inputs

vjoy virtual joystick

Closed Loop Testing

UDP stream to log Steering + Accl. i/p

Synchronized screen capture

predicted steering + acceleration

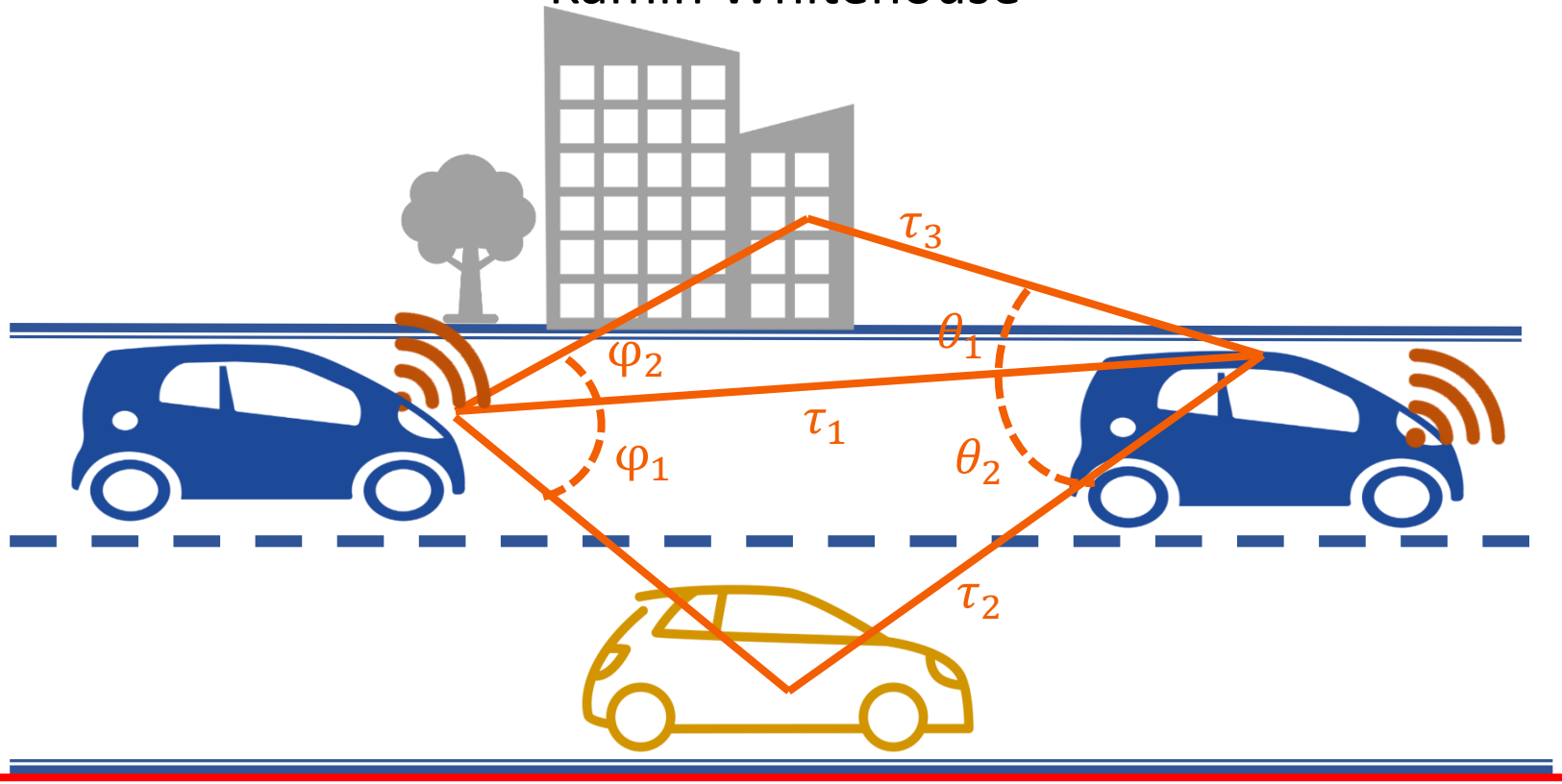
DeepRacing Agile Controller

end-to-end learning

Each image is labeled with steering and acceleration data

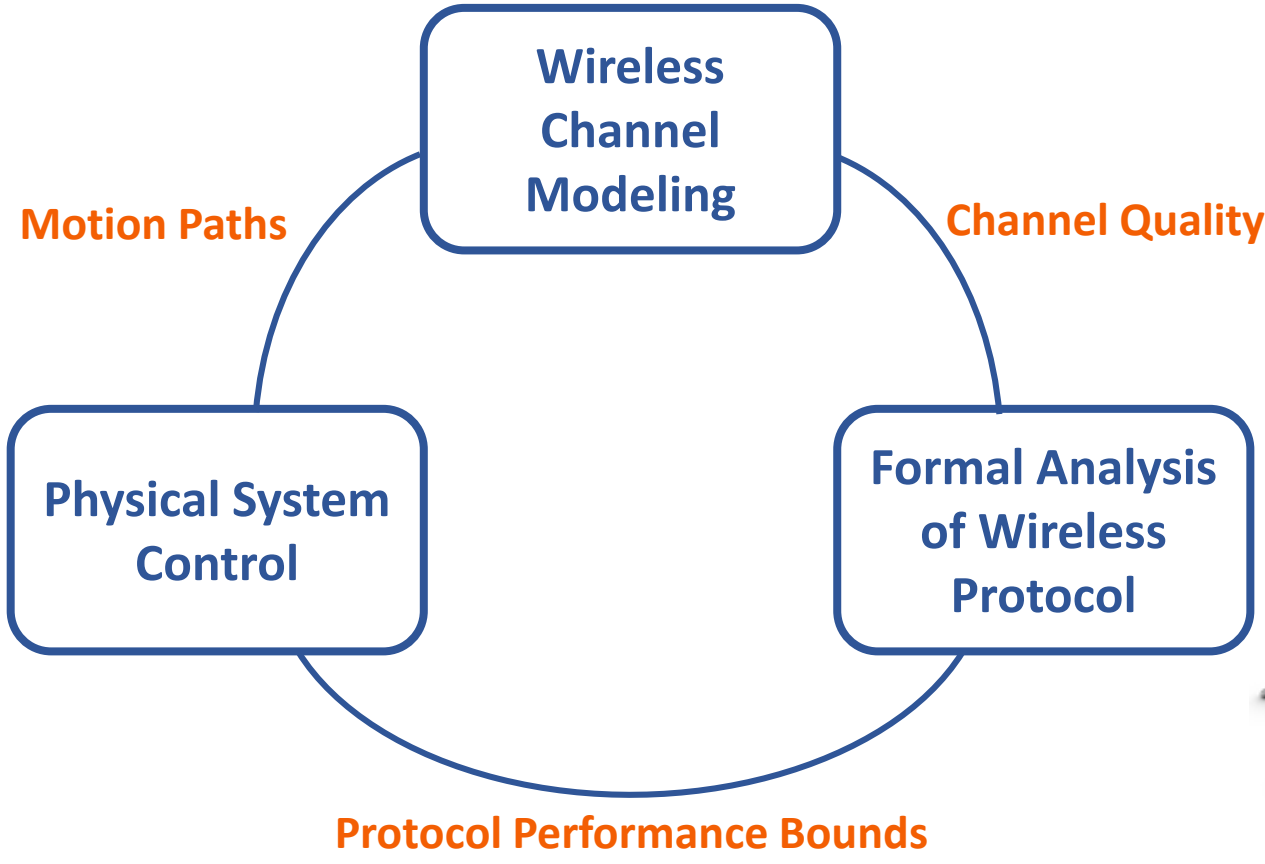
Safety-Critical Wireless Mobile Systems

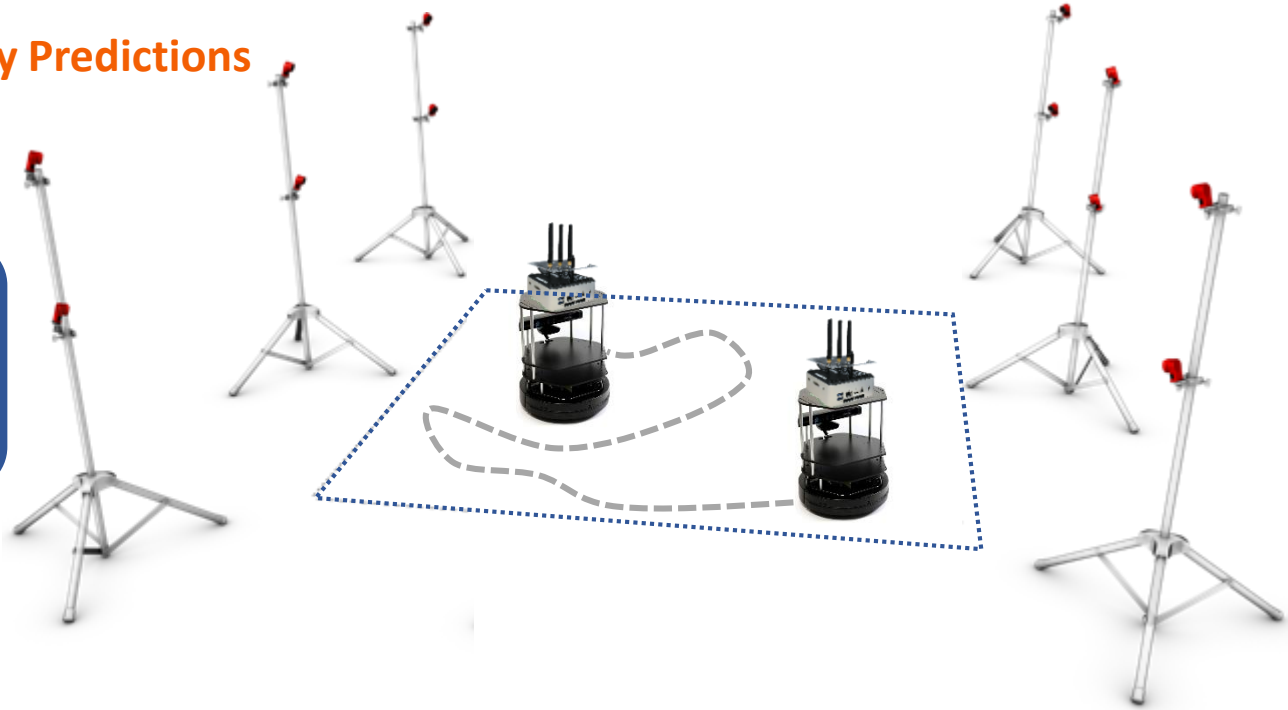
Mahmoud Elnaggar, Hassan Jafarzadeh, Elahe Soltanaghaei, Cody Fleming, Kamin Whitehouse



Can we provide system-level safety guarantees, while having unreliable wireless communication?

Approach & Experimental Setup





19

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PLATOON-BASED INTERSECTION CONTROL STRATEGIES FOR CONNECTED AND AUTOMATED VEHICLES

Seunghan (Francis) Ryu, Byungkyu Brian Park

LinkLab & ESE, University of Virginia

"How to **improve** transportation **system** for the future"

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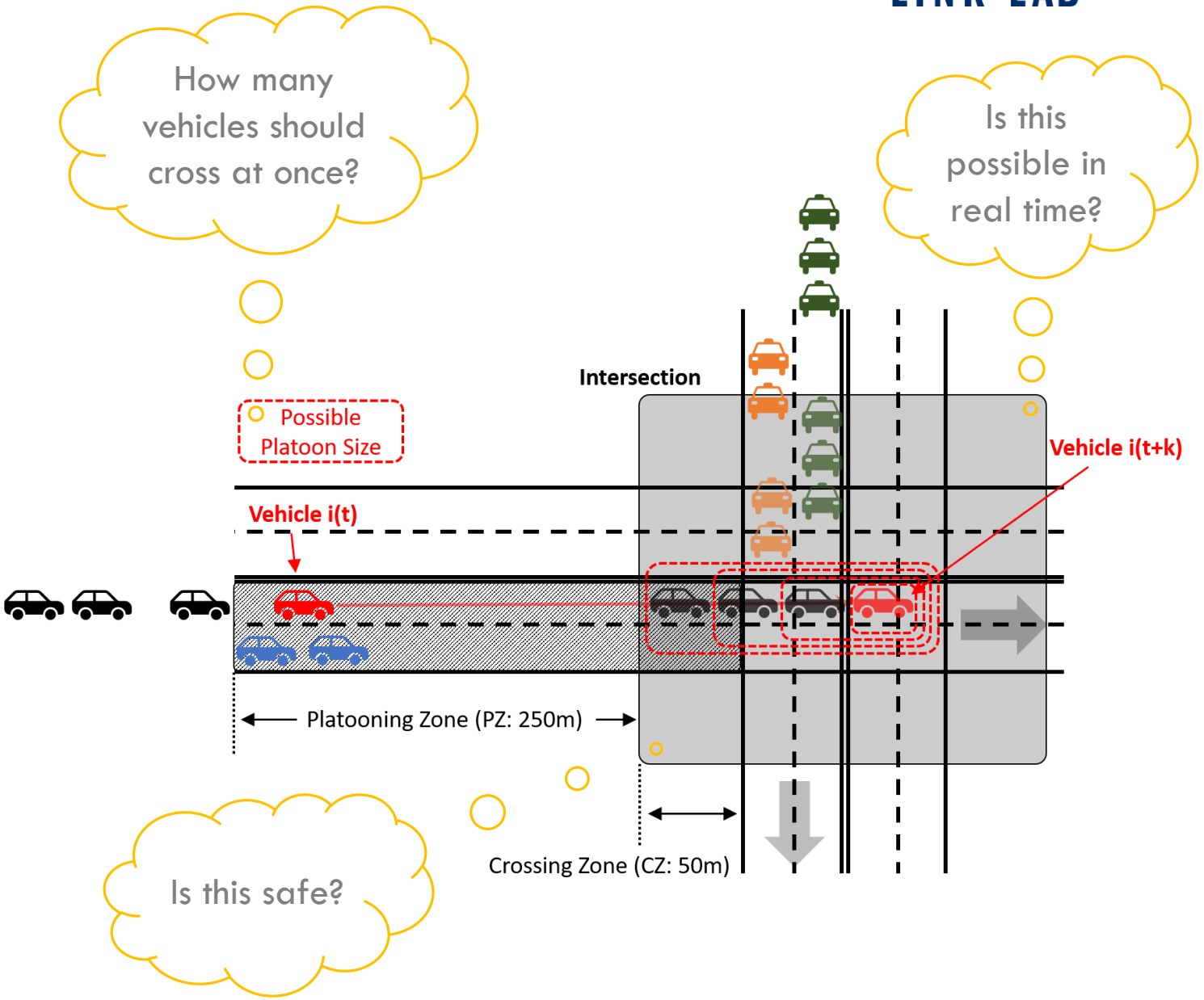
SYSTEM ARCHITECTURE



Autonomous Mobile Robots Lab (DemoRoom: RiceHall 028)

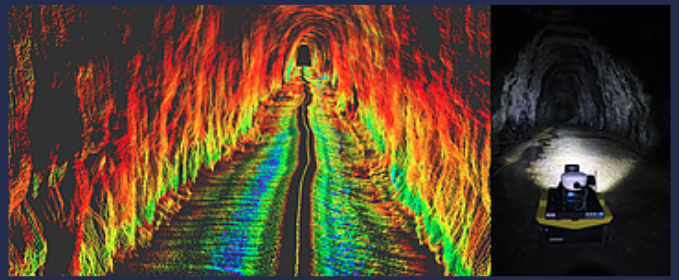
Prof. Nicola Bezzo, Carmelo Di Franco, Esen Yel, Paul Bonczek, Rahul Peddi, Shijie Gao, Ishika Paul

University of Virginia

Rice 028

Research Topics:

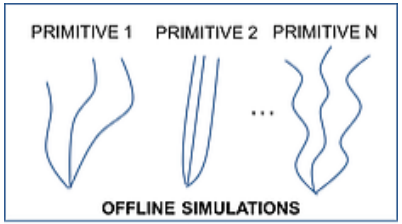
- Adaptive Scheduling, Planning & Control of UAVs (DEMO)
- Attack Resilient Control of Autonomous Cyber-Physical Systems (Poster)
- Coordination of Heterogeneous Robotic Systems (DEMO)
- Assured Autonomy (Poster)
- Mapping, Localization, & Environment Monitoring (DEMO + Poster)
- Human-Robot Interaction (DEMO)

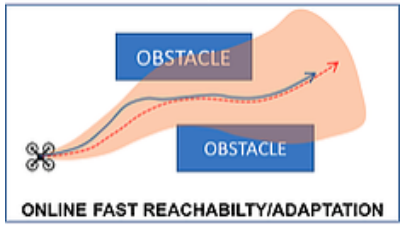


POSTER: *Verified Fast Run-time Planning for Safe Autonomous Systems Operations,* Esen Yel, **Carmelo Di Franco**, Nicola Bezzo

Rice 028

Reachability analysis has been demonstrated to be a powerful tool, however, It suffers from computational complexity.

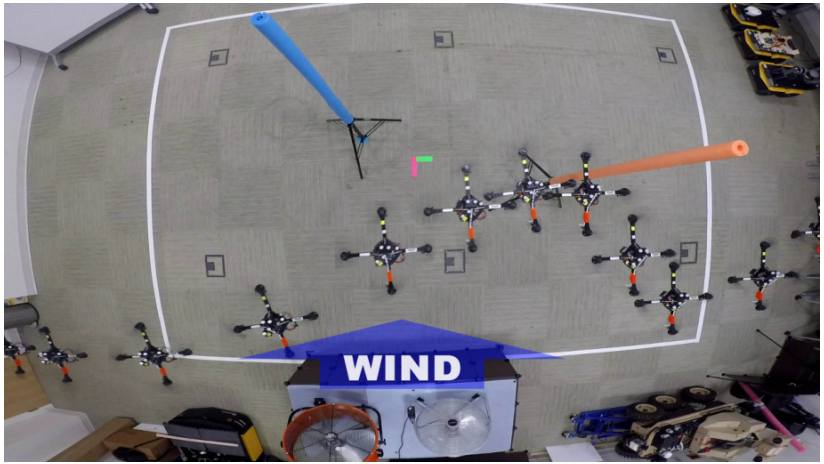




Two-Stage Approach

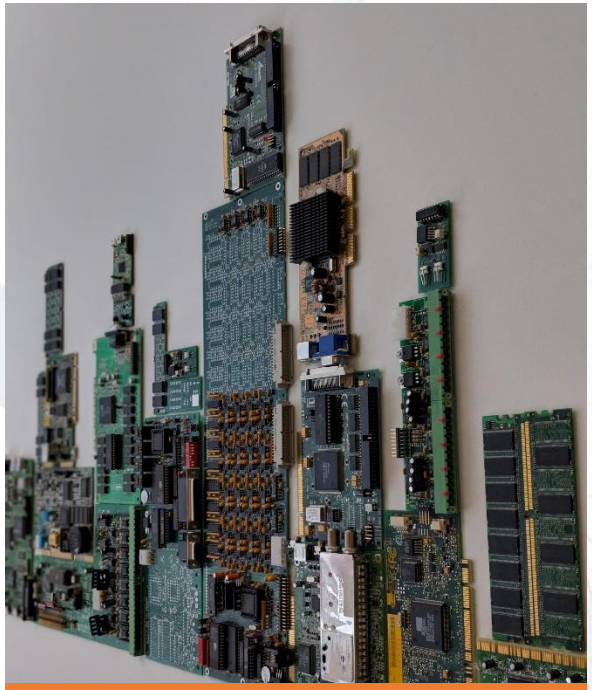
Offline Stage: train and verify a Deep Neural Network with a set of safe/unsafe labeled initial positions

Online Stage: Use the trained DNN for verified and fast run-time planning



UVA ENGINEERING
LINK LAB

Smart Cities



Smart Cities

Link Lab's work encompasses the full volume, variety, and velocity of data created by the Internet of Things. Utilizing open systems of sensors, software, and effectors, our work explores impacts across built, natural, mobility, and societal environments.

Areas of Research:

Community Engagement and Youth Development
Construction Automation
Cyber Security and Resilience
Energy Efficient and Self-Powered Sensors
High-powered, Distributed, and Edge Computing
Infrastructure and Utilities Monitoring and Resilience
Intelligent Transportation and Traffic Congestion
Public Safety and Security
Smart Buildings and Connected Communities
Smart Manufacturing
Water and Energy Management

Smart Cities: Data-Driven Flooded Roadway Prediction

Katie Carlson | Ashif Chowdhury | Andrew Kepley
Ethan Somerville | Kevin Warshaw

Advisor: Jonathan Goodall

- Background: Climate change and rising sea levels contribute significantly to increased coastal flooding

- Goal: Create a system for accurate floodwater data collection and presentation

- Two projects/sub-goals:
  - Create an effective system for gathering floodwater data
  - Create an effective storage platform for the collected data

THE THINGS NETWORK → → influxdb

14

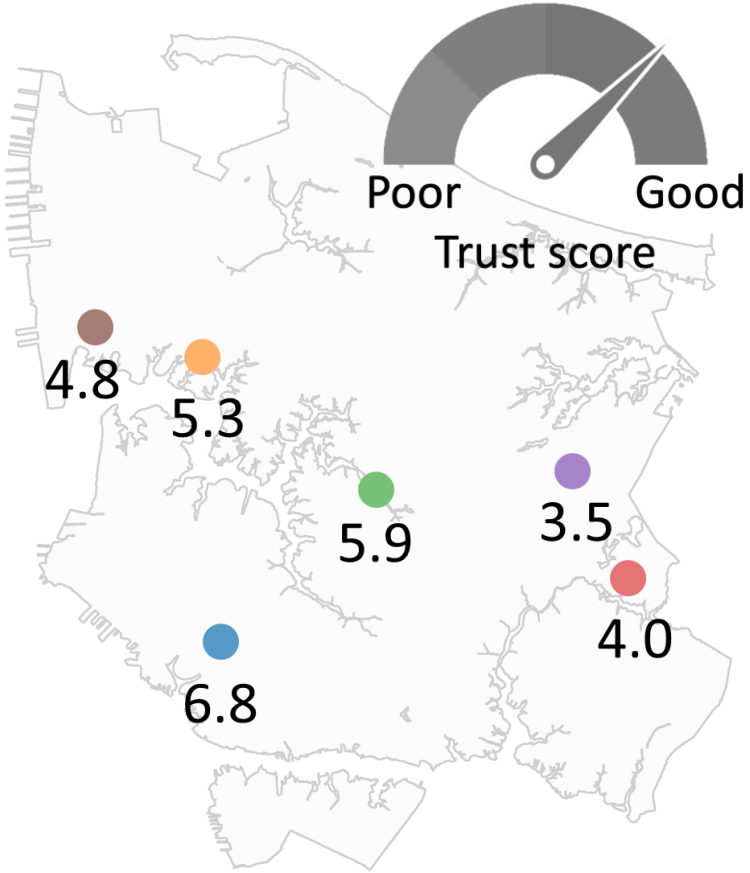
How can we build trust in crowdsourced data for managing smart cities?

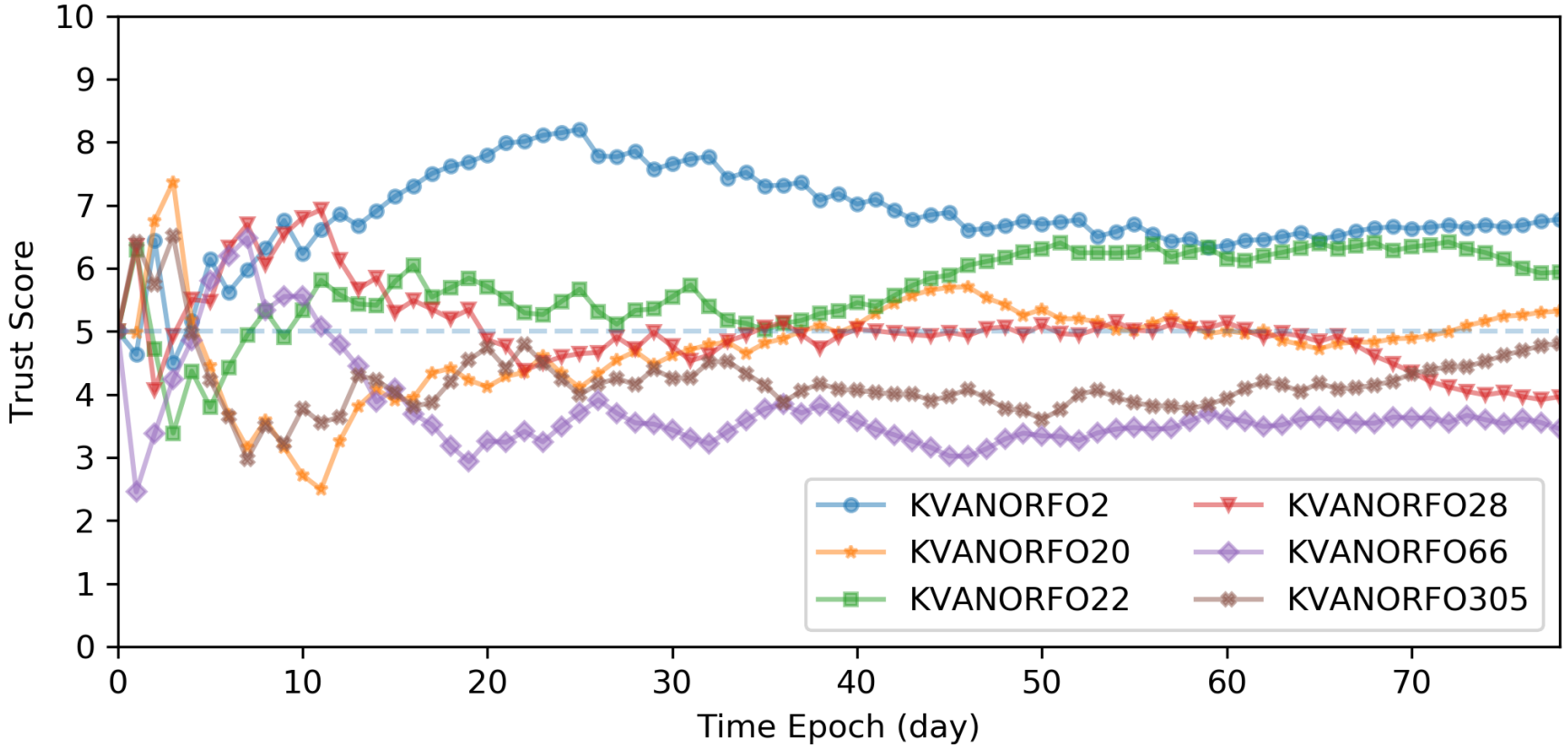
Alexander B. Chen
Madhur Belh
Jonathan L. Goodall

Engineering Systems and Environment
Computer Science

University of Virginia

How can we build trust in crowdsourced data for managing smart cities?





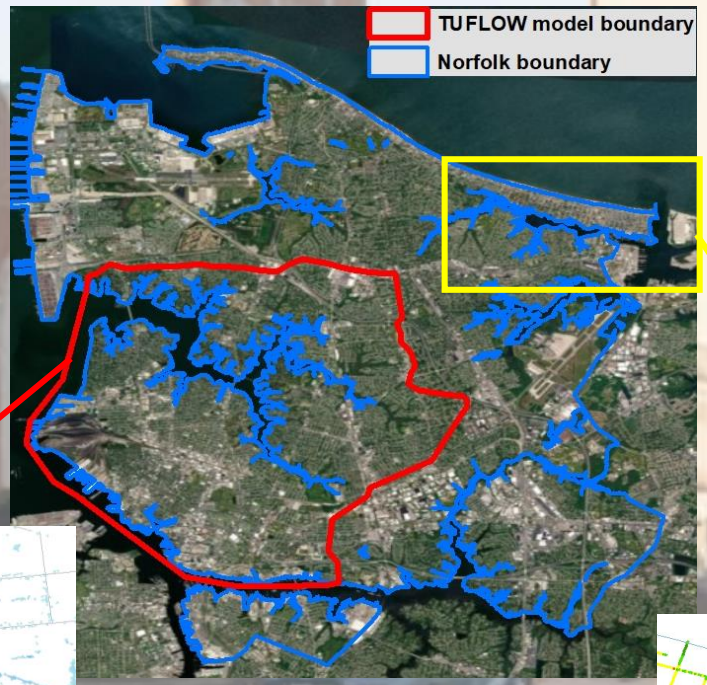
How can we use machine learning to predict which streets will flood?

Faria Tuz Zahura
Jeffery Sadler
Jonathan Goodall

Department of Engineering Systems and Environment

UVA ENGINEERING
LINK LAB

How can we use machine learning to predict which streets will flood?



2D physics based flood model

TUFLOW

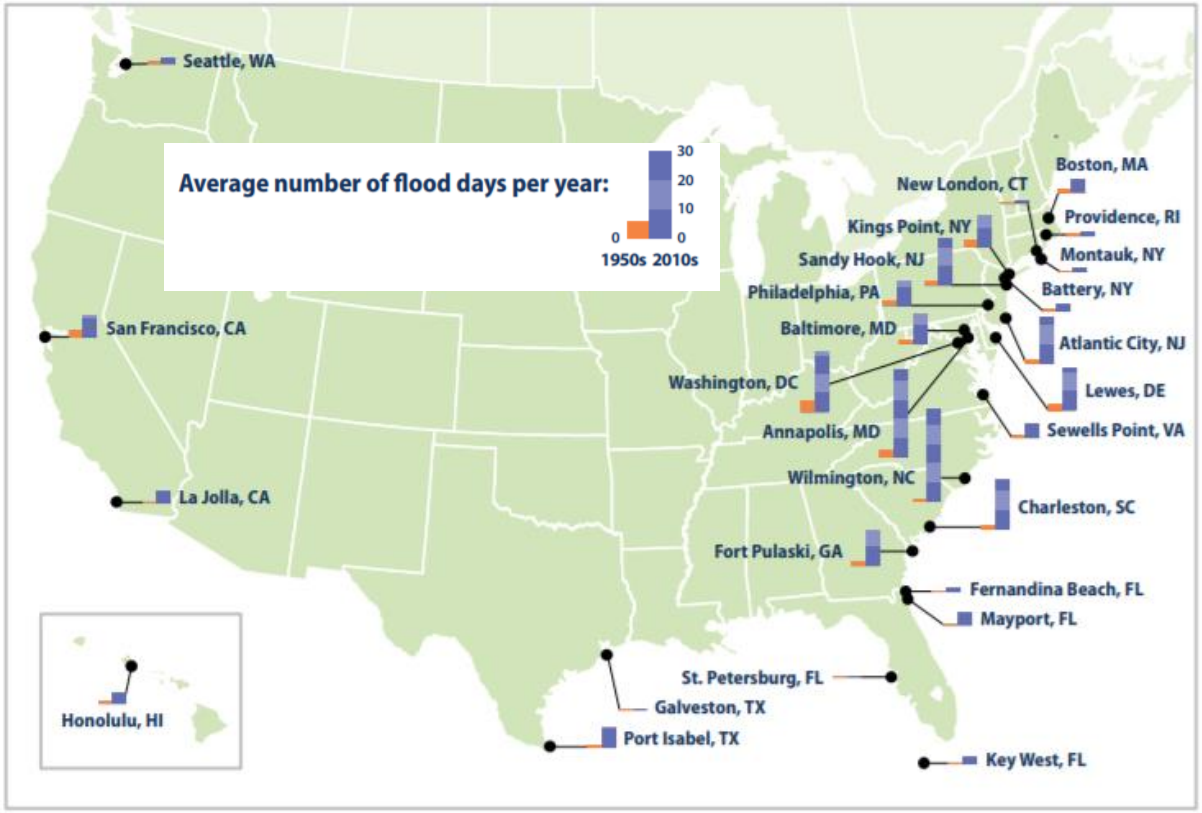
Machine Learning

Random Forest

Data Predictive Approach to Estimate Transportation Impacts of Nuisance Flooding

Shraddha Praharaj, Graduate Student
T. Donna Chen, Assistant Professor
Madhur Behl, Assistant Professor

Frequency of Flooding Along US Coasts 2010-2015 VS 1950-1959 (source: NOAA)



UNIVERSITY of VIRGINIA ENGINEERING

UVA ENGINEERING LINK LAB

NOAA tide level

HRSD rainfall data

VDOT continuous count station data

City of Norfolk flooding data

HRRTDM roadway features

Streetlight Data

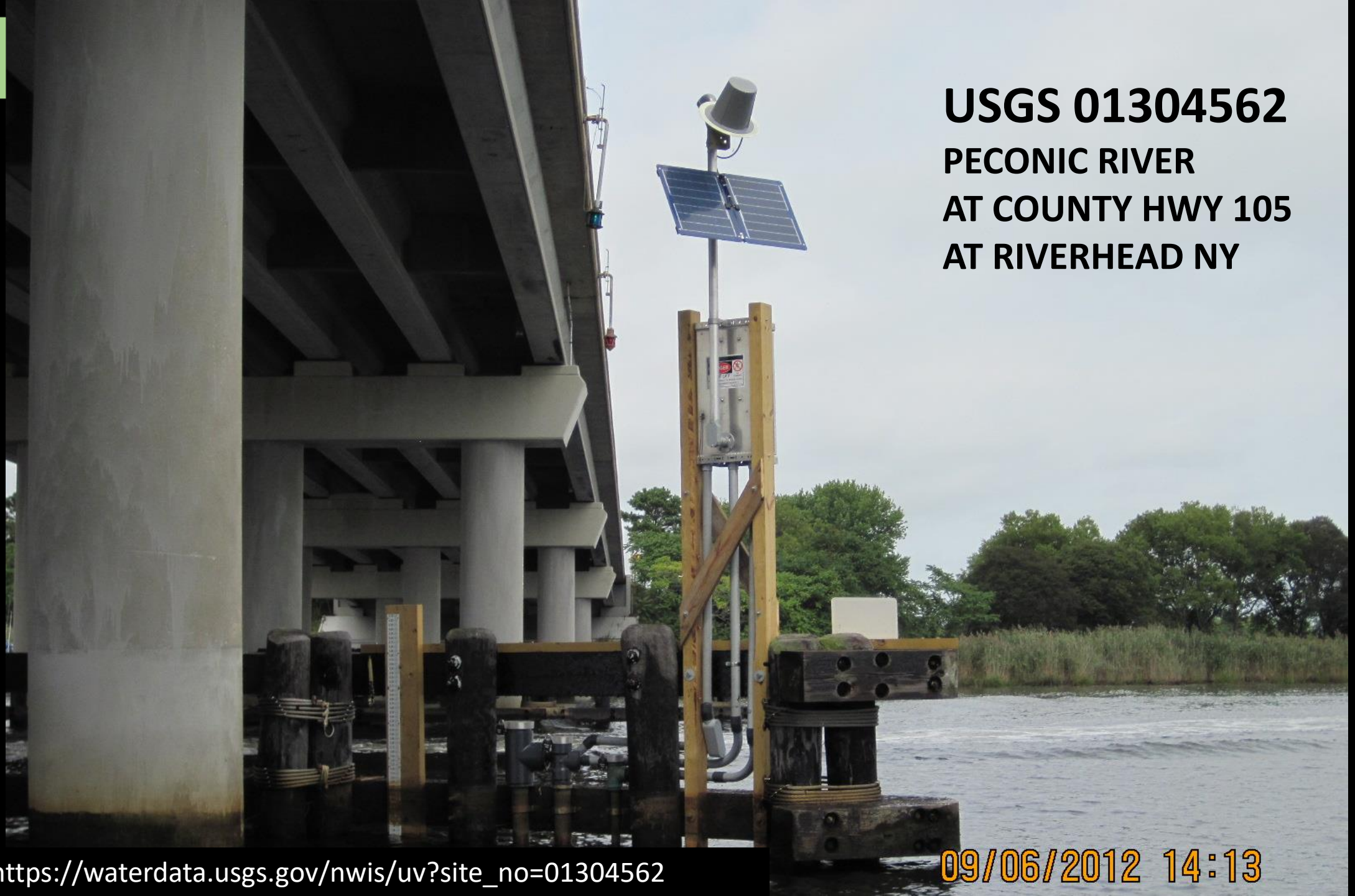
DATA PREDICTIVE MODEL

Estimate change in traffic flows on flood and non- flood days over the entire city

Provides vehicular volume estimates on **red links** based on the ground truth data collected at **black dots**

Data Trustworthiness

- Low
- High

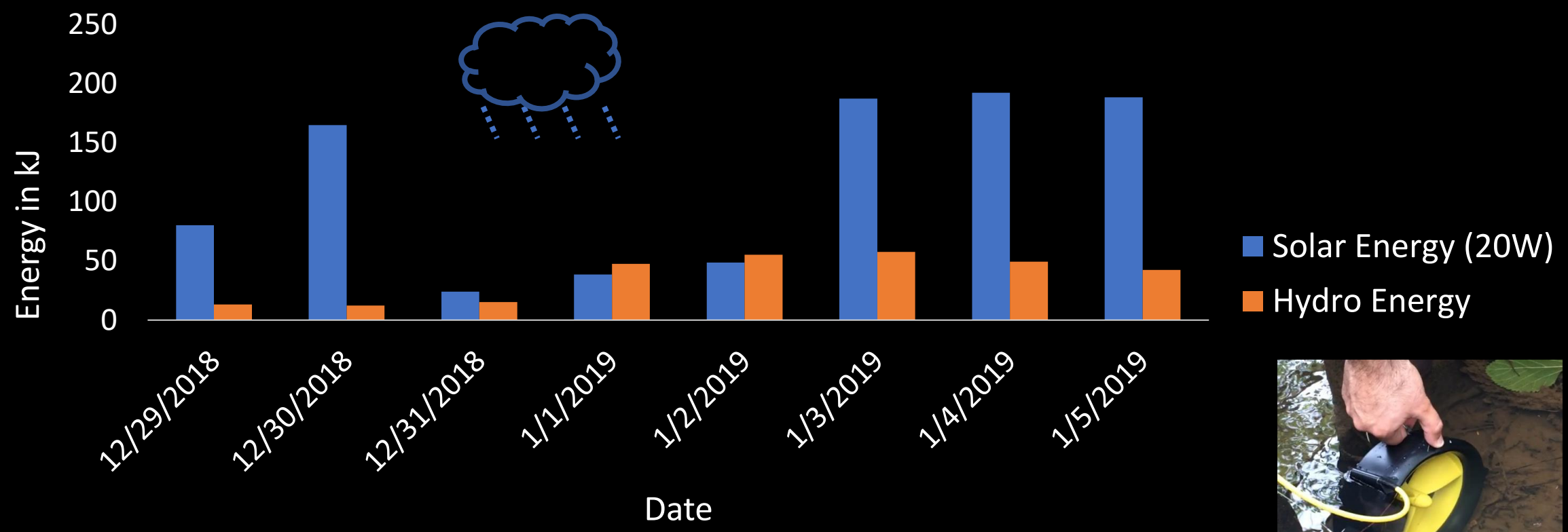


USGS 01304562

PECONIC RIVER
AT COUNTY HWY 105
AT RIVERHEAD NY

Source: https://waterdata.usgs.gov/nwis/uv?site_no=01304562

Towards Self-Powered Water Quality Sensors



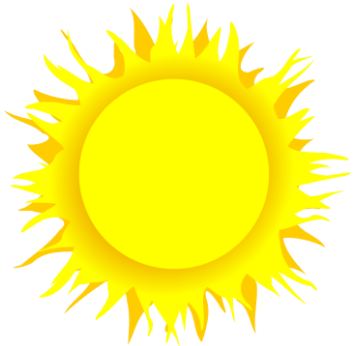
USGS Site 03332345: TIPPECANOE RIVER AT BUFFALO, IN

UNIVERSITY of VIRGINIA

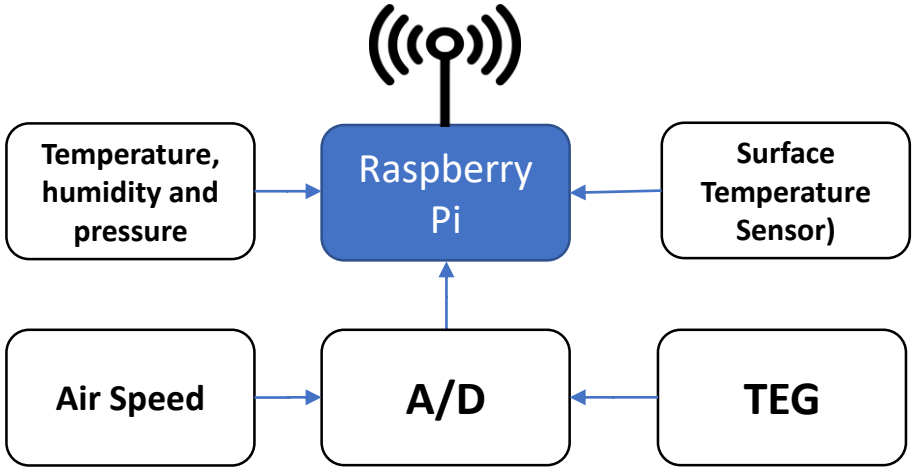
UVA ENGINEERING
LINK LAB

Energy Harvesting Models for Self-Powered IoTs

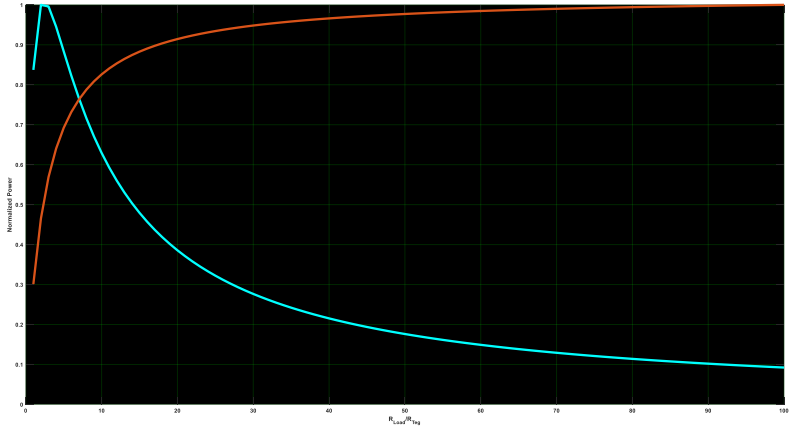
Energy Resources

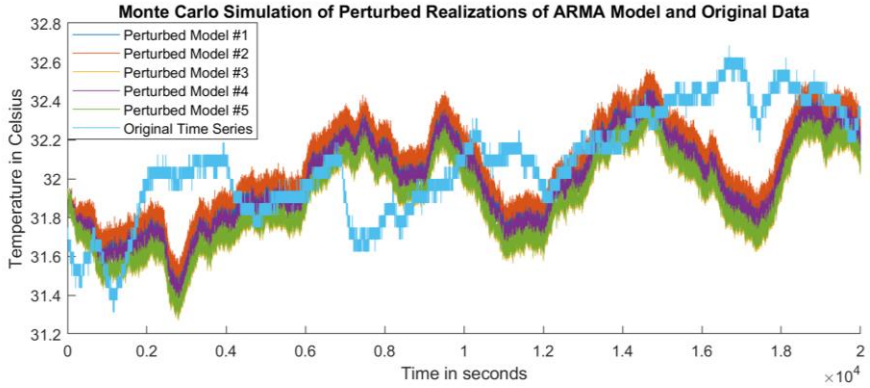


Data Collection



Modeling





Are Individuals' Stated Preferences for EVs Consistent with Real-World EV Adoption Patterns?

A case study in Virginia

24

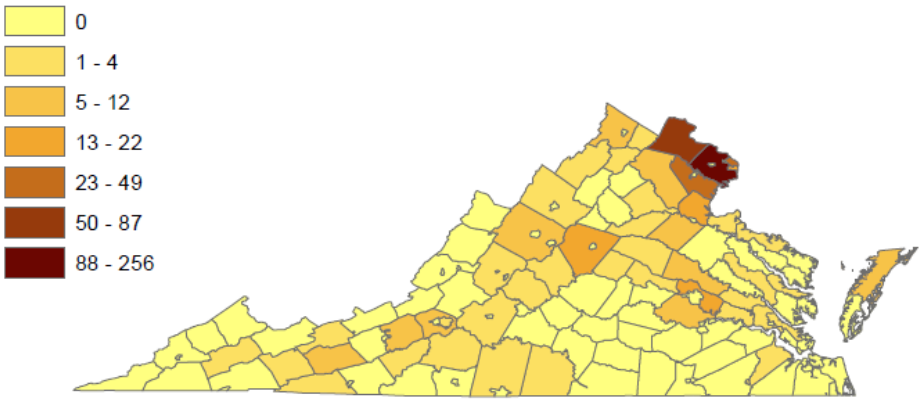
Wenjian Jia, T. Donna Chen,
Department of Engineering Systems & Engineering

Individual vehicle choice survey

VS

DMV EV registration counts

$	$22,000	$27,000	$33,000	$32,000
CO_2	1.19 ton	0.79 ton	0.33 ton	0
	0	0	30 miles	100 miles
			Every 70 miles	Every 70 miles
...				



Year 2014

UVA ENGINEERING
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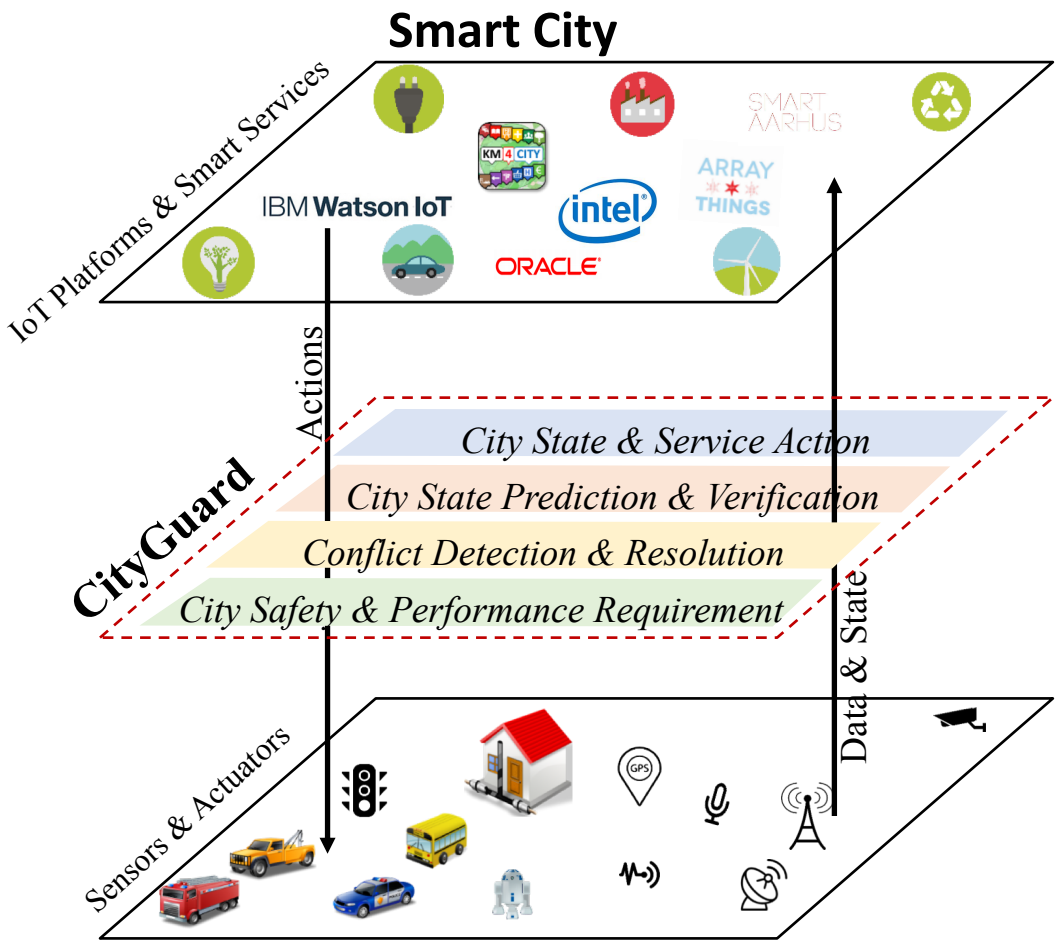
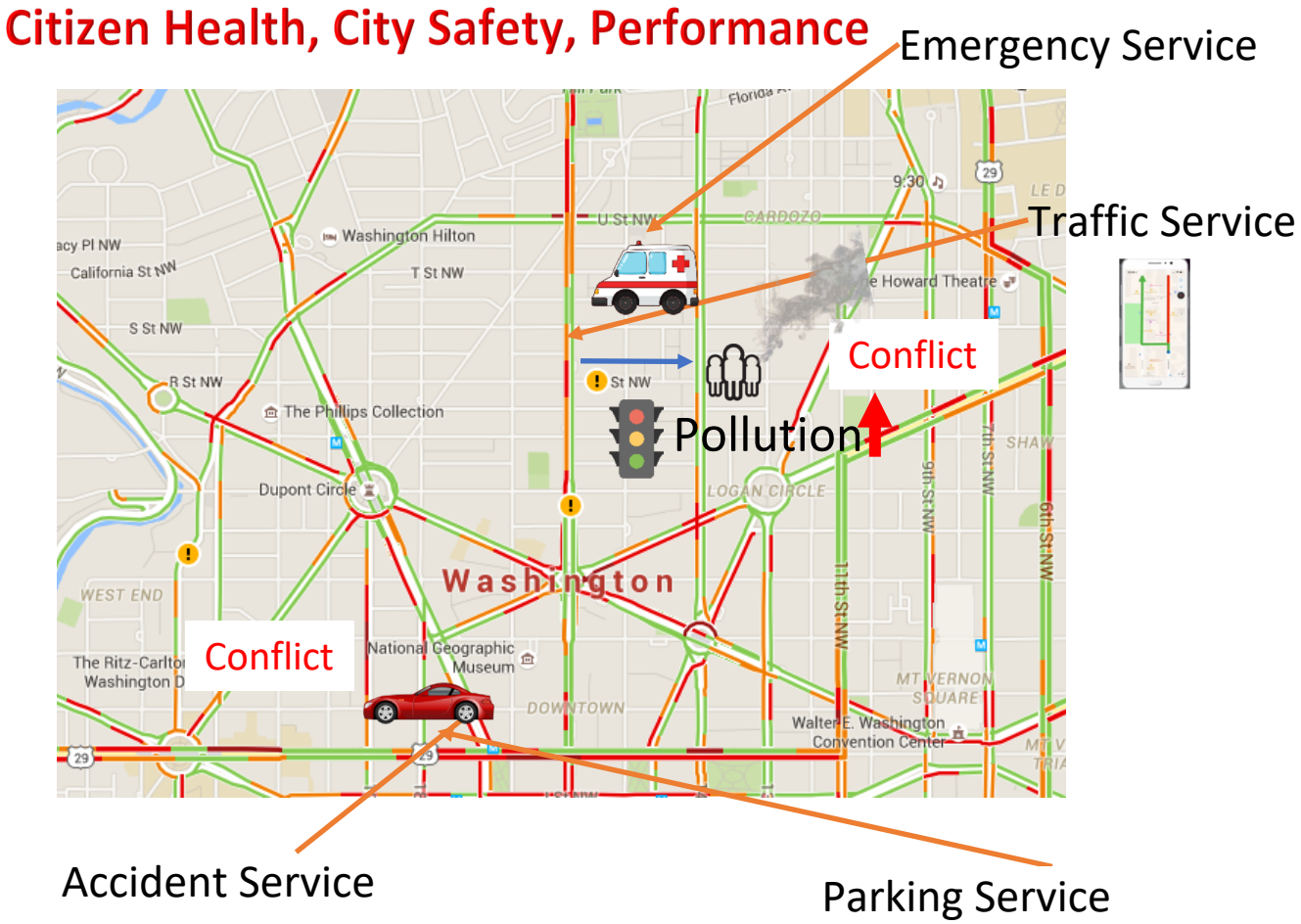
Conflict Detection and Resolution among Smart Services in Smart Cities

Meiyi Ma, Lu Feng, John Stankovic





11

A Multi-modal Approach for Monitoring Driver's Emotions And Behavior in The Wild

Arash Tavakoli, Arsalan Heydarian

Link Lab Open House, Spring 2019

Behavioral
Responsive and
Automated
Intelligence Laboratory

UVA ENGINEERING
LINK LAB

A Multi-modal Approach for Monitoring Driver's Emotions And Behavior in The Wild

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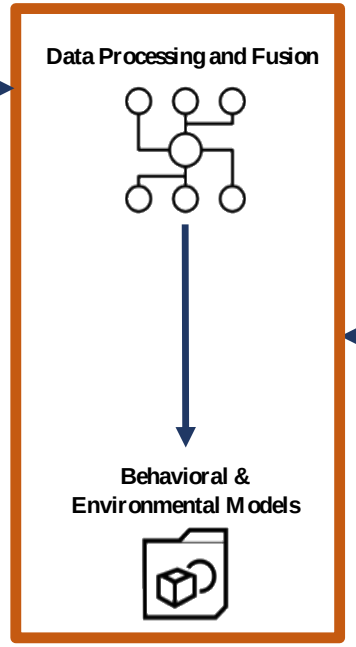
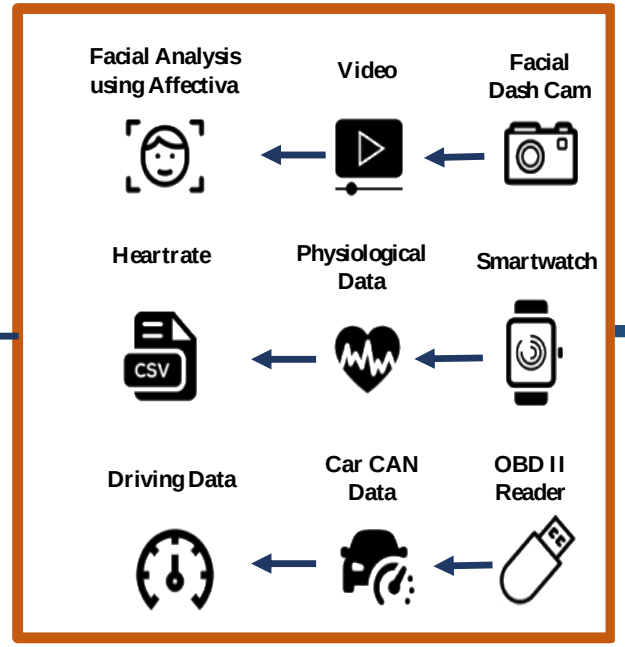
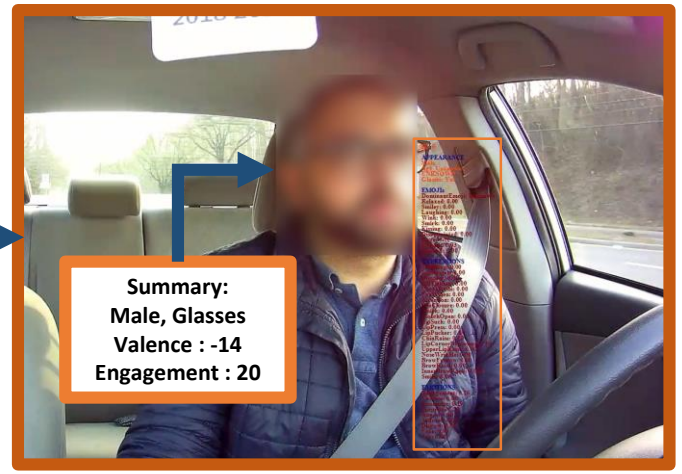
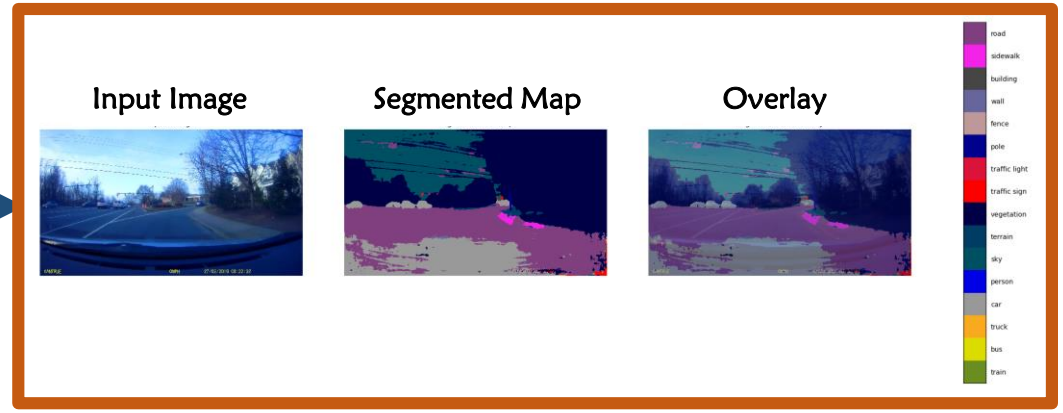
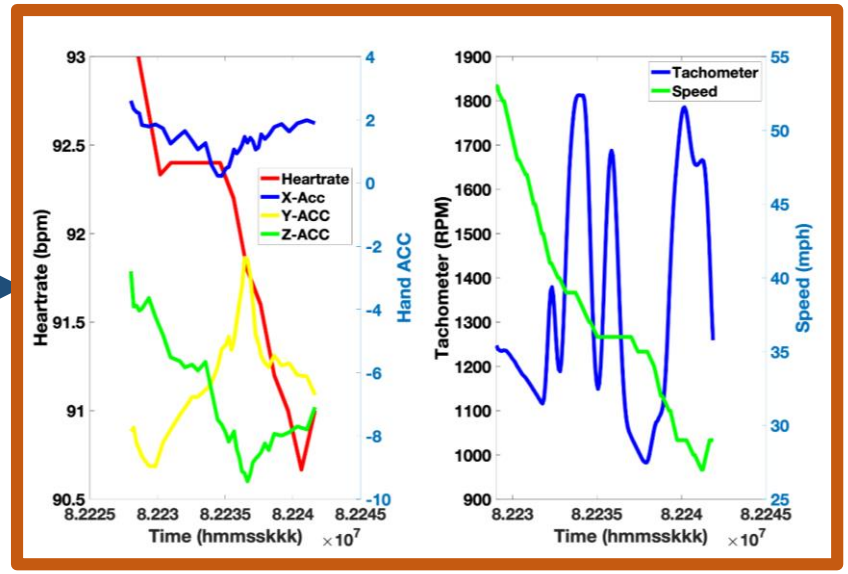










Behavioral Responsive and Automated Intelligence (BRAIn) Laboratory

VLC based IoT for Indoor applications

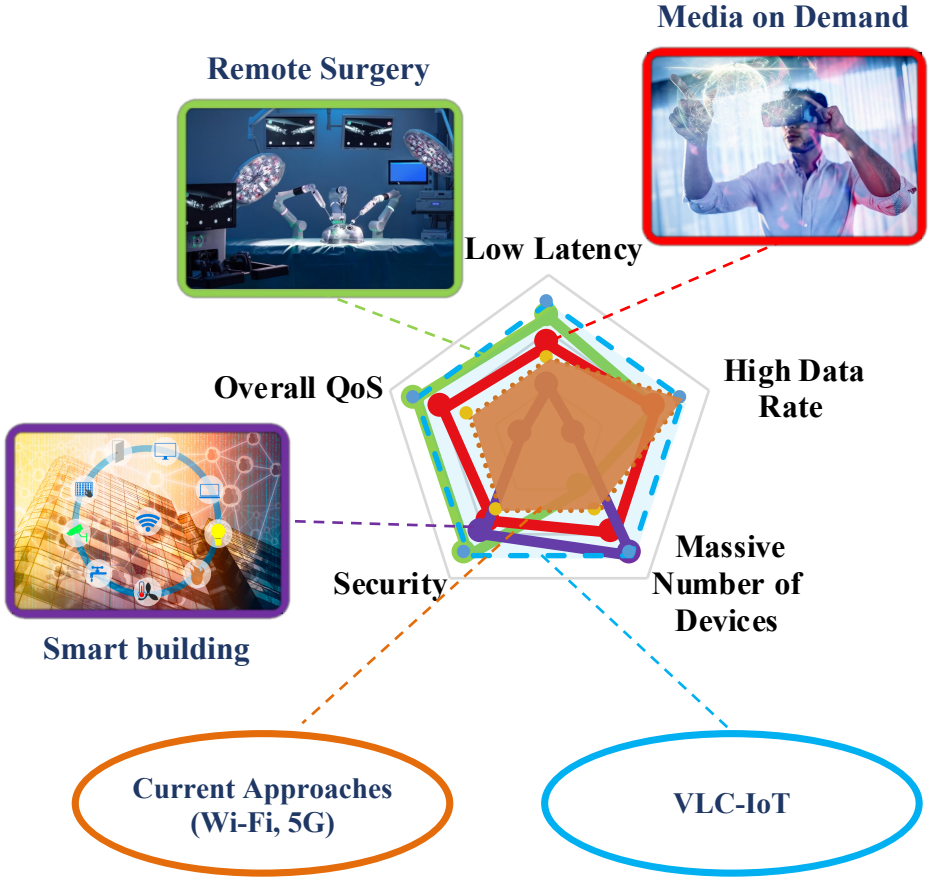
Jie Lian, Zafer Vatansever, **Hamid Hosseinianfar**, Maite Brandt-Pearce

LINK LAB

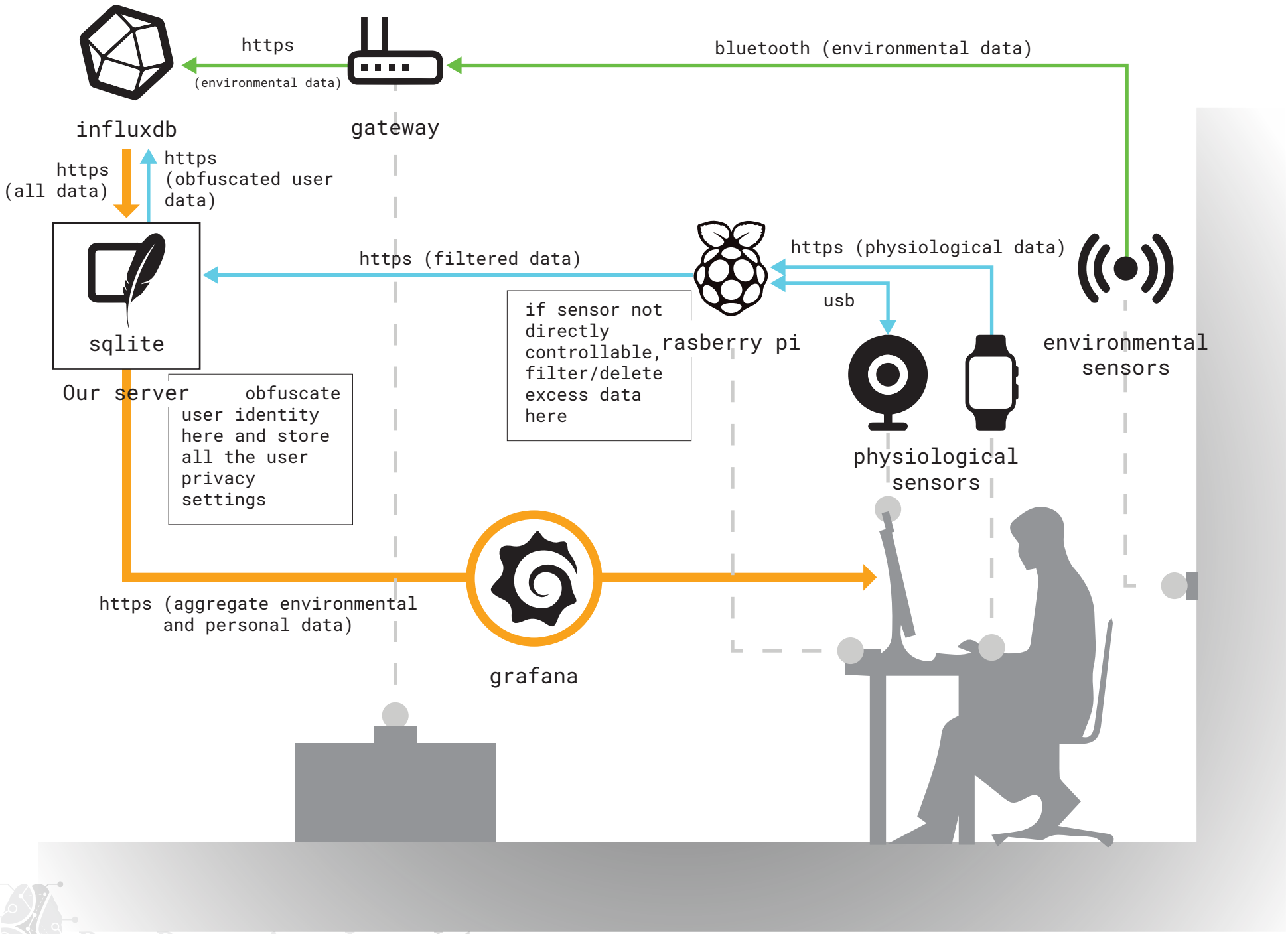
1. Why IoT is hot topic?
2. **Why the current communication technologies are not suitable?**
3. How VLC-IoT is a proper candidate?

Long-Range Paradigm

Short-Range Paradigm



LINK LAB


https
(environmental data)
bluetooth (environmental data)
influxdb
gateway
https
(all data)
https
(obfuscated user
data)
https (filtered data)
https (physiological data)
usb
sqlite
Our server
obfuscate
user identity
here and store
all the user
privacy
settings
if sensor not
directly
controllable,
filter/delete
excess data
here
rasberry pi
environmental
sensors
physiological
sensors
https (aggregate environmental
and personal data)
grafana

Living Link Lab: Human-centric sensing to enhance Occupant Experience and Building Operations

Alan Wang, Arsalan Heydarian

29

CONTACT SENSORS
Enocean WSR00-30

42

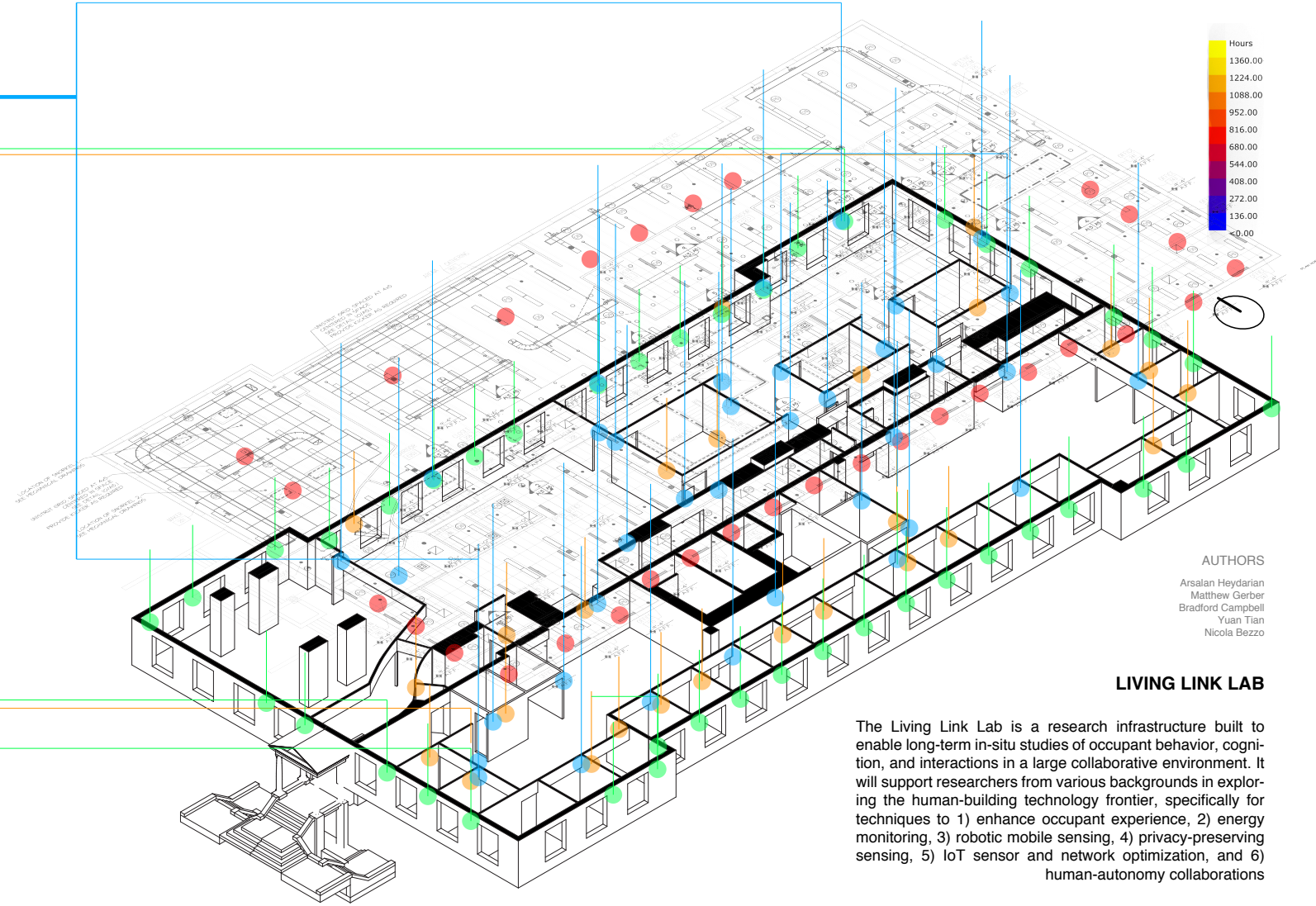
PROXIMITY BEACONS
Estimote

41

TEMP AND HUMIDITY SENSOR
PressacSensing
MINI-TEMPHUM 902Mhz

9

LIGHT LEVEL SENSORS
Enocean ELLSU-W-EO



AUTHORS

Arsalan Heydarian
Matthew Gerber
Bradford Campbell
Yuan Tian
Nicola Bezzo

LIVING LINK LAB

The Living Link Lab is a research infrastructure built to enable long-term in-situ studies of occupant behavior, cognition, and interactions in a large collaborative environment. It will support researchers from various backgrounds in exploring the human-building technology frontier, specifically for techniques to 1) enhance occupant experience, 2) energy monitoring, 3) robotic mobile sensing, 4) privacy-preserving sensing, 5) IoT sensor and network optimization, and 6) human-autonomy collaborations

Behavioral Responsive and Automated Intelligence Laboratory