Safe and Efficient Cyber-Physical Operation System for Construction Equipment

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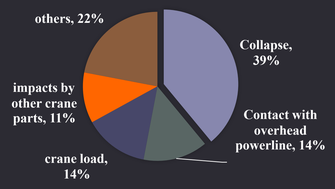
Introduction

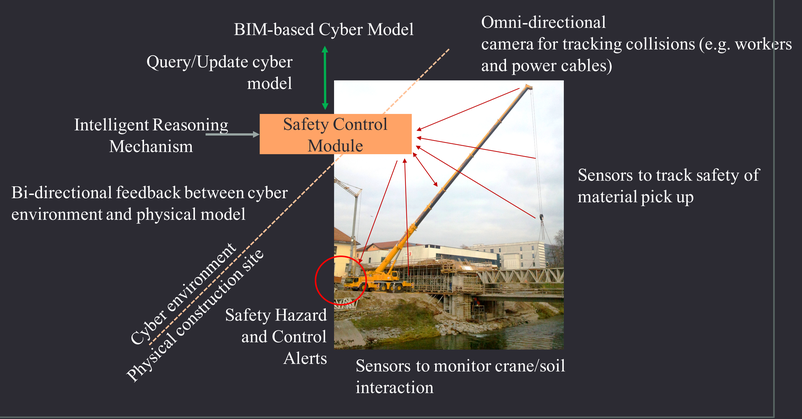
- Safety in Crane Operations



632 crane-related deaths from 610 construction incidents, averaging 43 deaths per year (between 1992 and 2006)

Census of fatal occupational injuries (U.S. Bureau of Labor Statistics)

A safe and Efficient Operation System



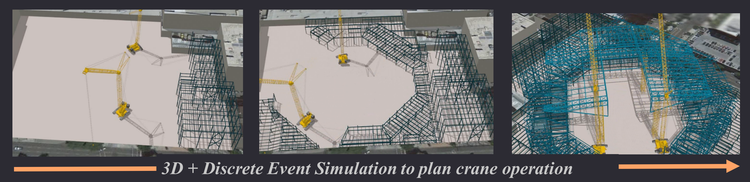
Project Objectives

Improve the safety and efficiency of construction equipment operations through advances in robotics, computer vision, and construction management. We will improve frequency, detail, and applicability of safety planning, monitoring, and control of equipment operations, with five key components:

- Planning: virtual models of the physical environments by building 4D semantically rich CAD models, wherein the actual location and working condition of the crane are simulated in real-time
- Estimation and analysis on the state of equipment: estimate (a) Payload position, orientation, size, shape, mass distribution, and connection point (b) the ground type and the ground force distribution; (c) stress and strain on the entire crane structure. predict the trajectory of crane and of payload and will compute worst-case time to collision with obstacles in the environment.
- Monitoring crane environment: simultaneously localize and map the crane in the 3D surrounding environment. When available, we will also leverage RFID tags – together with these video feeds– to detect and track current and forecasted location of workers, equipment, materials, and other site objects (e.g. power lines) with respect to the crane using feedback from visual sensors
- Control feedback to the crane: restrict applied forces and torques to computed bound, similar to anti-lock brakes; devise solutions to modify trajectory of crane and of payload to avoid collision, by optimal control or similar to "tunnel in the sky".
- Control feedback to the operator: a higher resolution mapping between the center of pressure of the crane and the position of stimulation on the operator's body, and in turn significantly reduce the variance of the center of pressure position when the user is presented with feedback.

Planning

- Model-driven 4D simulation and optimization of the site layout for crane operation

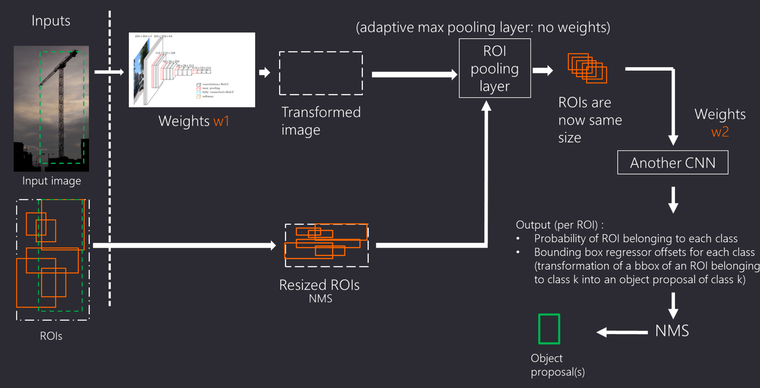


3D + Discrete Event Simulation to plan crane operation

- Failure Mode Effects Analysis and Fault Tree Analysis (FTA)
  - mobile crane related accident reports by the National Institute for Occupational Safety and Health (NIOSH) used for developing models for mobile crane safety analysis
- Safety rules
  - checklist of items for review within the safety hazard recognition process through modeling. Safety logistics, excavation safety, lift monitoring, and struck by object are considered.

State Estimation

- Joint recognition and pose estimation of mobile crane and payload (a very large-scale real-world dataset is being collected)

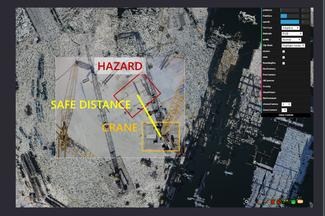


Preliminary Results with Faster R-CNN

- Contact state estimation: hypothesis that the complex interaction between a mobile crane and the ground can be modeled as soft finger contact.
- Equilibrium analysis.

Monitoring Crane Environment

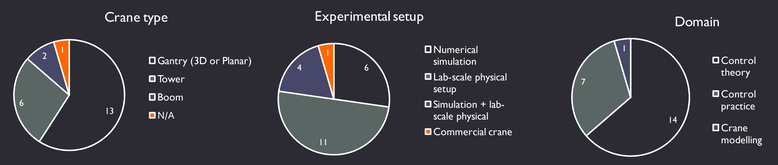
- Construct 3D models of the site from live video feeds in real-time using Plan
- Detect safety hazards
- Detect, track, and forecast motion trajectories of workers, equipment, and material
- Map motion trajectories, deviations, and safety hazards



Tracking workers in real-time on a construction site and reporting both their pose and their proximity to other workers, equipment, and material in the scene for safety monitoring

Crane and Operator Control Feedback

- Gap in Body of Knowledge on Crane Control Models



Meta-analysis revealed that most work on crane modeling and control focuses on gantry or tower cranes in numerical simulation, validated with experiments in lab-scale (not real-size) prototypes

Ongoing Work

- Model-driven 4D planning
- Building massive real-world dataset of construction sites for recognition and pose estimation of mobile crane and payload
- Tracking workers in proximity of cranes for safety hazard recognition
- New models for crane operation (in collaboration with leading industry partners)

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