U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Context-Aware Safety Information Display for Nuclear Field Workers

Advanced Sensors and Instrumentation Annual Webinar

October 29, November 5, November 12 , 2020

Presenters:
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Alper Yilmaz, The Ohio State University
PI: G. Edward Gibson, Arizona State University

Project Overview

- Goal and Objective

The project team plans to develop an “Intelligent Context-Aware Safety Information Display” (ICAD) for nuclear workers:

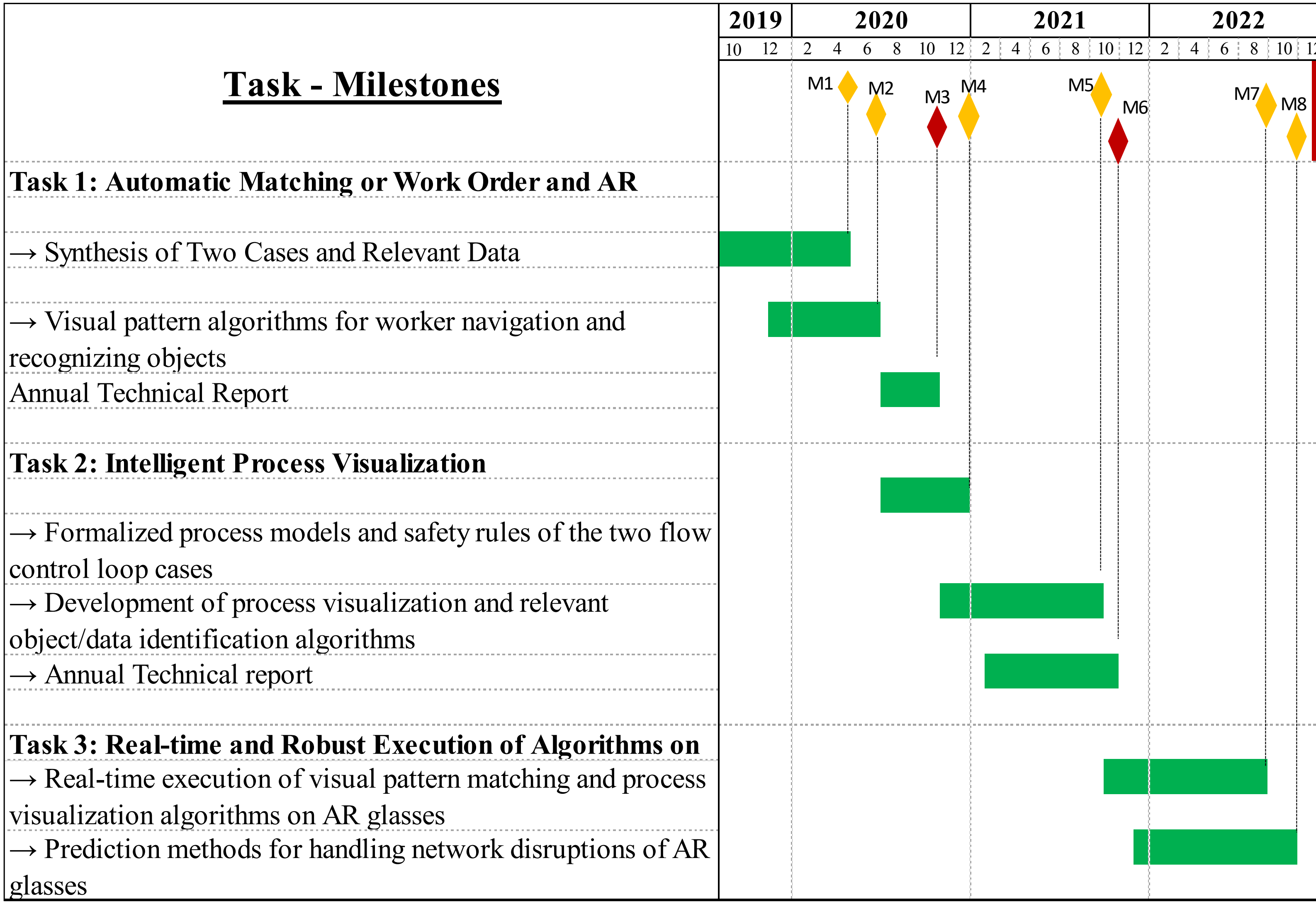
- Overlay of location- and task- relevant hazard information in real-time views of field workers for preventing risky operations and ignorance of hazards
- Real-time guidance in assessing workspace risks, locating task-relevant objects, and carrying out the tasks in the correct order

- Participants (2020)

Principal Investigator:	Dr. George Edward Gibson, Jr., Arizona State University (ASU)
Co-Principal Investigators:	Dr. Pingbo Tang, Carnegie Mellon University (CMU) Dr. Alper Yilmaz, The Ohio State University (OSU)
Collaborators:	Dr. Ronald Laurids Boring, Idaho National Laboratory (INL) Mr. Thomas Myers, Duke Energy
Graduate Students:	Ms. Jinding Xing, CMU Dr. Zhe Sun, CMU Mr. Shehan R Perera, OSU

Project Overview

- Schedule



Summary of accomplishments

- Milestones, deliverables, outcomes for FY20

- 4/30/2020: A Synthesis of Two Cases and Relevant Date Sets Prepared for Testing Visual Pattern Matching Algorithms

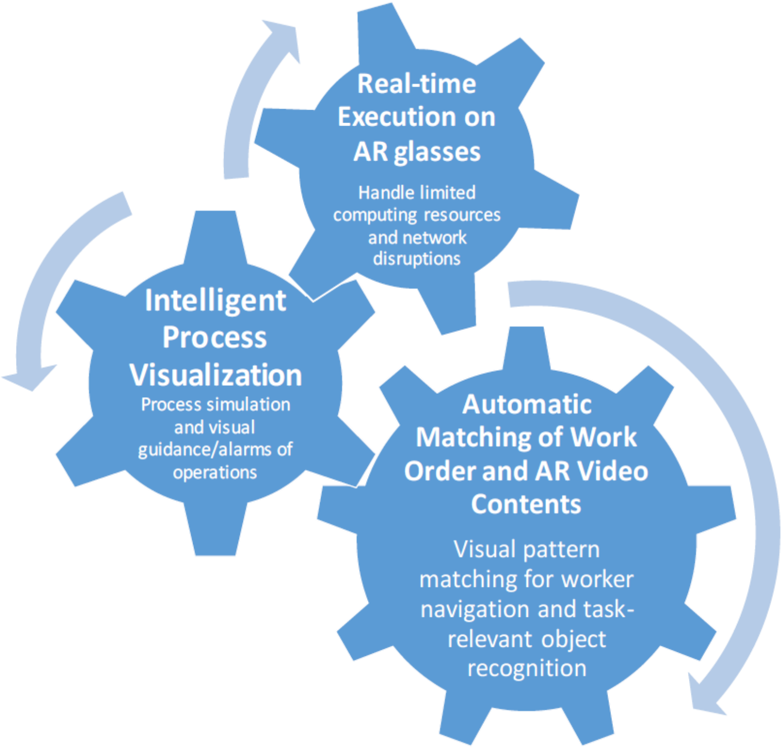
- 6/30/2020: Design and Initial Development of Visual Pattern Algorithms for Worker Navigation and Recognizing Objects Related to the Two Cases

- 10/31/2020: Annual Report - The Development and Initial Testing Results of the Visual Pattern Algorithms for Worker Navigation and Recognizing Objects Related to Two Cases of Nuclear Flow Loop Control

Technology Impact

- Advances the state of the art for nuclear application
  - Real-time computer vision-based mobile smart safety information display augmented by safety-compliance checking algorithms for guiding nuclear field workers in recognizing field hazards and preventing operational accidents
- Supports the DOE-NE research mission
  - Innovative real-time visual sensing, integrated visualization of sensory data within field views, and digital/electronic field support systems for nuclear facilities
- Impacts the nuclear industry
  - Visual inspections and accountability of digital platforms for data-driven nuclear power plant operations
  - Areas radiation monitoring via remote monitoring or as part of personnel dosimetry
  - Fieldworker “Head-Up Display” to provide design/engineering along with real-time sensory data and field information
- Will be commercialized
  - CMU, OSU, and ASU plan to collaborate to commercialize the developed product

Accomplishments (1/7)



Task 1

Knowledge representation

- Task complexity
- Operation logs
- Operator's eye movement pattern

Development of Visual Pattern Matching Methods

Task 2

Context-aware management

- Operation logs
- Workers' field operation and observation patterns

Augmented Reality Display

Task 3

Information visualization

- Ergonomics design

Nvidia Jetson & Testing

Current Progress

CMU: Coding NPP Operation Processes → Task complexity

OSU: 2D/3D Computer Vision Methods → Development of Visual Pattern Matching Methods

INL/CMU: Extract Task Segments from Operation Logs and Field Notes → Operation logs

CMU/INL: Machine Learning for Mining Operation Patterns → Workers' field operation and observation patterns

OSU: Augmented Reality for Displaying Context-Relevant Safety Information → Augmented Reality Display

Accomplishments (2/7)

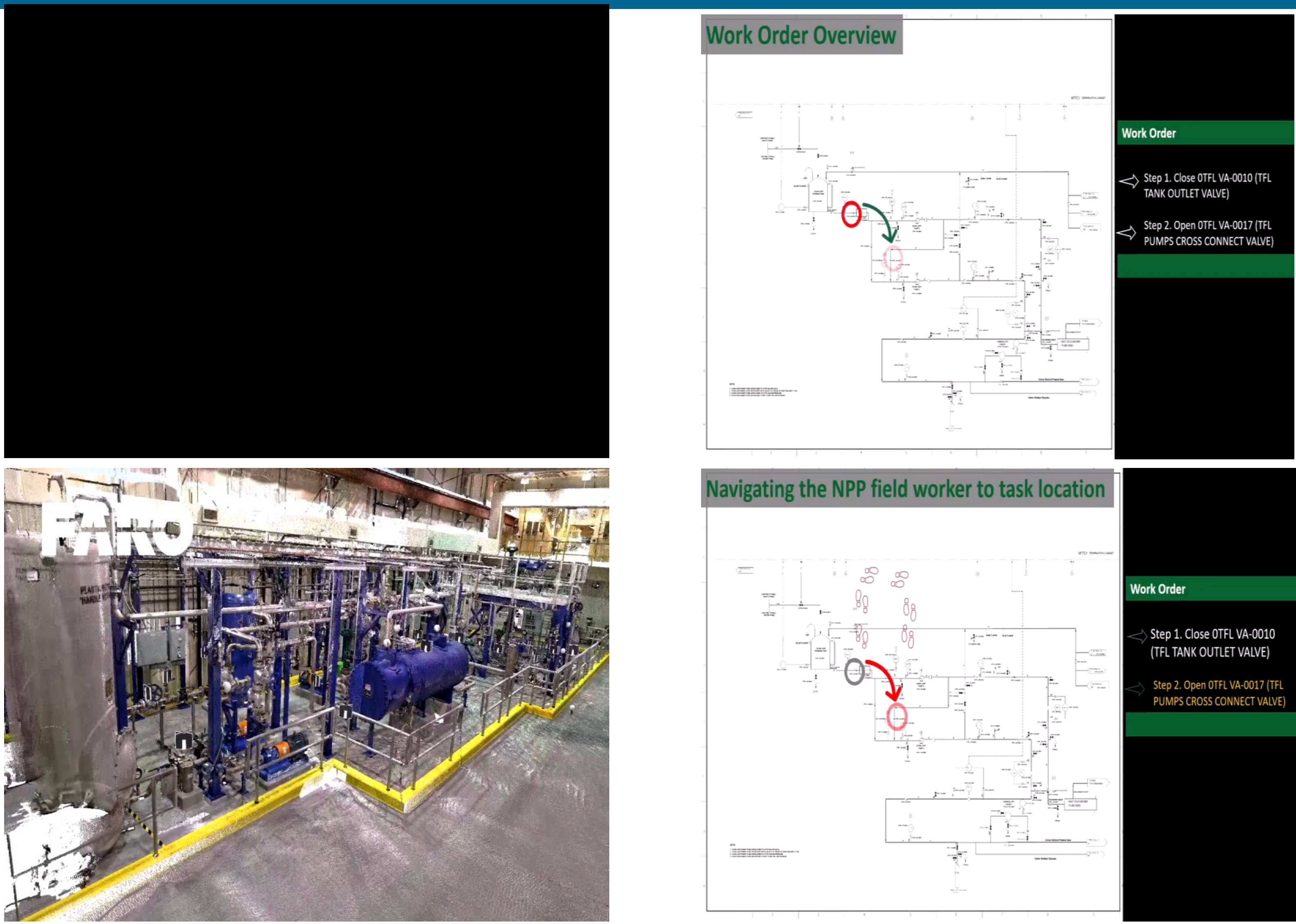


Figure 1. Demo of the Context-aware safety information display for NPP field operators

Accomplishments (3/7)

Context-aware reasoning of tasks

- Descriptions about the operational process's activities, objects operating in each activity;
- Prerequisite relationship between activities;
- Identify objects relevant to the on-going activities and filter out irrelevant objects;
- Guide the field workers to recover from operational errors and unexpected incidents.

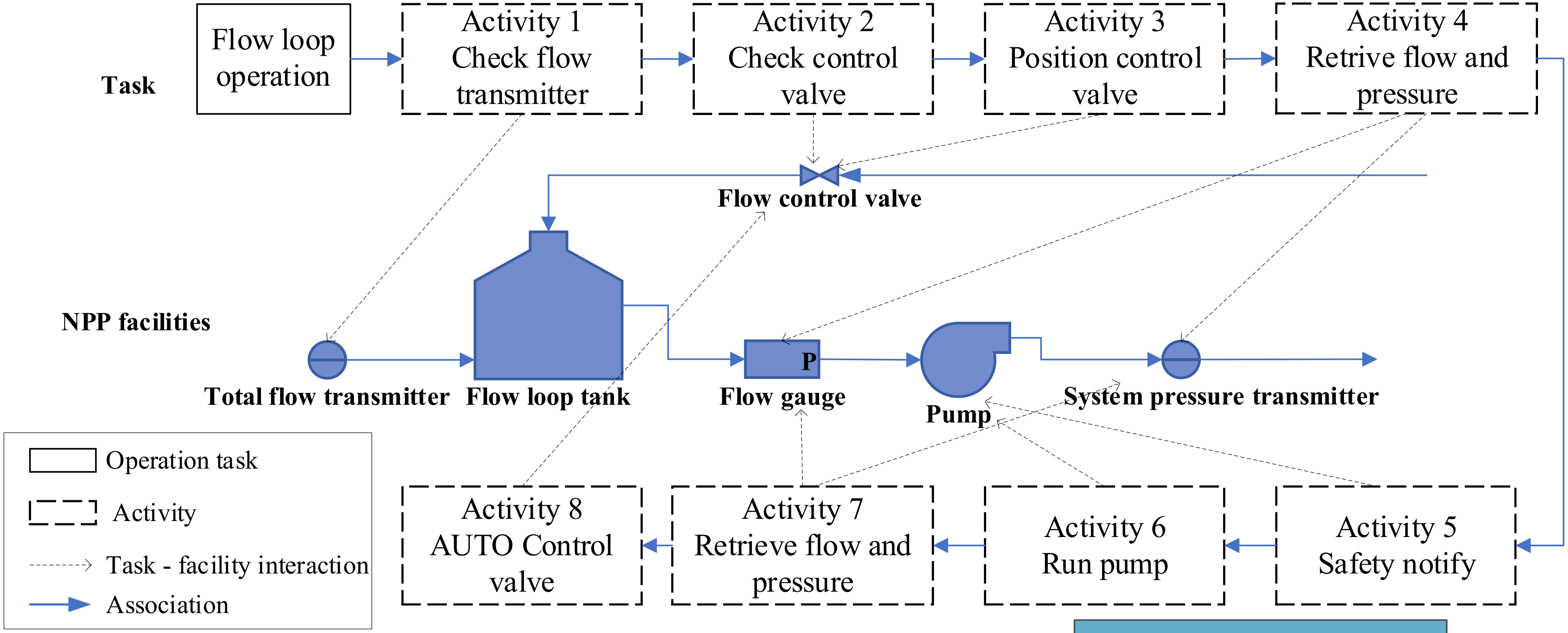


Figure 2. Flow loop training procedure

CMU: Coding NPP operation tasks

Accomplishments (4/7)

Knowledge representation of NPP operation procedures that can support the computations of operational complexity of workflows and spatiotemporal reasoning about relationships between objects involved in the workflows for identifying error-prone tasks, safety-related objects, and hazardous spaces.

Task = Operation + Object (color, location, type)

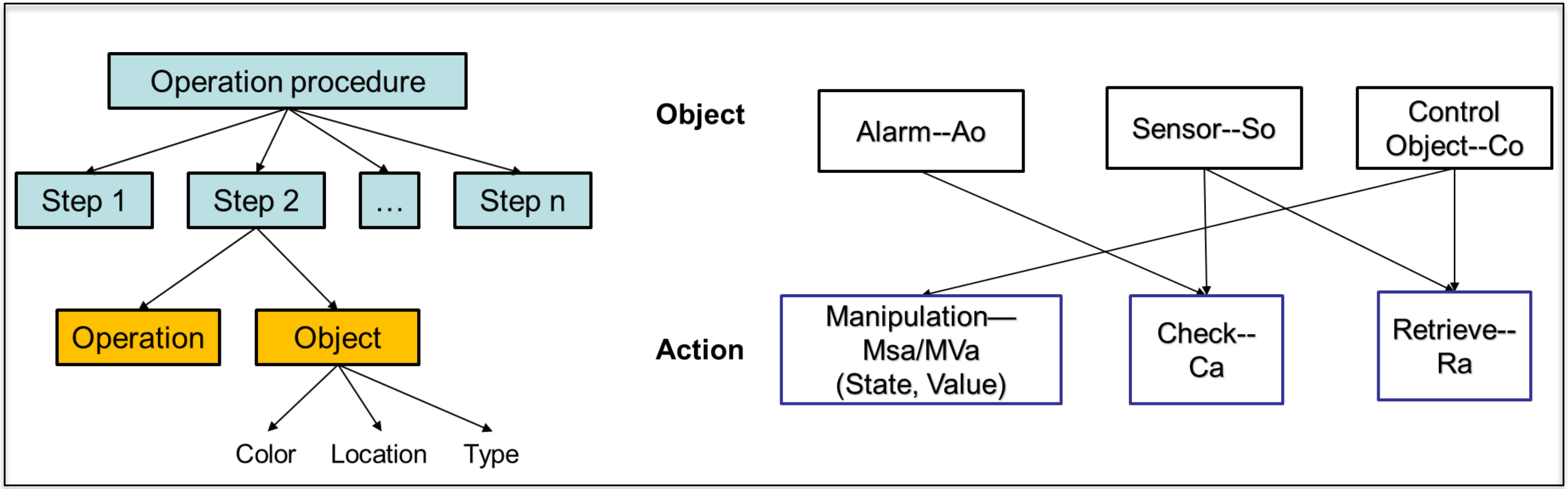


Figure 3. An abstraction of the Nuclear Power Plant operational tasks

CMU: Coding NPP operation tasks

Accomplishments (5/7)

- Actions and observing tasks along the timeline for identifying complex procedures

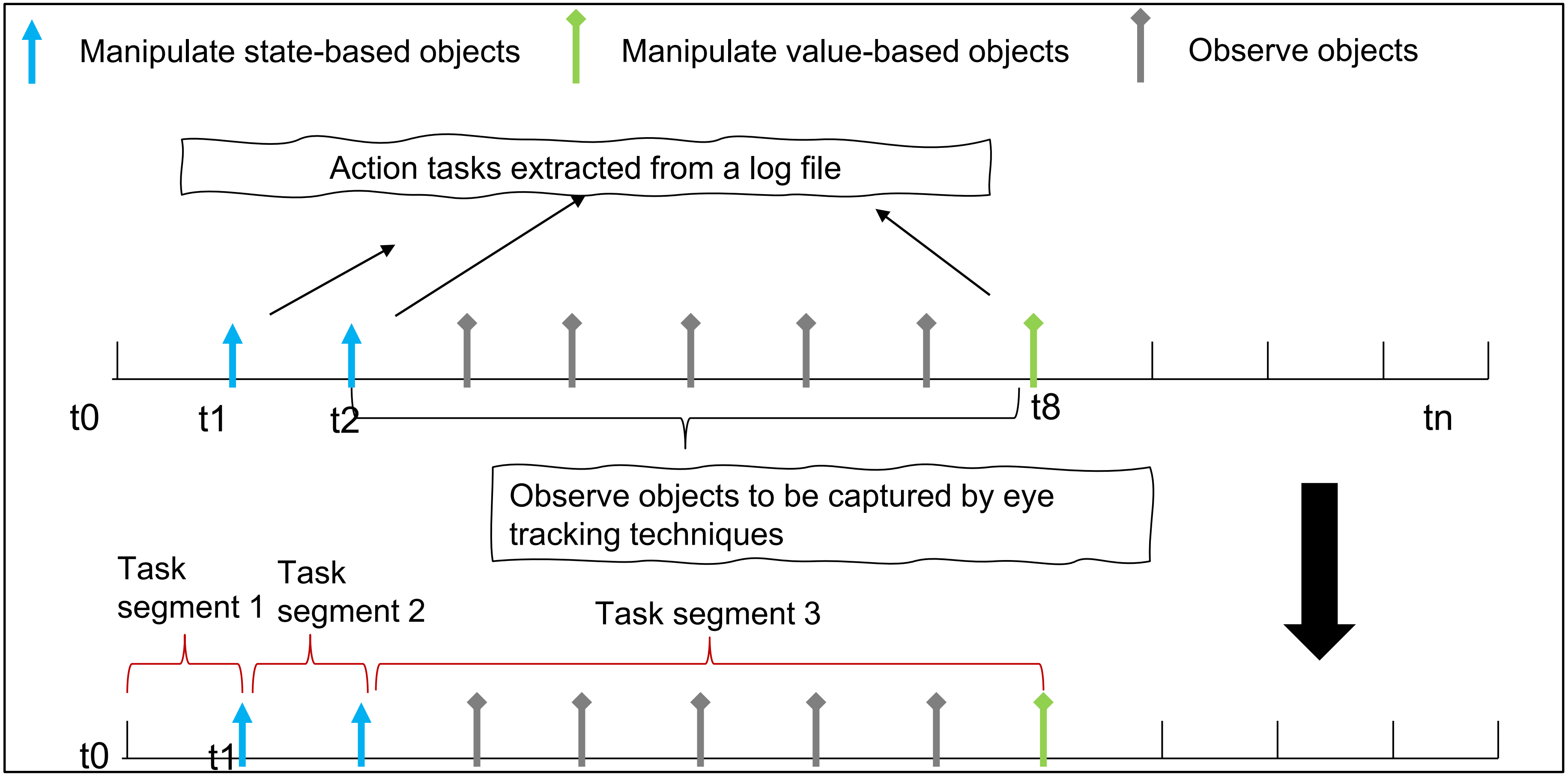


Figure 4. Extracting task segments from the operation logs

INL/CMU: Extract task segment from operation logs

Accomplishments (6/7)

- **Updated Approach**
  - Overall Semi Short-Term Target
    - Using the recently acquired video data from Duke Energy, help locate the worker in 3D space and help identify the objects in view
- **In Progress**
  - Generating framewise segmentation labels for video data from duke energy
    - Once generated build and test a segmentation/detection pipeline to identify objects on the workorder
  - Researching into combining 2D and 3D information to help locate the working in 3D space.
    - 2D data obtained by the camera
    - 3D data obtained by the LIDAR point clouds

OSU: Augmented Reality for Displaying Safety Information

OSU: 2D/3D Computer Vision methods

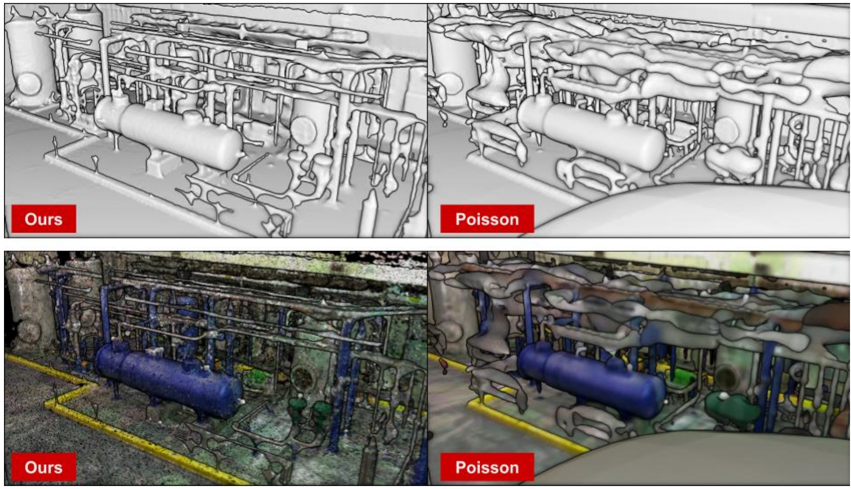


Figure 5. LIDAR Reconstruction

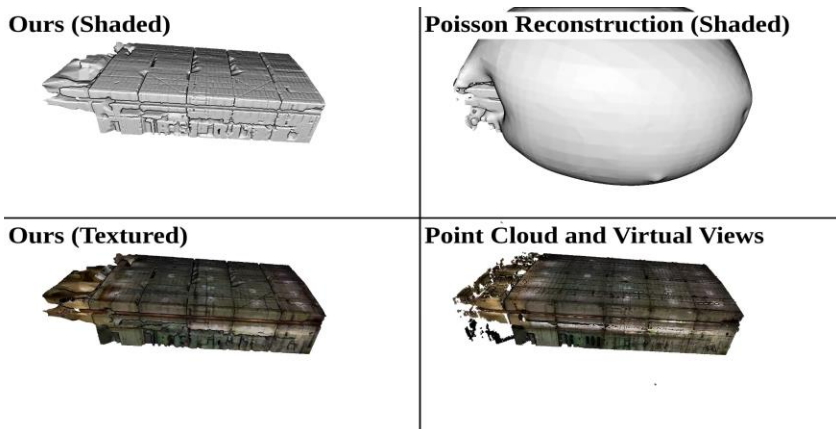


Figure 6. 3D Texture Model

Accomplishments (7/7)

Publications:

- Sun, Z., Xing, J., Tang, P., Cooke, N. J., & Boring, R. L. (2020). Human Reliability for Safe and Efficient Civil Infrastructure Operation and Maintenance–A Review. Developments in the Built Environment, 100028.
- Xing, J., Tang, P., Yilmaz, A., Boring, R. L., and Gibson, G. E. (2021). “Monitoring Defects in Attention Allocations of Nuclear Power Plant Operators through Eye Tracking and Task Analysis.” Proceeding of ASCE Lifeline Conference 2021, American Society of Civil Engineers (ASCE), Los Angeles, CA, USA.

Scientific Data Collected:

- Labeled images, videos, and laser scanning imagery data collected from a flow loop training facility for testing and demonstrate the proposed technical framework.

Algorithms and Software Tools Developed:

- An extensible imagery data loading process for handling various formats of labeled imagery data
- Comparative analysis of deep learning (DL) network models that has the potential of automatically extracting objects and related information from field videos

Conclusion

In the first year, the project team has achieved the following accomplishments:

- Designed an eye-tracking experiment based on two typical procedures (the training flow loop operation in the NPP field and the reactor startup procedure in the NPP control room);
- Formalized detailed knowledge representations featured with objects' and subtasks' properties related to typical nuclear power plant operations;
- Drafted a data collection protocol that will be used to collect the NPP field operation data;
- Completed data labeling of NPP field images collected by Duke Energy collaborators, and finished an extensible data loading process for labeled imagery data;
- Explored deep learning (DL) network models to automatically extract objects and related information from field videos during NPP operations.

Impacts:

- This project will produce knowledge and technical approaches for building a context-aware intelligent augmented reality (AR) device that will help achieve productive and safe NPP maintenance workflows.
- The safer and more efficient operations of NPPs will create positive social, economic, and technical impacts for the nuclear industry.

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