Context-Aware Safety Information Display for Nuclear Field Workers

Advanced Sensors and Instrumentation (ASI) Annual Program Webinar
October 24 – 27, 2022

Presenter: Pingbo Tang, PhD, Associate Professor

Carnegie Mellon University/Civil and Environmental Engineering

Project Overview – Research Scope

Context-Aware Safety Information Display for Nuclear Field Workers

Objectives

- The developed display should integrate the real-time overlay of physical workspaces with maintenance processes and safety information visually displayed through Augmented Reality (AR) glasses.
- The purpose of the display is to assist and guide field workers in assessing workspace risks, locating task-relevant objects, and carrying out the tasks in the correct order in a safe manner.

Research areas

Human reliability | Work process modeling | Operation safety

Major techniques

Survey and interview | Augmented Reality | Computer vision | Natural language processing

Outcomes

- Document and publish research progress in peer-reviewed journals
- Delivery of AR Glasses with context-aware safety information display functions

Project Overview – Participants

PI:

George Gibson, ASU

ASU: Arizona State University
CMU: Carnegie Mellon University
INL: Idaho National Laboratory
OSU: Ohio State University
DE: Duke Energy

Co-PI & Collaborators:

Pingbo Tang, CMU

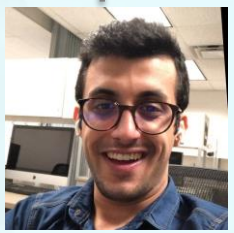
Ron Boring, INL

Alper Yilmaz, OSU

Tom Myers, DE

Ph.D. Students:

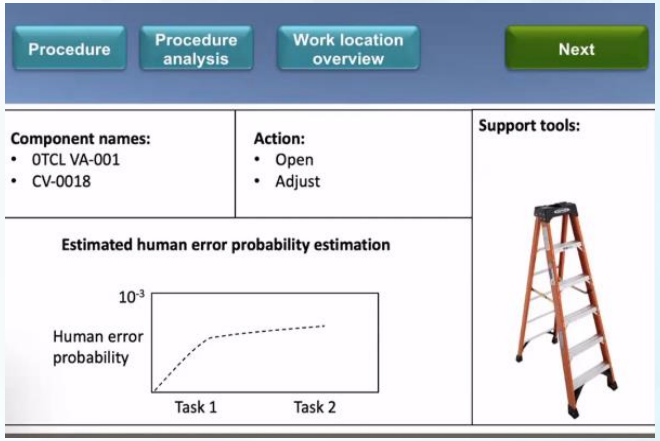
Jinding Xing, CMU



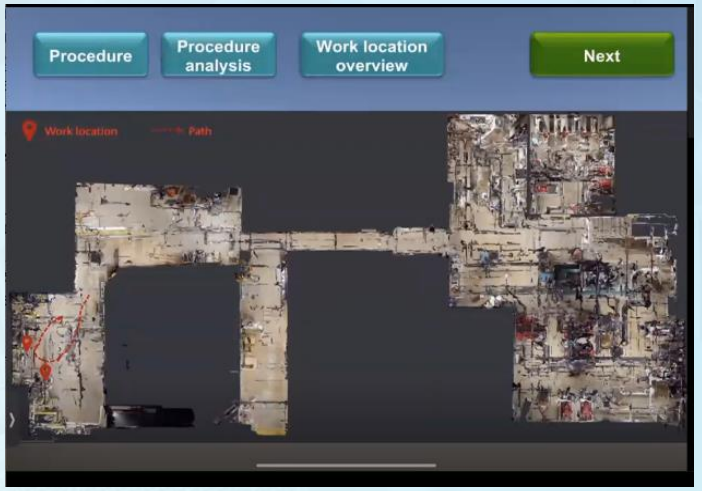
Pouyan Boreshnavard, OSU

Technology Impact – AR Display

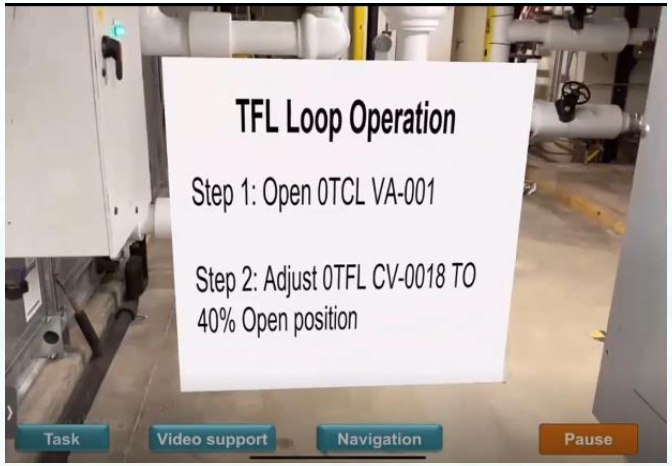
The interface of the developed display



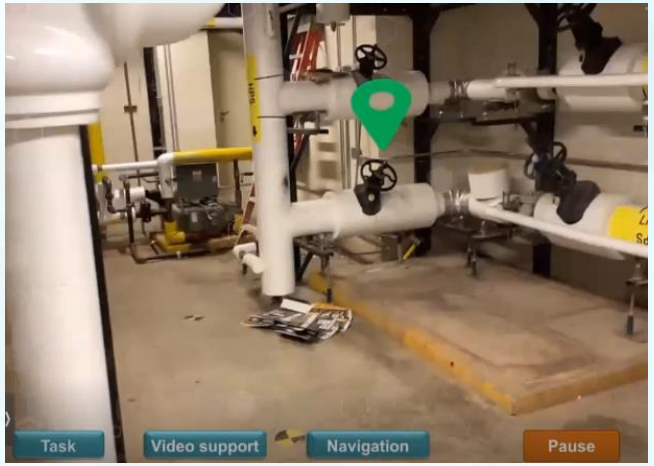
Safety hazards information



Path planning and real-time worker locating



Operation guidance

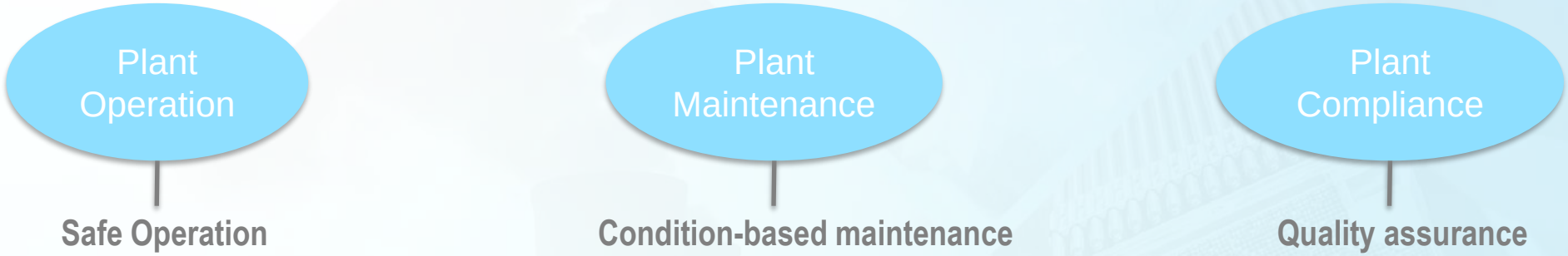


Highlight critical object

HoloLens 2 AR display for Nuclear Field workers

Technology Impact – Description of the Technology

Where does it operate?



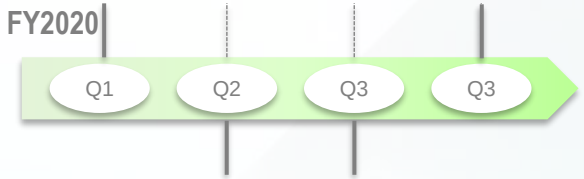
Who should be interested in this technology?

- Personnel (e.g., field operator) conduct operation activities outside the main control room.
- These activities include:
  - Starting and stopping electricity generation equipment as needed
  - Overseeing readings and making observations to establish system goals and get to know the status, thereby taking actions to correct any detected equipment problems

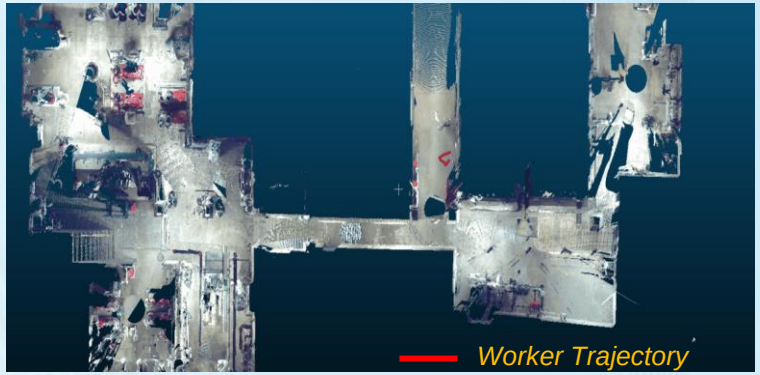
Results and Accomplishments – Overview

A synthesis of Two Cases and Relevant Date Sets

Formalized process models and safety rules of the two flow control loop cases



Visual pattern algorithms for worker navigation and recognizing objects related to the two cases

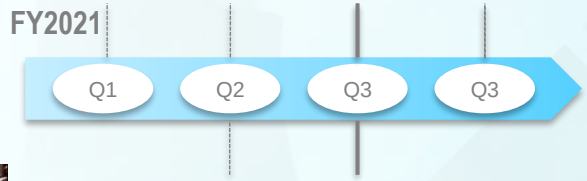


Real-time tracking of worker location

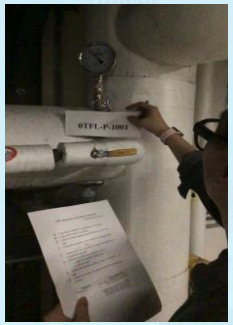
Campus mechanical room for developing and testing the developed algorithms

Computer vision for detecting control objects

Nuclear operation process modeling, reasoning, and object detection from field videos

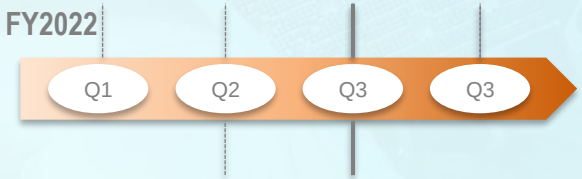


Process visualization and relevant object/data identification algorithms



A student operator perform operational tasks

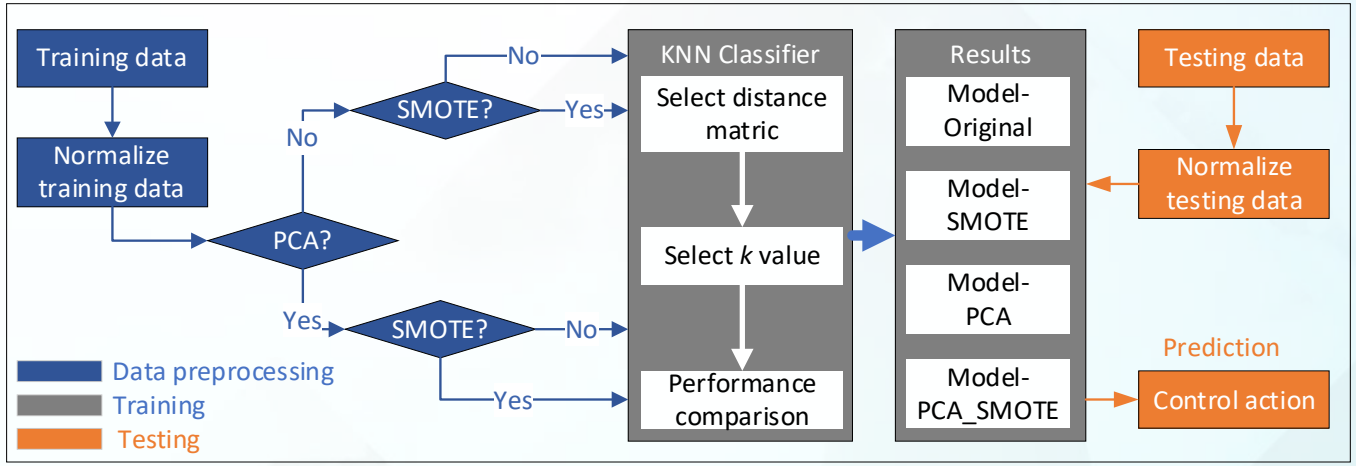
Real-time execution of visual pattern matching and process visualization algorithms on AR glasses



Visual pattern matching and process visualization algorithms on AR glasses

Results and Accomplishments – Work Conducted in FY22

Algorithm for Analyzing Operation Logs of Nuclear Power Plants for Safety and Efficiency Diagnosis of Real-Time Operations.



The framework of the proposed method for predicting switch parameters.

The operating state of NPP at a specific time is represented by a set of analog parameters and switch parameters. The changes of switch parameters reflect the operator's control decision.

Time (s)	Work status (control action/wait)	Core temperature (DEG F)	Cooling flow (KPPH)	…
1	Wait	181.16	20.45	
2	Valve A ON	182.50	20.22	
3	Rod 1	184.03	20.12	
4	Wait	185.60	20.11	
5	Valve B ON	187.40	20.09	
6	Rod 1	189.23	20.08	

Model input: Time series of analog parameters in the last three seconds

Model output: Work status at the fourth second

Jinding Xing, Pengkun Liu, Pingbo Tang, Alper Yilmaz, Ronald Laurids Boring, George Edward Gibson Jr, Analyzing Operation Logs of Nuclear Power Plants for Safety and Efficiency Diagnosis of Real-Time Operations. In 29th International Workshop on Intelligent Computing in Engineering, EG-ICE 2022. Aarhus, Denmark.

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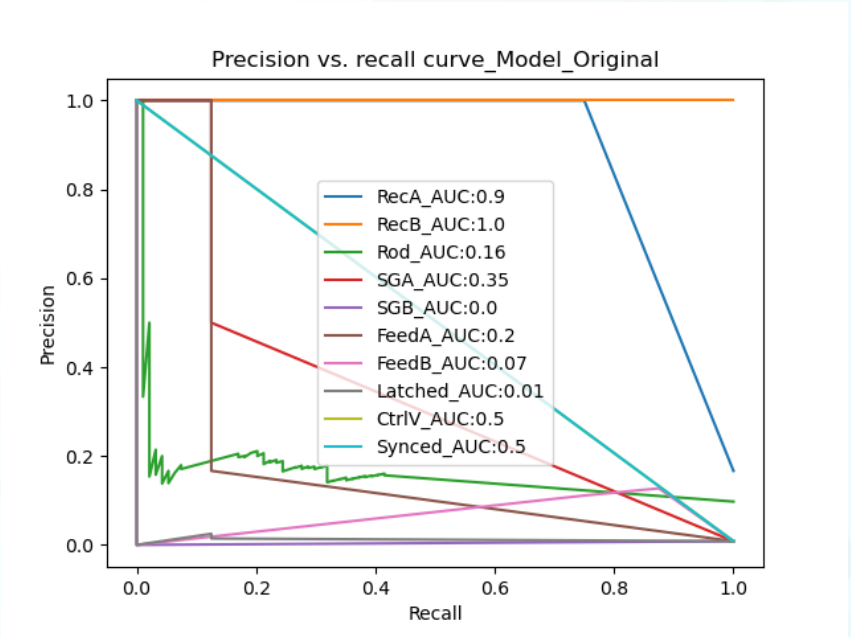

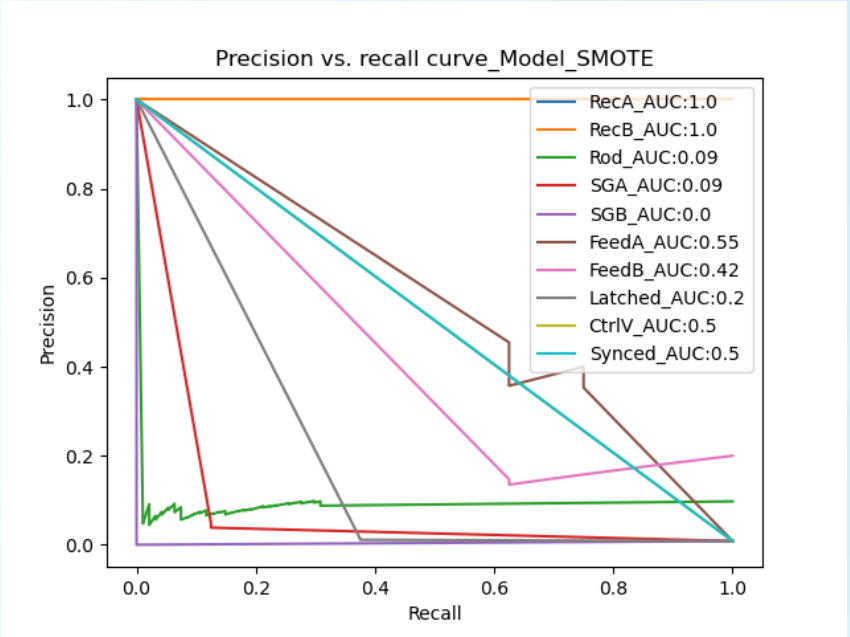

This study proposed a variant of models based on KNN classifiers that uses analog parameters to infer the most suitable control actions.

The testing results indicate that the model with SMOTE data (F1 score 0.323) augmentation has better prediction performance than the models without SMOTE (F1 score 0.263) .

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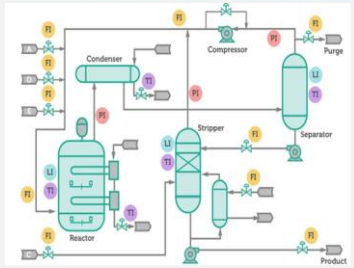
Results and Accomplishments – Field Interview and Survey

Surveyed and interviewed 45 experienced nuclear field operators in the U.S.

Created a classification of critical information for different tasks and contexts:

- Three type of information

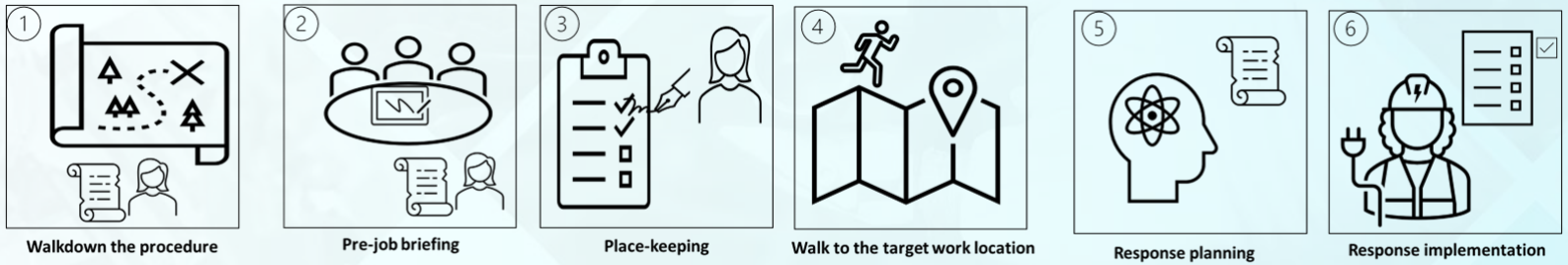
Workspace dynamics: the location, quantity, size, and state of components on the work package timelines.



Workflow prognostics: the dependency between the function of a component and process variables.

Hazards: Unique hazards such as radiation, confined spaces, or conditions that may pose a danger to personnel or damage component.

- Six work stages



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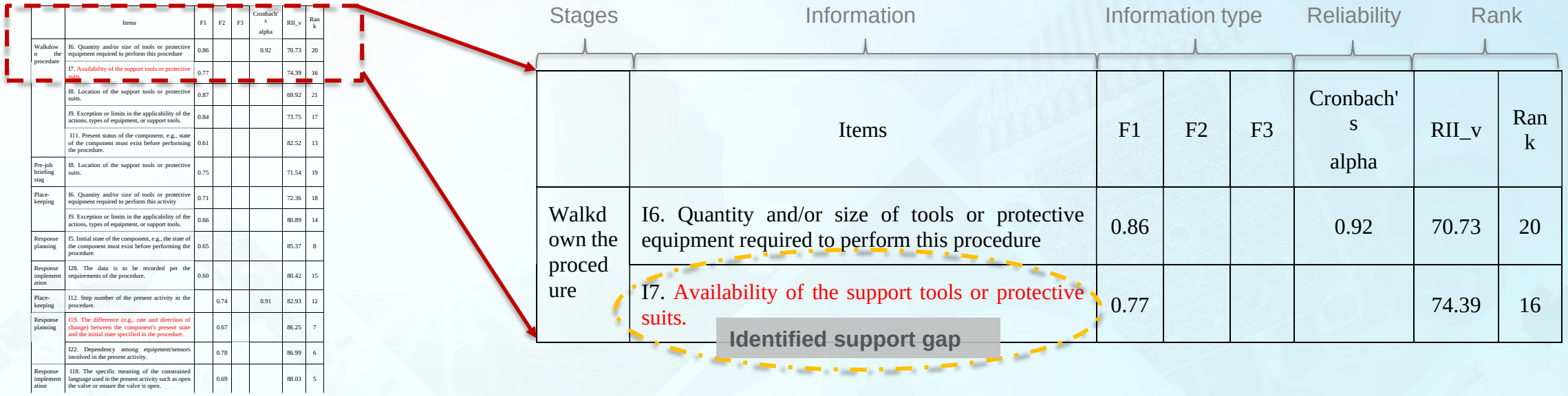


	Items	F1	F2	F3	Cronbach's alpha	RII_v	Rank
Walkdown the procedure	I6. Quantity and/or size of tools or protective equipment required to perform this procedure	0.86			0.92	70.73	20
	I7. Availability of the support tools or protective suits.	0.77				74.39	16
	I8. Location of the support tools or protective suits.	0.87				69.92	21
	I9. Exception or limits in the applicability of the actions, types of equipment, or support tools.	0.84				73.75	17
	I11. Present status of the component, e.g., state of the component must exist before performing the procedure.	0.61				82.52	13
Pre-job briefing stag	I8. Location of the support tools or protective suits.	0.75				71.54	19
Place-keeping	I6. Quantity and/or size of tools or protective equipment required to perform this activity	0.71				72.36	18
	I9. Exception or limits in the applicability of the actions, types of equipment, or support tools.	0.66				80.89	14
Response planning	I5. Initial state of the component, e.g., the state of the component must exist before performing the procedure.	0.65				85.37	8
Response implementation	I28. The data is to be recorded per the requirements of the procedure.	0.60				80.42	15
Place-keeping	I12. Step number of the present activity in the procedure.		0.74		0.91	82.93	12
Response planning	I19. The difference (e.g., rate and direction of change) between the component's present state and the initial state specified in the procedure.		0.67			86.25	7
	I22. Dependency among equipment/sensors involved in the present activity.		0.78			86.99	6
Response implementation	I18. The specific meaning of the constrained language used in the present activity such as open the valve or ensure the valve is open.		0.69			88.03	5

Stages | Information | Information type | Reliability | Rank

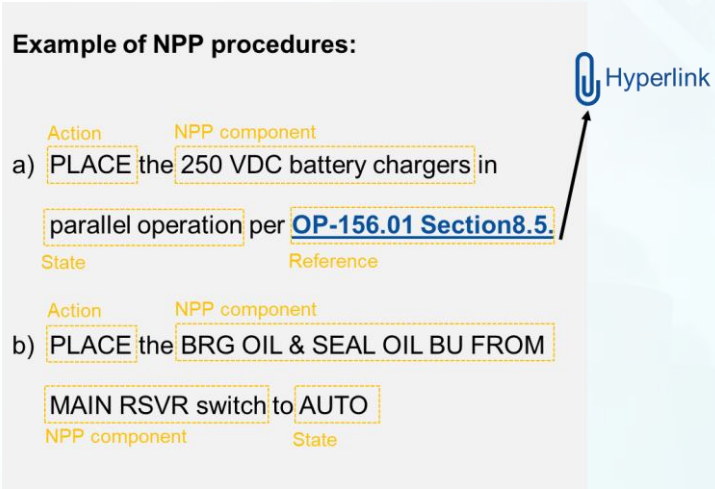
	Items	F1	F2	F3	Cronbach's alpha	RII_v	Rank
Walkdown the procedure	I6. Quantity and/or size of tools or protective equipment required to perform this procedure	0.86			0.92	70.73	20
	I7. Availability of the support tools or protective suits.	0.77				74.39	16

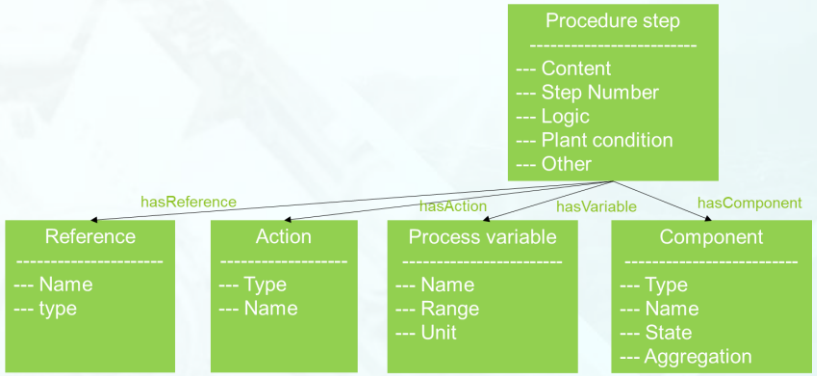
Identified support gap

Identified information that are critical for ensuring worker safety

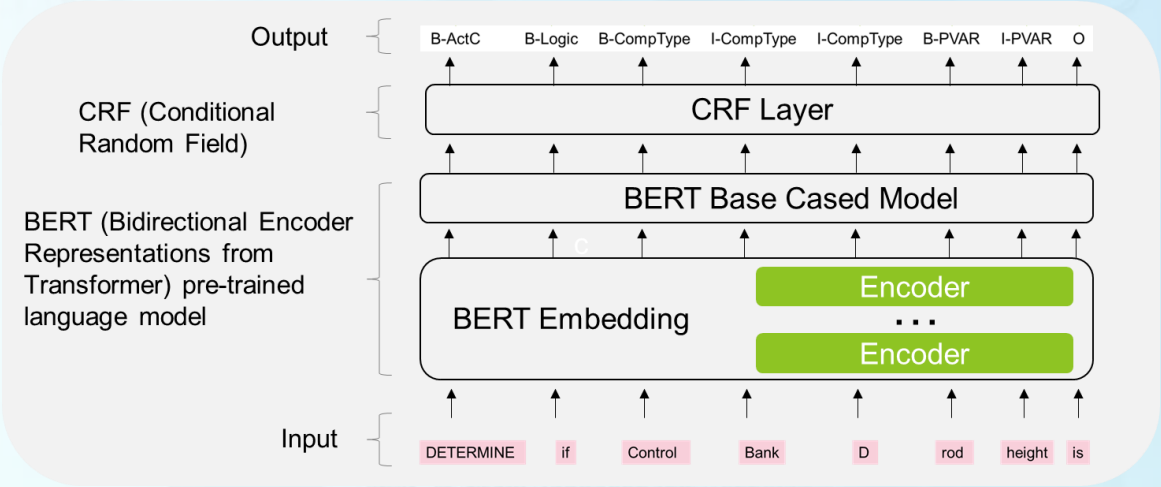
Results and Accomplishments – Overview

Natural Language Processing (NLP) for automatically extracting critical information from work packages.

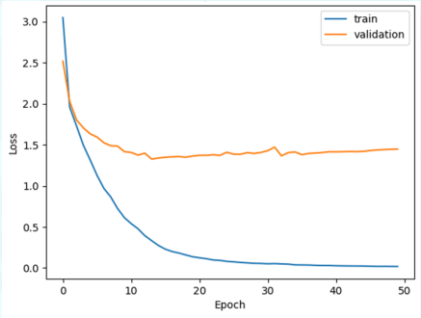




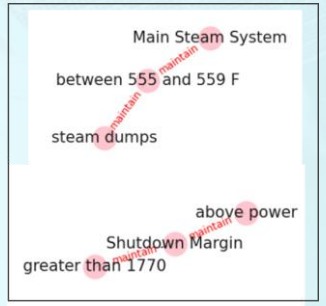
Procedure step, reference, action, process variable and component are types of critical information included in the procedures.



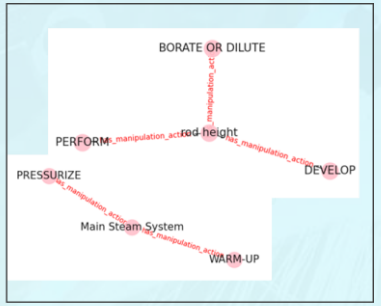
The architecture of the proposed BERT-CRF model for NPP operating procedure named entity recognition



Training results trained on 50 epochs



Maintain



Control action: manipulation (left), check (right)

Visualizing and reasoning process safety constraints, component properties by querying the knowledge graph.

Results and Accomplishments – Augmented Reality Development

Marker-less AR for the NPP field operations

3D scan of the campus mechanical room

Non-recursive Bayesian Filter based real time worker locating

Unity engine as the development platform

NLP-based work package information extraction

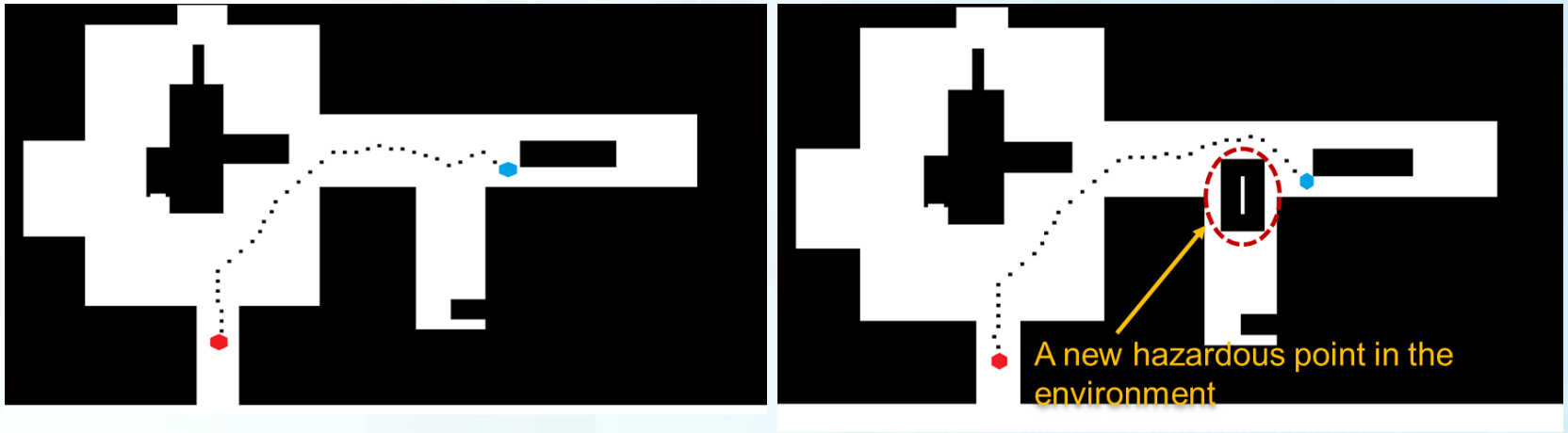
HoloLens 2 AR display for Nuclear Field workers

Vuforia area target generator to extract visual features for AR tracking and registration of the augmented information

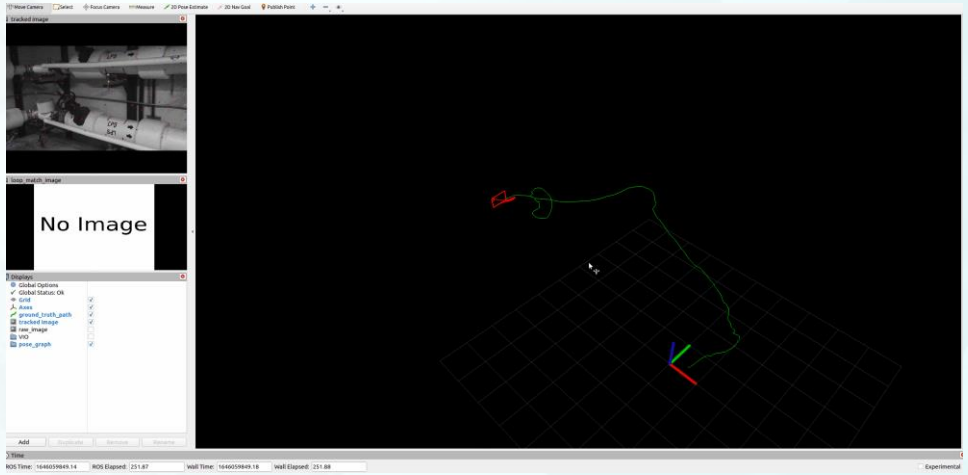
Scan the QR code to view the AR demo video

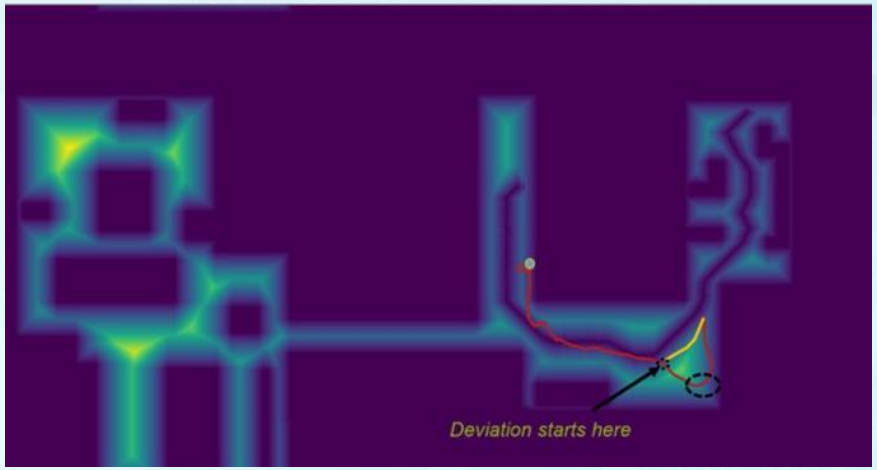
Results and Accomplishments – Dynamic Indoor Navigation

Online hazard location and path planning by considering hazards and safety constraints.



Real-time tracking for detecting deviations from the planned path



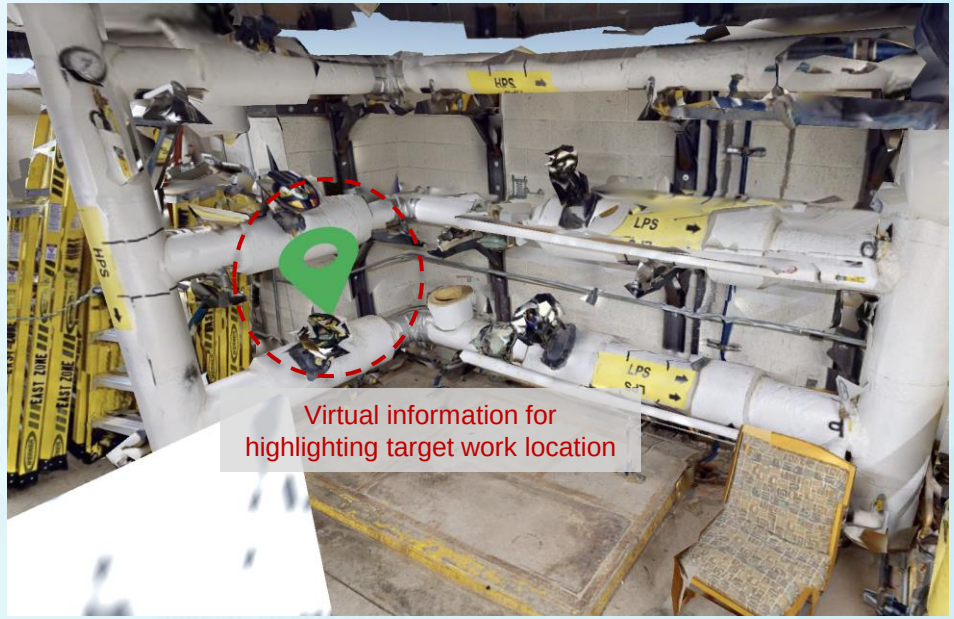


Addressed Challenges

Addressed challenges:

- Reliable highlights of operations and relevant objects in a noisy background (with similar objects closely located) in the AR video views
  - Vuforia area target generator to extract visual features from pre-scanned sparse point cloud for object tracking and virtual information alignment.

- Real-time tracking for detecting deviations from the planned path
  - Non-recursive Bayesian Filter (NBF) for correcting deviation in worker trajectory prediction
  - NBF is a probabilistic approach to use incoming measurement along with prior info to predict the next measurement (correction)



Align the virtual information in environment with many similar valves closely located

Remaining Challenges for Field Implementation

Remaining challenges:

- Time consuming to scan the point cloud model of commercial power plants
- Hardware, most AR Glasses have limited computation capability
- Ergonomics, such as limited field of view, view occlusion
- Reliability of the AR support tool, such as the quality and alignment accuracy of the visual information
- …

AR is a powerful tool to improve operation safety and productivity:

- Best practice for using AR: identify the right scope of work, people and groups
- Identify potential human error traps related to using AR and develop strategies
- …

Publications

Liu, Pengkun, Jinding Xing, Ruoxin Xiong, and Pingbo Tang. Sharing Construction Safety Inspection Experiences and Site-Specific Knowledge through XR-Augmented Visual Assistance, Proceedings of the 1st Future of Construction Workshop at the International Conference on Robotics and Automation, Philadelphia, U.S.A, May 23, 2022

Xing J., Liu P., Tang P., Yilmaz A., Boring R., Gibson Jr G.. Analyzing Operation Logs of Nuclear Power Plants for Safety and Efficiency Diagnosis of Real-Time Operations, 29th International Workshop on Intelligent Computing in Engineering (EG-ICE), Aarhus, Denmark, July 6-8, 2022

Kochanek, S., Xing, J., Yilmaz, A., Gibson, G. E., and Tang, P. Using Computer Vision to Reduce Human Errors of Operating on the Wrong Control Valves in Nuclear Power Plants. Proceedings of the 13th International Conference on Applied Human Factors and Ergonomics (AHFE 2022), New York, New York, USA, 10 pages, July 28, 2022.

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Thank You