LD2401 FY25 Renewal Proposal

Robotic Collaboration for Particulate Free SRF Assembly

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U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Scope of the Application

Develop a robotic collaboration system for particle free assembly of SRF cavities

- **goal**:
  - improve the performance of SRF cryomodules

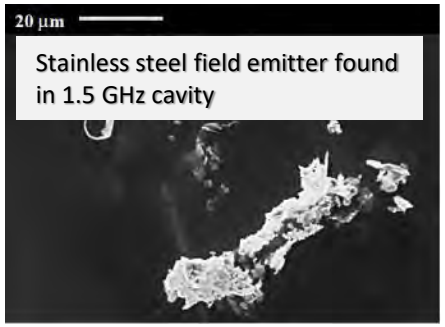
- **objective**:
  - reduce field emission by reducing particulate contamination

- **approach**:
  - develop robotic collaboration methods for the assembly process
  - start with the delicate inner adapter assembly of C50/C75 style cavity pairs

- **mission relevance**:
  - improve quality, consistency, cost, and safety of SRF cavity and cryomodule production

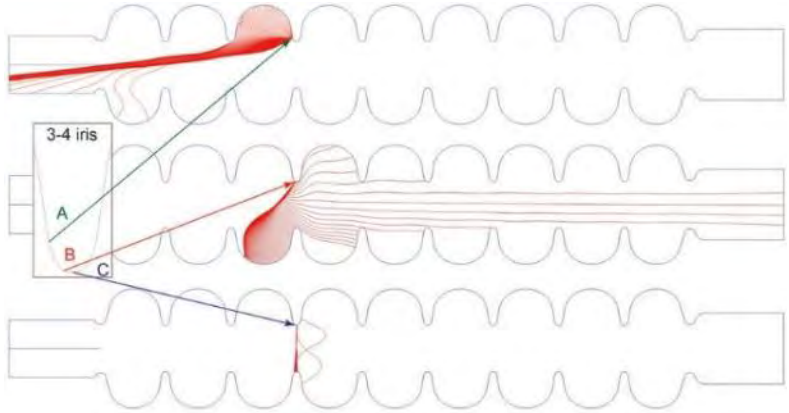
Background and Significance

- **Field emission caused by microscopic particulate contamination**
  - field emission is electron emission from a surface due to high electric fields
  - secondary electrons can cause a self amplified build-up of an electron cloud



J. Knobloch, IEEE Trans. Appl. Superc. 9(2) (1999) 1016.

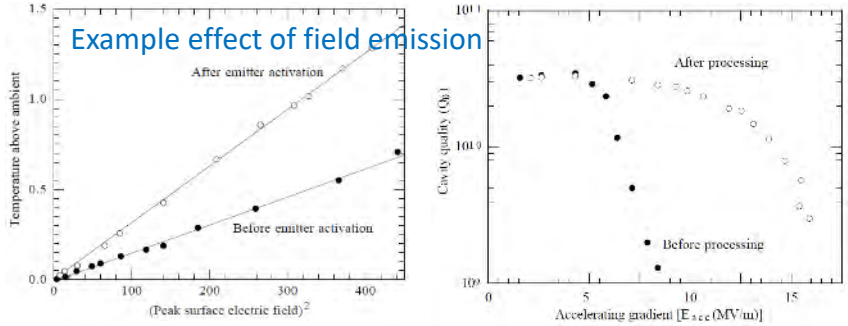
- Causes performance degradation
  - increased heat loss and radiation
  - limits the operation performance of SRF accelerators



H. Sakai et al., Phys. Rev. AB 22, 022002 (2019).

- Several cleaning steps are used, however
  - not always successful
  - not all applicable after cavity or cavity-string assembly
- To avoid contamination, use cleanroom
  - with very low concentration of airborne particulates
- Risk of field emission is observed to increase after assembly
  - new sources of pollution introduced

Example effect of field emission



J. Knobloch, IEEE Trans. Appl. Superc. 9(2) (1999) 1016.

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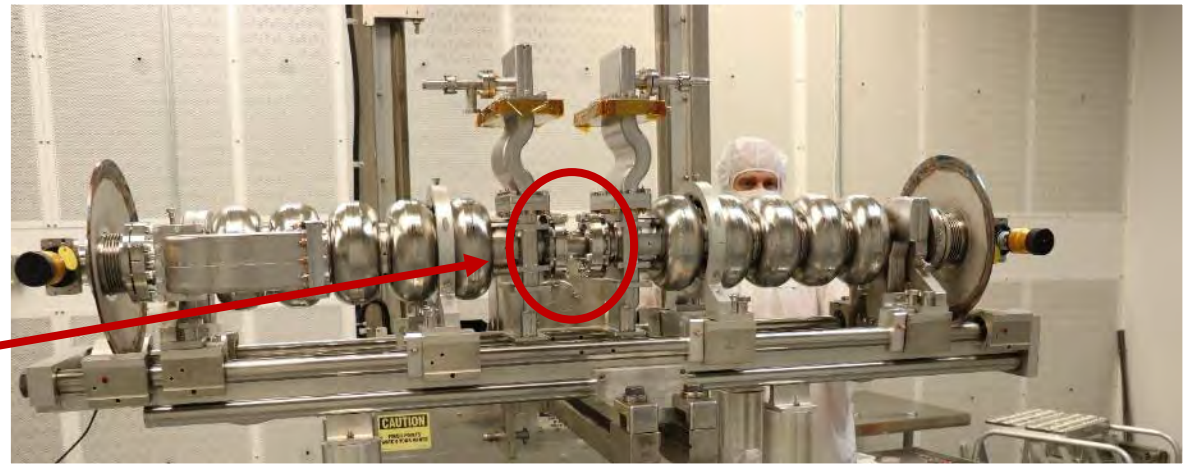
Research Proposal

- **Robotic collaboration helpful to reduce the amount of generated particulate**
  - well controlled movement generating less particulates
  - well suited to perform tedious operations
- Particulates are “generated” by
  - movement of parts, people, etc.
  - scraping metal against metal
    - positioning flanges
    - threading bolts into the flanges

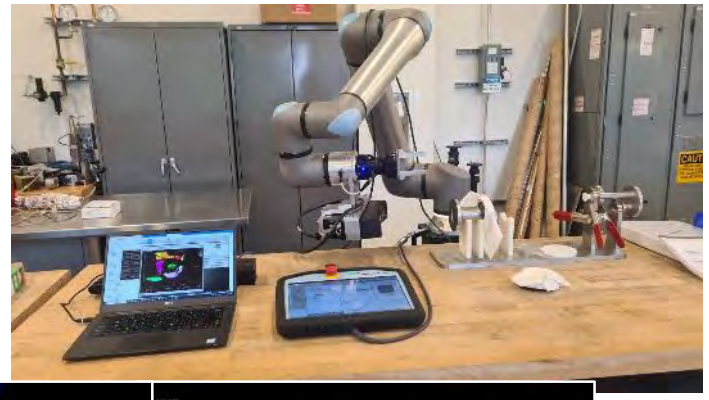


- **C50/C75 cavity pair inner adapter**
  - considered the most tricky and “dirty” work,
  - if flanges not parallel, creates gap in beamline vacuum
  - important for CEBAF energy reach
- **Robot arm** can be programmed to well defined speed and path of motion
  - minimizes risk of particulate contamination inside the cavity

FY24 Progress Report

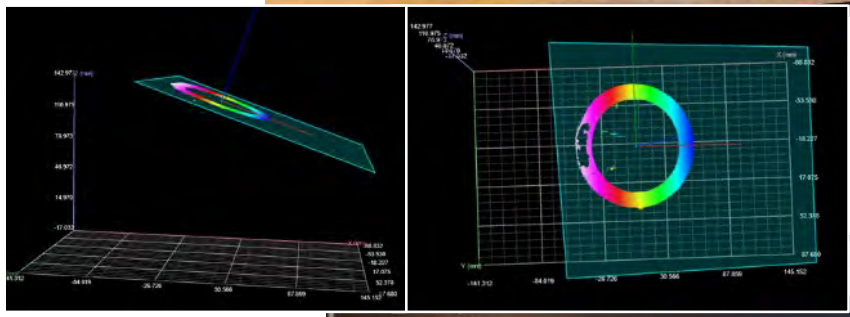
1. Procured robotic system

- **Universal Robot UR20**, 20 kg payload and 1300 mm reach
- **Robotiq Hand-E**, 5 kg payload and 50 mm opening, modifiable fingers
- **LMI Gocator 3250**, 3D snapshot camera with internal image processing



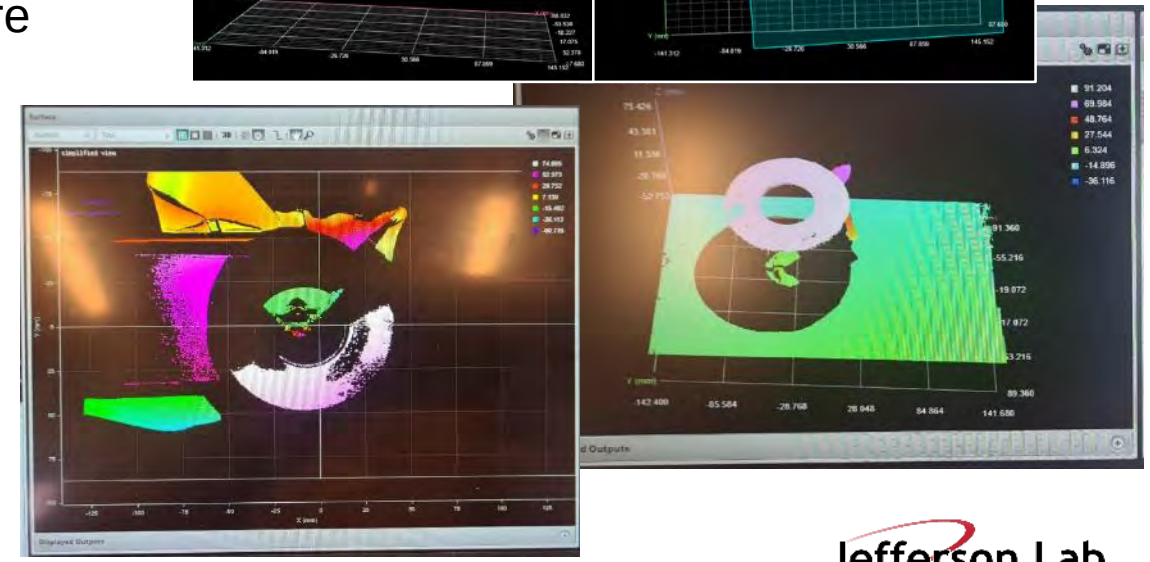
2. Learned to pick and place objects

- move robot arm in a controlled manner
  - *limited by 360° joint rotation and singularities*
  - *software enables relative and repetitive movements*
- vision system & gripper linked to the robot arm software



3. Positioning

- identify parts and send coordinates to the robot arm
- part identification quality depends on optimizing light conditions
  - *intensity, distance, and angle affect image quality*



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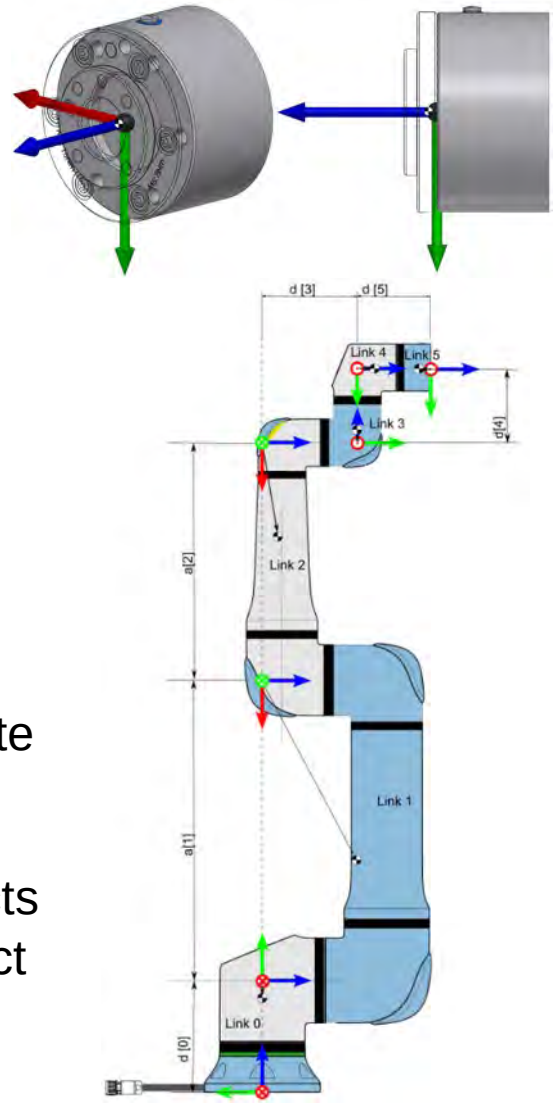
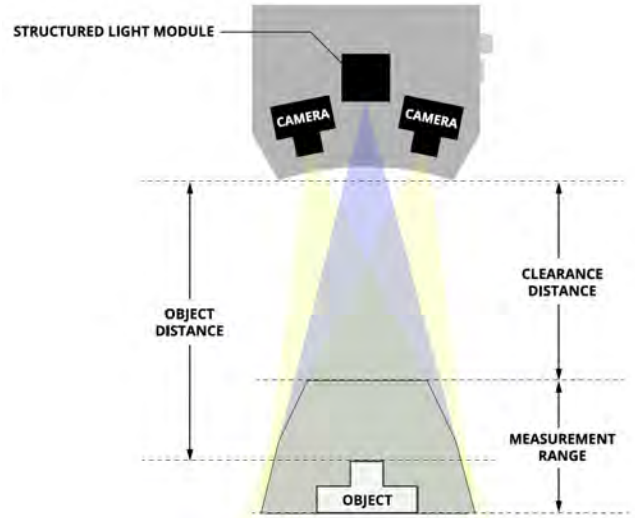
FY24 Progress Report

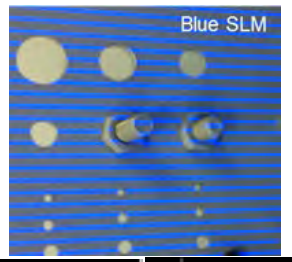
Main implementation efforts

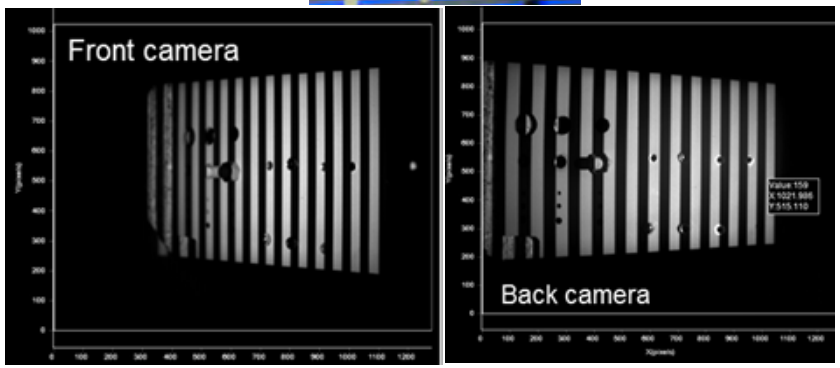
- **Coordinate System Translations**
  - from camera to tool-center-point (TCP)
    - *tool-center-point (TCP) offset & rotation with respect to robot tool output flange*
    - *TCP includes object handled by robot*
  - robot software translates movements between base and TCP

- **Snapshot Imaging**
  - use 2 ping-pong balls to calibrate coordinate system rotation with respect to robot TCP
  - object must be within measurement range
  - light intensity adjustment for different objects
  - use internal software functions to find object and determine centre point & plane









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FY25 Research Plan and Timeline

3. Implement accurate positioning

- optimize gripper fingers to improve grabbing
  - *affects accurate positioning*
- optimize force application

4. Test assembly on mock-up

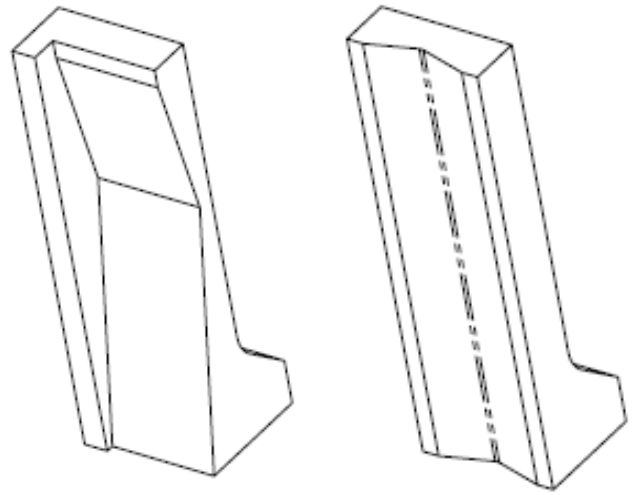
- run through whole assembly procedure
  - measure particulate generation
- training cleanroom technicians
  - set and test safety controls

5. Install in cleanroom

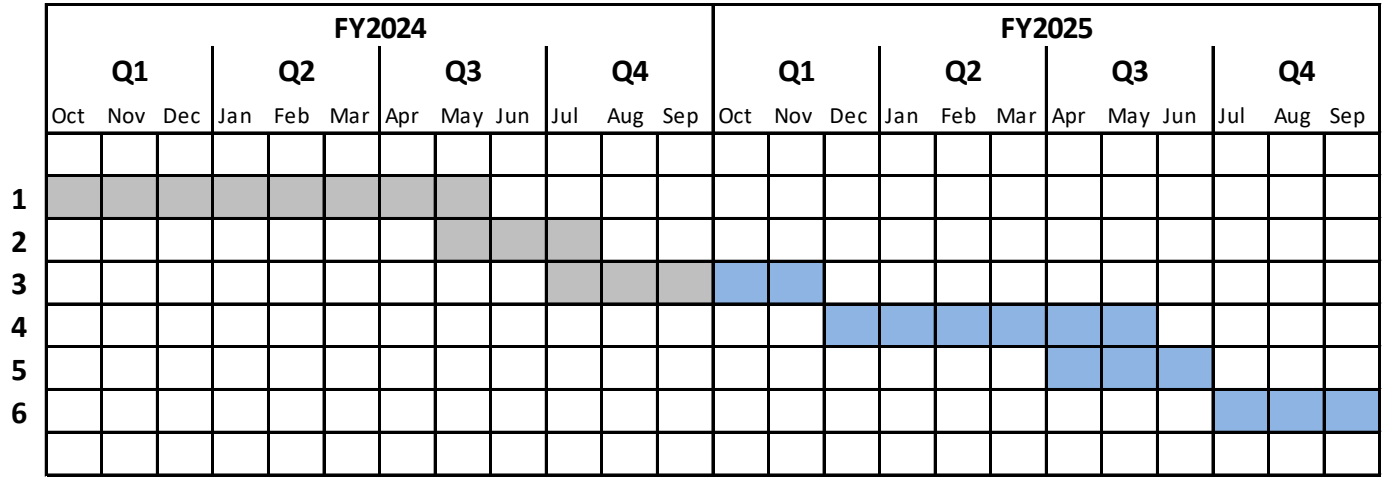
- **[NEW]** use a pedestal to stabilize robot on the double floor

6. Actual assembly in cleanroom

- with subsequent test in VTA



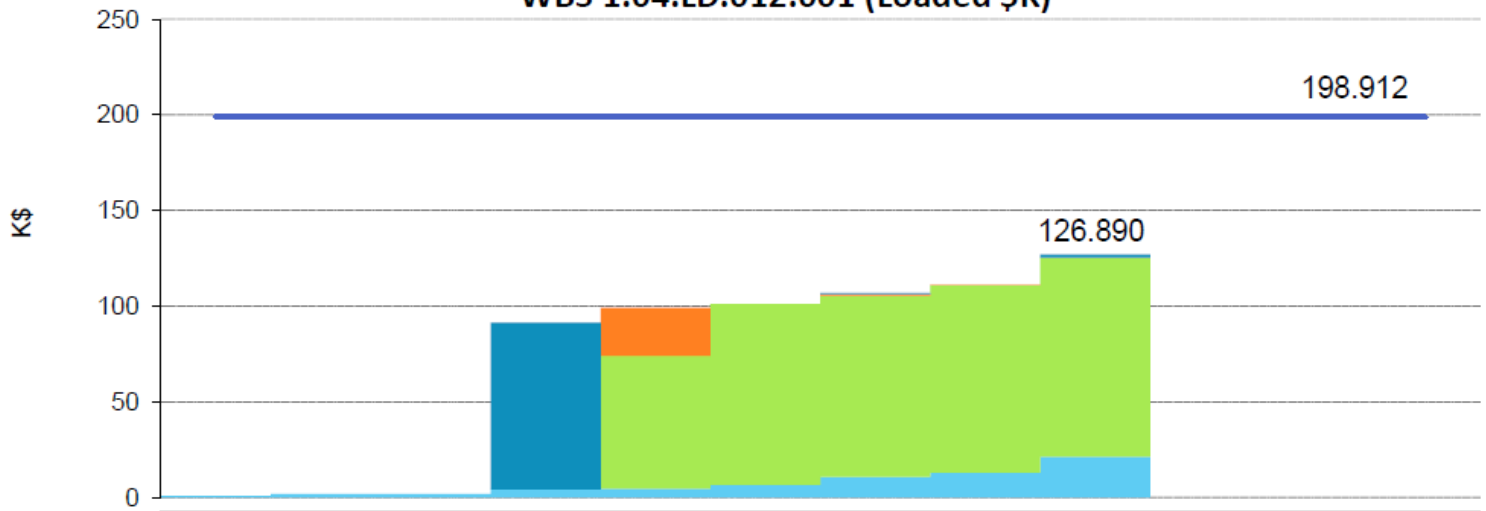
Robotic Collaboration for Particle Free SRF Assembly



FY24 Financial Report

- procured robot with larger reach and payload capability as camera + gripper = 7 kg
- final components delivered 3 months later than foreseen (end-May)
  - have been low in personnel resources
  - working hard and catching up: 186 hours up to 30 June; 121 hours during 1-15 July

Robotic Collaboration for Particle Free SRF Assembly
Roger Ruber (LD2401)
WBS 1.04.LD.012.001 (Loaded $K)



	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24
YTD Spending	0.810	1.673	1.673	91.298	99.079	101.061	106.777	110.940	126.890	0.000	0.000	0.000
Pending	0.000	0.000	0.000	87.087	0.000	0.000	0.429	0.000	1.548	0.000	0.000	0.000
Open Obligations	0.000	0.000	0.000	0.000	25.092	0.000	1.008	0.227	0.000	0.000	0.000	0.000
Expenses	0.000	0.000	0.000	0.000	69.487	94.585	94.585	97.936	103.981	0.000	0.000	0.000
Labor	0.810	1.673	1.673	4.210	4.500	6.476	10.754	12.777	21.361	0.000	0.000	0.000
Funding	198.912	198.912	198.912	198.912	198.912	198.912	198.912	198.912	198.912	198.912	198.912	198.912

Budget

Requested Budget for Effort by Investigator					
Name of Investigator	**Role (PI, Co-I, etc.)**	**FY25 Budget ($)**	**FY25 Effort (% FTE)**	**Total Budget ($)**	**Total Effort (%FTE)**
Roger Ruber	PI		30		30
Justin Kent	engineering		11		11
Danny Forehand	engineering		11		11
Cleanroom Technician	assembly assistance		11		11
	Subtotal for personnel	***119,900***	***63***	***119,900***	***63***
Equipment	robot arm cleanroom suit	5,000		5,000	
	cleanroom pedestal & installation	24,886		24,886	
Materials/ Supplies	assembly mock-up	20,000		20,000	
	Subtotal for equipment and materials/supplies	***49,886***		***49,886***	
	Total Direct Costs	***169,800***		***169,800***	
Material Handling	6.12%	1,829		1,829	
Facilities & Infrastructures	19.49%	23,371		23,371	
	Total Indirect Costs	***25,200***		***25,200***	
	Total for effort	**195,000**		**195,000**	

Questions and Answers

1. Given the issues of the sensing system to cleanly resolve the items to be picked up by the robotic arm, you have focused on investigating the ambient lighting.

   What about studies of the background beneath the components to improve contrast?

Answer:

In our experience, surface and its edges are important.

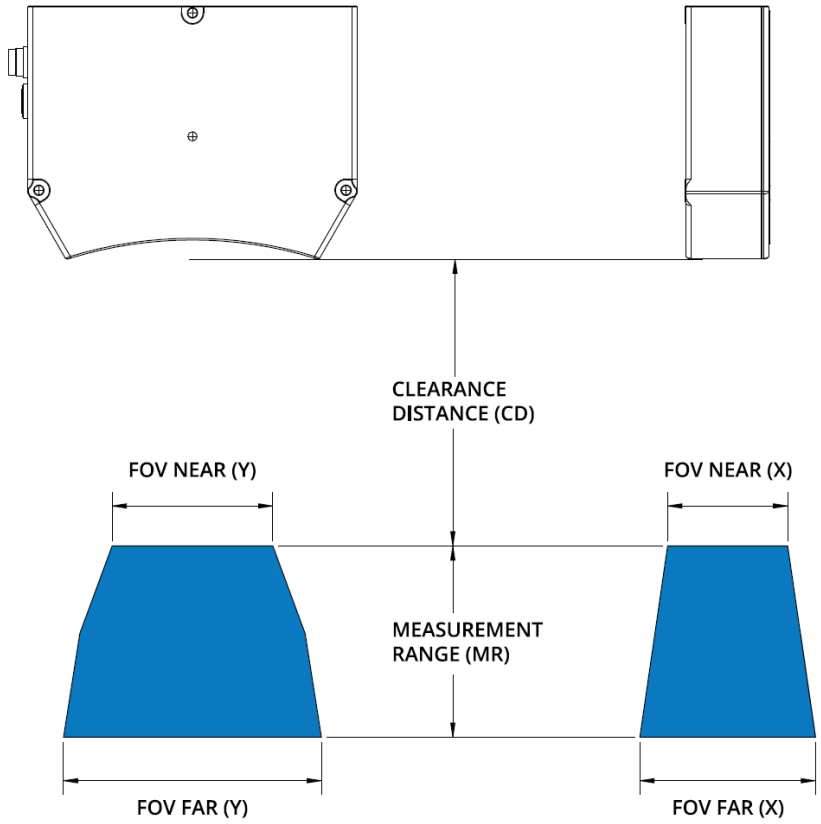
Data filters can be applied to smooth, decimate etc. data, or for diffuse or reflective material surface.

Camera uses **stereo correlation**,
based on distance between cameras and viewing angle.

Targets (background) beyond the measurement range will result in invalid data.

At the **far end** of the measurement range (MR),
the field of view (FOV) is larger, but the resolution is lower.

At the **near end**,
the field of view (FOV) is smaller, but the resolution is higher.



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FY24 Supplemental Budget Proposal

Acquire a 2nd robot to perform “blow-off” cleaning of parts

- Standard cleanroom procedure
  - *every part is cleaned before use*
  - blow-off nozzle with ionized nitrogen while measuring particulate levels
  - **until zero counts** are reached for particulate >0.3μm
    - *can take a few minutes to more than an hour*

- **Robot is well suited for this tedious and repetitive task**
  - *does not get tired nor injured from repetitive movement*
  - mount ionized nitrogen nozzle and particle counter on robot tool output flange
  - robot 1 can pick-up the part, robot 2 cleans with ionized nitrogen
  - no human interaction, reduces risk of particulate

- Requested budget $43.4k
  - Universal Robots UR5e, mobile pedestal, blow-off gun (particle counter available from cleanroom)