CRITICAL DESIGN REVIEW

TEAM G

EXCALIBR

“

PROJECT DESCRIPTION

Multi-sensor Capture System :

Audio-Visual Sensors

Calibration:

- Fast
- Efficient
- Accurate
- Precise
- Repeatable
- Reproducible

"

USE CASE

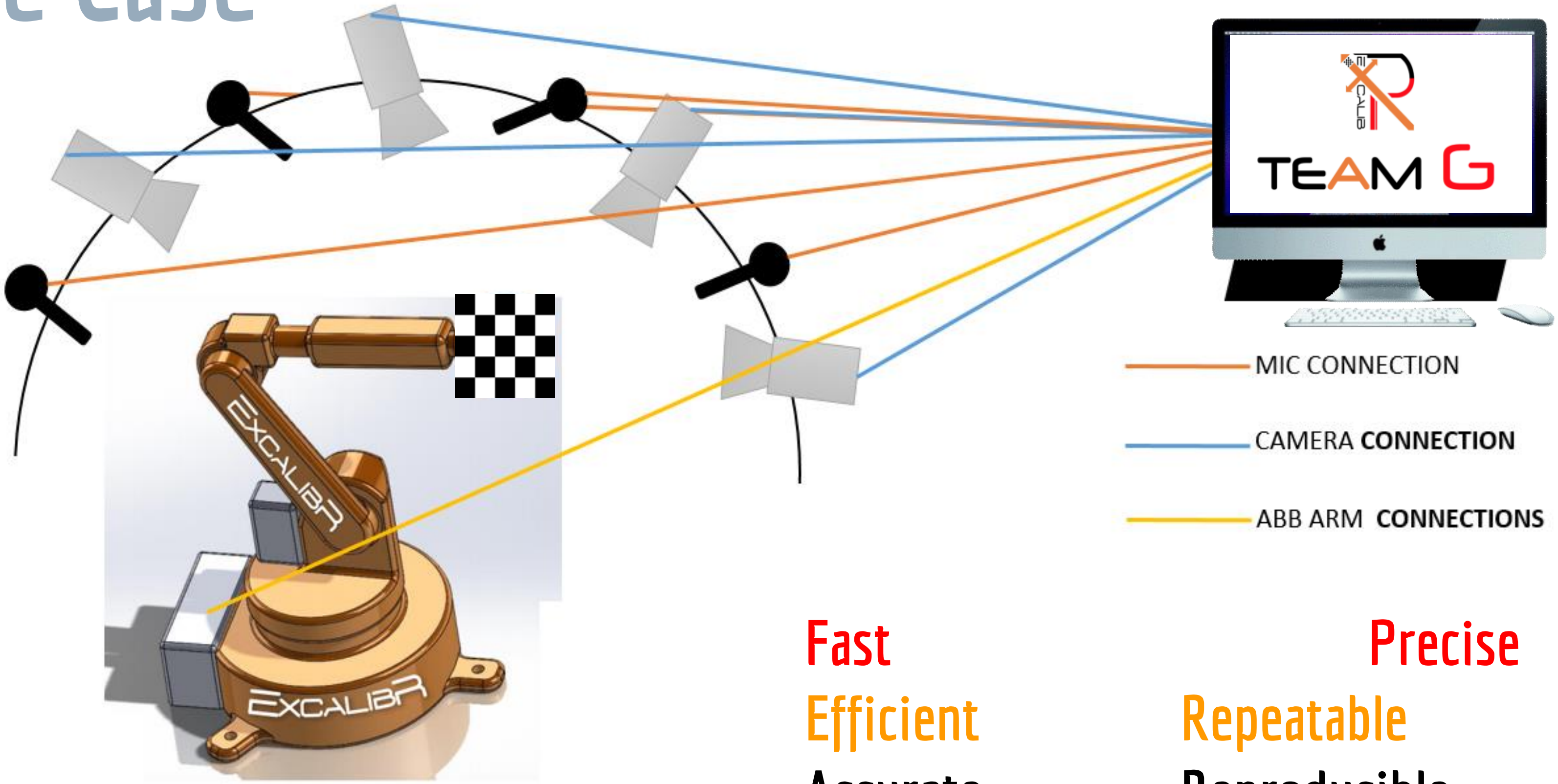
Use Case

Manually

Tired Engineer

Dubious Results

Use Case



Fast
Efficient
Accurate

Precise
Repeatable
Reproducible

“

SYSTEM LEVEL REQUIREMENTS

Functional Requirements

MANDATORY SYSTEM LEVEL REQUIREMENTS
Functional Requirements: M.F.1: Operate Autonomously M.F.2: Fabricate calibration target M.F.3: Control and Manipulate the calibration target by robot arm M.F.4: Take high-resolution, stable and clear pictures of calibration target M.F.5: Implement geometry camera calibration algorithms on RGB cameras M.F.6: Calibrate the camera on end-effector for light-field calibration M.F.7: Implement photometric calibration and generate camera response function curve for GRB cameras M.F.8: Implement sensor noise correction on RGB cameras M.F.9: Build the calibration pipeline for multi cameras

Performance Requirements

MANDATORY SYSTEM LEVEL REQUIREMENTS	DESIRABLE SYSTEM LEVEL REQUIREMENTS
Performance requirements: M.P.1: One-click Operation M.P.2: Fabricate the target with 50 micrometers tolerance M.P.3: Manipulate the robot with 100 micrometers accuracy M.P.4: Take pictures with multiple RGB cameras more than 10MP at 30fps M.P.5: Complete one geometry calibration in at most 8 hours M.P.6: The sensor noise correction algorithm must reduce the variance of the flat-field image for 90% or more. M.P.7: Avoid collisions - keep a distance 0.3m away from the dome extremities and sensors M.P.8: Build calibration pipeline for 20 GRB cameras M.P.9: The reprojection error of the geometry calibration result should be less than 1 pixel. M.P.10: Complete light field calibration in 4 hours.	**Performance requirements:** D.P.1: Build calibration pipeline for 100 GRB cameras D.P.2: The reprojection error of the geometry calibration result should be less than 0.1 pixel.

Non-Functional Requirements

MANDATORY SYSTEM LEVEL REQUIREMENTS	DESIRABLE SYSTEM LEVEL REQUIREMENTS
Non-functional requirements: M.N.1: Complete the project by May, 2017. M.N.2: Keep budget within $5,000. M.N.3: Make the system user-friendly.	**Non-functional requirements:** D.N.1: Create a user-friendly GUI or physical button

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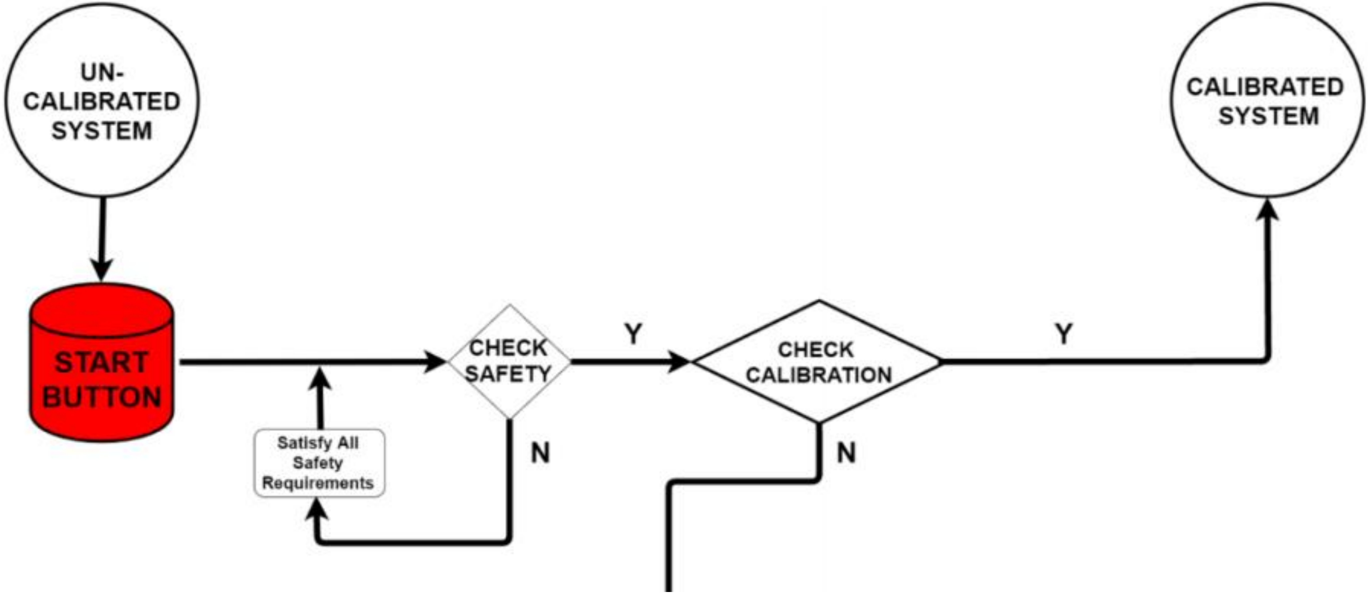
ARCHITECTURES

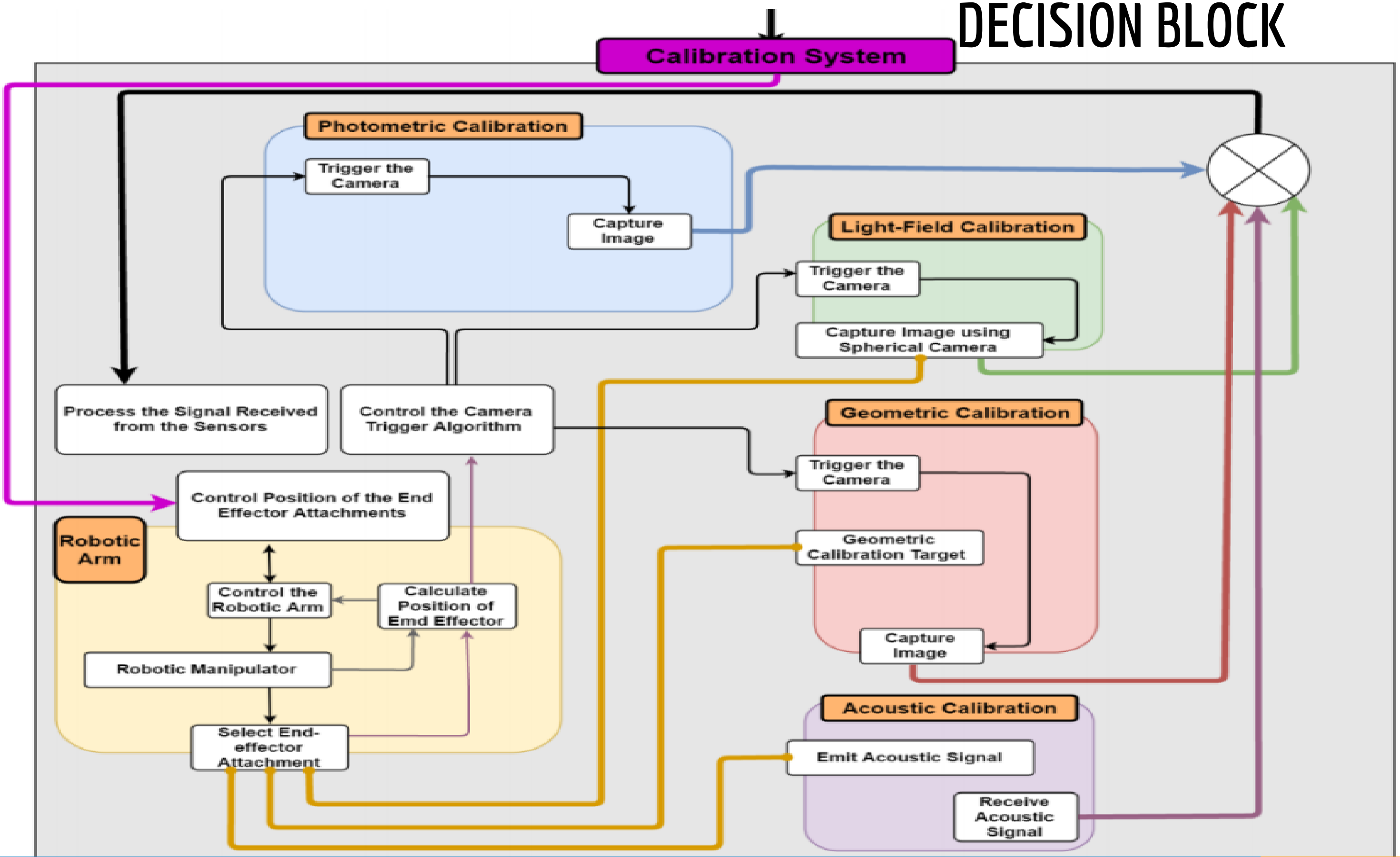
Functional Architecture



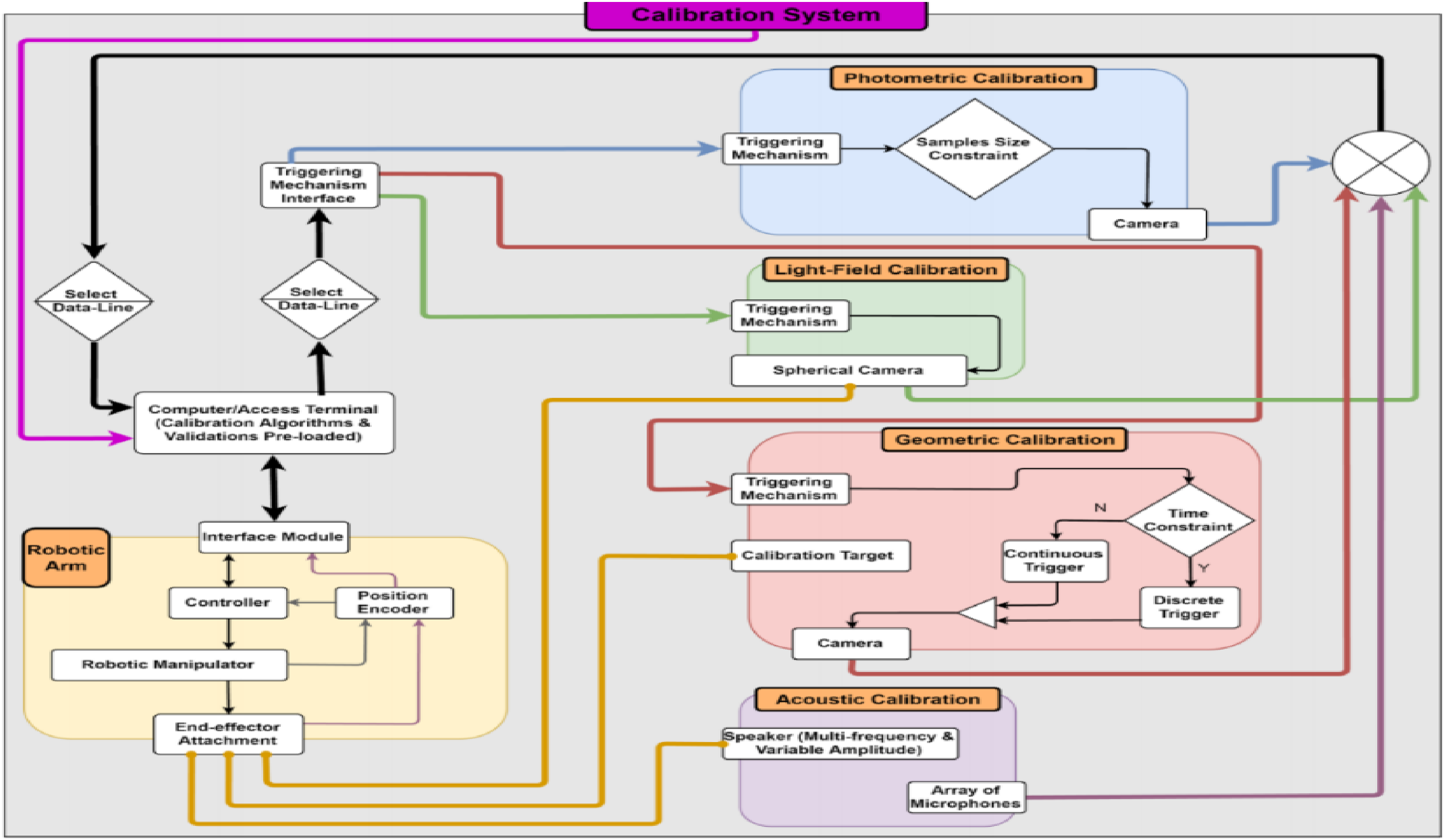
DECISION
BLOCK

Functional Architecture

DECISION BLOCK



Cyber-Physical Architecture



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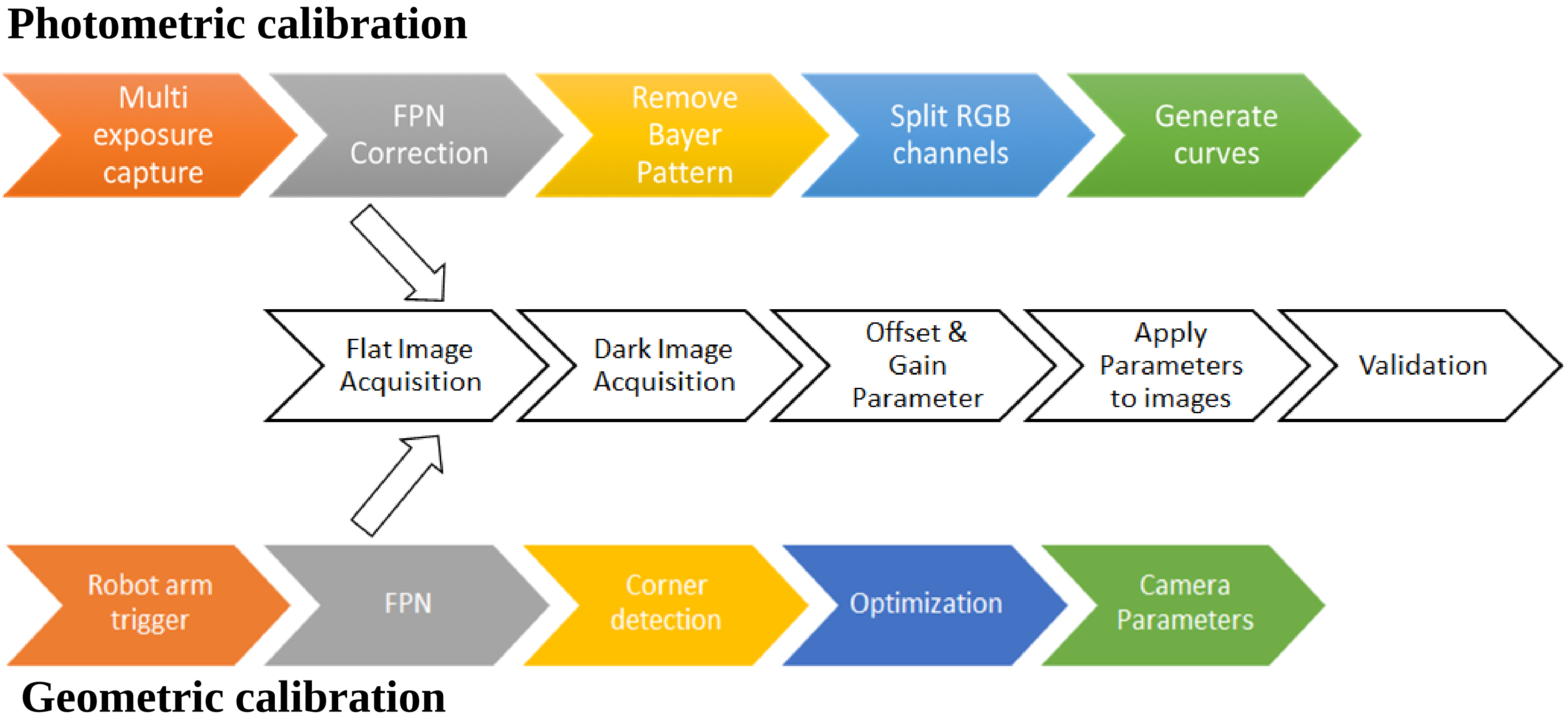
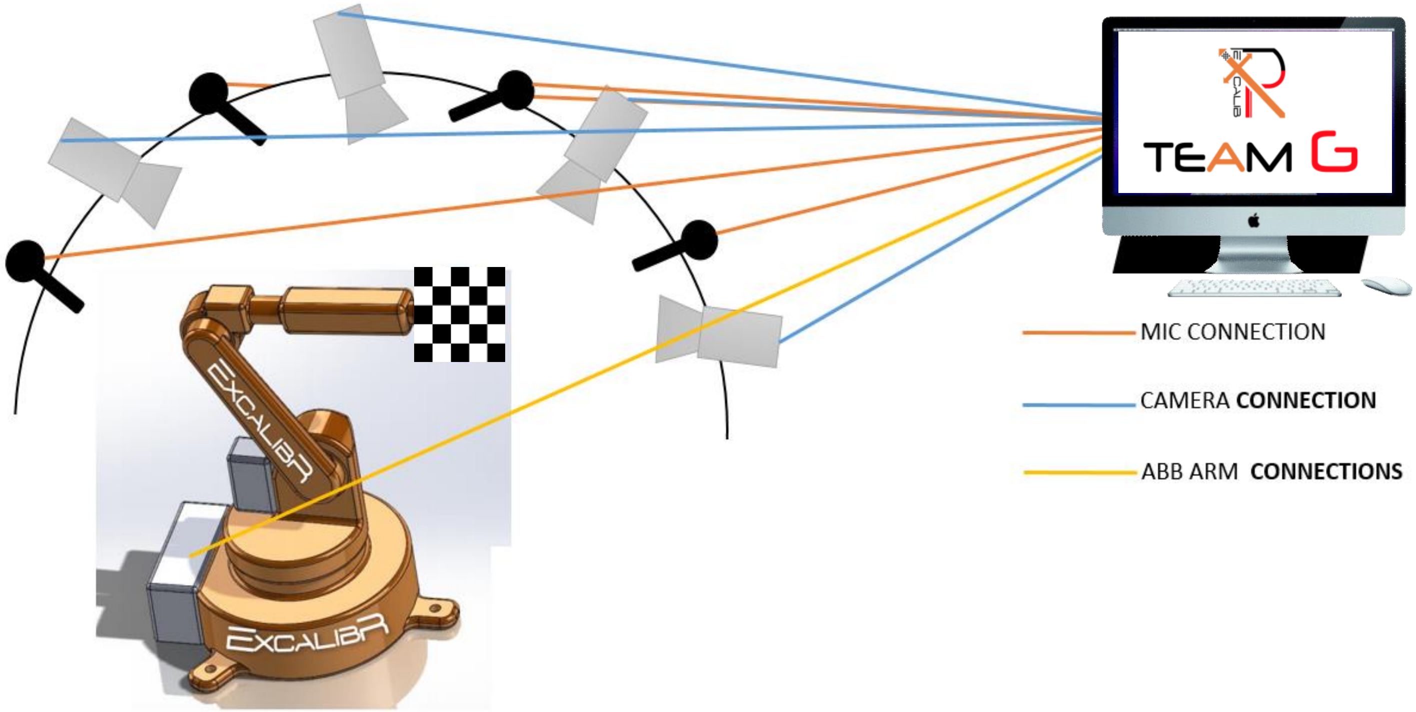
CURRENT SYSTEM STATUS

Subsystem dependency



Overall system description



Targeted requirements

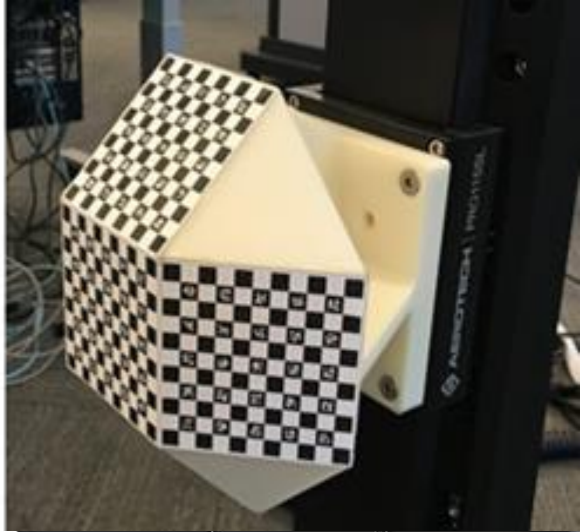
Subsystem	Functional requirements	Performance requirements
Calibration target	M.F.2: Fabricate calibration target	
Aerotech robot arm	M.F.1: Operate Autonomously M.F.3: Control and Manipulate the calibration target by robot arm	M.P.3: Manipulate the robot with 100 micrometers accuracy
Photometric calibration	M.F.7: Implement photometric calibration and generate camera response function curve for GRB cameras M.F.8: Implement sensor noise correction on RGB cameras	M.P.4: Take pictures with multiple RGB cameras more than 10MP at 30fps M.P.6: The sensor noise correction algorithm must reduce the variance of the flat-field image for 90% or more.
Geometric calibration	M.F.4: Take high-resolution, stable and clear pictures of calibration target M.F.5: Implement geometry camera calibration algorithms on RGB cameras M.F.9: Build the calibration pipeline for multi cameras	M.P.4: Take pictures with multiple RGB cameras more than 10MP at 30fps M.P.5: Complete one geometry calibration in at most 8 hours M.P.9: The reprojection error of the geometry calibration result should be less than 0.5 pixel.

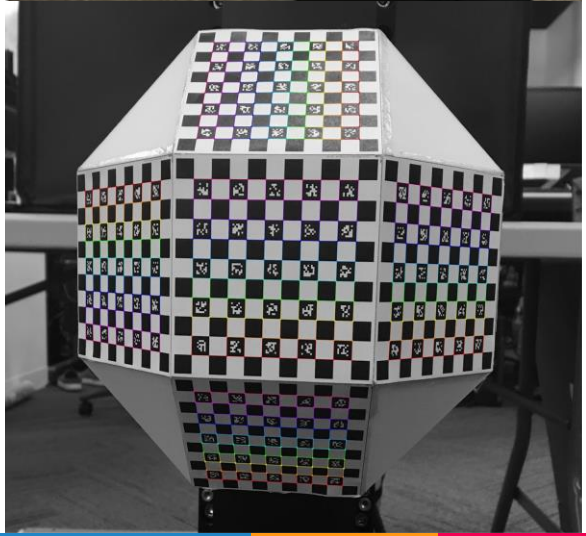
Calibration Target

1. 3D shape (Rhombicuboctahedron)

2. Corner detection work

3. Postpone because of sponsor concern



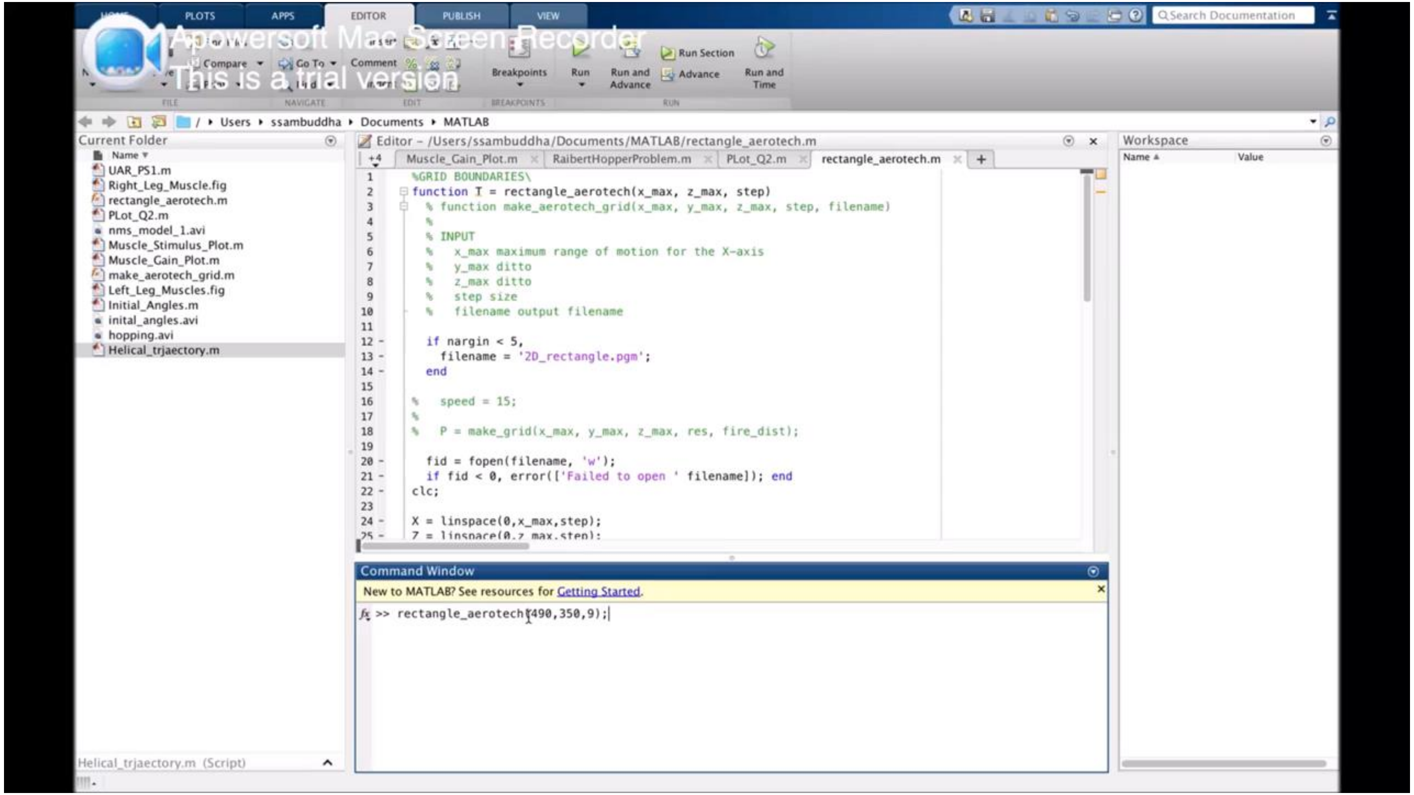


Subsystem: Robotic Arm

1. PSO Triggered Image Capture

2. Trajectory Generation

3. Autonomous Operation- Script generation in MATLAB

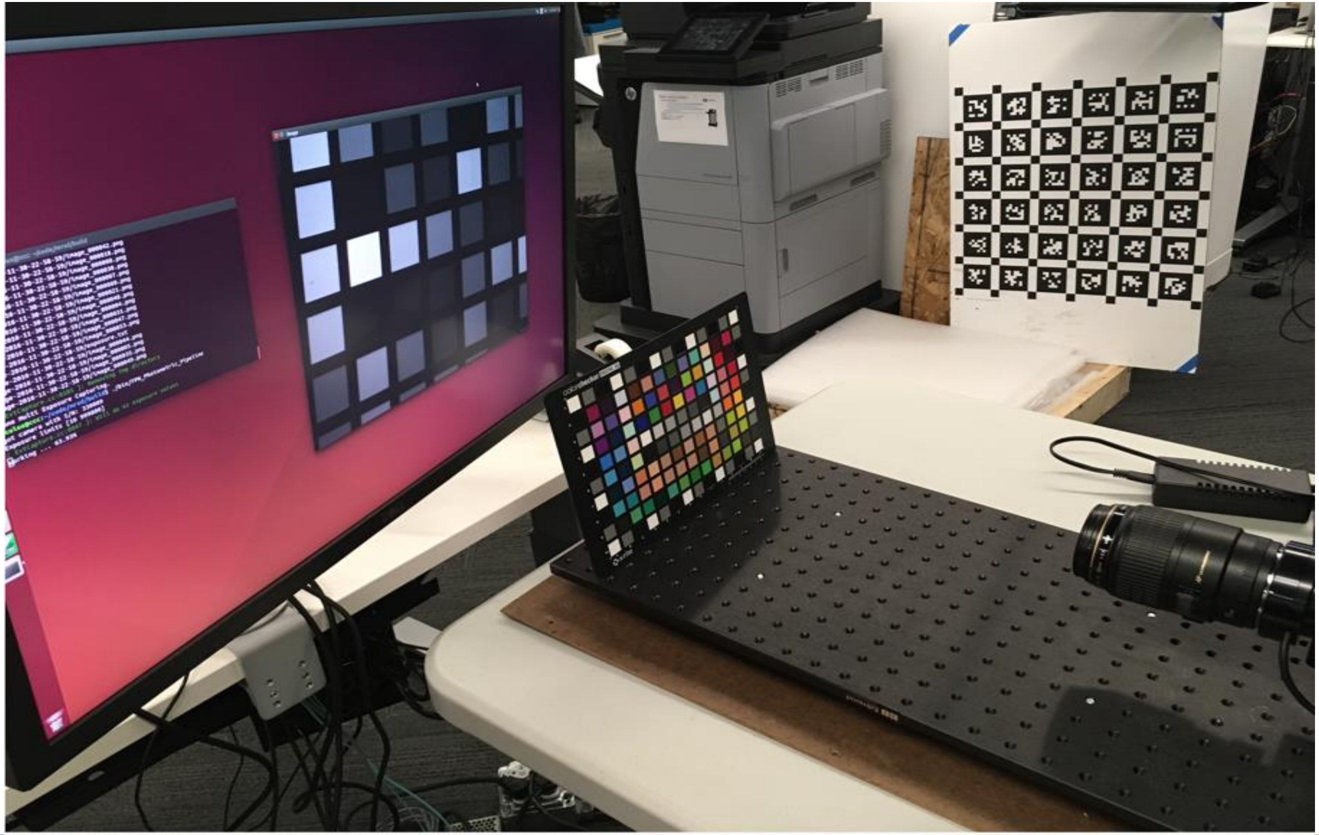

Apowersoft Mac Screen Recorder
This is a trial version
PLOTS
APPS
EDITOR
PUBLISH
VIEW
Search Documentation
Compare
Go To
Comment
Breakpoints
Run
Run and Advance
Run Section
Advance
Run and Time
/ Users ssambuddha Documents MATLAB
Current Folder
Name
UAR_PS1.m
Right_Leg_Muscle.fig
rectangle_aerotech.m
PLot_Q2.m
nms_model_1.avi
Muscle_Stimulus_Plot.m
Muscle_Gain_Plot.m
make_aerotech_grid.m
Left_Leg_Muscles.fig
Initial_Angles.m
inital_angles.avi
hopping.avi
Helical_trjaectory.m
Helical_trjaectory.m (Script)
Editor - /Users/ssambuddha/Documents/MATLAB/rectangle_aerotech.m
Muscle_Gain_Plot.m
RaibertHopperProblem.m
PLot_Q2.m
rectangle_aerotech.m
%GRID BOUNDARIES\
function T = rectangle_aerotech(x_max, z_max, step)
% function make_aerotech_grid(x_max, y_max, z_max, step, filename)
%
% INPUT
% x_max maximum range of motion for the X-axis
% y_max ditto
% z_max ditto
% step size
% filename output filename
if nargin < 5,
filename = '2D_rectangle.pgm';
end
% speed = 15;
%
% P = make_grid(x_max, y_max, z_max, res, fire_dist);
fid = fopen(filename, 'w');
if fid < 0, error(['Failed to open ' filename]); end
clc;
X = linspace(0,x_max,step);
Workspace
Name
Value
Command Window
New to MATLAB? See resources for Getting Started.
>> rectangle_aerotech(490,350,9);

Photometric Calibration

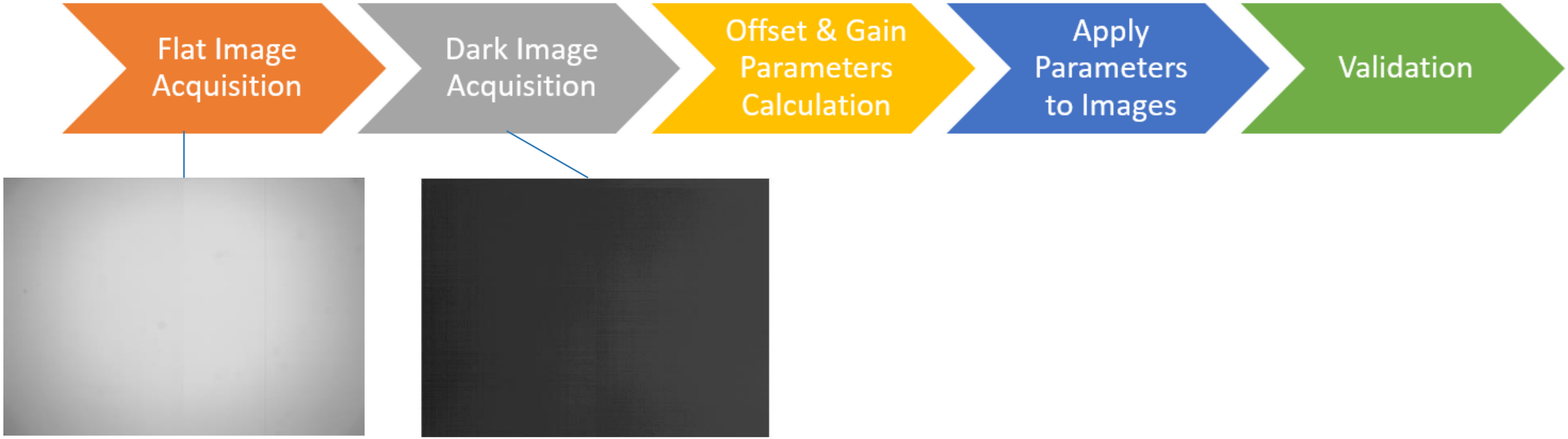
$$Z_{ij} = f(E_i \Delta t_j)$$

Z - pixel value
E - radiance
f - response function
t - exposure time

Multi-exposure Capturing

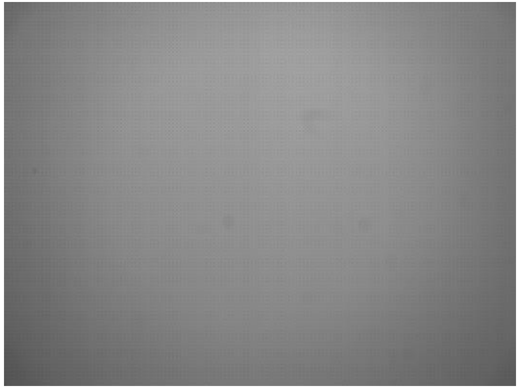


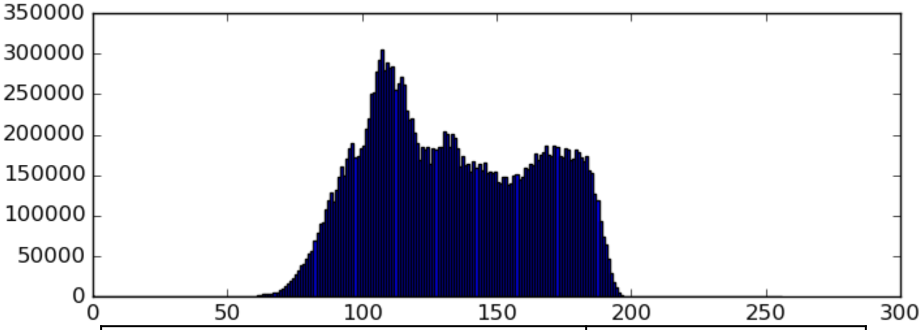
FPN



$$Corrected\ Image = \frac{(Raw - Dark) \times median(Flat - Dark)}{(Flat\ Field\ Image)} = (R - D) \times G$$

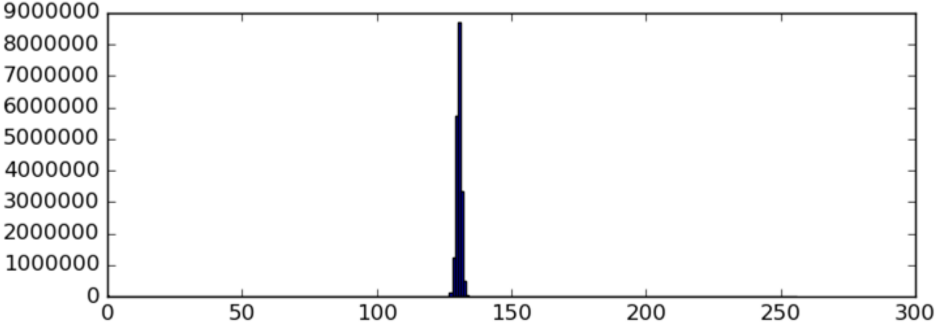
Flat Image (Raw)



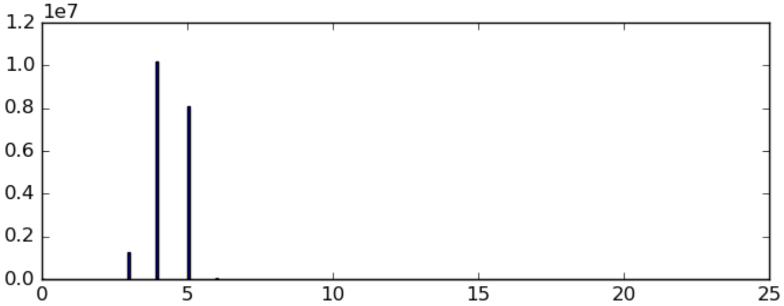


FVE performance requirement	Result
Reduce the variance of the flat-field image by 90% or more	Reduce the variance by 96.9926%

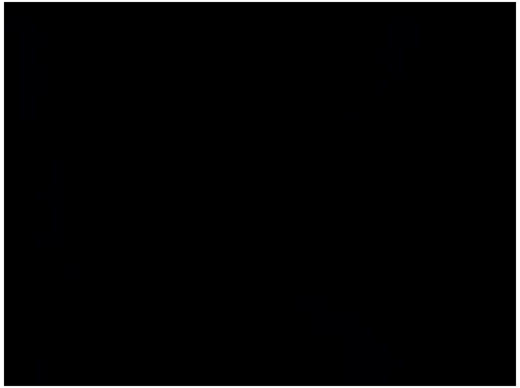
Flat Image (Corrected)

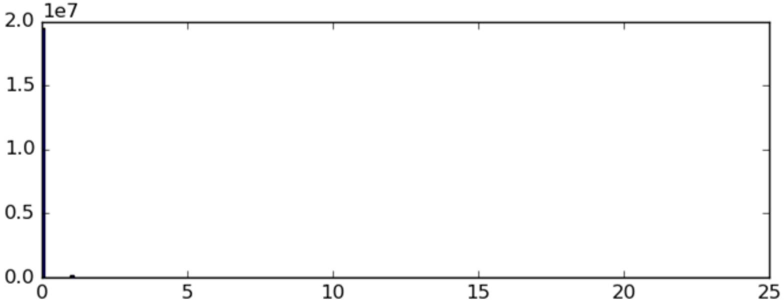


Dark Image (Raw)

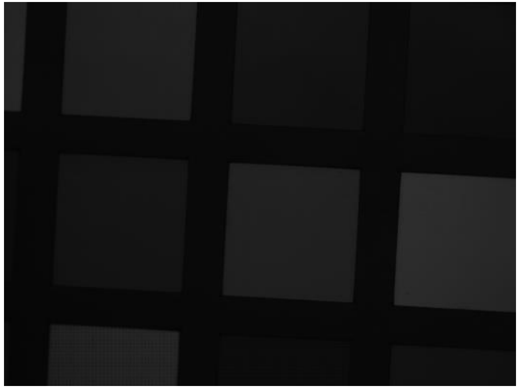


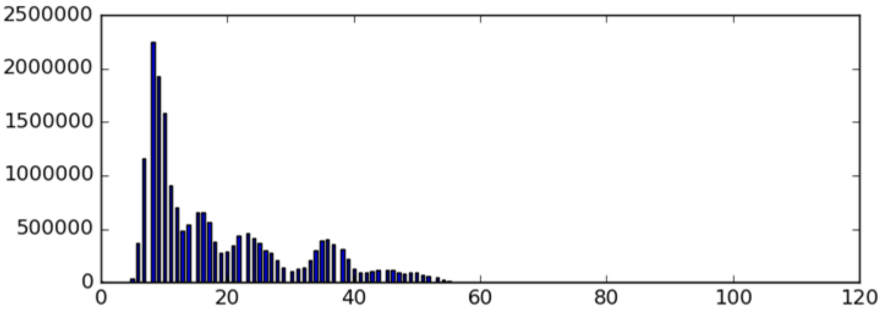
Dark Image (Corrected)



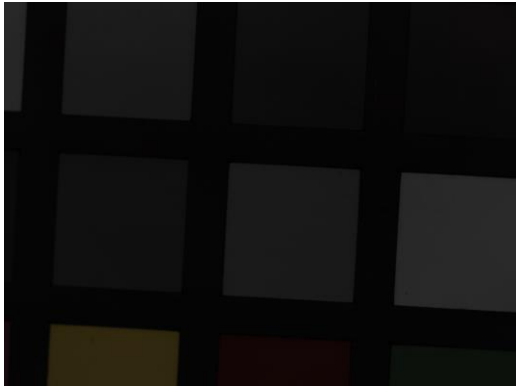


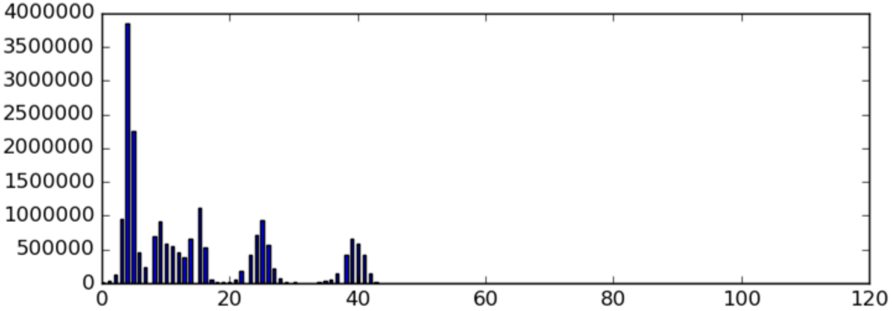
Test Image (Raw)





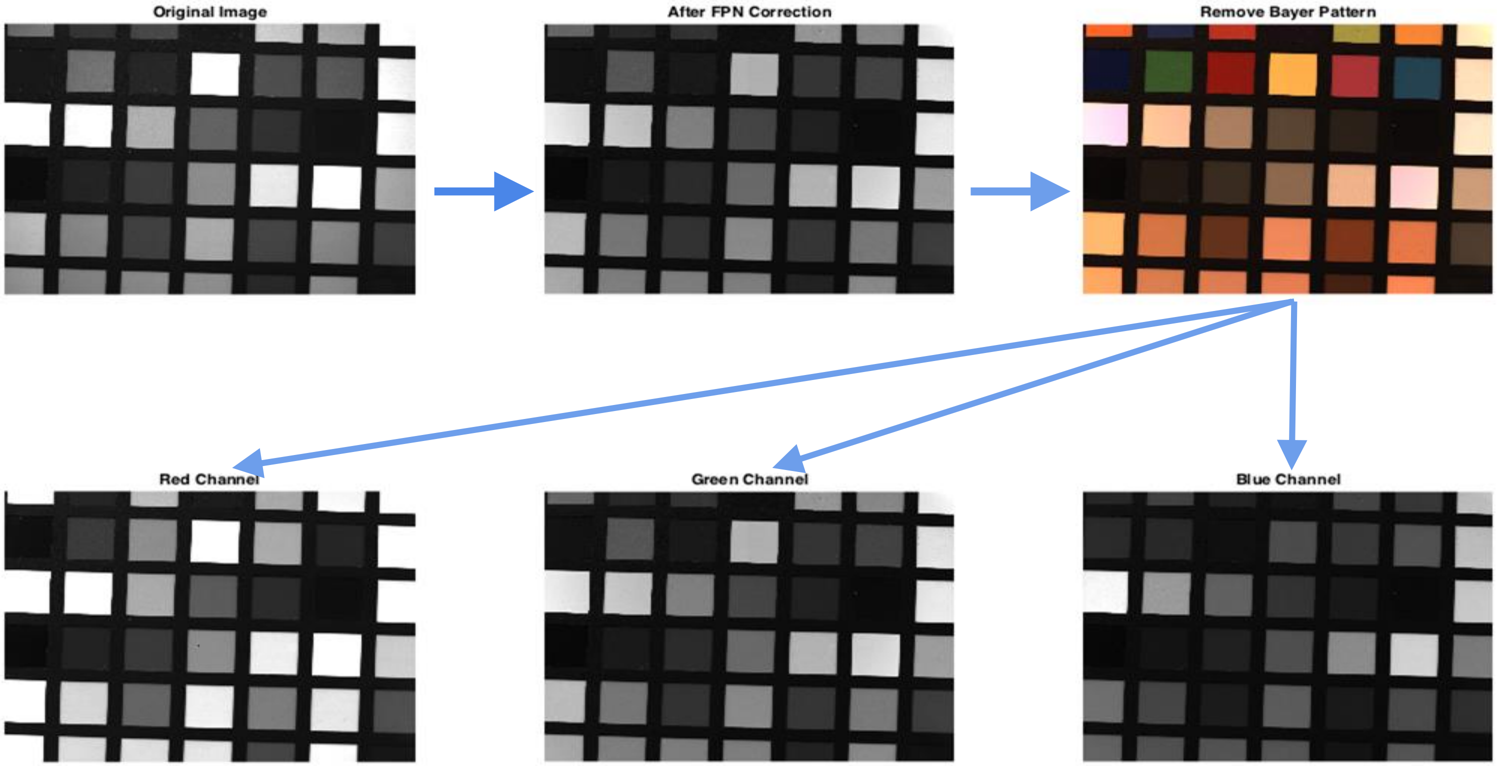
Test Image (Corrected)



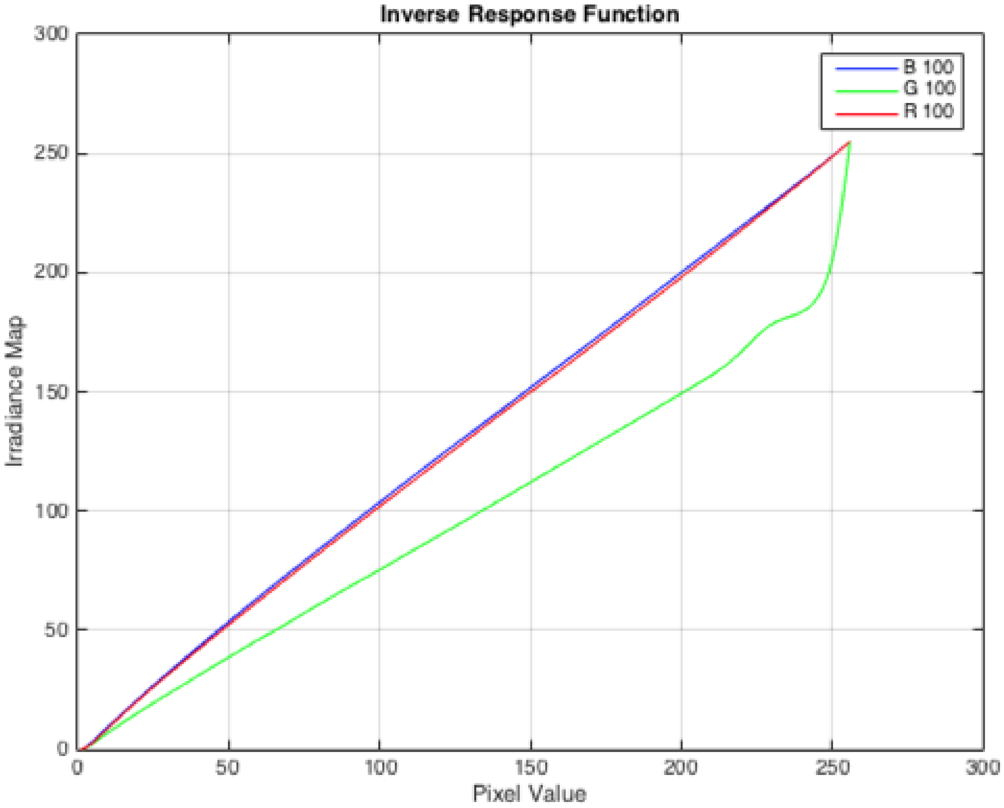


Bayer Pattern

Image Processing Flow: Splitting Channels

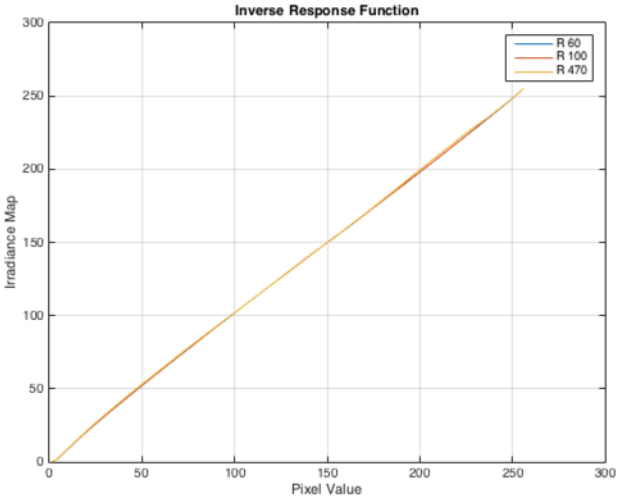


Result: ICRF Curve

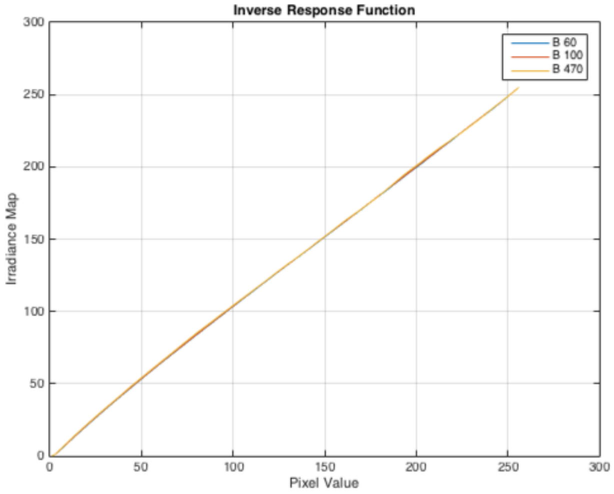


FVE requirement	Result
Successful generation of an inverse camera response function	Successfully done

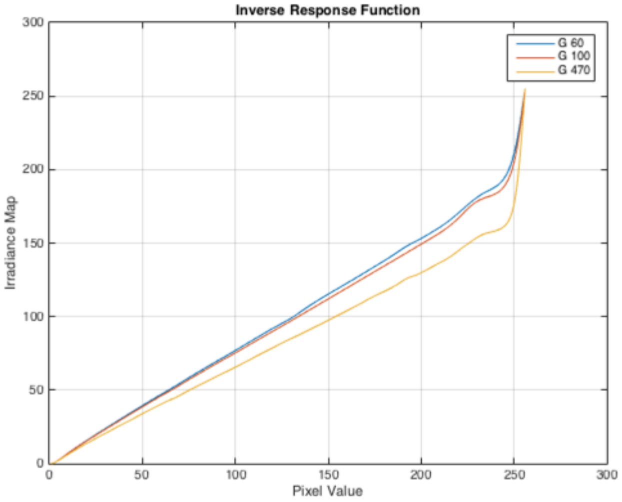
Analysis: ICRF Curve



R



B



G

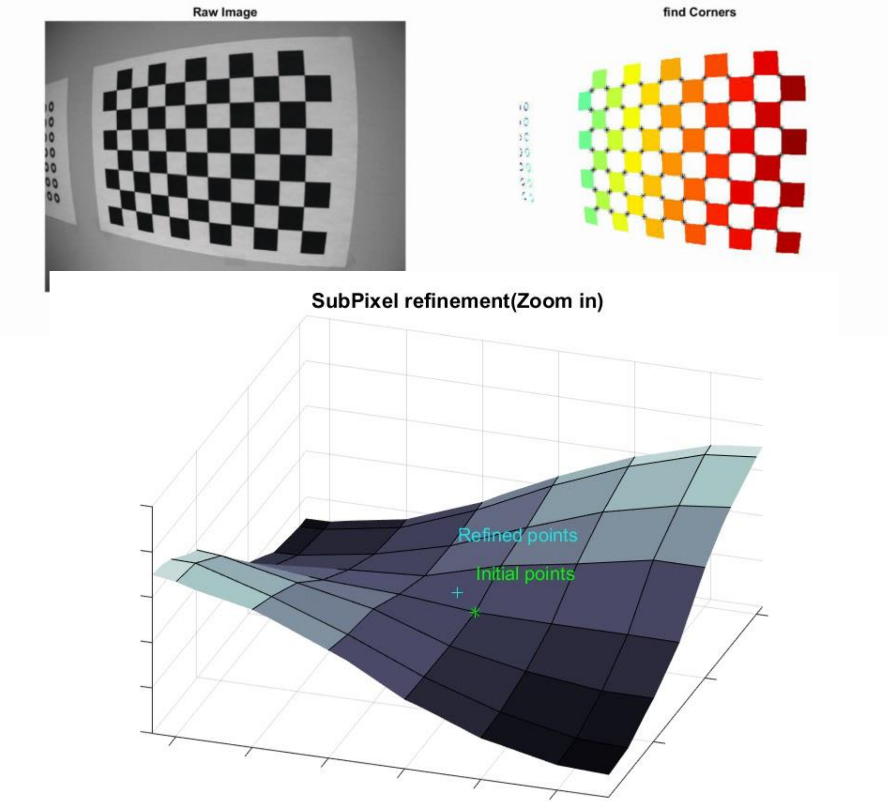
Subsystem: Geometric Calibration

-Corner detection

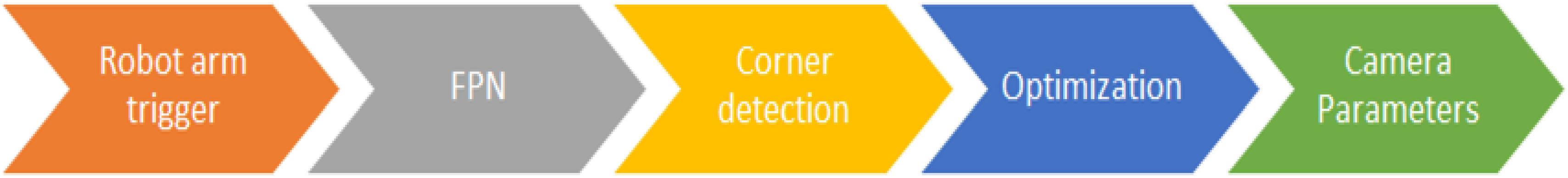
- -quadrangle method
- -subpixel refinement

-Optimization

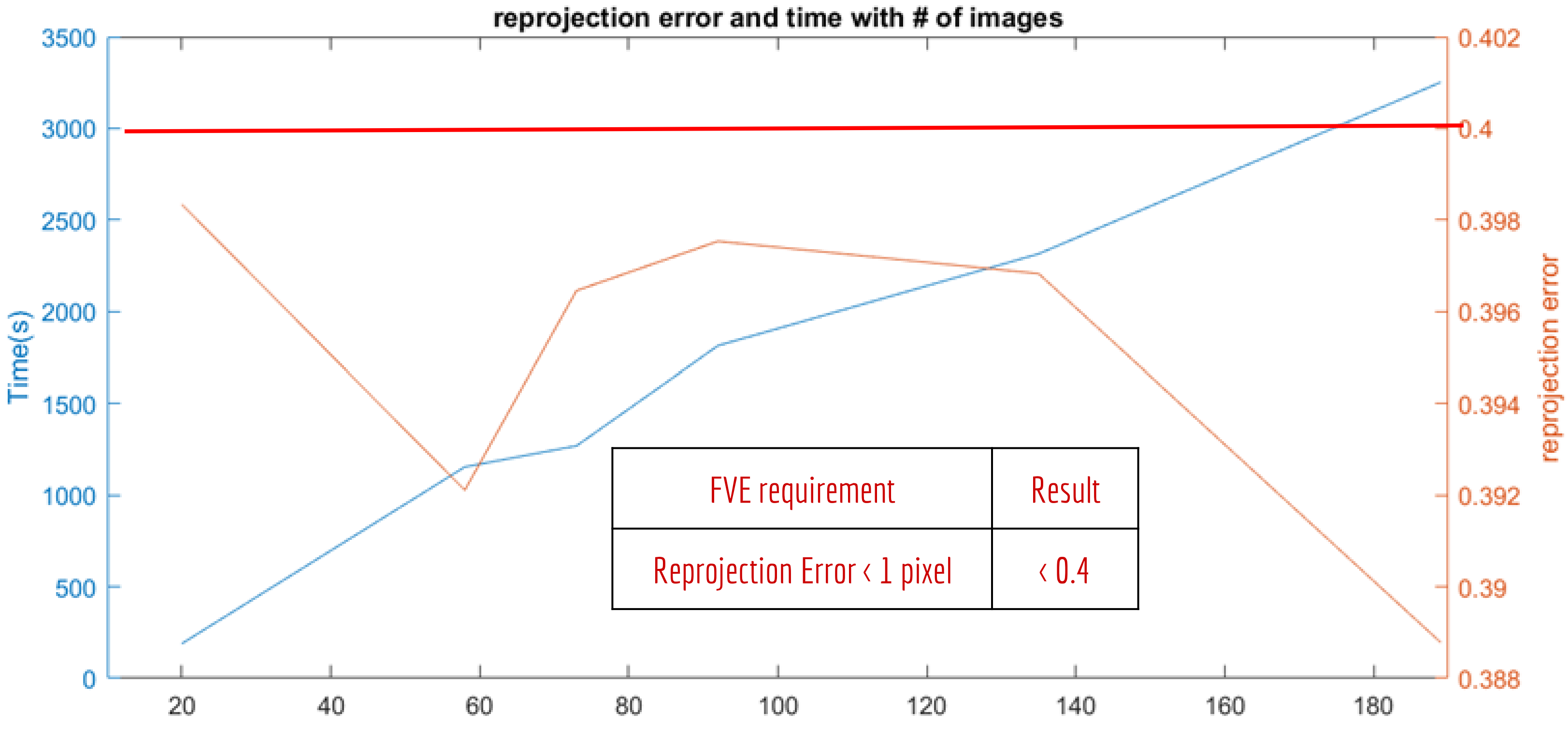
- -linear estimation
- -bundle adjustment



Geometric Calibration



Result: Geometric Calibration



FVE requirement	Result
Reprojection Error ‹ 1 pixel	‹ 0.4

Result: Time Cost

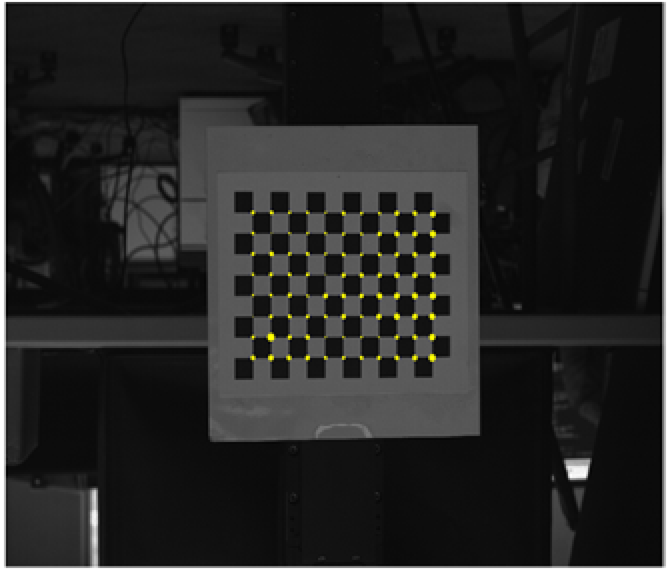
For 144 images,

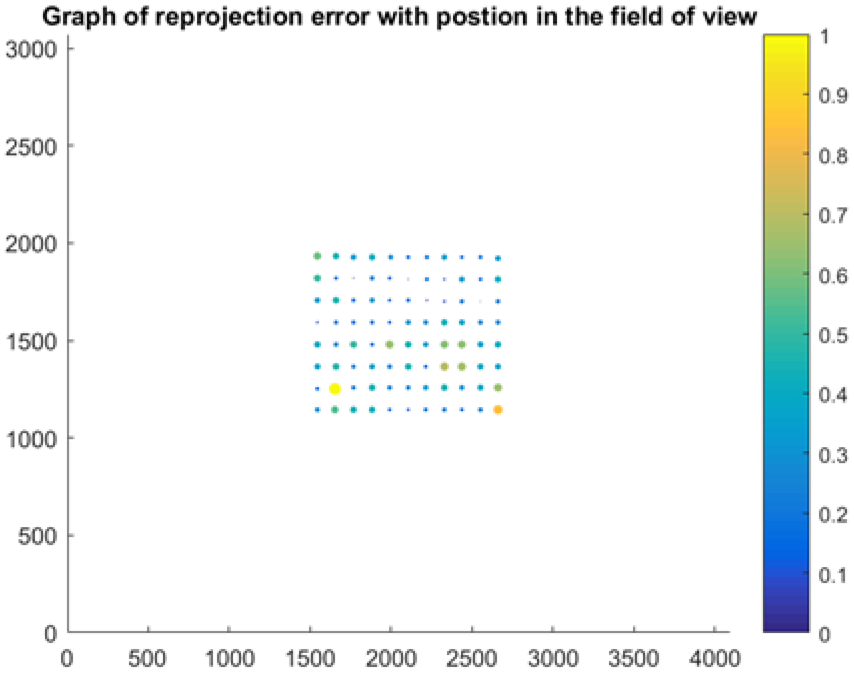
1 Computer → 4198s

To complete in 8 hours,

→20 such computers required

Analysis: Reprojection Error

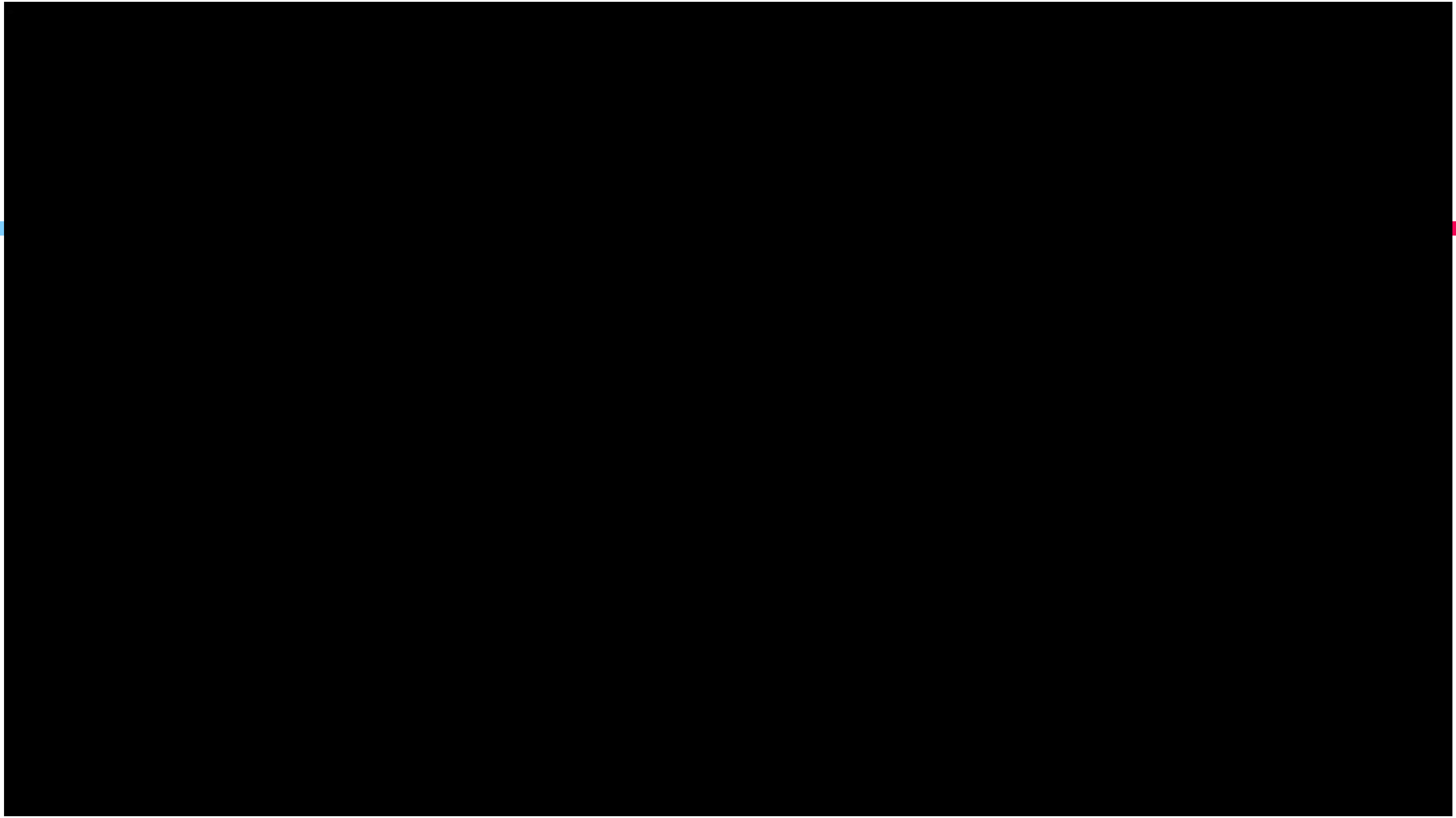




Systematic error indicates a defect in the calibration target

Conclusion

STRENGTH	WEAKNESS
• Reprojection Error: 0.4 pixel • Fixed Pattern Noise Removal: 96.7% Variance • Robot positional accuracy: 10 micrometer	• Validation for Photometric Calibration:Pending • Geometric Calibration: Slower than expected • Imperfect Calibration Target:Manufacturing Defect



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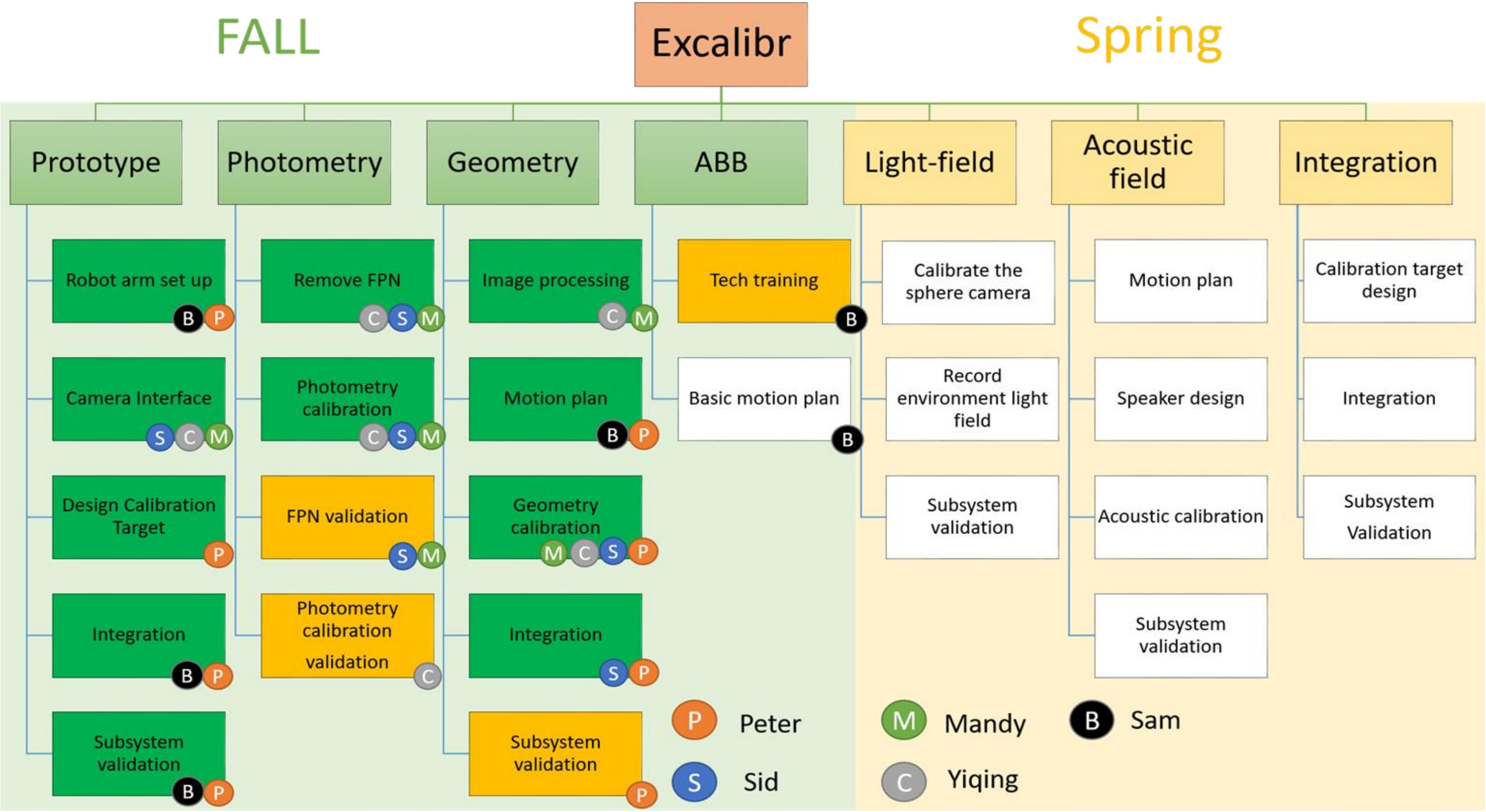
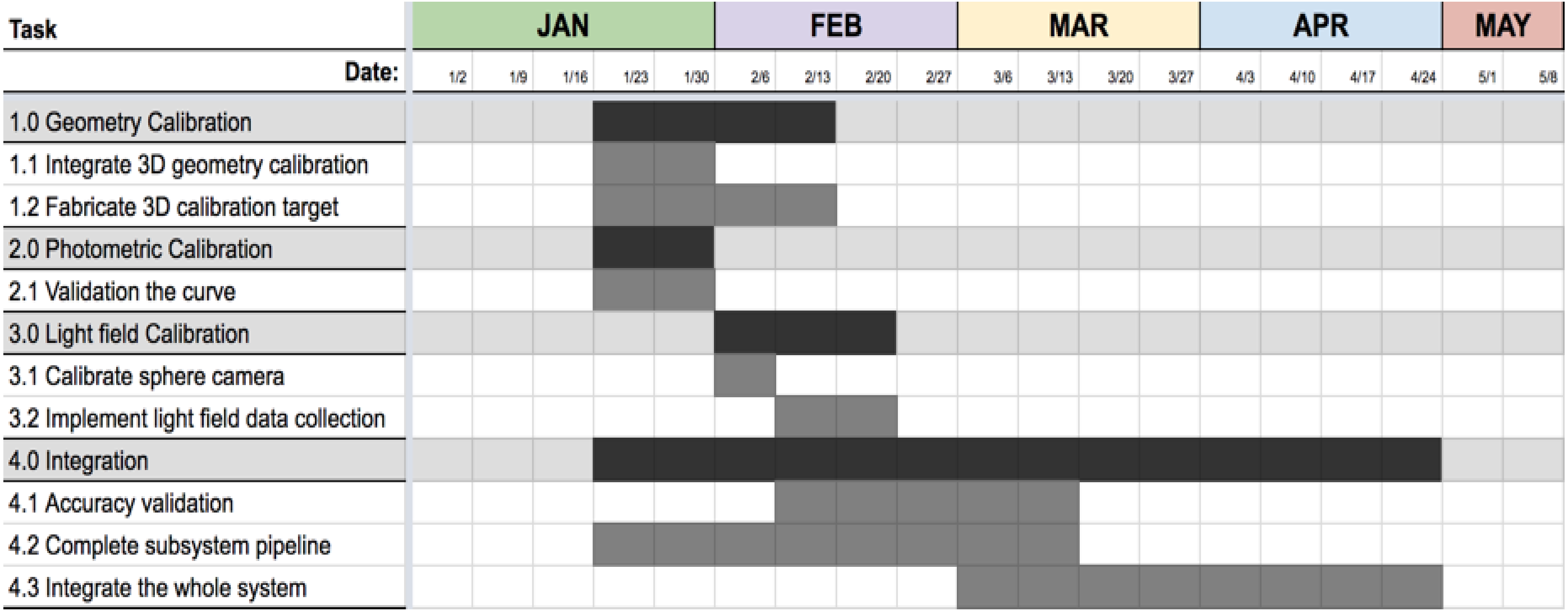
PROJECT MANAGEMENT

Work Breakdown Structure



Schedule



Task
JAN
FEB
MAR
APR
MAY
Date:
1/2
1/9
1/16
1/23
1/30
2/6
2/13
2/20
2/27
3/6
3/13
3/20
3/27
4/3
4/10
4/17
4/24
5/1
5/8
1.0 Geometry Calibration
1.1 Integrate 3D geometry calibration
1.2 Fabricate 3D calibration target
2.0 Photometric Calibration
2.1 Validation the curve
3.0 Light field Calibration
3.1 Calibrate sphere camera
3.2 Implement light field data collection
4.0 Integration
4.1 Accuracy validation
4.2 Complete subsystem pipeline
4.3 Integrate the whole system

Test Plan

Date	Capability Milestones
PR 7	Integrate 3D geometry calibration algorithm & Photometric calibration validation
PR 8	Fabricate 3D calibration target
PR 9	Implement light field data collection
PR 10	Accuracy validation
PR 11	Complete the integration of the subsystem pipeline
PR 12	Integrate the whole system and apply to more than 20 RGB cameras

Spring Validation

Location: Oculus Research, indoors place within a 7ft x 7ft x 5ft space.	**Equipment:** ABB Robotic Arm, A3200 N drive controllers, 3D Calibration target, Computer Terminal, RGB EVT Cameras.

Test Steps:

Step 1 - Light field calibration

1. Implement calibration process on the sphere camera.
2. Mount the sphere camera on the robot arm and move it according to a pre-designated trajectory to collect illumination data of the environment.
3. Show the processing time and light field data.

Step 2 - Geometry calibration for more than 20 cameras

1. Move the 3D calibration target according to a pre-designated trajectory and set points for triggering more than 20 RGB cameras and store the images.
2. Remove the FPN of the images and apply the response function to the images.
3. Use the filtered image for geometric calibration of the cameras.
4. Show the processing time and the camera calibration result.

Performance Matrix:

1. Light field Calibration: Successfully generate the light field data.
2. Geometry Calibration: Reprojection error is less than 0.5 pixel & complete the whole process within 12 hours.

Budget

MRSD Total Budget: (USD)5000

Budget List						
#	Item	Quantity	Unit(s)	Cost per unit (USD)	Cost (USD)	Purchaser
1	AEROTECH PRO225SL	1	set	20,000	20,000	Oculus
2	AEROTECH PRO115SL	2	set	15,000	30,000	Oculus
3	AEROTECH A3200 Controller	3	set	1,000	3000	Oculus
4	Emergent:HR-12000 with lens	3	set	5,400	16,200	Oculus
5	Desktop PC	2	set	1,500	3,000	Oculus
6	3D printing material(PLA)	1.5	kg	47.47	71.2	Oculus
7	Cable carriers	12	ft	19.63	236	Oculus
				Total cost (USD)	**72506.8**	
				Amount spent from TeamG budget (USD)	**0**	

Risk Management

R1.1 Robot arm malfunction

R1.2 Camera malfunction

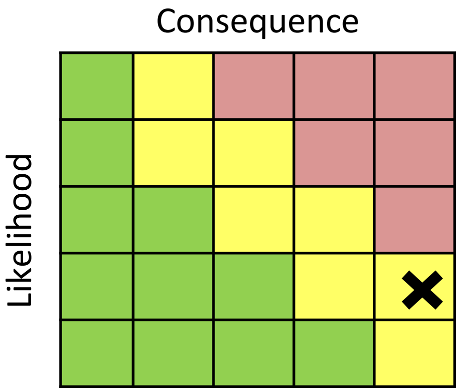
R1.3 Integration failure

R1.4 PSO trigger problem

R1.5 Memory deficiency

R1.6 Validation Difficulty

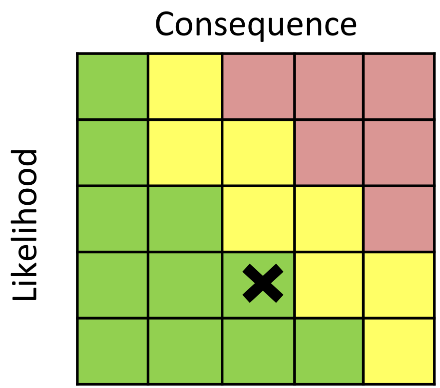
Risk ID	Risk Title	People	Date Submit	Date updated
R 1.1	Robot arm malfunction	Sam/Peter	20/10/2016	31/10/2016

Possible Consequences	Risk Type	Likelihood & Consequence
Unable to move calibration target Unable to collect image data	Technical Schedule	

Risk Reduction Plan

Risk Reduction Plan	Date	Expected outcome	Comment
1. Follow User manual	10/20/2016	Get a standard operation process	
2. Contact manufacturer for proper motor use method	11/10/2026	Motor speed and usage recommendation	

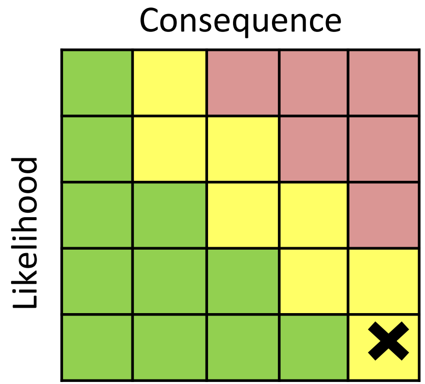
Risk ID	Risk Title	People	Date Submit	Date updated
R 1.2	Camera malfunction	Mandy/Cece/Sid	20/10/2016	31/10/2016

Possible Consequences	Risk Type	Likelihood & Consequence
Unable to take pictures	Technical Schedule	

Risk Reduction Plan

Risk Reduction Plan	Date	Expected outcome	Comment
1. Contact the sponsor to prepare the spare camera	20/10/2016	Get a standard operation process	

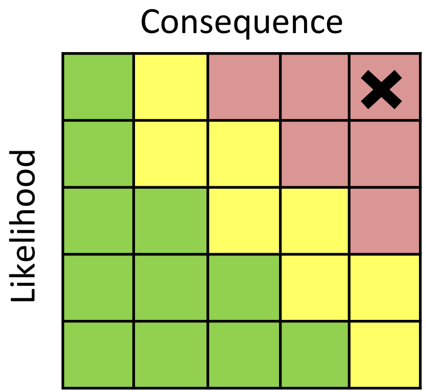
Risk ID	Risk Title	People	Date Submit	Date updated
R 1.3	Integration failure	All members	23/10/2016	31/10/2016

Possible Consequences	Risk Type	Likelihood & Consequence
1. Delay schedule 2. May affect the accuracy	Technical Schedule Cost Programmatic	

Risk Reduction Plan

Risk Reduction Plan	Date	Expected outcome	Comment
1. Split the integration into smaller steps	25/11/2016	Integrate geometric and photometric calibration first in the end of the semester	
2. Verify each steps before move on to the next step	30/11/2016	Validate the result of geometric and photometric calibration in Fall semester and then continue other calibrations	

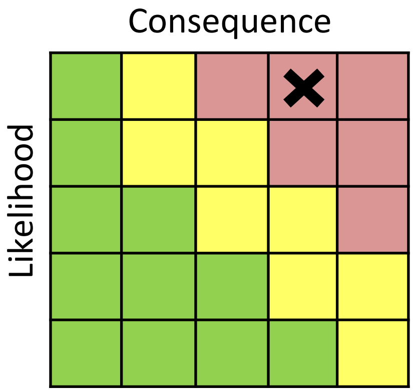
Risk ID	Risk Title	People	Date Submit	Date updated
R 1.4	PSO trigger Problem	Sam/Peter	20/10/2016	31/10/2016

Possible Consequences	Risk Type	Likelihood & Consequence
Unable to Trigger camera to collect data when X or Y or Z axis moves	Technical Schedule Cost Programmatic	

Risk Reduction Plan

Risk Reduction Plan	Date	Expected outcome	Comment
1. Use Sample code using X Y Z to create a trigger signal	20/10/2016	Can use X Y Z axis to trigger camera	
2. When move to specific position, give a mandatory trigger the camera	30/10/2016	Add Complexity in motion planning	Not costing too much time, because the motion pattern is still easy.
3. Contact manufacturer for help	10/11/2026	Problem analyzing and trouble shooting	

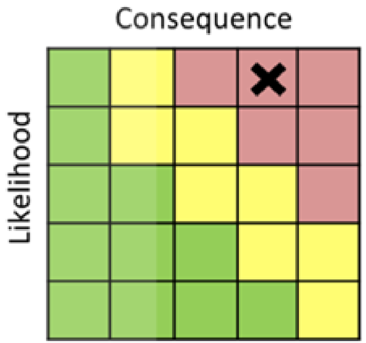
Risk ID	Risk Title	People	Date Submit	Date updated
R 1.5	Memory Deficiency Problem	Cece/Mandy/Peter/Sid	23/10/2016	31/10/2016

Possible Consequences	Risk Type	Likelihood & Consequence
Incapable of processing input data Currently, we encounter this problem in photometric calibration. This problem might appear in geometric calibration as well.	Technical Schedule Cost Programmatic	

Risk Reduction Plan

Risk Reduction Plan	Date	Expected outcome	Comment
1. Report to sponsor	27/10/2016	Downsample images	Acceptable at current stage
2. Discuss with sponsor	15/11/2016	Use hardware with larger memory	

Risk ID	Risk Title	People	Date Submit	Date updated
R 1.6	Validation Difficulty	Cece/Mandy/Peter/Sam	3/11/2016	15/11/2016

Possible Consequences	Risk Type	Likelihood & Consequence
1. Unable to get exact positions of robot arm → Incorrect calculation and validation of geometric calibration 2. Unable to confirm the validity of irradiance map or fixed pattern parameters → Failing to reconstruct objects with accurate colors / illuminus	Technical Schedule Cost	

Risk Reduction Plan

Risk Reduction Plan	Date	Expected outcome	Comment
1. Discuss with sponsor	14/11/2016	Get instructions	Negotiate a balance between course requirements & sponsor requirements
2. Search for applicable methods/ instruments	20/11/2016	Use instruments to evaluate calibration results	
3. Descope	5/12/2016	Remove some processes	

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CONCLUSIONS

Resultant key activities

A clear and reachable scope and plan

Tracking progress weekly

Explicit work break down

Lessons learned

- ▷ Camera calibration knowledge
- ▷ Cooperation skills
- ▷ Team Building & Mutual Respect
- ▷ No PROCRASTINATING!

Thank you!

Q&A