Material examination and classification using computer vision

construction robotics | international M.Sc.programme

Material examination and classification using computer vision

1 Introduction

2 Research methods

3 Dataset

4 Particle Size Detection Approaches

5 Result

6 Implementation Plan

7 Schedule

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1 Introduction

1.1 Task description

1.2 Motivation and Problem Statement

1.3 Objectives

2 Research methods

3 Dataset

4 Particle Size Detection Approaches

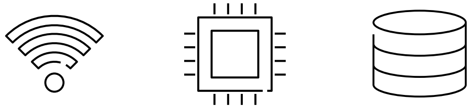
5 Result

6 Implementation Plan

7 Schedule

Task Description

Material examination and classification using computer vision



Intelligent Construction Sites

- Piles of materials are often delivered to the construction site.
- Unmanned intelligent construction management
- Integration of robots with RGB-D cameras
- The biggest challenge of these studies is related to materials with similar shapes and textures.[1]→(Granular materials)
- Granular material recognition and classification

Goals and Applications

- Particle size and distribution prediction ✔
- Particle shape and type recognition
- Enhancing construction efficiency and accuracy

[1] Maryam Soleymani, Construction Material Classification on Imbalanced Datasets Using Vision Transformer Architecture (Vit)

Objectives & Workflow

Material examination and classification using computer vision

Automated Particle Size Detection Workflow

1. System Setup
1.1 Install ROS
1.2 Install Luxonis DepthAI SDK
1.3 Install PyTorch and Required Libraries

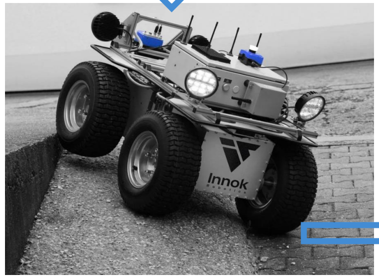
2. Launch RGBD Camera Node
2.1 Start Camera
2.2 Capture Depth and RGB Images

3. Develop ROS Node for Image Processing and Distance Checking
3.1 Create and Configure ROS Package
3.2 Write and Compile Image Processing Node

4. Controlling the Mobile Robot
4.1 Create Robot Control Node
4.2 Integrate Robot Control with Image Processing

5. Particle Size Detection Approaches
5.1 Segmentation-based Approach
5.2 Regression-based Approach
5.3 Classification-based Approach

6. Execution Flow
6.1 Robot Moves to Material Pile
6.2 Camera Ensures 30mm Distance
6.3 Capture RGB Image
6.4 Process Image with Pre-trained CNN Model
6.5 Predict Particle Size
6.6 Display Results



input

5.1 Segmentation-based Approach
5.1.1 Pre-process Image
5.1.2 Apply Segmentation Model
5.1.3 Identify and Measure Particles
5.1.4 Post-process and Output Results

SAM
OpenCV

5.2 Regression-based Approach
5.2.1 Pre-process Image
5.2.2 Extract Features
5.2.3 Apply Regression Model
5.2.4 Predict Particle Size
5.2.5 Post-process and Output Results

CNN regression

5.3 Classification-based Approach
5.3.1 Pre-process Image
5.3.2 Apply Classification Model
5.3.3 Classify Particles by Size Range
5.3.4 Post-process and Output Results

CNN classification

Grain Size:
μ=x.xx
σ=x.xx
Categories： x

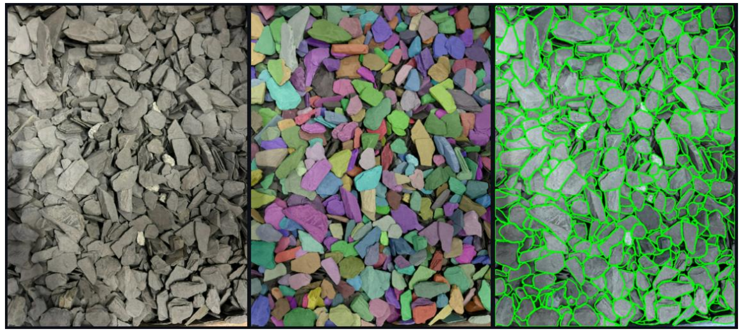
output

Slide by Baiyi

Research methods

Material examination and classification using computer vision

- **Segmentation-Based Method**
- Segment materials into individual particles using a segmentation model (e.g., SAM).
- Extract features from each particle.



- **Regression-Based Method**
- Use a CNN model to extract features from each image.
- Map features to numerical values.
- Training set results correlate features with specific numerical outcomes.

Grain Size:
μ=x.xx
σ=x.xx

- **Classification-Based Method**
- Train a CNN model to extract features from each image.
- Map features to corresponding labels.

Categories： x

I conducted a custom dataset to evaluate the effectiveness of each method. ⇨ **The dataset plays a decisive role in the usability of the trained models.**

Slide by Baiyi

Dataset

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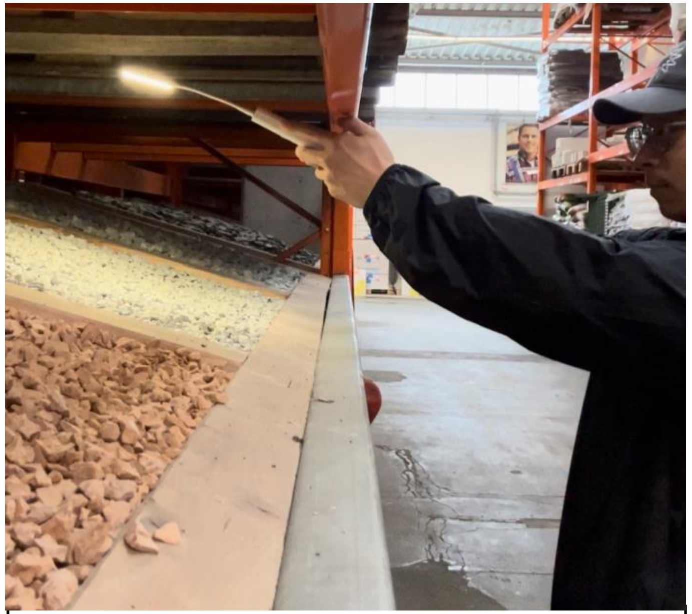
Dataset Preparation

- **Image Source:** Collected from Aachen Bauhaus and OBI, including 20 types of construction granular materials.
- **Product Diversity:** Ranges from 1-3mm gravel to 40-60mm marble.
- **Sampling and Labeling:** Products are representing the construction industry. (The most common construction particle size range is 0.075-80mm[1]). These products have <u>small grain size variances</u> and <u>have been labeled</u>. Easier for labeling, feature extraction, and machine learning.



- **Image Specifications:**
- Manual photography
- Consistent lighting conditions
- Fixed camera distance: 30mm
- Image resolution: 3024x4032 pixels

[1] K.V. Anusree, G.M. Latha, Characterization of sand particle morphology: state of the art, Bull. Eng. Geol. Environ. 82 (2023) 269.

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4.1 Segmentation-based Approach

4.2 Regression-based Approach

4.3 Classification-based Approach

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Particle size detection approaches

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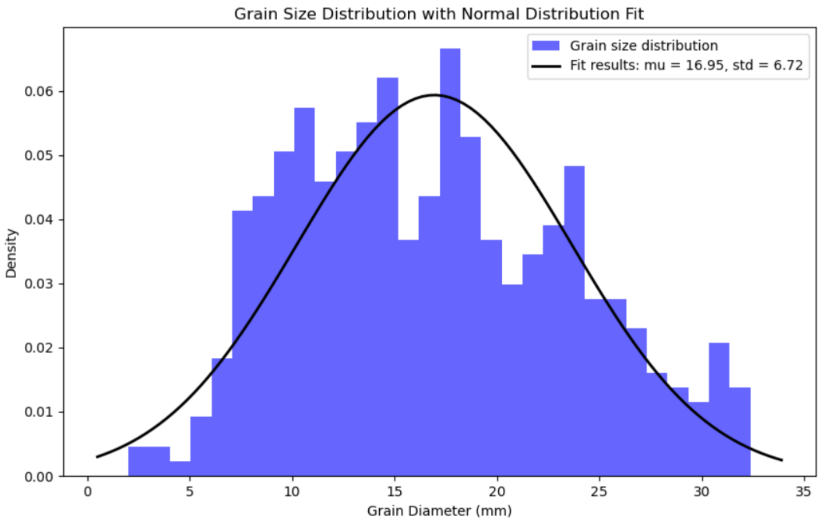
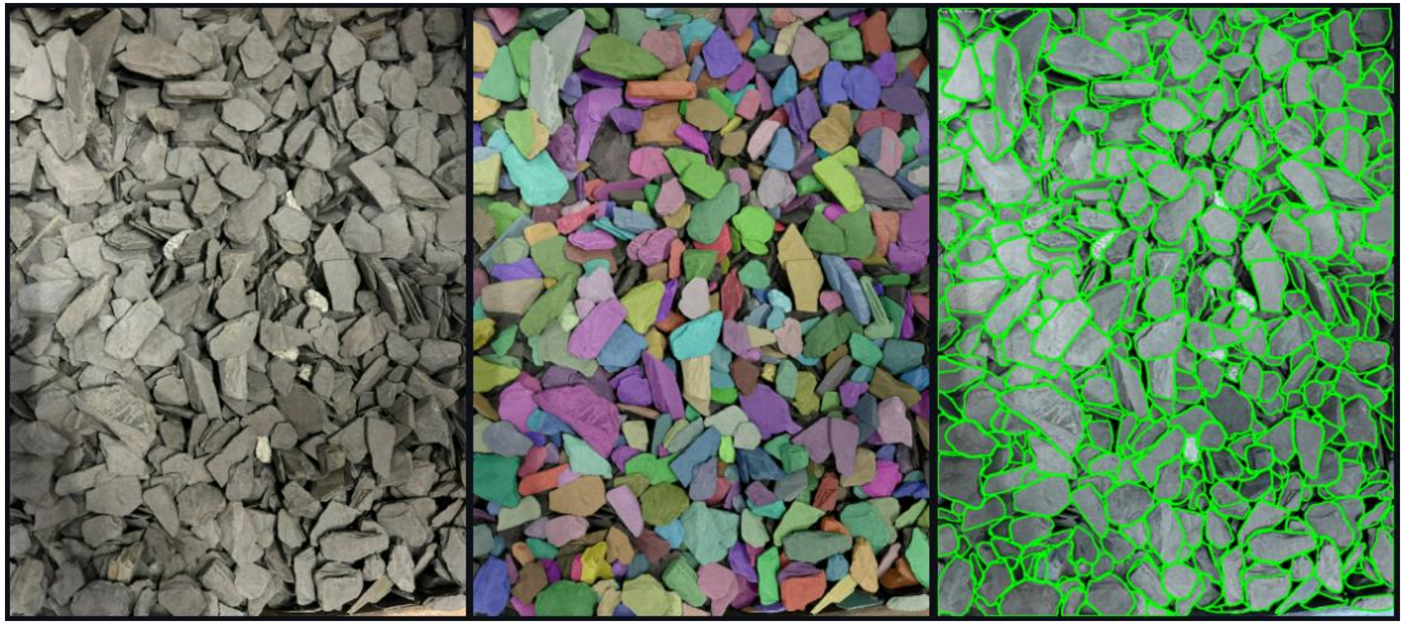
- **Segmentation-Based Method**
- Segment materials into individual particles using a segmentation model (e.g., SAM).
- Extract features from each particle using OpenCV .
- Estimate particle size distribution.





Limitations:
- Accuracy depends on segmentation quality.
- Small particles (<3mm) may appear larger due to image resolution limits.
- Large particles (>30mm) may be over-segmented due to shadows and occlusions.
- Best suited for particles sized 3-30mm.
- Segment Anything Model (SAM) is computationally intensive and time-consuming.

Particle size detection approaches

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- **Regression-Based Method**
- Use a CNN model to extract features from each image.
- Map features to numerical values.
- Training set results correlate features with specific numerical outcomes.


```
C:\Users\guoba\anaconda3\python.exe "E:\granular materials classification and particle size identification\code\CNN_predict_ResNet50_regression_with_mu_and_std.py"
Prediction for transformed image 0: mu=10.72, std=7.36
Prediction for transformed image 1: mu=9.74, std=7.45
Prediction for transformed image 2: mu=9.17, std=6.91
Prediction for transformed image 3: mu=10.39, std=6.93
Prediction for transformed image 4: mu=8.03, std=6.38
Prediction for transformed image 5: mu=9.89, std=7.76
Prediction for transformed image 6: mu=10.57, std=7.8
Prediction for transformed image 7: mu=10.43, std=7.86
Prediction for transformed image 8: mu=9.42, std=7.32
Prediction for transformed image 9: mu=9.65, std=7.04
Average Predicted Grain Size for E:\granular materials classification and particle size identification\old\input\marmorkiesel_weiss_7-15mm.jpg: mu=9.8, std=7.28

Process finished with exit code 0
```

```
C:\Users\guoba\anaconda3\python.exe "E:\granular materials classification and particle size identification\code\CNN_predict_ResNet50_regression.py"
Prediction for transformed image 0: 9.02
Prediction for transformed image 1: 8.86
Prediction for transformed image 2: 8.84
Prediction for transformed image 3: 9.42
Prediction for transformed image 4: 9.64
Prediction for transformed image 5: 9.15
Prediction for transformed image 6: 9.71
Prediction for transformed image 7: 9.32
Prediction for transformed image 8: 9.15
Prediction for transformed image 9: 13.24
Average Predicted Grain Size for E:\granular materials classification and particle size identification\old\input\marmorkiesel_weiss_7-15mm.jpg: 9.64

Process finished with exit code 0
```

input

Grain Size:
μ=x.xx
σ=x.xx

output

Particle size detection approaches

Material examination and classification using computer vision

- **Classification-Based Method**
- Train a CNN model to extract features from each image.
- Map features to corresponding labels.

Category	Characteristics	Product Names
Fine Pebbles and Gravel	Small size, rounded to semi-rounded, smooth to medium roughness	Marmorkiesel_Weiss_7-15mm, Marmorkiesel_Weiss_15-25mm, Marmorkiesel_Gruen_15-25mm, Quarzkies_Rund_Hell_8-16mm, Kies_2-8mm, Kies_8-16mm, Kies_1-3mm
Medium Pebbles and Gravel	Medium size, rounded to semi-rounded, smooth to medium roughness	Marmorkiesel_Weiss_25-40mm, Marmorkiesel_Weiss_40-60mm, Marmorkiesel_Schwarz_40-60mm, Quarzkies_Rund_Hell_16-32mm, Kies_16-32mm, Marmorsplitt_7-12mm, Splitt_2-5mm
Large Pebbles and Broken Stones	Large size, irregular shape, rough texture	Bruchsteine_Veronarot_30-60mm, Schieferplaettchen_22-40mm, Marmorsplitt_Veronarot_9-12mm, Marmorsplitt_Donaublau_8-12mm, Basaltsplitt_8-12mm, Granitsplitt_8-12mm, Marmorkiesel_Weiss_15-25mm

Categories： x

Classification Criteria:
Combines particle size, shape, and smoothness.
Three categories:
1 Small particles
2 Medium-sized particles (aesthetic, suitable for decoration and outdoor paving)
3 Large and rough particles (suitable for construction, providing higher friction)
Challenges: Overfitting issues during training.Current training paused to explore alternative methods.

Result

Material examination and classification using computer vision

Method	Key Characteristics	Advantages	Limitations
Segmentation-Based	Segments images into individual particles, extracts features (e.g., diameter, area)	Detailed particle size distribution (average size, variance)	Dependent on segmentation quality, less effective for very small (<3mm) or large (>30mm) particles
Regression-Based	Uses CNN to extract features, maps to numerical values	High accuracy with consistent conditions, faster than segmentation, adjustable labeling	Dependent on consistent testing conditions, potential overfitting issues
Classification-Based	Combines size, shape, and smoothness into categories	Broad applicability, practical for varied uses	Overfitting during training, further optimization needed

Research methods

Material examination and classification using computer vision

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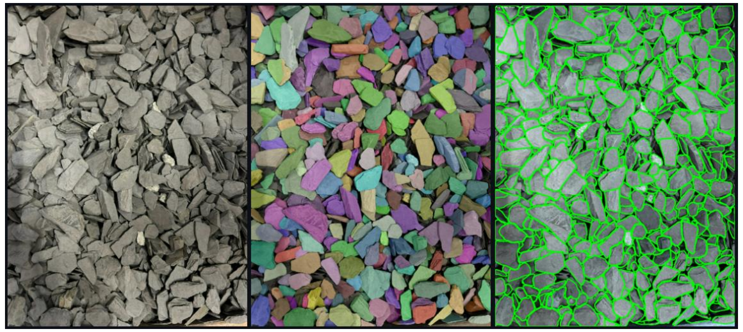
- Extract features from each particle.



- **Regression-Based Method**
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Grain Size:
μ=x.xx
σ=x.xx

- **Classification-Based Method**
- Train a CNN model to extract features from each image.
- Map features to corresponding labels.

Categories：x

Slide by Baiyi

Implementation plan

Material examination and classification using computer vision

Step 1:

Deploy the robot to navigate to the material pile.

Step 2

Ensure the camera is positioned at the optimal 30mm distance.

Step 3

Capture RGB images under controlled lighting conditions.

Step 4

Utilize a pre-trained CNN model to process the images.

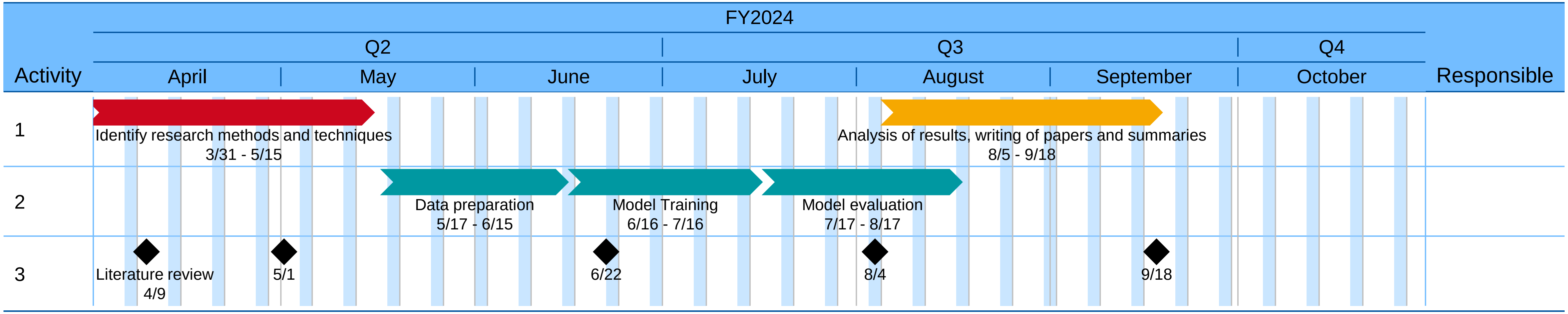
Step 5

Predict the particle size using the model.

Step 6

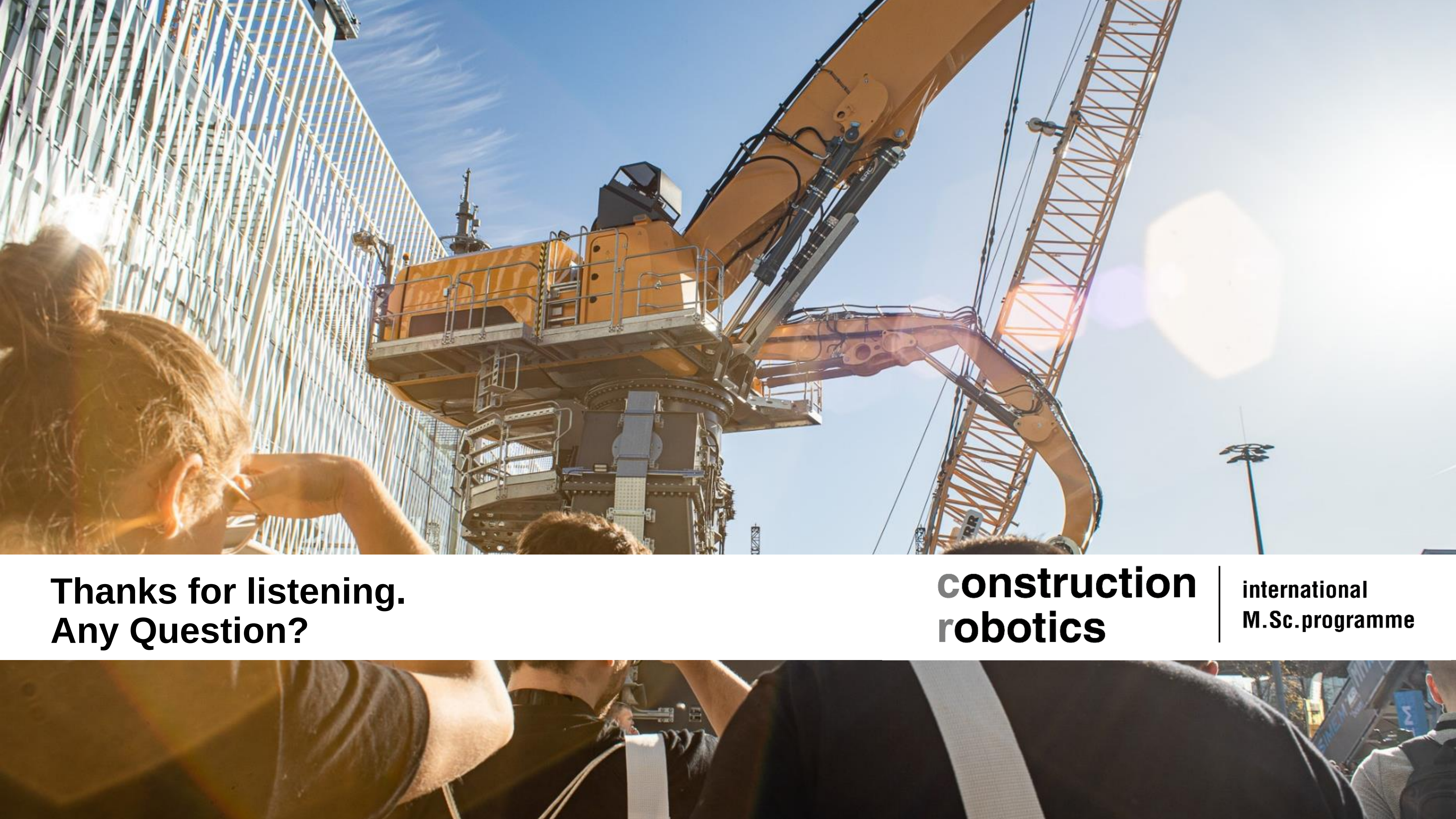
Display and analyze the results for construction site management.

Schedule


FY2024
Q2
Q3
Q4
Activity
April
May
June
July
August
September
October
Responsible
1
Identify research methods and techniques
3/31 - 5/15
Analysis of results, writing of papers and summaries
8/5 - 9/18
2
Data preparation
5/17 - 6/15
Model Training
6/16 - 7/16
Model evaluation
7/17 - 8/17
3
Literature review
4/9
5/1
6/22
8/4
9/18

Sources

https://paperswithcode.com/task/material-recognition/codeless
https://www.cs.columbia.edu/CAVE/software/curet/ https://www.csc.kth.se/cvap/databases/kth-tips/index.html
https://www.fmdsa.org/research-network/ http://opensurfaces.cs.cornell.edu/
https://en.wikipedia.org/wiki/Convolutional_neural_network https://image-net.org/challenges/LSVRC/
https://towardsdatascience.com/r-cnn-fast-r-cnn-faster-r-cnn-yolo-object-detection-algorithms-36d53571365e
https://arxiv.org/abs/1312.6229 https://viso.ai/deep-learning/vgg-very-deep-convolutional-networks/
http://yann.lecun.com/exdb/publis/pdf/farabet-pami-13.pdf https://arxiv.org/abs/2304.07193



Thanks for listening.
Any Question?

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