A Real-Time Analysis of Rock Fragmentation Using UAV Technology

Thomas Bamford, Kamran Esmaeili, Angela P. Schoellig

CAMI 2016

Lassonde Institute of Mining
UNIVERSITY OF TORONTO

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Introduction

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Interdisciplinary team at the University of Toronto

Thomas Bamford

- Masters Student
- Applications of UAVs in mining

Kamran Esmaeili

- Assistant Professor, Lassonde Institute of Mining
- Mine optimization; geomechanical mine design; application of geostatistical techniques in mine planning and design

Angela P. Schoellig

- Assistant Professor, Institute for Aerospace Studies
- Robotics; UAVs; controls for robot autonomy; machine learning in robotics

Motivation – applications of UAVs in mining

- UAV technology has been introduced to the mining environment for:
  - Terrain surveying
  - Surveillance and monitoring
  - Volume calculations
- All of the benefits that UAVs can offer to the industry have not yet been achieved.

Dynamic Systems Lab UAV fleet

Motivation for rock fragmentation measurement

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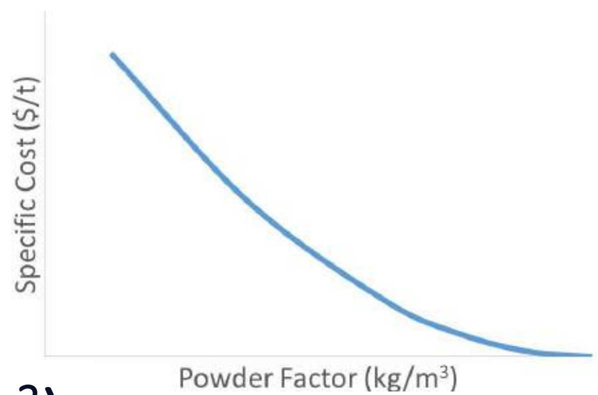
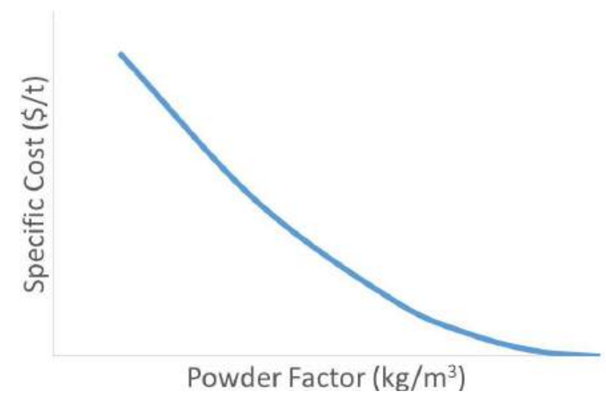
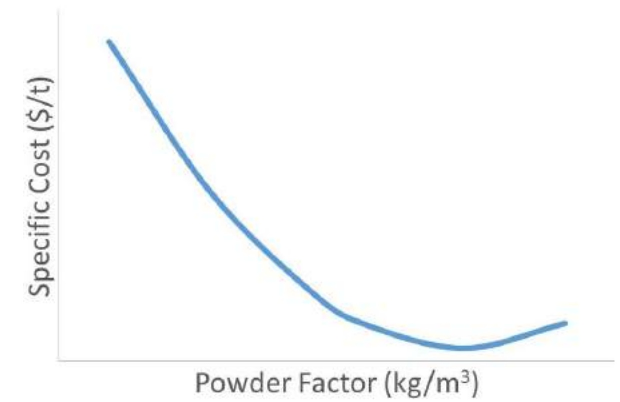
Blasting → Loading → Hauling → Crushing Grinding

Specific Cost ($/t)

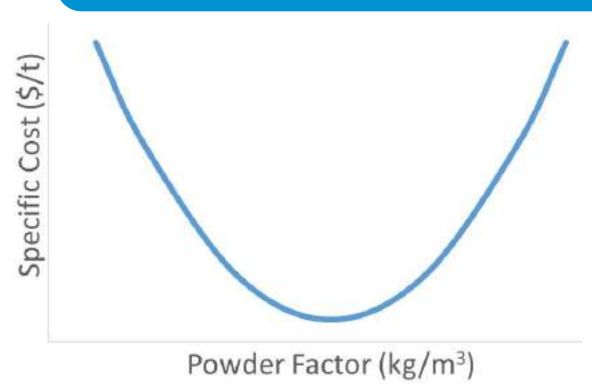
Powder Factor (kg/m³)







= Total Mining Operation



McKenzie (1967)

Motivation for rock fragmentation measurement

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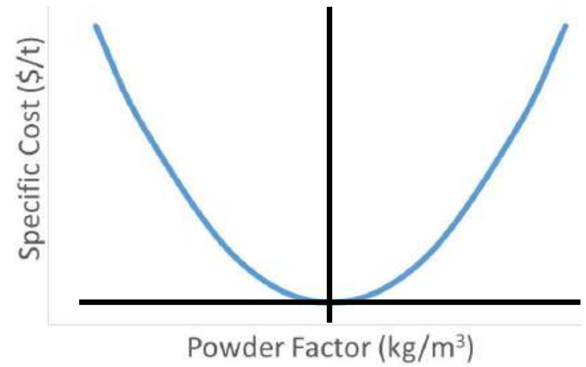
Blasting → Loading → Hauling → Crushing Grinding

2% 6% 21% 44%

Distribution of Energy Consumption in Mining

= Total Mining Operation



DOE (2007)

Current methods to measure rock fragmentation

1. Visual observation

Current methods to measure rock fragmentation

2. Screening (or sieve analysis)

Screening at the University of Toronto.

Current methods to measure rock fragmentation

3. Equipment monitoring
4. Image analysis

Image analysis (Onederra et al., 2015)

4. Image analysis

- Widespread commercial application.
- Can be used for real-time monitoring.

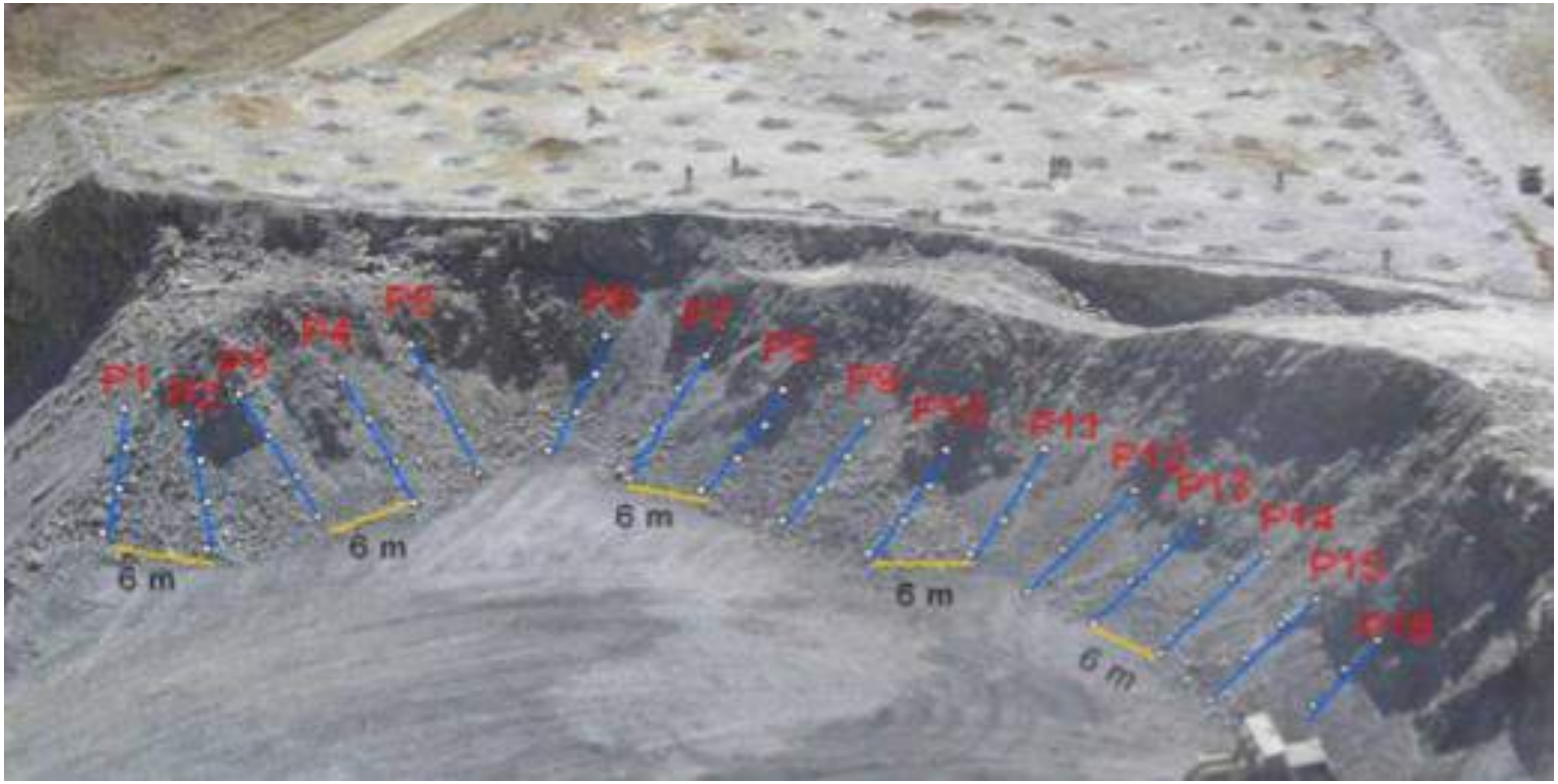


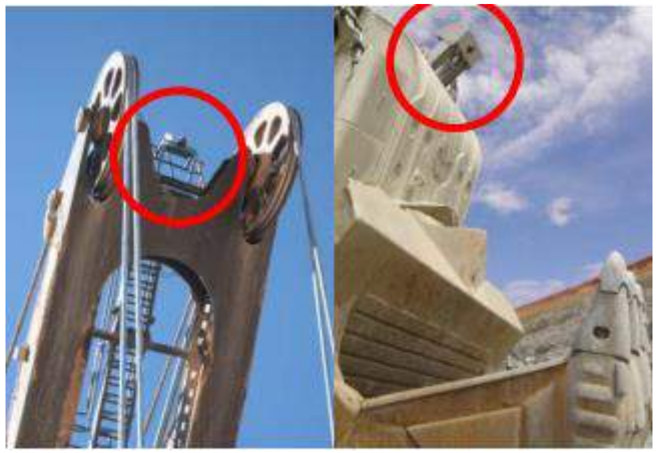
Image analysis (Onederra et al., 2015)

Implementation of image analysis

Locations that image analysis have been implemented (from left to right):

- Toe of muckpile;
- Shovel boom or lip of truck bucket;
- Crusher or orepass tipping points;
- Conveyor belts.

(Onederra et al .,2015)



(Chow & Tafazoli, 2011)

(Maerz & Palangio, 2004)

(Maerz & Palangio, 2004)

Advantages and challenges of image analysis

Advantages:

- Does not have to interrupt production;
- Non-intensive sampling;
- Can take many samples;
- Low cost.

Challenges:

- The inhomogeneous nature of muckpiles;
- Fragment geometry;
- Image quality;
- Environment (dust, vibration, etc.);
- Image processing errors (occlusion, fusion and disintegration).

Advantages and challenges of image analysis

Advantages:

- Does not have to interrupt production;
- Non-intensive sampling;
- Can take many samples;
- Low cost.

Added Advantages with a UAV system:

- High temporal and spatial resolution;
- Inaccessible areas can be sampled;
- Target specific rock size regions;
- Additional data can be collected (e.g. photogrammetry);
- System keeps operator out of harm's way.

Challenges:

- The inhomogeneous nature of muckpiles;
- Fragment geometry;
- Image quality;
- Environment (dust, vibration, etc.);
- Image processing errors (occlusion, fusion and disintegration).

Experiment Setup & Methods

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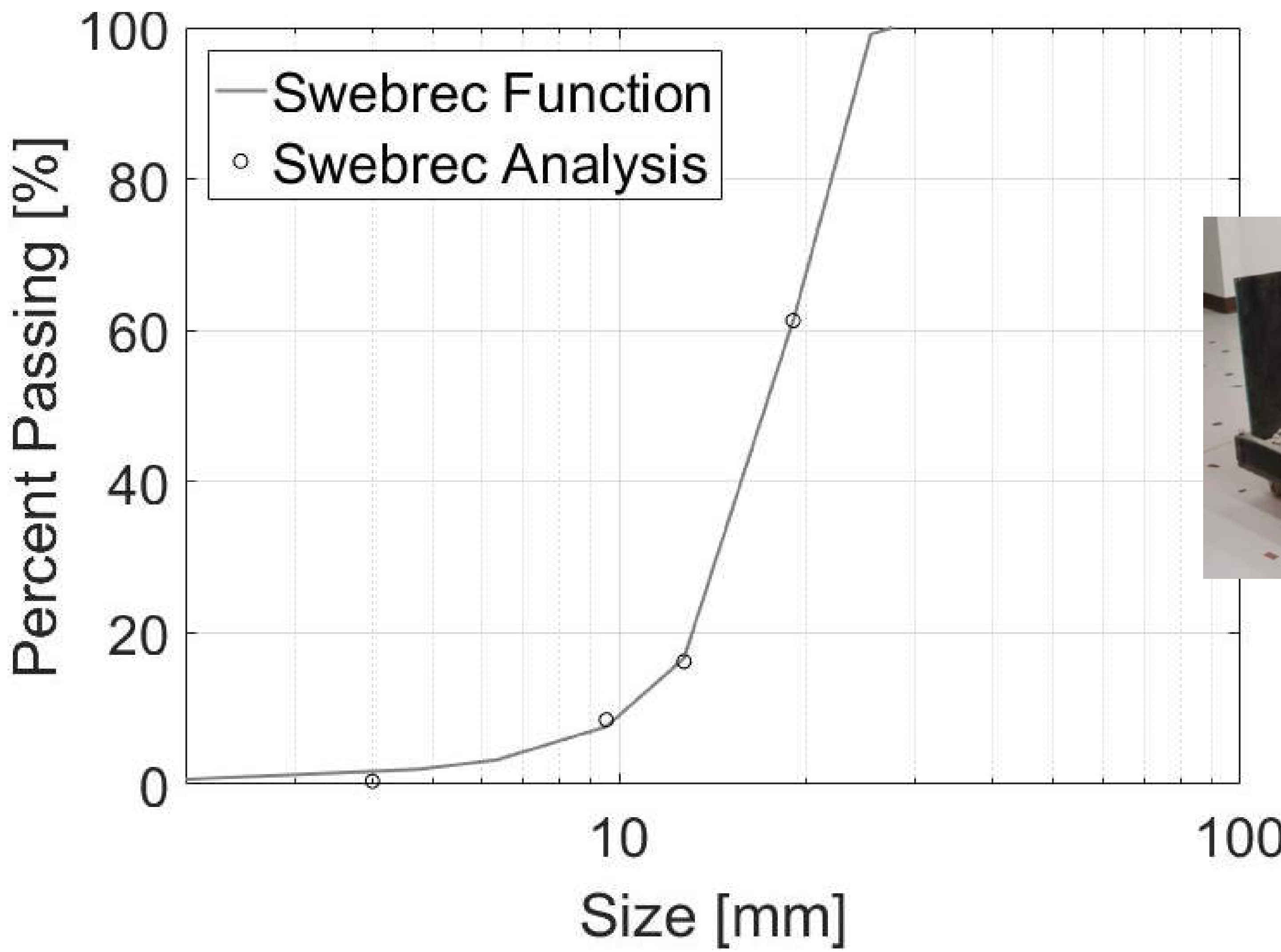
Sieving and data baseline

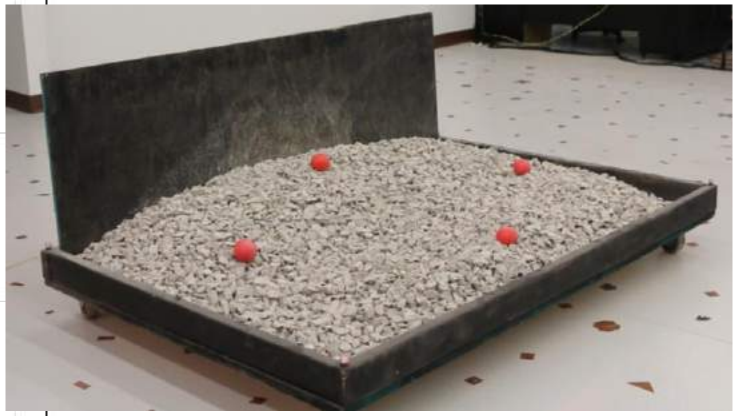

Sieve analysis to create baseline for rock fragmentation measurement.

Sieving and data baseline

Swebrec function used to fit rock size distribution to sieve analysis data:

$$P(< x) = \frac{1}{1+f(x)}, \text{ with } f(x) = \left[\frac{\ln x_{max}/x}{\ln x_{max}/x_{50}}\right]^b$$





Rock pile in lab, 371 kg

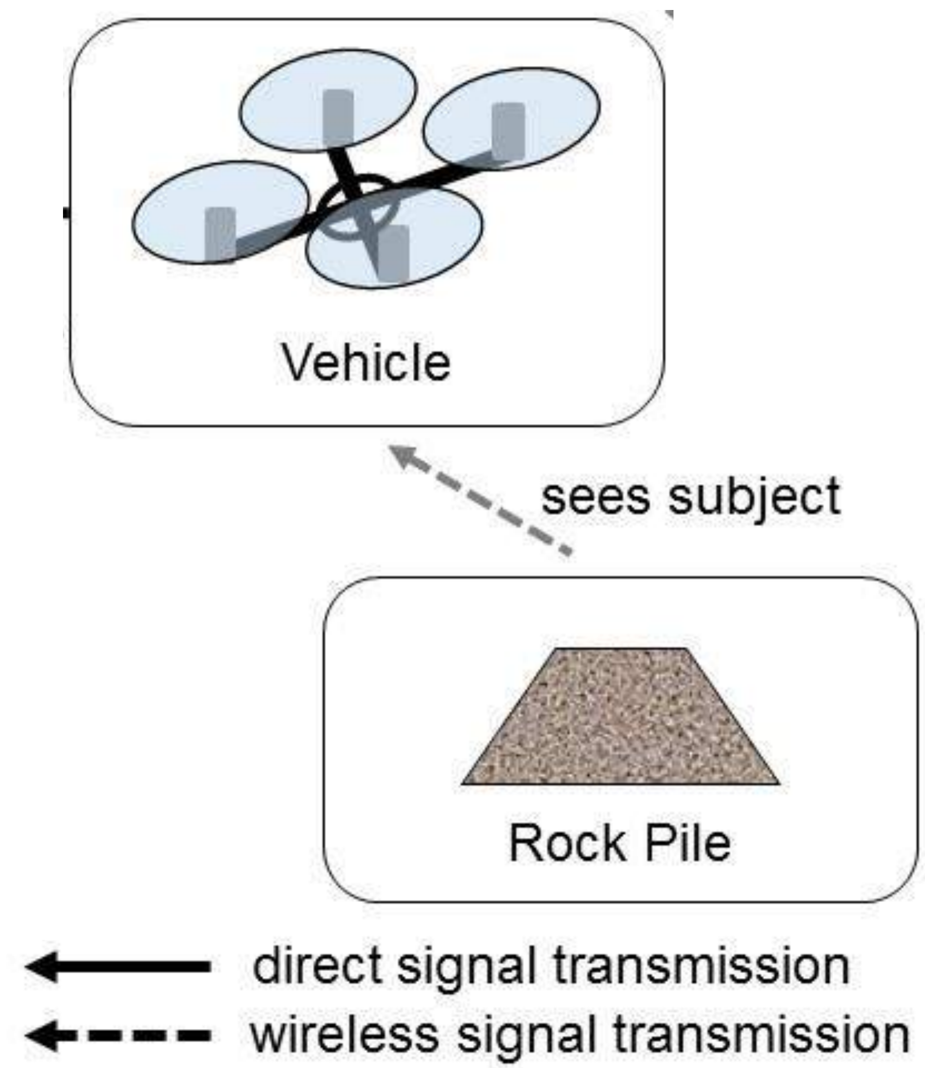
Curve parameters: $x_{max} = 27.53mm$, $x_{50} = 17.84mm$, $\mathrm{b} = 2.79$

UAV used in experiments

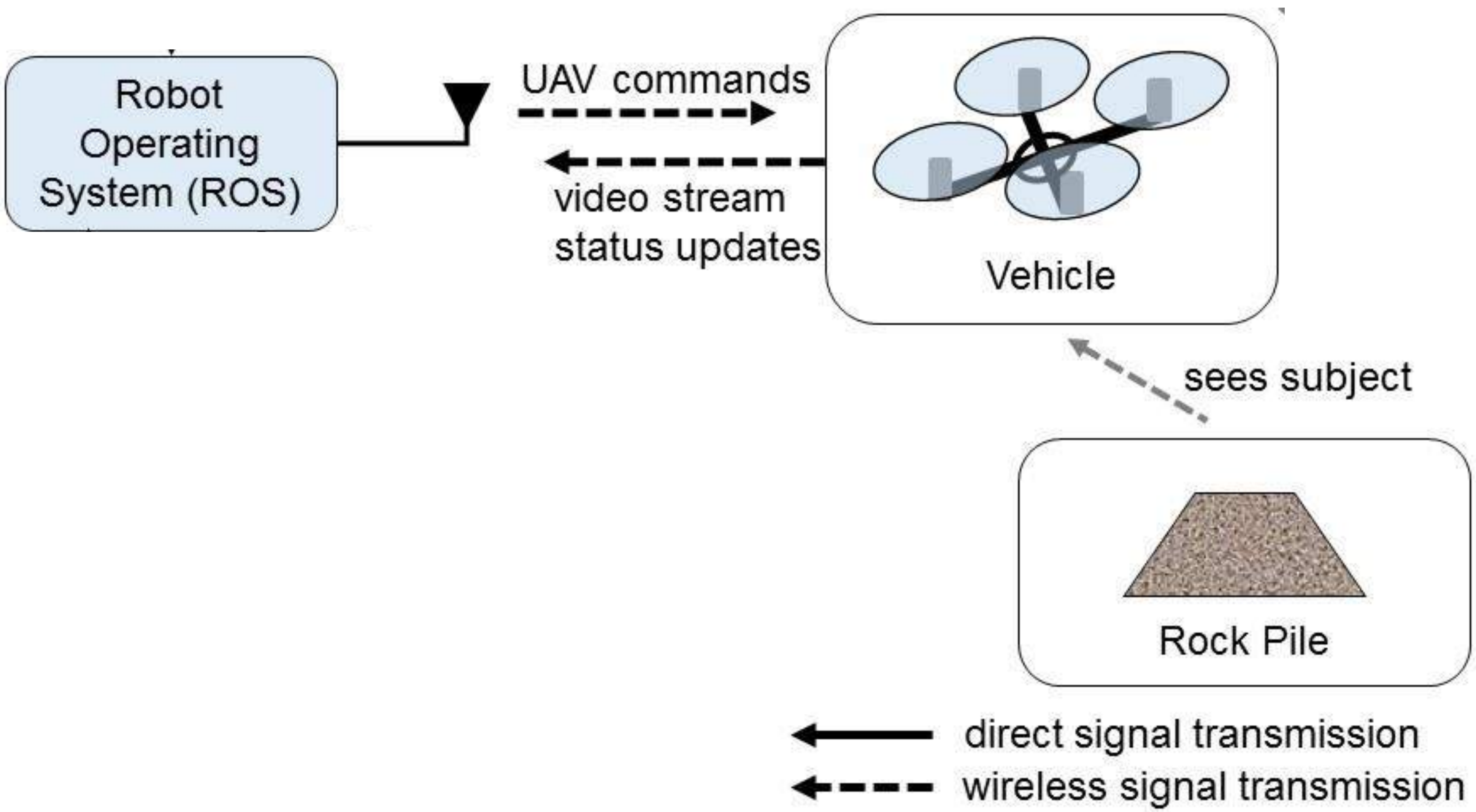
Parrot Bebop 2

- 14 megapixel camera;
- 1080p video;
- Approximately 25 minute flight time;
- Operates up to 2 kilometer range;
- 500 gram weight.

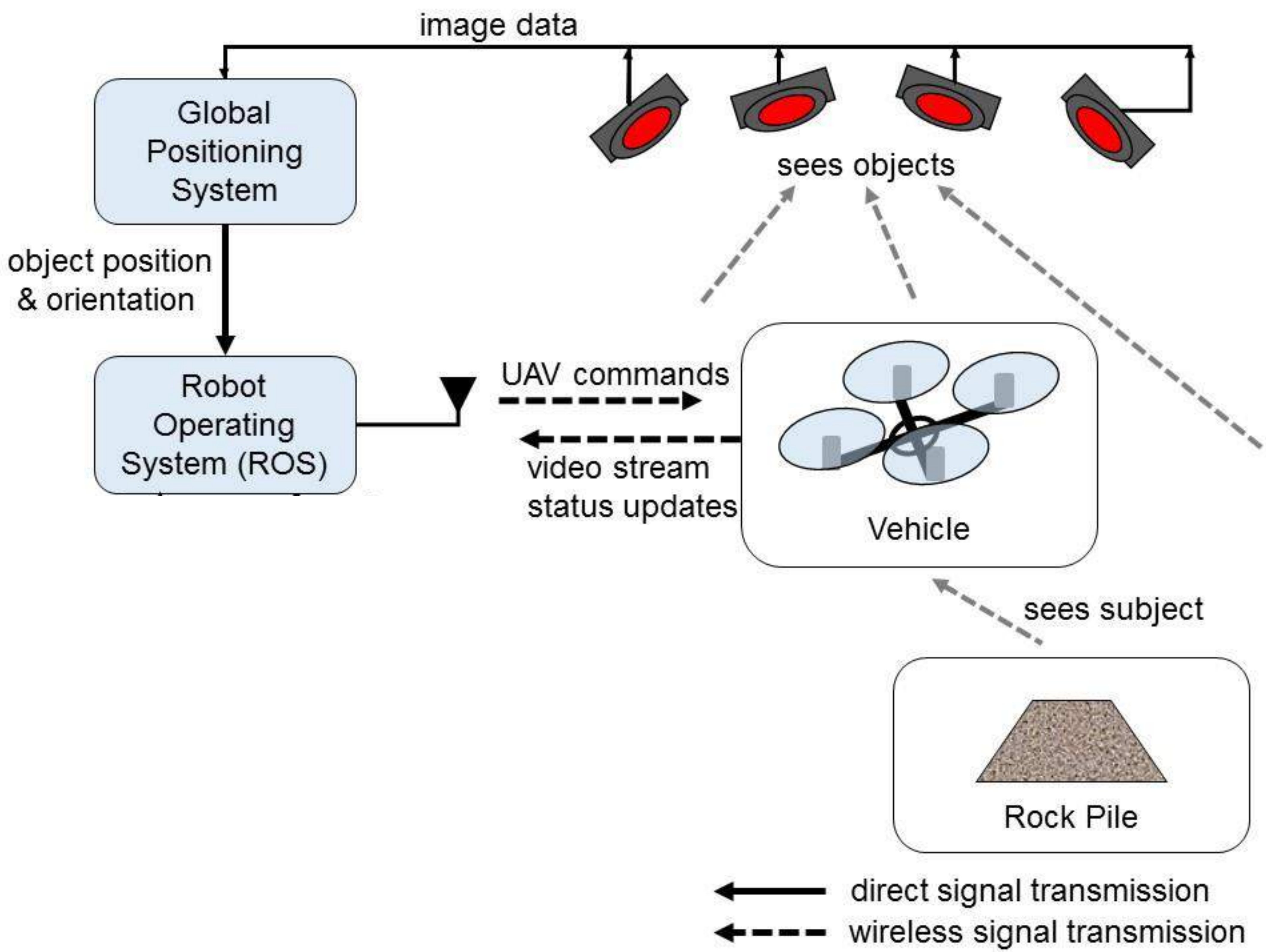
System overview



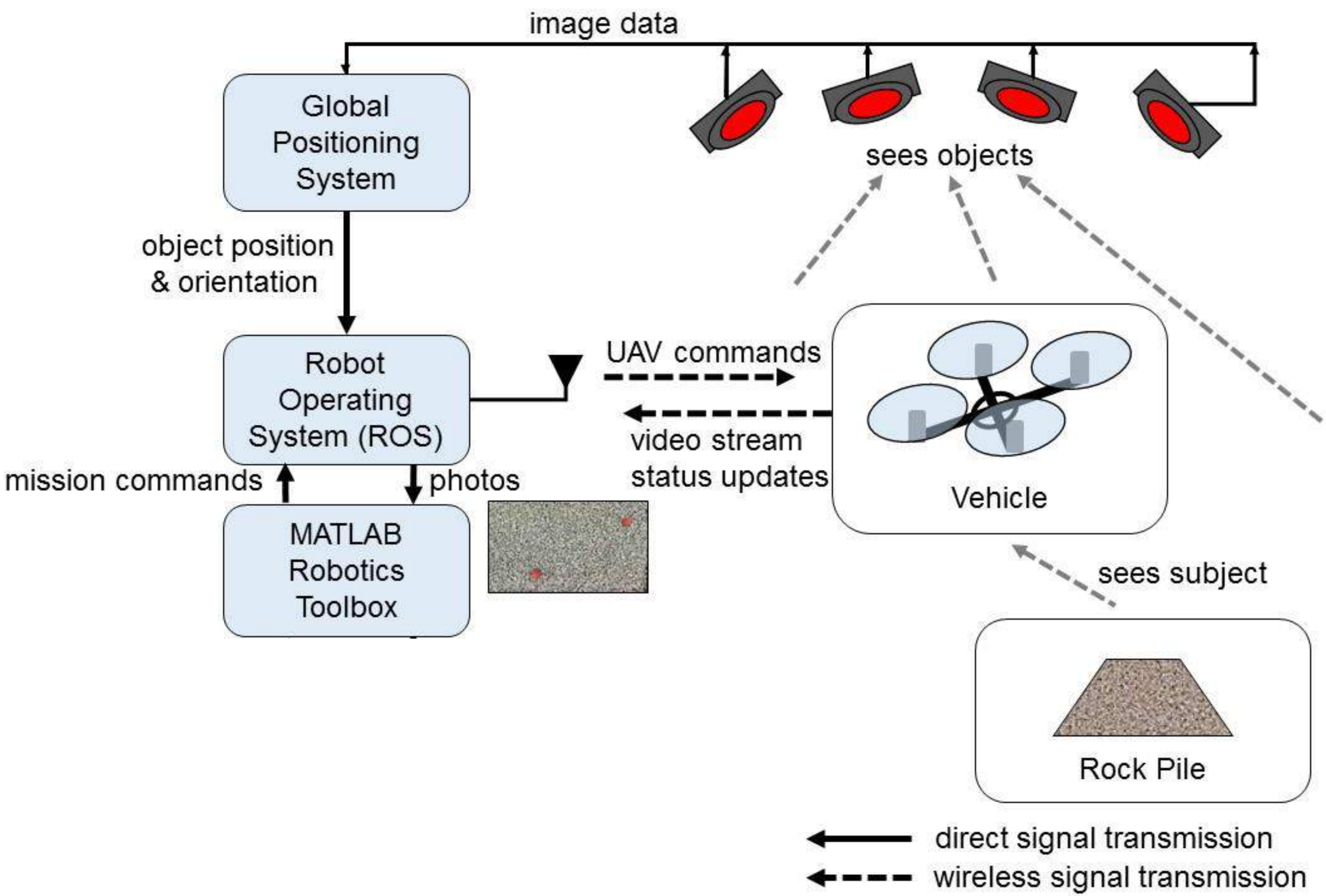
System overview



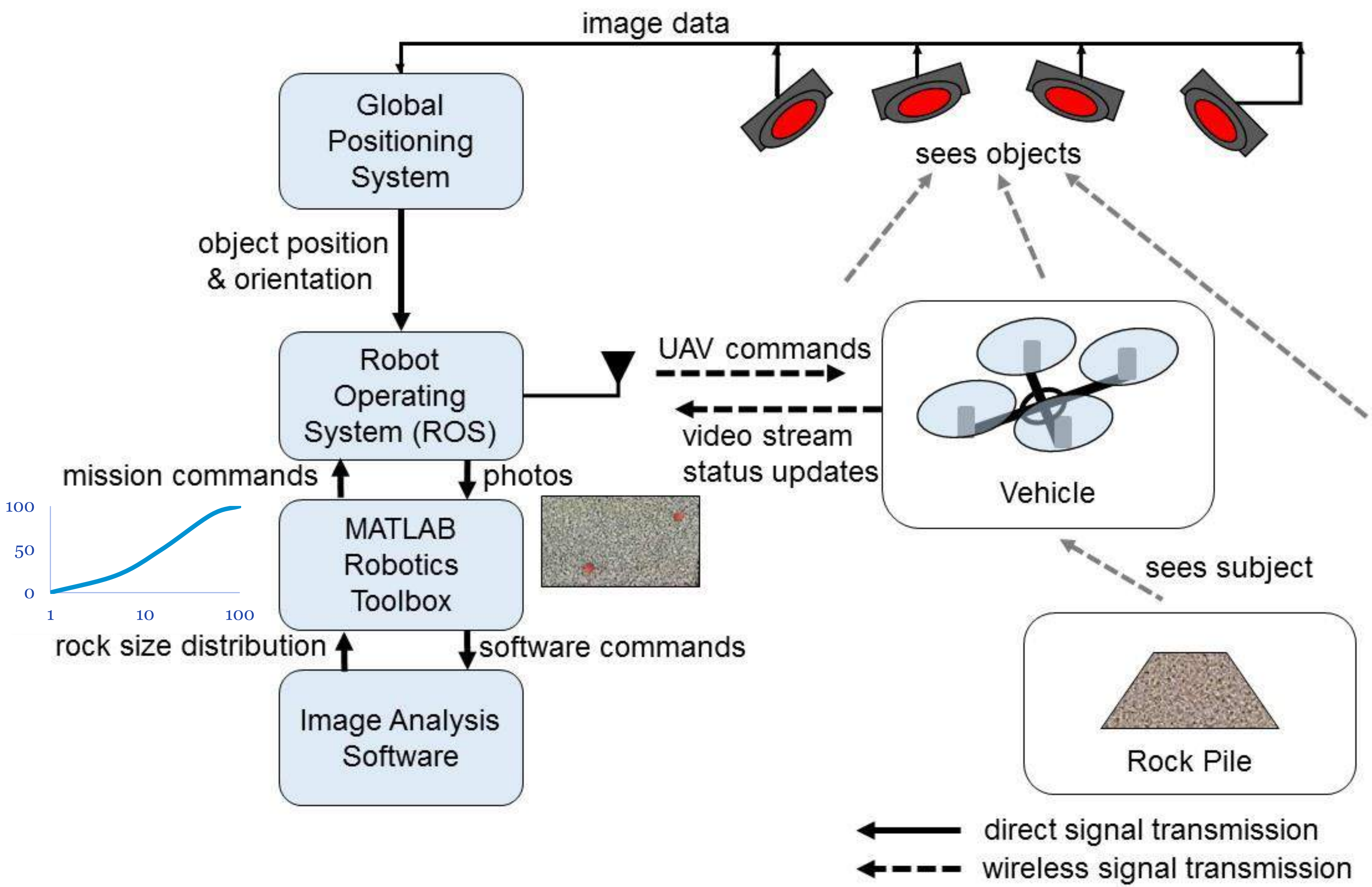
System overview



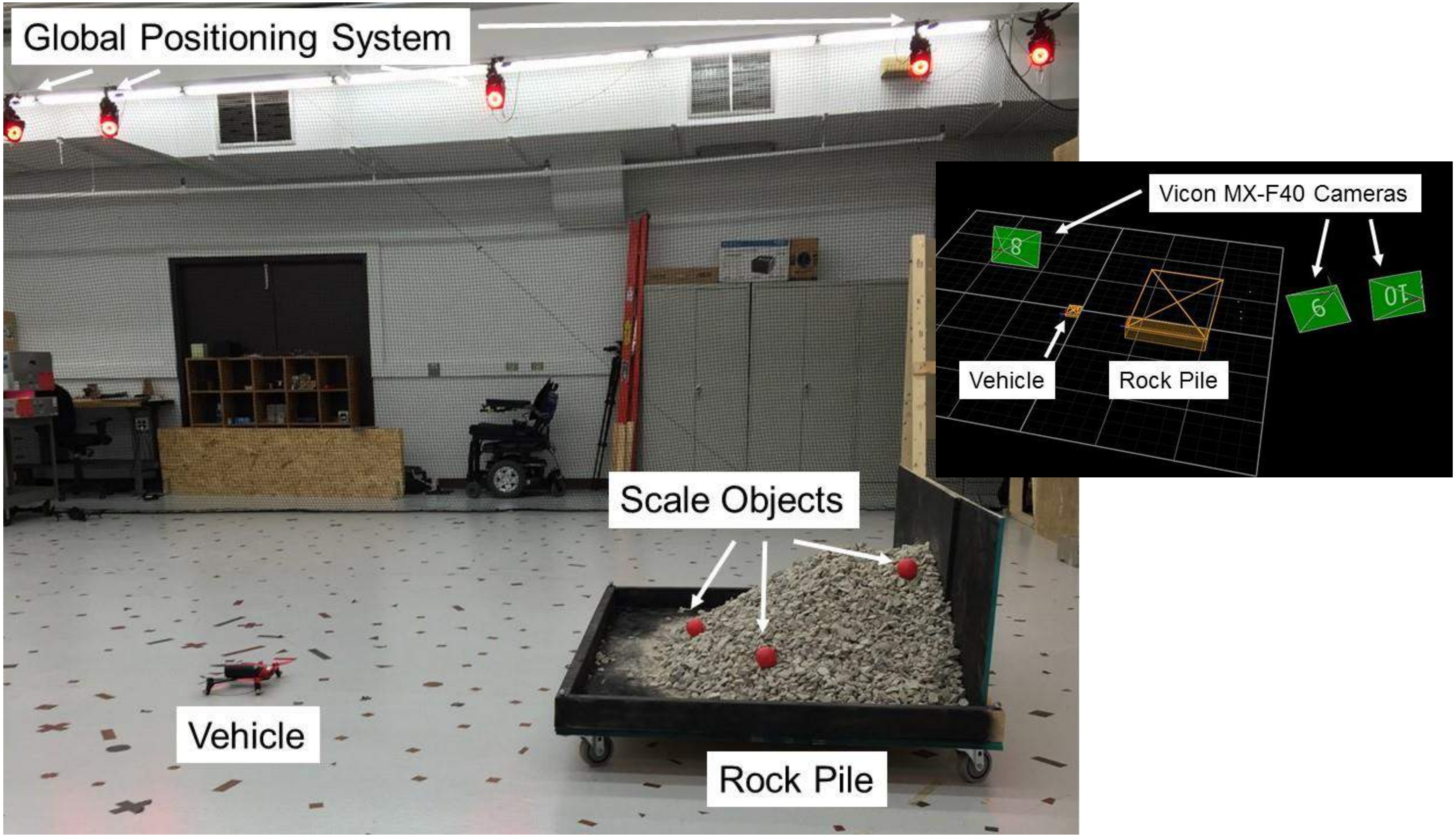
System overview



System overview

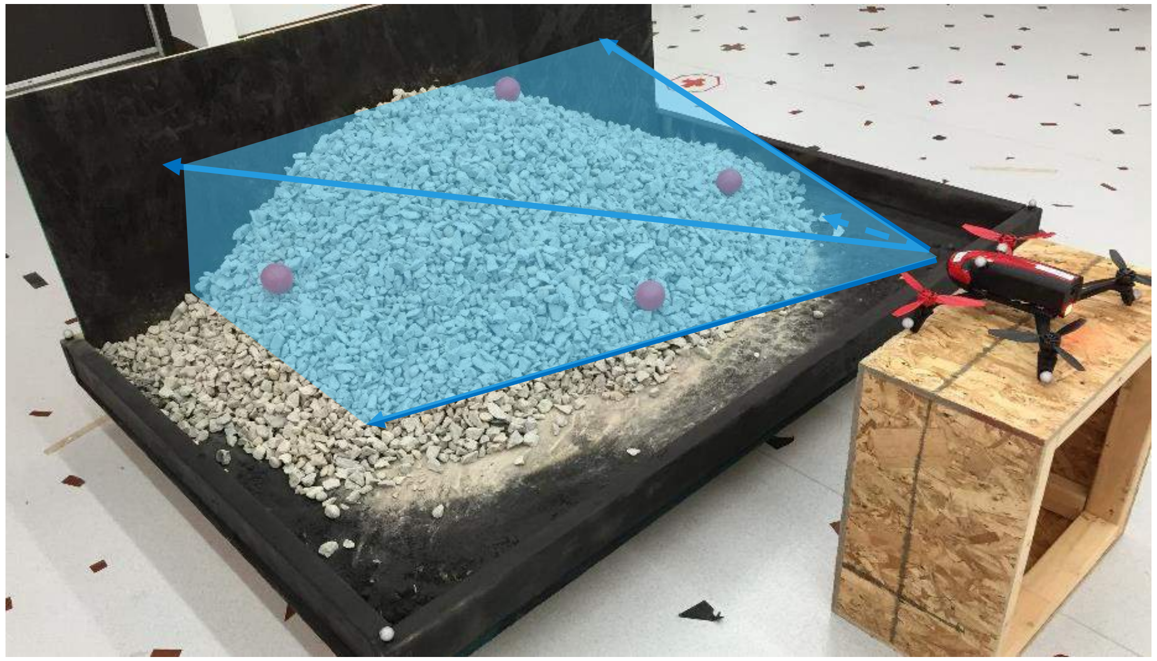


UTIAS indoor robotics lab



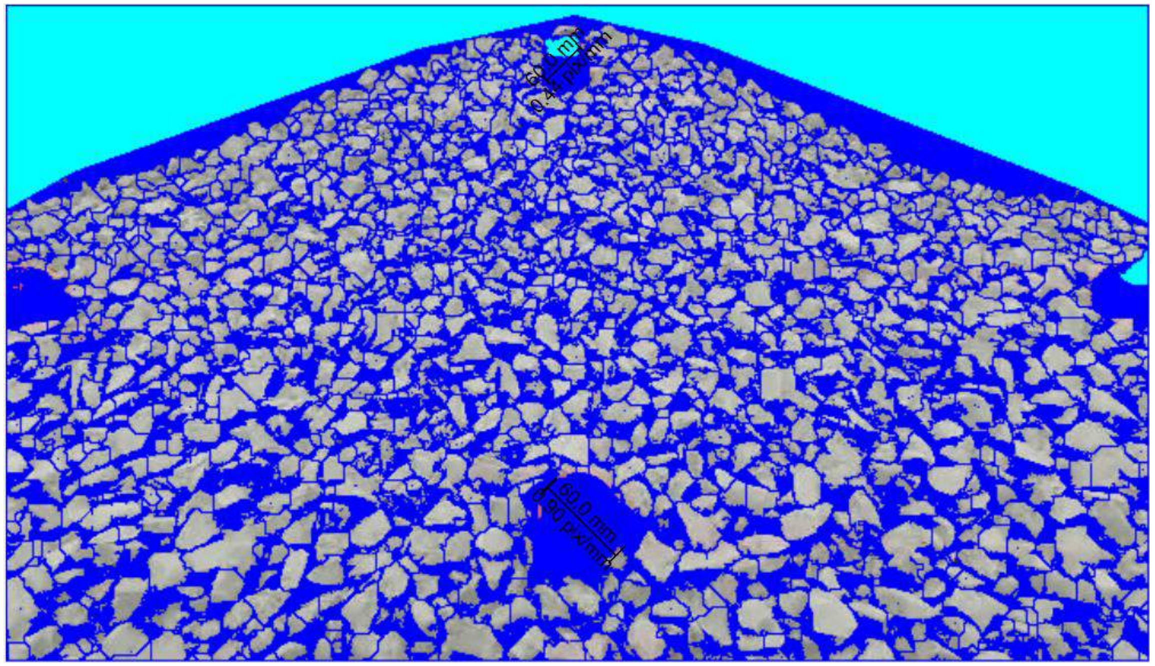
Lab environment to provide optimal conditions for UAV flight prior to testing concepts in the field.

UAV set up as a fixed camera for conventional image analysis



Capturing images at the toe of the muckpile.

Raw photo with scale objects identified.



Delineated photo with masked areas in Split-Desktop.

UAV in flight for automated image analysis

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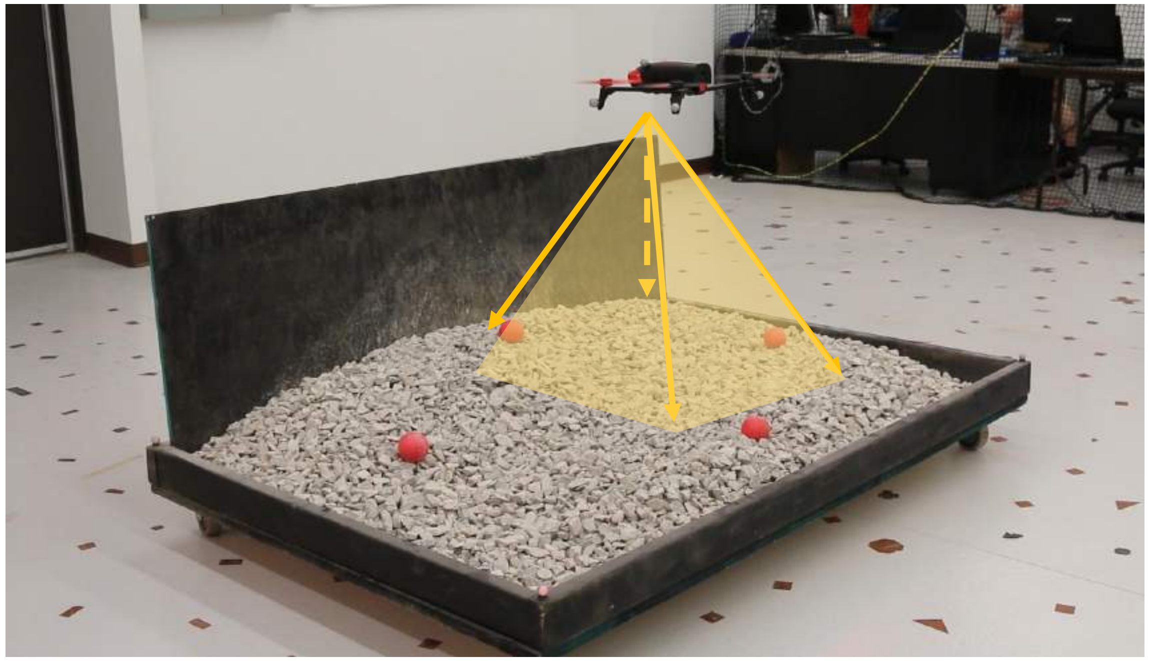
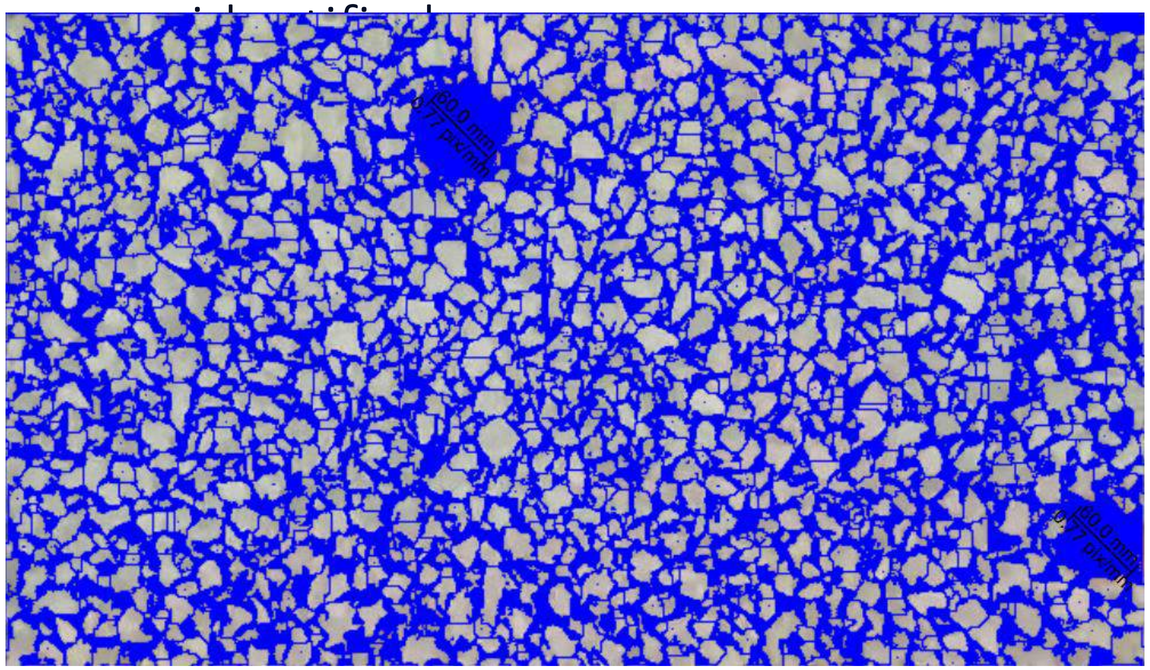


Capturing images on top of the muckpile.

Raw photo with scale objects



Delineated photo in Split-Desktop.

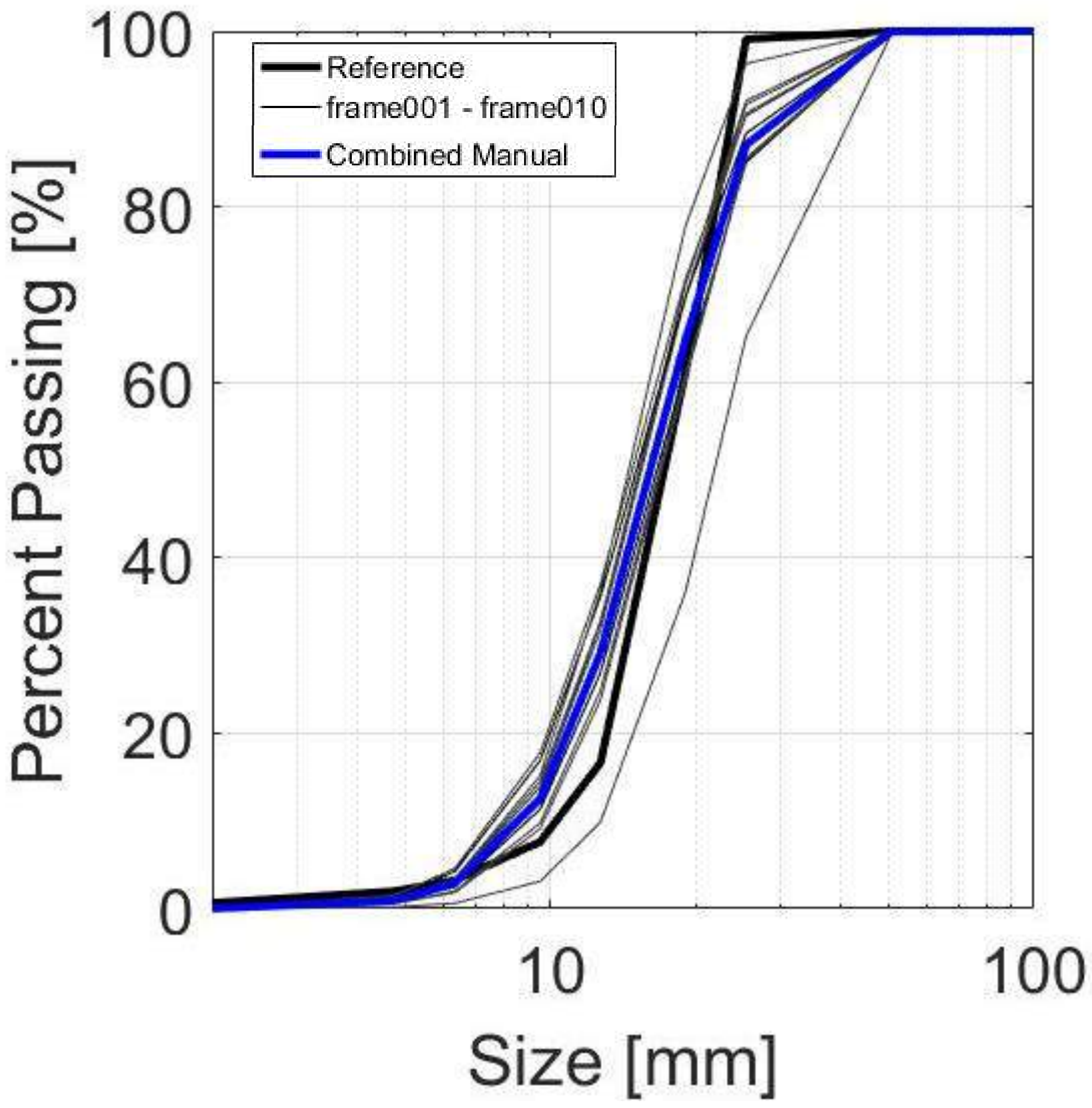
Video demonstration of automated image analysis

Note: the vehicle is autonomously flying – no manual piloting.

Results and Discussion

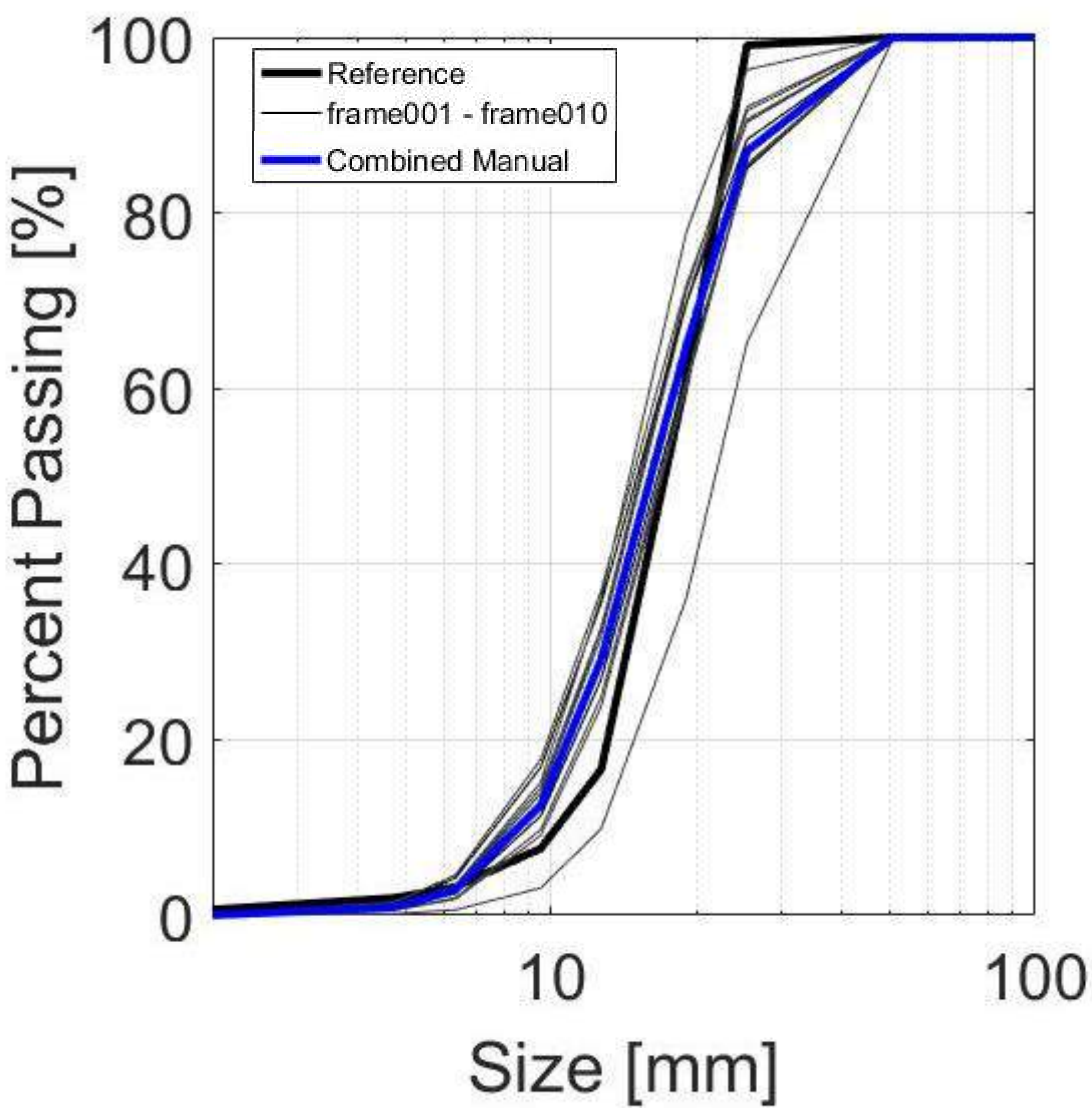
Rock size distribution

Manual, fixed-camera rock size distribution.

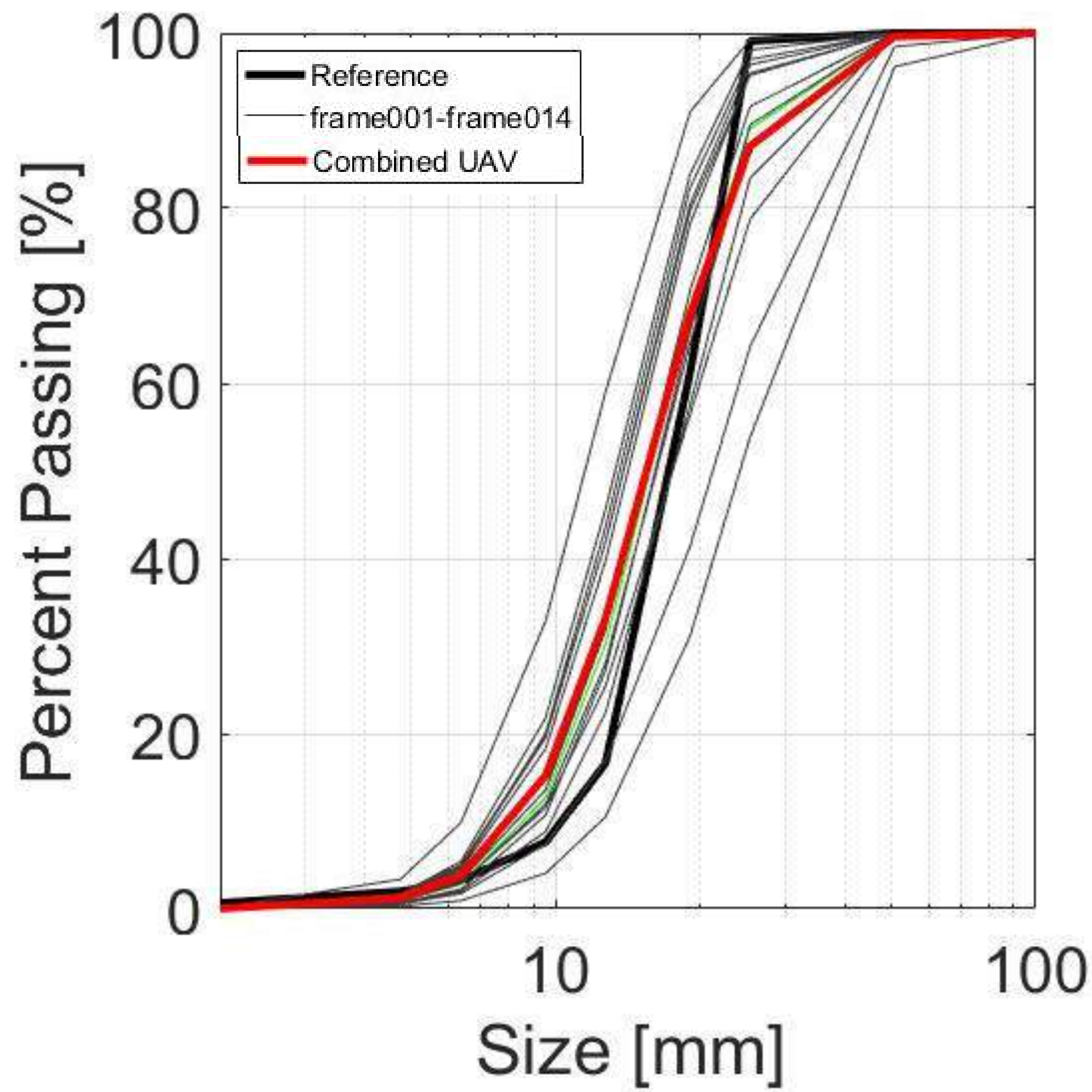


Rock size distribution

Manual, fixed-camera rock size distribution.



Automated UAV rock size distribution.



Error distribution

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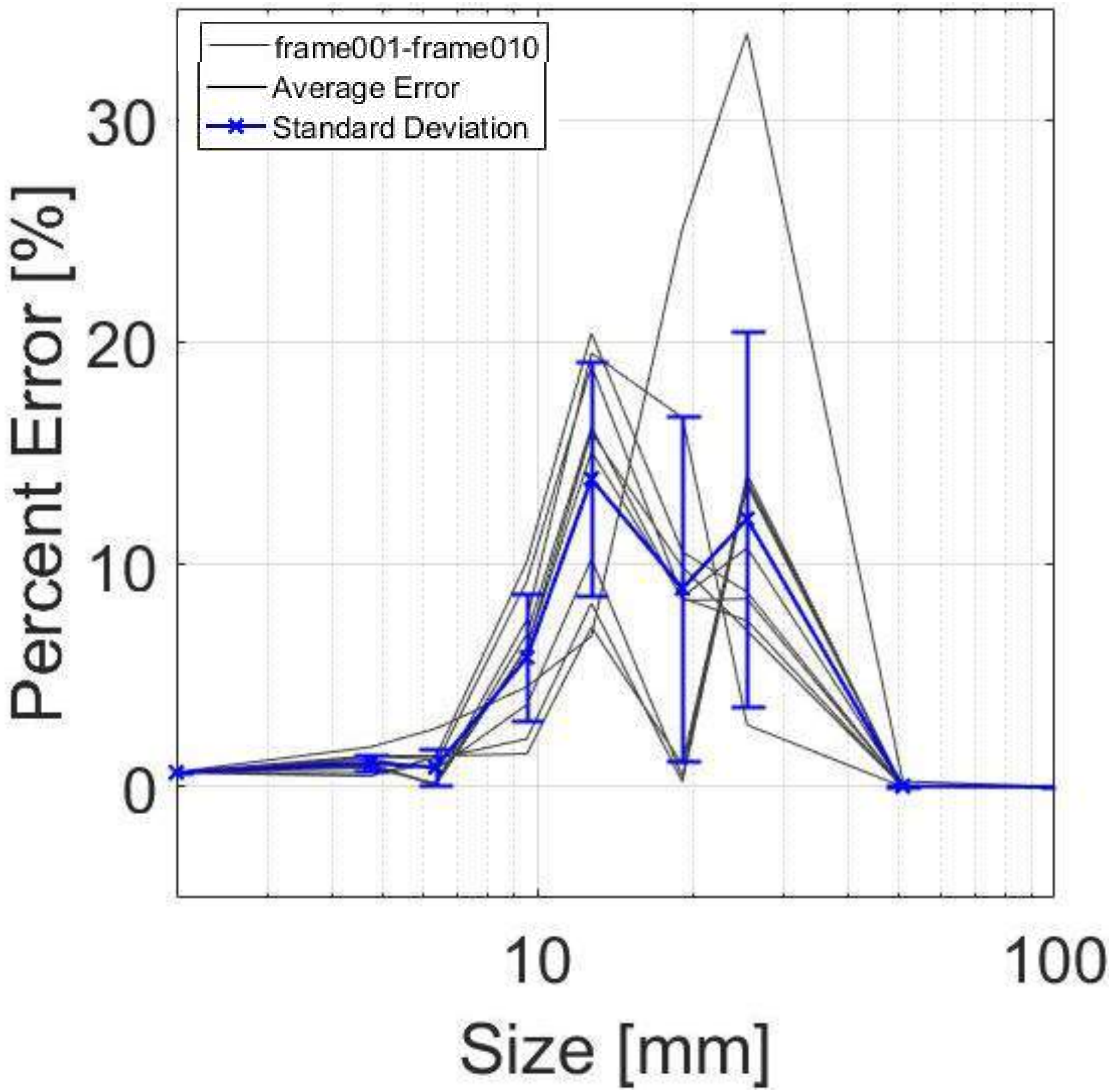
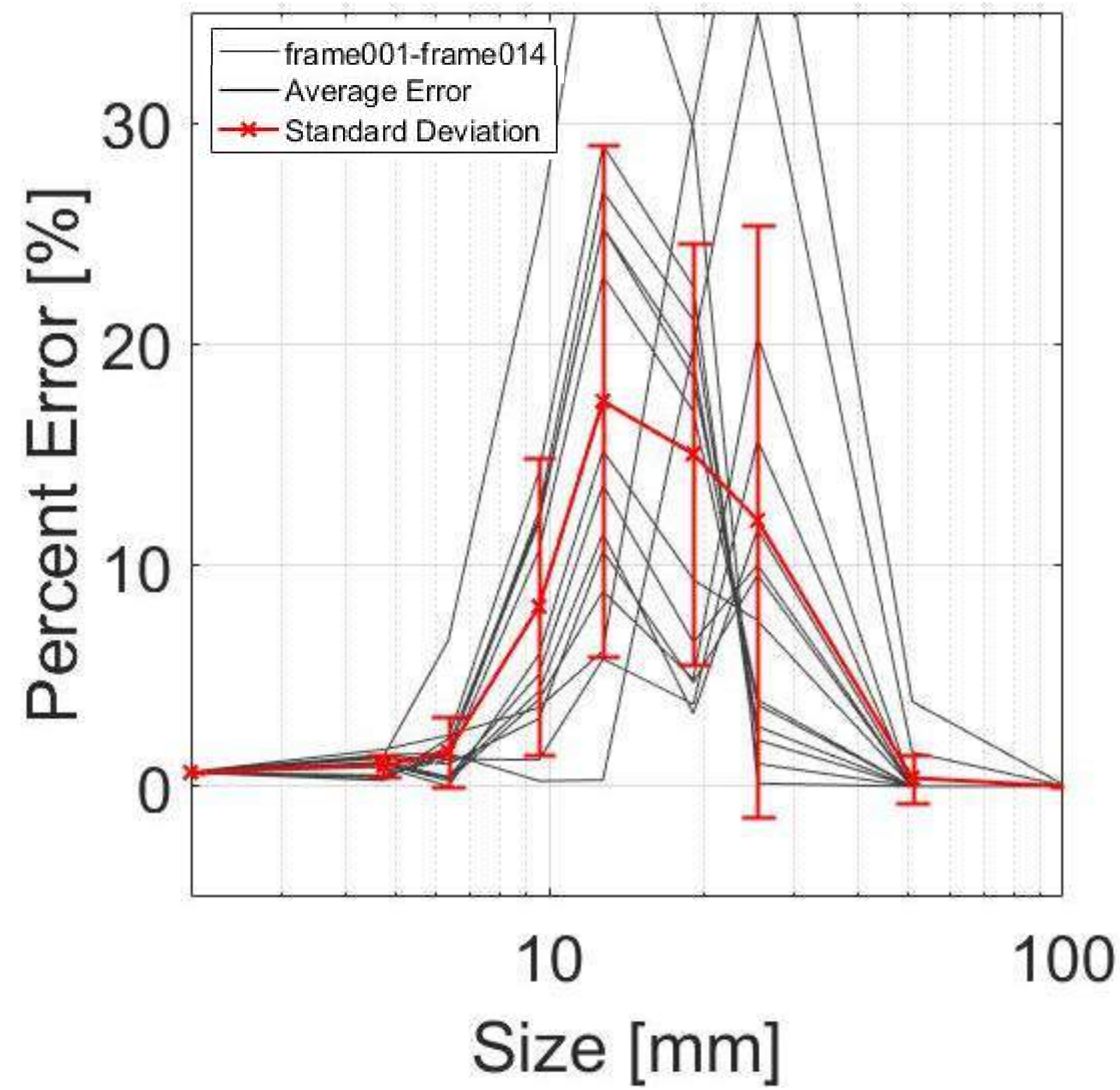
Manual, fixed-camera error distribution.



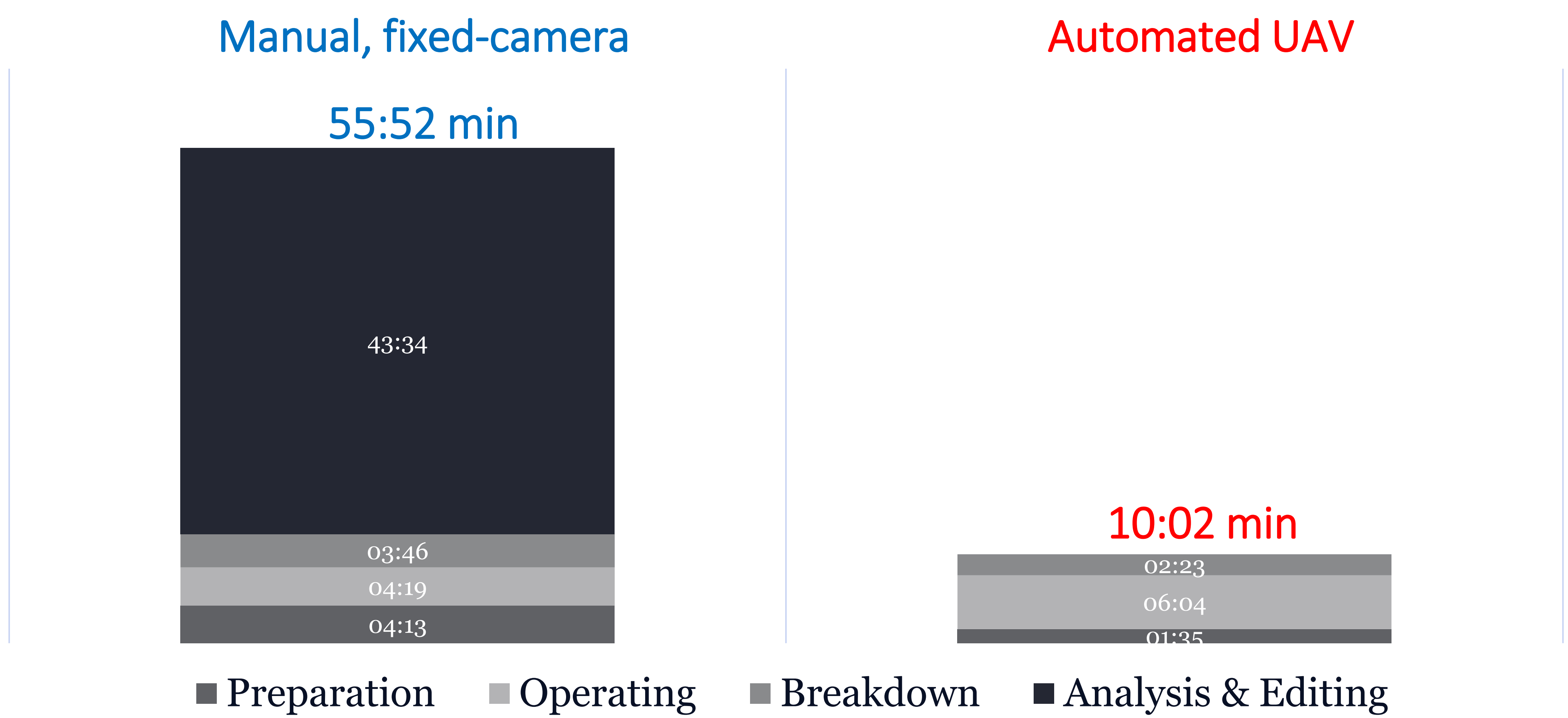
Automated UAV error distribution.



- Relative to the rock size distribution measured in the sieve analysis

Summary of collected data

Time Entries:

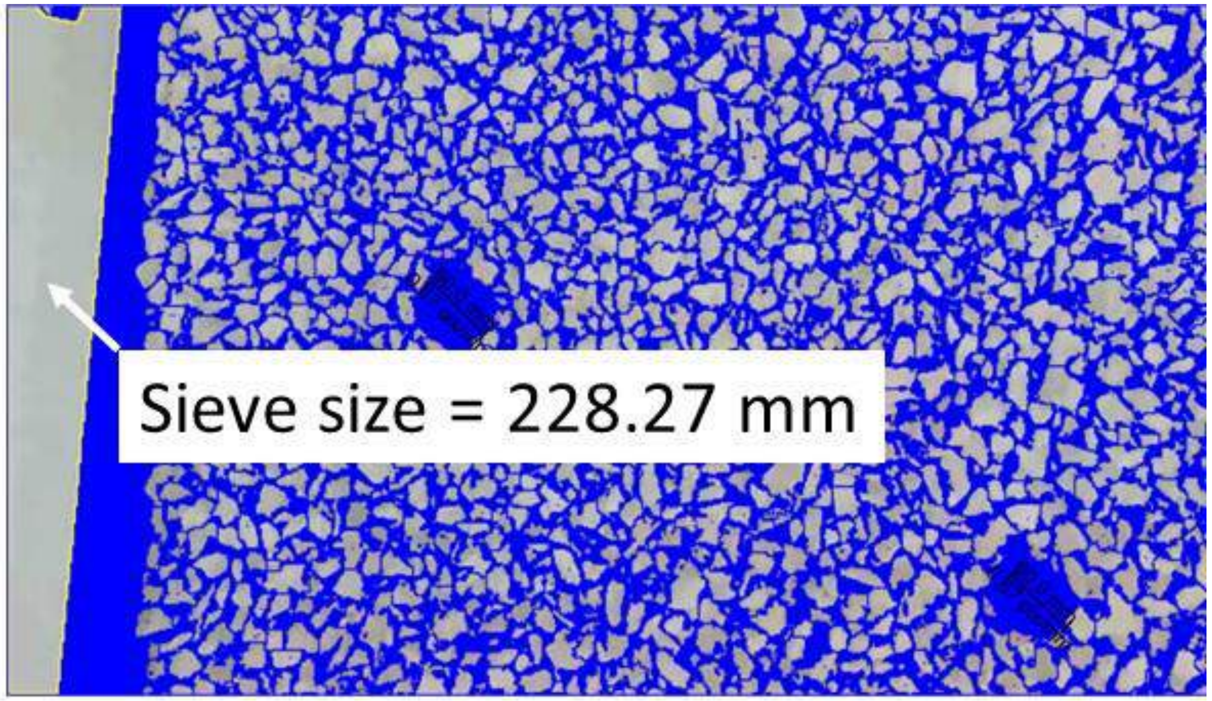


Accuracy: Within 14% Within 17%

- Considered very accurate since the findings of Sanchidrian et al. (2009) suggest error can reach 30% in coarse region to beyond 100% in fines region.

Sources of error

The largest errors were caused by the scale of the experiment since bin edges interfered with rock size measurement.



Bin edge interfering with rock size measurement.

✓ With an optimized combination of picture location and orientation (or minor image editing), this source of error can be eliminated.

Current work

Rock fragmentation analysis:

- Investigating flight plan optimization for image collection
  - Impact of UAV location and camera angle;
  - Image overlap and fines cut-off;
  - Lighting conditions;
  - Tracking a moving target;
  - Remove scale objects.

Future work

Rock fragmentation analysis:

- Implementation in an active mining environment
  - Gain insight into prediction accuracy, the value added, and its ability to be incorporated into mine-to-mill optimization
- 3D image analysis

3D image analysis

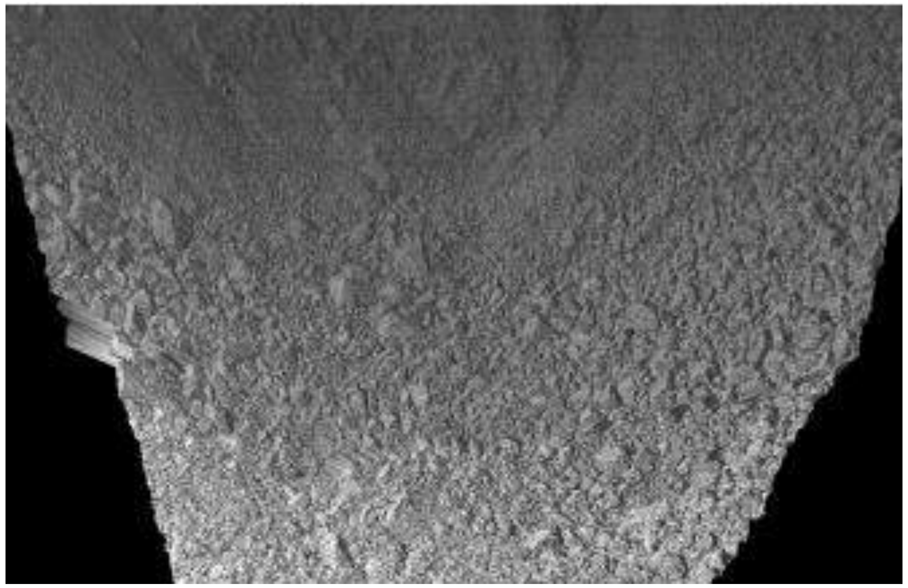
3D measurement techniques have been developed using LIDAR stations or stereo cameras to overcome some of the preceding limitations.

Advantages:

- Eliminates need for scale objects;
- Reduces error produced by the uneven shape of the rock pile.

Limitations:

- Significant time required to capture images in some cases.

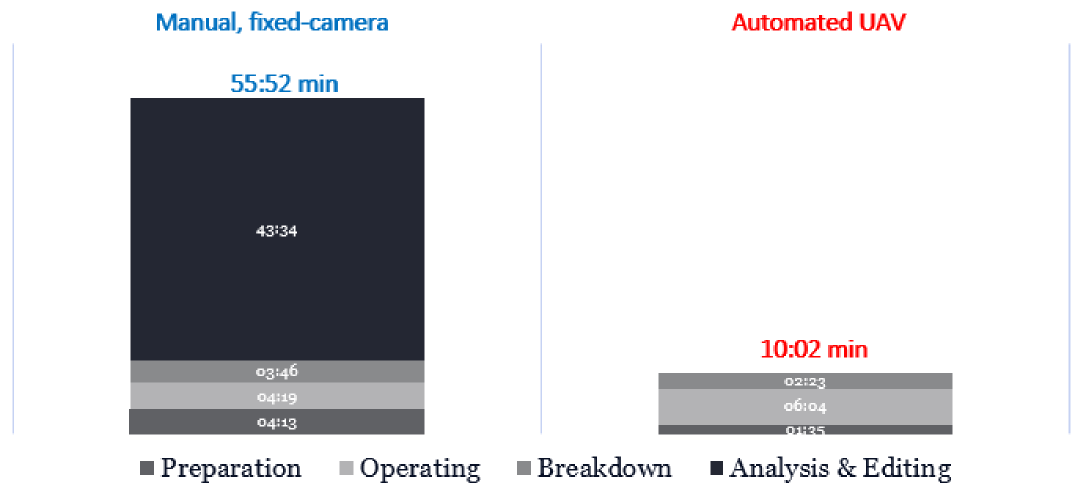


3D surface of a blasted muckpile (Turley, 2013)

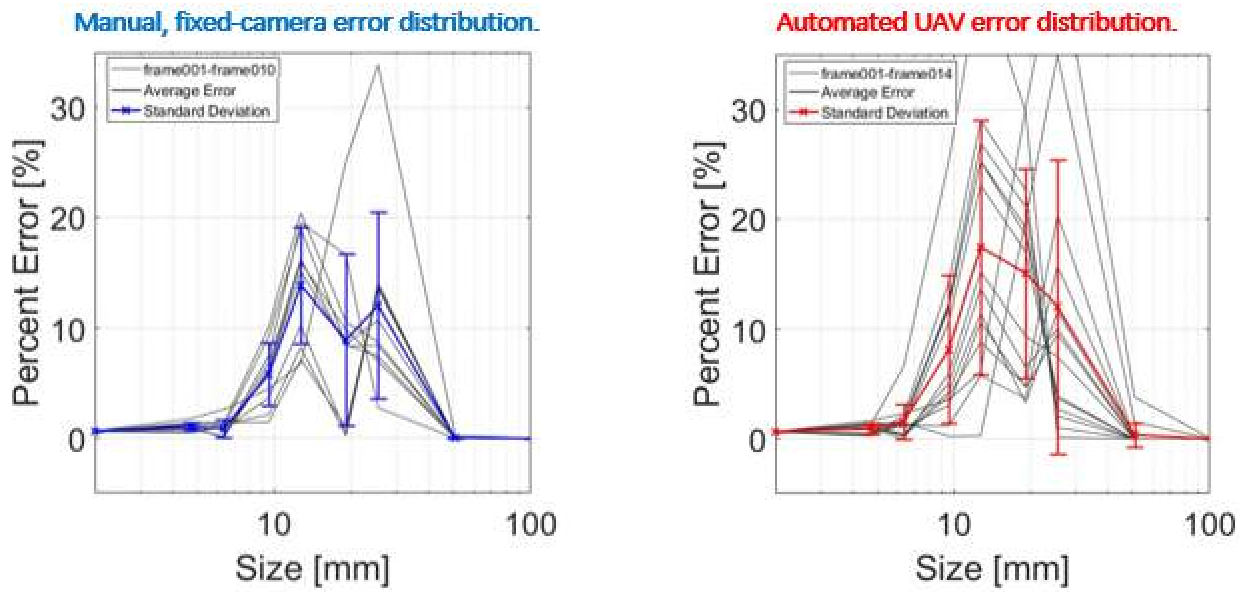
Conclusions

Summary of results

- Overall, automated UAV analysis performed better than conventional method in terms of time effort (**20% of the time**).



- On average, predicted rock size distribution **within 17% of sieving analysis**:



- UAV technology provides **many operational advantages** for real-time data collection.

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Thank you!

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