Stereoscopic Measurements of Clouds

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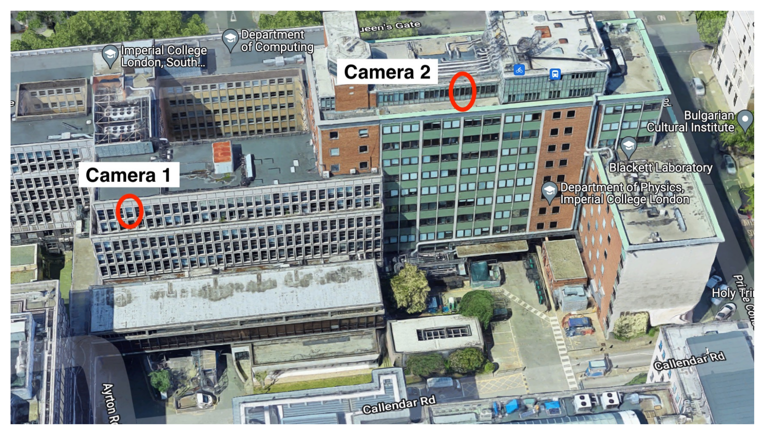
Introduction

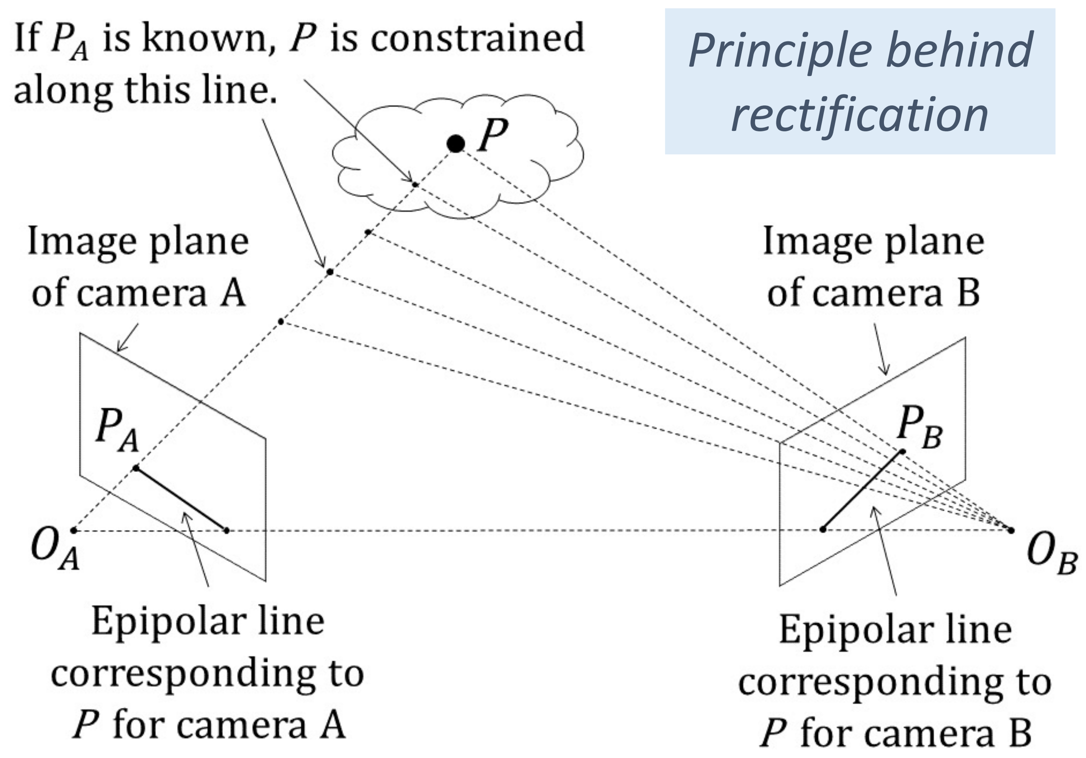
One of the largest uncertainties in estimates of Earth's radiative balance is the effect of clouds. Observations of cloud dynamics are useful to constrain these radiative estimates. However, the temporal resolution of existing cloud observation methods is limited. We propose that if a robust stereo matching algorithm can be developed to measure cloud structure from videos, this would be a low-cost and high-resolution method to gain additional data.

We are using stereo-matching algorithms from the OpenCV computer vision library [1] to calculate cloud base height (CBH), distance and cloud velocity from time-lapse videos from two Raspberry Pi cameras. By validation with lidar data and weather observations from London airports, we show the reliability of this method for different conditions.



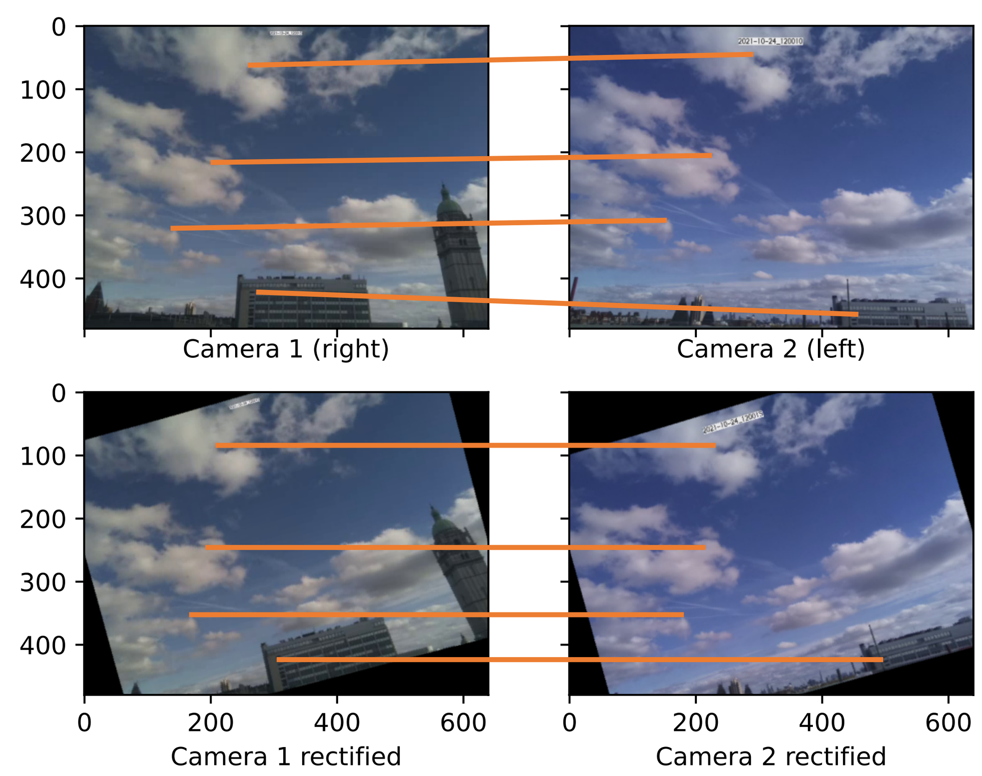
Locations of cameras within Huxley and Blackett Laboratory

1. Rectification



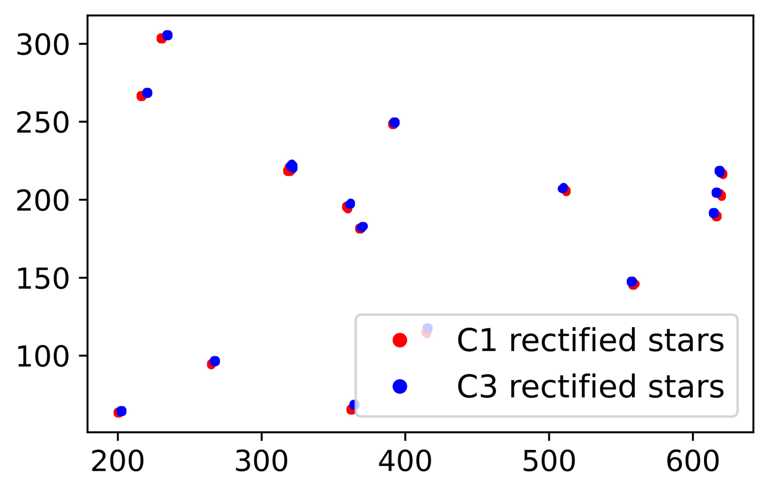
Principle behind rectification

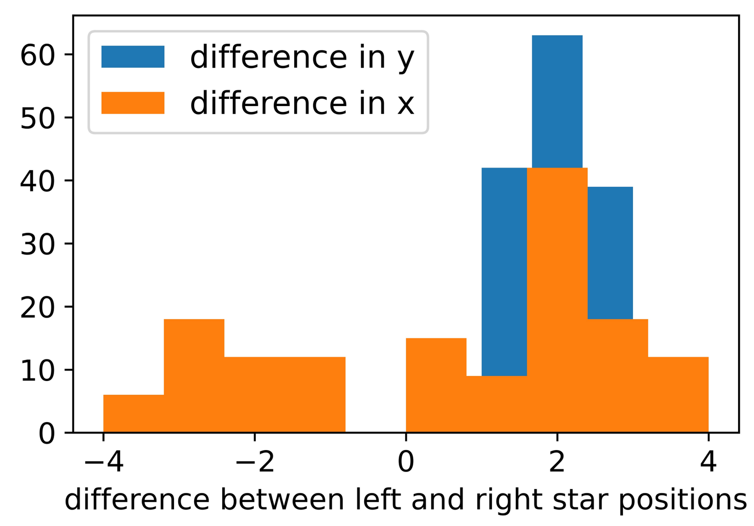
Rectified/unrectified epipolar lines



Rectification warps the images so that corresponding pixels lie on horizontal lines, simplifying the search for correspondence to a 1D problem.

Testing rectification: stars are effectively at infinite distance so should have zero disparity. ▶





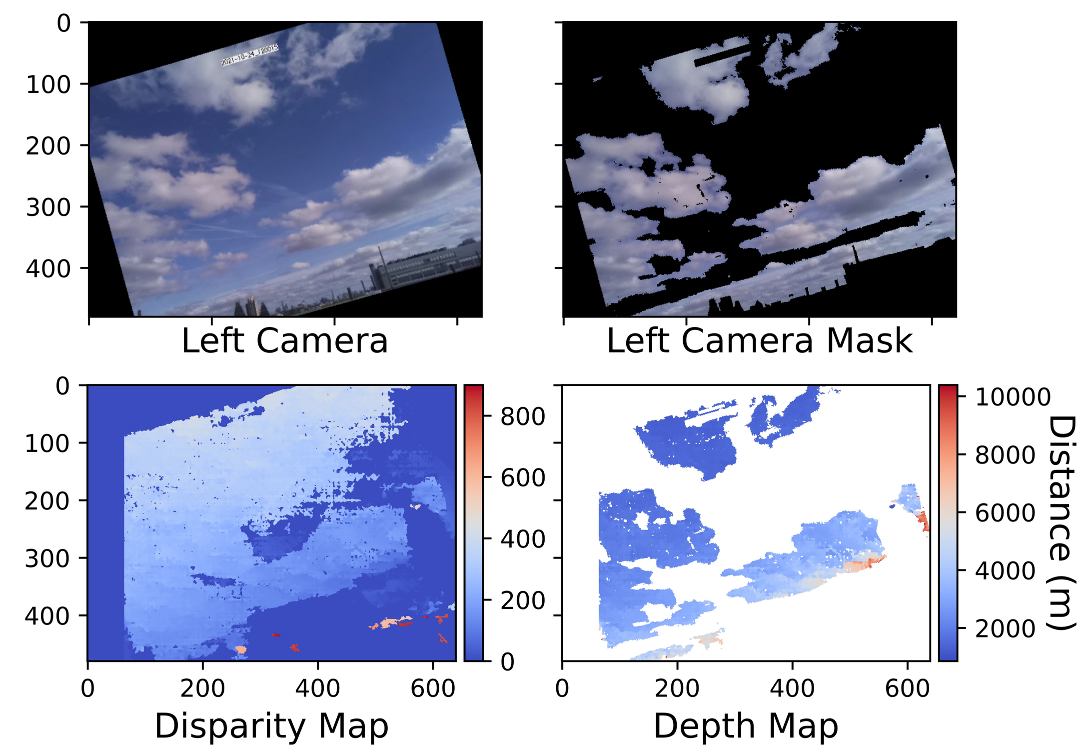
2. Disparity and depth

Disparity refers to the distance between two corresponding pixels in the left and right image. The 3D position of a point can be calculated from its disparity.

Depth is inversely proportional to disparity

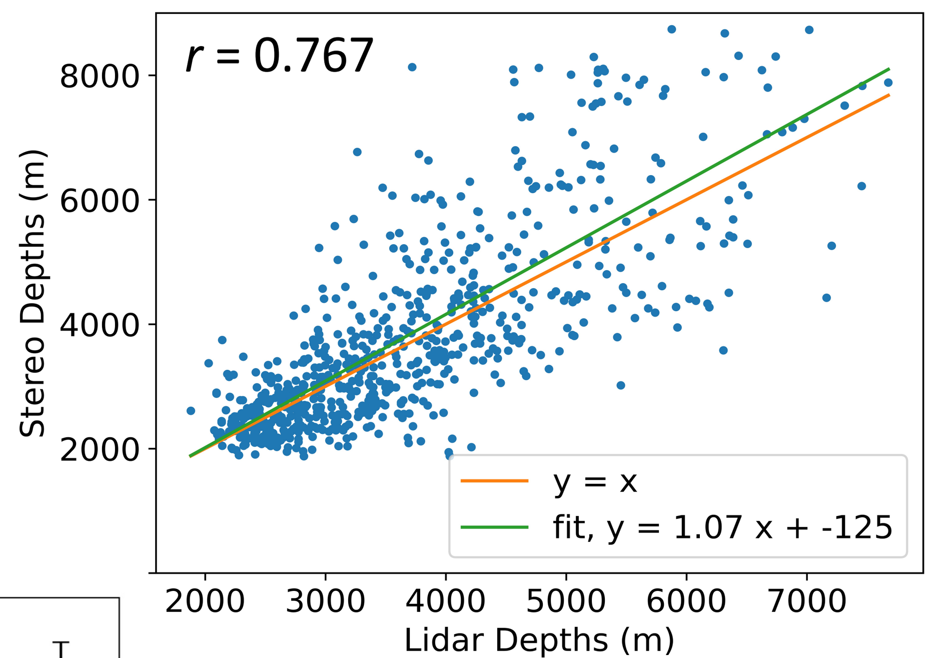
$$depth = \frac{f\ B}{disparity}$$

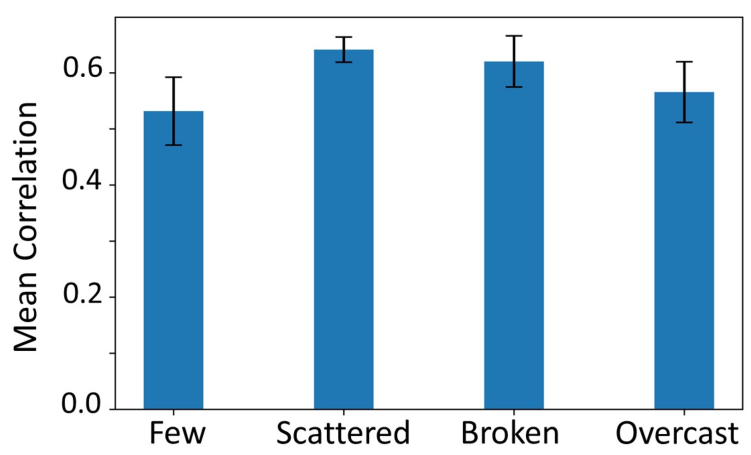
where f is the focal length of the camera, and B is the distance between the two cameras.



3. Validation of Cloud Heights

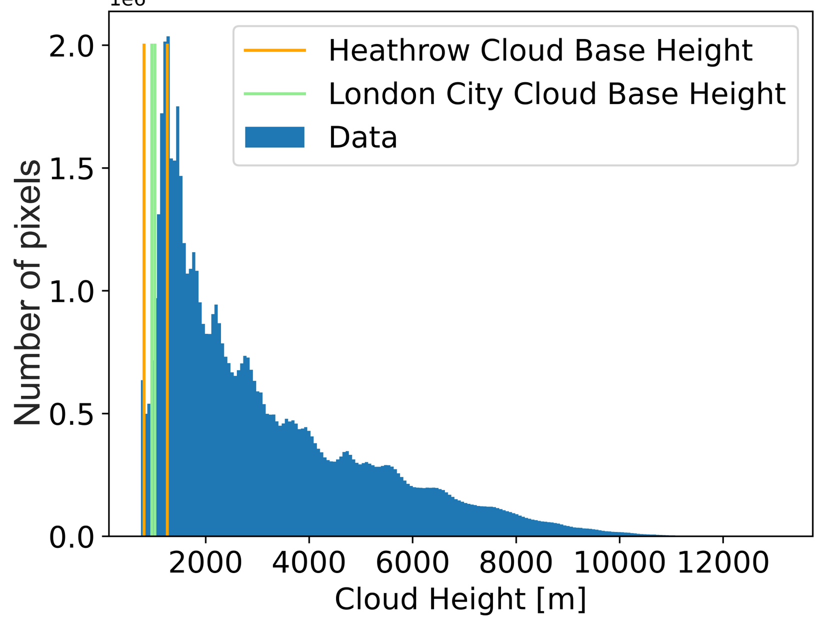
Comparison between depths calculated using the stereo matching algorithm and depths measured using lidar. Pearson correlation coefficient r = 0.767.





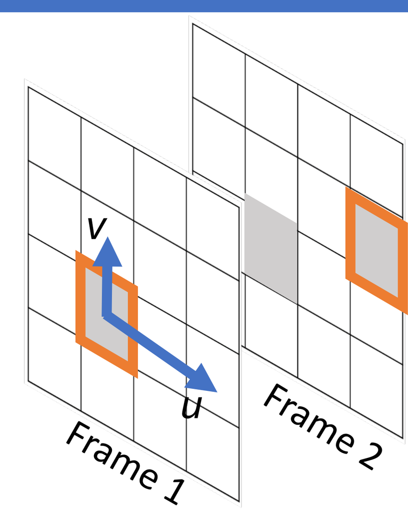
Correlation between lidar and stereo averaged over each hour and categorized by level of cloud cover.

Histogram of cloud heights from an hour of images with consistent cloud conditions. Measurements of CBH made at Heathrow and London City airports show good agreement with the stereo estimates.



4. Optical flow

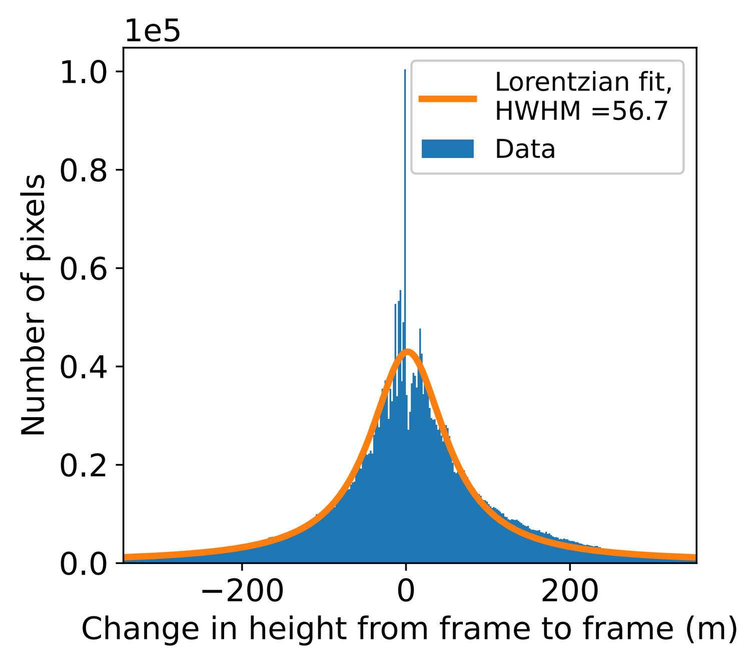
Optical flow is defined as the apparent motion of individual pixels on the image plane. To estimate the flow, we use a pre-trained model called Flownet2 [2]. This model provides displacement vectors for each pixel and frame.

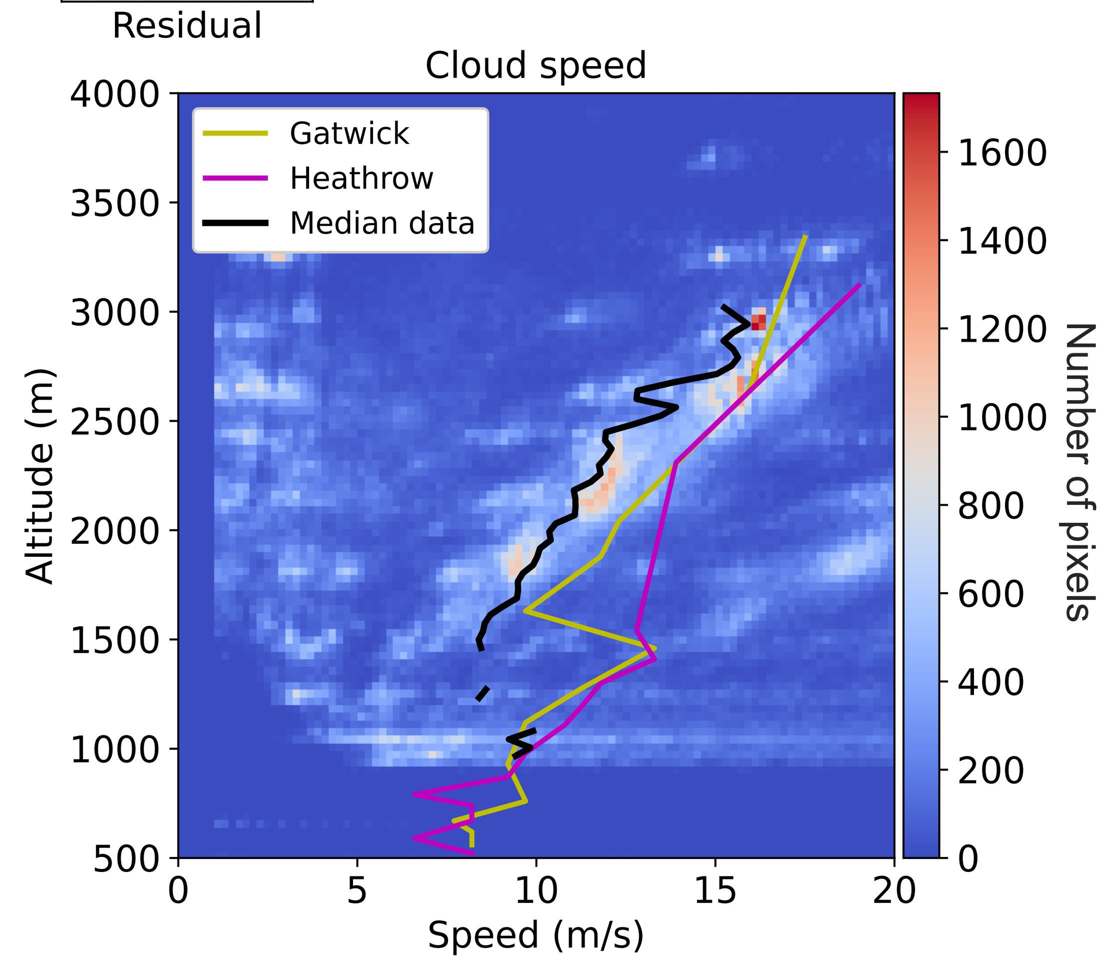


◀ *Visualisation of optical flow. Brightness = magnitude of displacement Colour = direction in image plane.*

◀ *Validation of optical flow algorithm. Optical flow results are used to warp frame 1 to estimate the predicted frame 2. The residual of frame 2 and warped frame 1 is 0, as expected.*

Histogram of the variation in height from frame to frame. ▶





By combining optical flow with our measurements for depths we can estimate cloud speed.

Cloud speed as a function of height. Median speed data is compared to windspeeds measured by aircraft landing at nearby airports.

5. Conclusion

Developed algorithm to analyse cloud parameters:

- Depth measurements validated using lidar
- CBH measurements validated using airport data
- Windspeed measurements validated using aircraft data

Perspectives:

- Train optical flow model on our own cloud videos
- Expand algorithm to determine wind direction
- Test algorithm for different days and weather conditions

References:
[1] G. Bradski, "The OpenCV Library", Dr. Dobb's Journal of Software Tools, 2000.
[2] E. Ilg, N. Mayer, T. Saikia, M. Keuper, A. Dosovitskiy and T. Brox, "FlowNet 2.0: Evolution of Optical Flow Estimation with Deep Networks", IEEE Conference on Computer Vision and Pattern Recognition (CVPR)", 2017.