Data in Brief

Contents lists available at ScienceDirect

Data in Brief

journal homepage: www.elsevier.com/locate/dib

Data Article

PFuji-Size dataset: A collection of images and photogrammetry-derived 3D point clouds with ground truth annotations for Fuji apple detection and size estimation in field conditions

Jordi Gené-Mola*, Ricardo Sanz-Cortiella, Joan R. Rosell-Polo, Alexandre Escolà, Eduard Gregorio

Research Group in AgroICT & Precision Agriculture - GRAP1, Department of Agricultural and Forest Engineering, Universitat de Lleida (UdL) – Agrotecnio-CERCA Center, Lleida, Catalonia, Spain

ARTICLE INFO

Article history:
Received 22 September 2021
Revised 12 November 2021
Accepted 19 November 2021
Available online 24 November 2021

Keywords:
Fruit detection
Fruit size
3D object detection
Structure-from-motion
Multi-view stereo
Agricultural robotics
Precision agriculture

ABSTRACT

The PFuji-Size dataset is comprised of a collection of 3D point clouds of Fuji apple trees (Malus domestica Borkh. cv. Fuji) scanned at different maturity stages and annotated for fruit detection and size estimation. Structure-from-motion and multi-view stereo techniques were used to generate the 3D point clouds of 6 complete Fuji apple trees containing a total of 615 apples. The resulting point clouds were 3D segmented by identifying the 3D points corresponding to each apple (3D instance segmentation), obtaining a single point cloud for each apple. All segmented apples were labelled with ground truth diameter annotations. Since the data was acquired in field conditions and at different maturity stages, the set includes different fruit diameters -from 26.9 mm to 94.8 mm- and different fruit occlusion percentages due to foliage. In addition, 25 apples were photographed 360° in laboratory conditions, obtaining high resolution 3D point clouds of this sub-set. To the best of the authors’ knowledge, this

DOI of original article: 10.1016/j.compag.2021.106343
* Corresponding author. Jordi Gené-Mola
E-mail address: jordi.genemola@udl.cat (J. Gené-Mola).
Social media: twitter (A. Escolà)
1 @grapudl

https://doi.org/10.1016/j.dib.2021.107629
2352-3409/© 2021 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)
is the first publicly available dataset for apple size estimation in field conditions. This dataset was used to evaluate different fruit size estimation methods in the research article titled “In-field apple size estimation using photogrammetry-derived 3D point clouds: comparison of 4 different methods considering fruit occlusion” (Gené-Mola et al., 2021).

© 2021 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/)

Specifications Table

| Subject          | Agriculture Engineering, Computer Vision and Pattern Recognition |
|------------------|---------------------------------------------------------------|
| Specific subject area | Precision Agriculture, Fruit Detection, Fruit Size Estimation, Machine Learning, Agricultural Robotics |
| Type of data     | Images                                                        |
|                   | 3D coloured point clouds                                      |
|                   | 3D instance (fruit) segmentation annotations                  |
|                   | Fruit size (diameter) annotations                             |
| How data were acquired | Ground truth fruit diameters were measured using a Vernier calliper. |
|                   | Raw images were taken using an EOS 60 DSLR Camera (Canon Inc. Tokyo, Japan) with an 18 MP CMOS APS-C sensor and an EFS 24 mm f/2.8 STM lens (38 mm film-equivalent focal length). |
|                   | - 3D point clouds were generated with Agisoft Professional Metashape software (v1.6.4, Agisoft LLC, St. Petersburg, Russia). |
|                   | - 3D apple segmentation ground truth was manually annotated by identifying the 3D points corresponding to each apple with CloudCompare software (Cloud Compare [GPL software] v2.9 Omnia). |
| Data format       | Raw images: JPG                                               |
|                   | Apple tree point clouds: LAZ                                   |
|                   | Apple segmented point clouds: TXT                             |
|                   | Apple size and location annotations: TXT                      |
| Parameters for data collection | Image acquisition: Images were acquired from a distance of 2.5 m with respect to the tree centres with a horizontal and vertical overlap between consecutive images higher than 75% and 85%, respectively. |
|                   | - 3D point cloud reconstruction: The parameters set to the Agisoft Professional Metashape Software were: camera alignment accuracy, “highest”; key point limit, “40000”; tie point limit, “4000”; dense cloud quality, “high”; depth filtering, “Mild”. |
| Description of data collection | The diameter of 615 Fuji apples was manually measured with the calliper. The 6 trees containing the measured apples were then photographed from different positions in order to reconstruct the corresponding 3D model using structure-from-motion and multi-view stereo techniques. The resulting 3D point clouds were manually segmented by identifying the points of all measured apples in the clouds (3D instance segmentation masks). Each segmented apple was pair-wised with its corresponding ground truth diameter. In addition, a set of 25 additional Fuji apples were picked and scanned in laboratory conditions. |
| Data source location | City/Town/Region: Agramunt, Catalonia                         |
|                   | Country: Spain                                                |
|                   | GNSS coordinates for collected samples/data: E = 336297 m, N:= 4623494 m, 312 m a.s.l., UTM 31T - ETRS89 |
| Data accessibility | Repository name: Dataverse                                    |
|                   | Data identification number: https://doi.org/10.34810/data141   |
|                   | DOI: https://doi.org/10.34810/data141                         |
|                   | Direct URL to data:                                            |
|                   | https://dataverse.csuc.cat/dataset.xhtml?persistentId=doi:10.34810/data141 |
| Related research article | J. Gené-Mola, R. Sanz-Cortiella, J.R. Rosell-Polo, A. Escola, E. Gregorio. 2021. In-field apple size estimation using photogrammetry-derived 3D point clouds: comparison of 4 different methods considering fruit occlusions., Comput. Electron. Agric. 188 (2021) 106343. https://doi.org/10.1016/j.compag.2021.106343 [1] |
Value of the Data

- First publicly available dataset for fruit detection and size estimation containing photogrammetry-derived 3D point clouds annotated with apple segmentation masks and fruit diameter ground truth. This dataset differs from previously published datasets [2–5] in: (1) data acquired at different maturity stages; (2) fruit location annotations in the form of 3D instance (apple) segmented point clouds; (3) providing the actual diameter of all apples labelled in the point cloud.
- The precision agriculture community can benefit from these data to test new fruit detection and size estimation methodologies, with applications in yield prediction [6,7] and automated harvesting [8,9].
- New fruit size estimation methods can be tested either using the original point clouds - containing a complete representation of 6 apple trees- or using the provided ground truth apple segmentation masks (640 apple point clouds).
- The dataset includes 615 apples scanned under in-field conditions at two different phenology stages: green apples at 70% of final size and red apples at advanced ripening. The data includes different fruit diameters -from 26.9 mm to 94.8 mm- and different fruit occlusion percentages -from 1.4 % to 99 %-. A 360° complete representation of the apples.
- This dataset allows all methods and results reported in the corresponding research paper [1] to be reproduced.

1. Data Description

This dataset includes three different data sub-sets. The first, called Orch2018, includes 303 apples captured under in-field conditions on October 3rd, 2018, when apples were at advanced ripening growth stage (reddish coloured). The second, called Orch2020, includes 312 apples captured under in-field conditions on July 16th, 2020, when apples were about 70% their final size (green coloured). Finally, the third sub-set of data, called Lab2020, was acquired on October 2nd, 2020. In this case, 25 apples of different sizes were imaged in laboratory conditions.

The data provided in this dataset include: (1) raw images used to generate the 3D point clouds with structure-from-motion and multi-view stereo techniques; (2) the 3D point clouds of the captured scene -3 apple trees in Orch2018 and 3 apple trees in Orch2020- (Fig. 1a); (3) the segmented point clouds for all apples present in the captured trees (Fig. 1b); (4) apple centroid ([X, Y, Z] coordinate) and diameter ground truth (Fig. 1c and d).

This dataset differs from previously published datasets [3,4] in:

- Data acquired in a different set of trees, different dates and at different phenology stages. While the data published in [3,4] included 11 trees scanned in 2017 when fruits were ripe, the present dataset was acquired in a different set of trees, at two different dates (2018 and 2020) and different maturity stages: green apples at 70% of their final size (Orch2020) and red apples at advanced ripening (Orch2018).
- Different type of fruit detection and location annotations. Previous published datasets included 2D instance segmented images [4], and/or 3D location annotations in the form of 3D bounding boxes [3,4]. Alternatively, the present dataset provides the 3D fruit location annotations in the form of 3D instance (apple) segmented point clouds. This 3D instance segmentation ground truth could not be reproducible from the annotations provided in [4] because the segmentation masks provided in the present dataset refer to the 3D point cloud, while the segmentation masks provided in [4] referred to 2D images.
- The present dataset provides the ground truth diameter and the apple centre [X,Y,Z] of all fruits in the point clouds for fruit size estimation.
The dataset can be downloaded from https://doi.org/10.34810/data141. Once unpacked, the data is structured as shown in Fig. 2. The first folder, /PFuji-Size_dataset/1-raw_images (27.2 GB), includes all raw images used to generate the point clouds. Images were saved in .JPG format and have a resolution of 5184 × 3456 pixels. A total of 168 and 180 images were acquired respectively from the eastern and western sides of the tree row captured in Orch2018, and a total of 228 and 280 images respectively from the eastern and western sides of the tree row captured in Orch2020. The images acquired in laboratory conditions are placed in the /PFuji-Size_dataset/1-raw_images/3-Lab2020 folder, which includes a total of 180 images per apple (25 apples × 180 images/apple = 4500 images). Section 2 describes in greater detail the methodology followed to acquire these images.

The second folder, /PFuji-Size_dataset/2-trees_point_clouds (400 MB) (Fig. 2), includes the point clouds of trees captured under in-field conditions. For each set of data –Orch2018 and Orch2020– two point cloud files were generated: one obtained from the eastern side of the tree row and the other from the western side. Each of these point clouds was saved in .LAZ format and contains between 8.8 M and 9.6 M points to 3D represent the three trees in each data sub-set: three trees in Orch2018 and three trees in Orch2020. The LAZ format is the compressed version of the standard LAS file format used for point cloud data records [10]. LAZ files can be directly opened by using a point cloud editing software such as CloudCompare (Cloud Compare [GPL software] v2.9 Omnia), or can be decompressed to LAS format by using the LASzip software https://laszip.org/.

Each pair of east-west point clouds were merged and segmented. Then, points corresponding to each apple were aggregated and saved, obtaining a single point cloud per apple (3D apple segmentation masks). The resulting apple point clouds (315 apples) were saved in the third folder, named /PFuji-Size_dataset/3-apple_point_clouds (229 MB) (Fig. 2). In addition, this folder also contains the 25 apple point clouds generated in laboratory conditions (Lab2020). All these apple point clouds were saved in .TXT files, where each row corresponds to a single 3D point, giving the information of [x, y, z, R, G, B], where, [x, y, z] is the point position in global coordinates, and [R,G,B] is the point colour with 8-bit resolution values ranging from 0 to 255.
Finally, the file /PFuji-Size_dataset/4-apples_GT_diameter_and_centre.txt (46 kB) includes the ground truth fruit diameters and location. Each row corresponds to an apple annotation giving the following information: apple identification name (Apple_ID), diameter [mm], apple centre X coordinate [m], apple centre Y coordinate [m], and apple centre Z coordinate [m]. Fig. 3 illustrates a histogram of the distribution of the ground truth diameters measured in each data sub-set. Apples measured in Orch2018 (303 apples) had a mean diameter of 77.4 mm and a standard deviation of 9.4 mm. Apples measured in Orch2020 (312 apples) had a mean diameter of 54.1 mm and a standard deviation of 5.1 mm. Finally, the distribution of apples scanned in Lab2020 (25 apples) shows a similar number of samples in each diameter interval, including apple diameters between 39 and 97 mm.

2. Experimental Design, Materials and Methods

The PFuji-Size dataset was acquired in a Fuji apple (Malus domestica Borkh. cv. Fuji) orchard located in Agramunt, Catalonia, Spain (latitude: 41° 44’ 47.07’’ N; longitude: 1° 01’ 52.23’’ E; 312 m a.s.l. ETRS89). The captured trees were trained in a tall spindle system and had a maximum canopy height of 3.5 m and width of 1.5 m, approximately.

The camera used was an EOS 60 DSLR with an 18 MP CMOS APS-C sensor and an EFS 24 mm f/2.8 STM lens (Canon Inc. Tokyo, Japan). A total of 348 and 508 images were taken to capture the trees in the Orch2018 and Orch2020 sets, respectively. Images were acquired following the experimental layout illustrated in Fig. 4. The distance between two consecutive horizontal camera positions was 0.2 m (Fig. 4a). From each horizontal position, a total of 12 photographs were
Fig. 3. Apple ground truth diameter histogram. The number of apples at different diameter intervals for Orch2018, Orch2020 and Lab2020 sub-sets are represented in orange, blue and red, respectively.

Fig. 4. Photographic process layout followed to capture trees from Orch2018 and Orch2020. (a) Isometric view of Orch2018 scene showing the horizontal separation between neighbouring images. (b) Transversal view of trees scanned in Orch2018 showing the camera positions: height and distance from the centre of the tree row.

acquired from 6 different heights (two photographs from each height) (Fig. 4b). The distance between two consecutive vertical camera positions was 0.3 m (Fig. 4b). With this configuration, the overlap between horizontal and vertical consecutive images was higher than 85% and 75%, respectively.

The camera used to acquire the Lab2020 set was the same as the one described for the Orch2018 and Orch2020 sets. However, the experimental layout was designed to obtain a high
resolution 360° representation of the apples. Each apple was held in a vertical screw mounted on a turntable. Images were acquired from 5 different camera heights: −10 cm, 0 cm, 10 cm, 20 cm and 30 cm with respect to the apple centre (Fig. 5a). From each camera height, the camera was tilted so that the apple centre appears at the centre of the image and 36 images were captured around the apple (every 10° rotation) (Fig. 5b), resulting in a total of 180 images per apple: 5 height positions * 36 images/position = 180 images.

Raw images were used to generate the 3D model of trees and apples by applying multi-view structure-from-motion based on bundle adjustment [11]. To this end, Agisoft Professional Metashape software (v1.6.4, Agisoft LLC, St. Petersburg, Russia) was used with the following settings: camera alignment accuracy, “highest”; key point limit, “40000”; tie point limit, “4000”; dense cloud quality, “high”; depth filtering, “Mild”. A set of reference markers were used to scale the generated point clouds. The markers used in the laboratory scanning (Lab2020) were placed on the turntable 80 mm apart (Fig. 5c). The markers used in Orch2018 and Orch2020 were placed at the bottom part of the trees (on the ground) 850 mm apart.

The point clouds generated in the Orch2018 and Orch2020 sets were segmented in order to obtain a single point cloud per apple. To do so, a semi-automatic segmentation was carried out (Fig. 6). First, the fruit detection methodology presented in [12] was applied. This methodology consists in segmenting apples in the images and projecting detections onto the 3D point cloud (Fig. 6.2). Image instance segmentation was carried out using the Mask-RCNN [13] trained
with the Fuji-SfM dataset [4]. The projection of image segmentation onto the 3D space was carried out using the pinhole camera model with intrinsic and extrinsic camera parameters calculated by Agisoft Professional Metashape software [14]. Since this method is subject to errors, the resulting segmentation was manually corrected by merging apple multi-detections (Fig. 6.3.a), splitting detections with more than one apple (Fig. 6.3.b), segmenting apples not detected (Fig. 6.3.e) and removing false positives. These manual point cloud editing processes (merge, split, segment...) were carried out using the CloudCompare software (Cloud Compare [GPL software] v2.9 Omnia).

Finally, the apple sizes were manually measured using a Vernier calliper. Since apples are not completely spherical, the measured distance was the largest horizontal diameter (Fig. 5d). Then, each measured apple was identified in the point cloud and the measurement was matched with the corresponding apple identification name (Apple ID).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

CRediT Author Statement

Jordi Gené-Mola: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization; Ricardo Sanz-Cortiella: Conceptualization, Investigation, Resources, Writing – review & editing; Joan R. Rosell-Polo: Investigation, Writing – review & editing, Project administration, Funding acquisition; Alexandre Escolà: Investigation, Writing – review & editing, Project administration, Funding acquisition; Eduard Gregorio: Investigation, Writing – review & editing, Supervision.

Acknowledgments

This work was partly funded by the Secretaria d'Universitats i Recerca del Departament d'Empresa i Coneixement de la Generalitat de Catalunya (grant 2017 SGR 646) and the Spanish Ministry of Economy and Competitiveness (project AGL2013-48297-C2-2-R). Part of the work was founded with the Grant RTI2018-094222-B-I00 (PAgFRUIT project) by MCIN/AEI/10.13039/501100011033 and by “ERDF, a way of making Europe”, by the European
References

[1] J. Gené-Mola, R. Sanz-Cortiella, J.R. Rosell-Polo, A. Escolà, E. Gregorio, In-field apple size estimation using photogrammetry-derived 3D point clouds: comparison of 4 different methods considering fruit occlusions, Comput. Electron. Agric. 188 (2021) 106343, doi: 10.1016/j.compag.2021.106343.

[2] Y. Lu, S. Young, A survey of public datasets for computer vision tasks in precision agriculture, Comput. Electron. Agric. 178 (2020) 105760, doi: 10.1016/j.compag.2020.105760.

[3] J. Gené-Mola, E. Gregorio, F. Auat Cheein, J. Guevara, J. Llorens, R. Sanz-Cortiella, A. Escolà, J.R. Rosell-Polo, LFW-air dataset: annotated 3D LiDAR point clouds of Fuji apple trees for fruit detection scanned under different forced air flow conditions, Data Br. 29 (2020), doi: 10.1016/j.dib.2020.105248.

[4] J. Gené-Mola, R. Sanz-Cortiella, J.R. Rosell-Polo, J.R. Morros, J. Ruiz-Hidalgo, V. Vilaplana, E. Gregorio, Fuji-SfM dataset: a collection of annotated images and point clouds for Fuji apple detection and location using structure-from-motion photogrammetry, Data Br. 30 (2020), doi: 10.1016/j.dib.2020.105591.

[5] J. Gené-Mola, V. Vilaplana, J.R. Rosell-Polo, J.-R. Morros, J. Ruiz-Hidalgo, E. Gregorio, K Fuji RGB-DS database: Fuji apple multi-modal images for fruit detection with color, depth and range-corrected IR data, Data Br. 25 (2019) 104289, doi: 10.1016/j.dib.2019.104289.

[6] N. Hänni, P. Roy, V. Isler, A comparative study of fruit detection and counting methods for yield mapping in apple orchards, J. F. Robot. (2019) 37, doi: 10.1002/rob.21902.

[7] A. Koizala, K.B. Walsh, Z. Wang, C. McCarthy, Deep learning – method overview and review of use for fruit detection and yield estimation, Comput. Electron. Agric. 162 (2019) 219–234, doi: 10.1016/j.compag.2019.04.017.

[8] C.W. Bac, E.J. Van Henten, J. Hemming, Y. Edan, Harvesting robots for high-value crops: state-of-the-art review and challenges ahead, J. F. Robot. 31 (2014) 888–911, doi: 10.1002/rob.21525.

[9] Y. Zhao, L. Gong, Y. Huang, C. Liu, A review of key techniques of vision-based control for harvesting robot, Comput. Electron. Agric. 127 (2016) 311–323, doi: 10.1016/j.compag.2016.06.022.

[10] The American society for photogrammetry & remote sensing, LAS specification - version 1.4-R13, 2013. https://www.asprs.org/wp-content/uploads/2010/12/LAS_1.4_r13.pdf.

[11] B. Triggs, P.F. McLauchlan, R.I. Hartley, A.W. Fitzgibbon, Bundle adjustment – a modern synthesis vision algorithms: theory and practice, Vis. Algorithms Theory Pract. (2000) 298–375, doi: 10.1007/3-540-44480-7_21.

[12] J. Gené-Mola, R. Sanz-Cortiella, J.R. Rosell-Polo, J.-R.R. Morros, J. Ruiz-Hidalgo, V. Vilaplana, E. Gregorio, Fruit detection and 3D location using instance segmentation neural networks and structure-from-motion photogrammetry, Comput. Electron. Agric. (2020) 169, doi: 10.1016/j.compag.2019.105165.

[13] K. He, G. Gkioxari, P. Dollar, R. Girshick, Mask R-CNN, Proc. IEEE Int. Conf. Comput. Vis 2017 (2017) 2961–2969, doi: 10.1109/ICCV.2017.322.

[14] Agisoft Metashape, Agisoft Metashape User Manual: Professional Edition, 2019 Version 1.5.