A Proof of Concept Pipeline for Digital Twins in Agriculture

farmchart.github.io

THE TEAM

We are a group of students with broad and varied experiences in different fields, ranging from creative work to technical service. The team has also significant experience of working together throughout the semesters. Combined with the previous work experience, this has allowed for the mutual trust needed to solve a complex issue such as this project.

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THE CLIENT

The client for the project was Digin, Norway's leading IT cluster based in Agder. Our project owner and point of contact throughout the project has been Reidar Jortveit. While Digin was not able to provide resources or expertise within the field of the project, because of their vast network, they were a valuable source of guidance and mentorship to help keep the project moving forward.

Project Description

About the Project

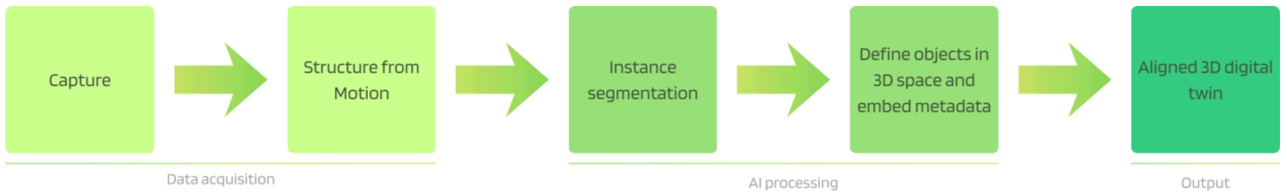
The project explores whether it is possible to create a proof of concept for a segmented, spatially accurate digital twin of smaller agricultural scenes using currently accessible technologies. The goal was to make a functioning pipeline by any means necessary, meaning the team was given full freedom to approach the problem. The ideal outcome would be a working capture and reconstruction pipeline, combined with instance-level segmentation where every plant and berries are their own separate object, then followed by the identification and labelling of these objects.

Challenges & Complexities

The main challenge of this problem is that small, detailed objects such as plants are inherently difficult to consistently reconstruct in 3D. There are many variables such as weather, growth lighting, and occlusion that makes it quite difficult to create reliable digital twins.

The tools needed to construct the pipeline are also quite resource intensive, requiring both expensive hardware for capture and high-end computing for processing. Furthermore, the scope of the project was arguably outside of the scope of the bachelor's degree, requiring the team to quickly adapt to and research several complex technologies.

Technology & Solution



Overview of the pipeline

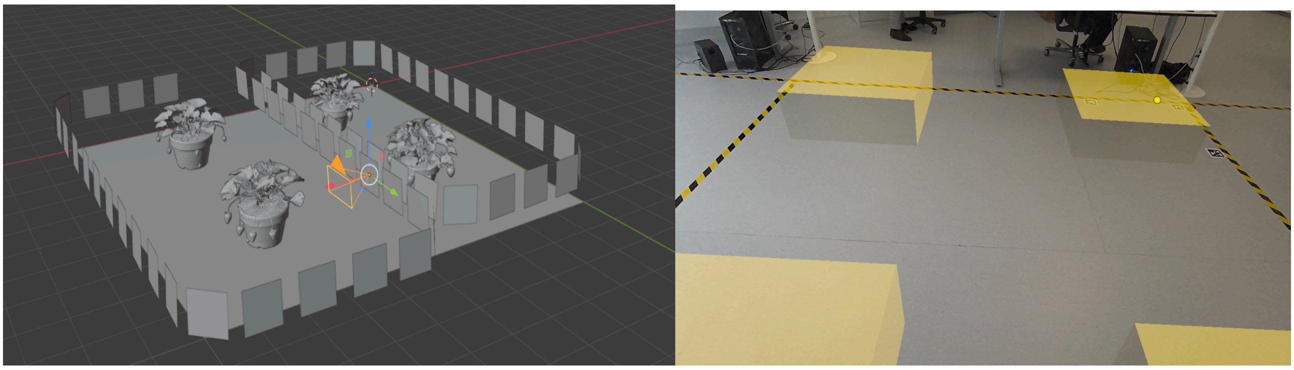
While several technologies were tested, such as LiDAR, the final project solution combines photogrammetry-based image capture using regular mirrorless cameras, reconstruction of a sparse point cloud with COLMAP, 3D Gaussian Splat (3DGS) training through LichtFeld Studio and image-based segmentation with the help of Meta's SAM3 AI segmentation model. Additionally, fiducial markers have been used during testing to scale and align the 3D reconstruction to a real-world coordinate system and measurements. This ensures that the plants and berries each have their own verifiable coordinates, which serves as a basis for connecting semantic data to the objects.

This pipeline explores how individual objects such as plants or berries can be located and segmented in a spatially accurate digital twin. Key technical choices were made around tools and methods that were theoretically suitable for outdoor agricultural environments.

Results

Collaboration with “Gårdsbriller” group

Digin had two groups working on agricultural solutions, our Farmchart team, which focused on creating a digital twin, and the “Gårdsbriller” group that focused on visualizing this digital twin in AR. Since a capture of strawberry plants in winter was not possible, a virtual scene based on real-life measurements was the substitute. The team succeeded in performing a full run of the pipeline; a simulated photogrammetry capture, reconstruction, 3D Gaussian Splat training and object segmentation at a berry level. This data was then transformed into a usable format for the other group, allowing for 3D bounding-box visualization of the identified plants with connected metadata.

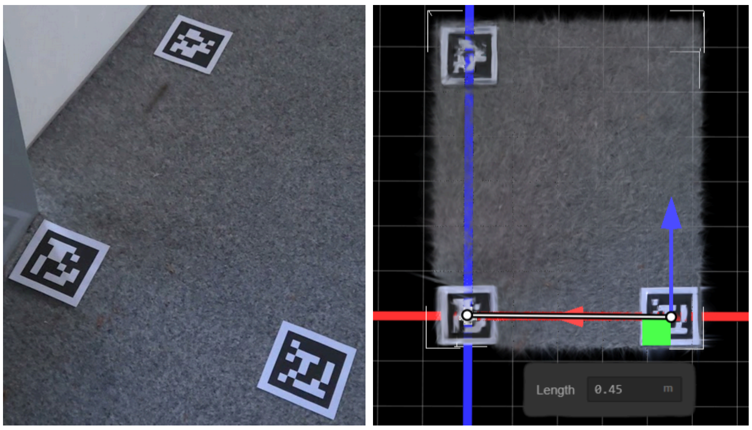


Simulated capture in Blender

We are particularly satisfied with the results from our segmentation workflow, taking advantage of the accuracy of the relative scale of the reconstruction together with per-pixel contribution from the segmentation masks of splats to produce precise object representations positioned in 3D space.

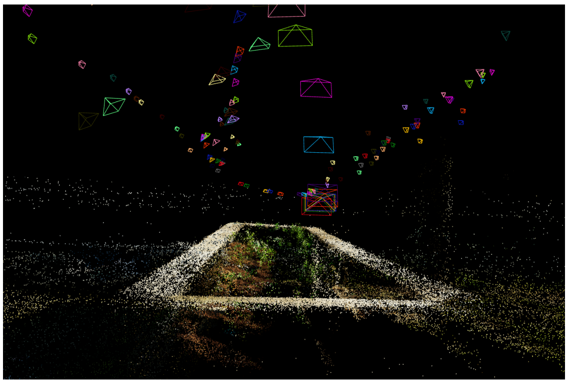
Using fiducial markers for scaling and alignment

By using fiducial markers, we were able to achieve a mm-accurate scale and alignment on the 3D reconstruction. This would create an accurate local coordinate system for the scene ensuring that each plant and even berries would have their own coordinates. This was tested in different scenes, including the same floor surface used for the AR collaboration outlined above. The method worked by using three markers as ground control points (GCP), with one serving as the origin marker. The real-world measurements were taken between the origin marker and the other GCP markers. These measurements, combined with the direction of the markers, was the basis for the scale and axis-directions.



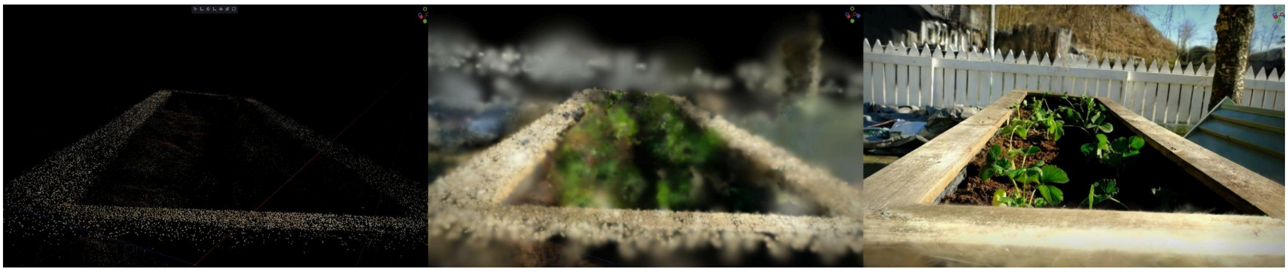
Example of alignment and scale with fiducial markers as ground control points

Outdoor Capture



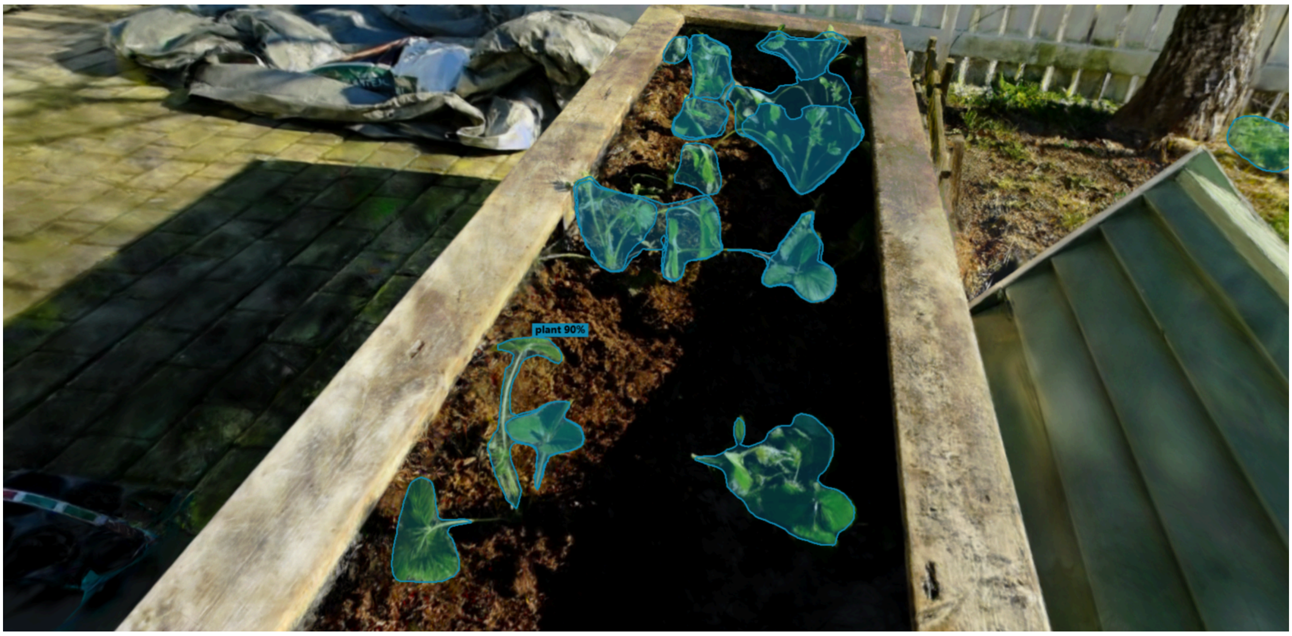
Sparse point cloud with camera poses.

Image masks generated from SAM3



Sparse point cloud → During 3DGS training → Finished 3DGS model

To properly test the pipeline in a relevant environment, an outdoor capture was executed on a small strawberry planter. The capture conditions were not ideal, despite this, 3D reconstruction and segmentation was a success. The result demonstrated that the pipeline is not limited to only indoor scenes or simulated Blender captures, but can also be applied to outdoor scenes.



Plants segmented with SAM3 and visualized using Spark.js