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Simulation of Urban Area Mapping and Classification System Using a 3D Camera in MATLAB

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Abstract—A methodology for efficiently capturing images of urban areas, specifically US city block scenes generated from the Unreal Engine, through the strategic planning of UAV flight paths. The process leverages the capabilities of the Unmanned Aerial Vehicles (UAV) toolbox to enable precise flight path planning. Subsequently, the acquired images undergo comprehensive processing and integration using a combination of MATLAB toolboxes, including Simulink, Image Processing Toolbox, and Computer Vision Toolbox. In this paper ultimate goal is to create an integrated map of the urban area. Furthermore, this paper demonstrates how to categorize the desired urban region effectively, employing the powerful features provided by the aforementioned MATLAB toolboxes.
Keywords— Unmanned Aerial Vehicles UAV, Image Processing, Simulink.

1. Introduction

The usage of Unmanned Aerial Vehicles (UAVs) as a novel tool for remote sensing has grown significantly during the past few years. They have been frequently used to quickly and efficiently examine how the landscape has changed.

The quick development and expansion of drones as a remote sensing platform, along with improvements in the miniaturization of tools and data systems, have led to a rise in the adoption of technology in urban areas and the remote sensing community. [4]

UAVs have proven beneficial in a variety of industries and applications, including precision agriculture, aerial photogrammetry, border and crowd surveillance, real-time monitoring, disaster management, and remote sensing. Aerial photos are images of the Earth taken from a high position, typically an aircraft or an unmanned aerial vehicle. Aerial photogrammetry is a method for creating aerial photos into two-dimensional or three-dimensional models (UAV) [5]. Making precise maps of the terrain is a task of aerial photogrammetry. Because of the uniform scale of maps, they offer orthographic views of important surfaces, enabling precise terrain measurements. For example, it is utilised in cartography, public safety, disaster relief, and land surveying. [5]

Unmanned aerial vehicle (UAV) and autonomous flight application development speed capabilities is provided by using MATLAB and Simulink. We may create flight control algorithms, simulate using a UAV plant model while taking environmental conditions into account, and visually represent the UAV flight path using MATLAB and Simulink. [5]

Semantic segmentation is made possible by the Simulation 3D Camera to categorise the environment. Semantic segmentation is the process of assigning a class label to each pixel in an image, such as a road, structure, or traffic sign. The creation of synthetic semantic segmentation data in accordance with a label classification scheme is carried out in the 3D simulation environment. These labels can be used to train a neural network for applications like road segmentation in automatic driving. The specific categorization strategy can be validated by visually displaying the semantic segmentation data.[2]

2. METHODOLGY

Software Used: MATLAB R2022b and Simulink

2.1 Planning UAV flight paths to take pictures of an urban scene with a camera is made possible by the capabilities included in UAV Toolbox. You may then combine these images and process them using the Computer Vision Toolbox, Image Processing Toolbox, and Deep Learning Toolbox to produce an accurate map of the urban area. The steps in the mapping process are as follows: [3]

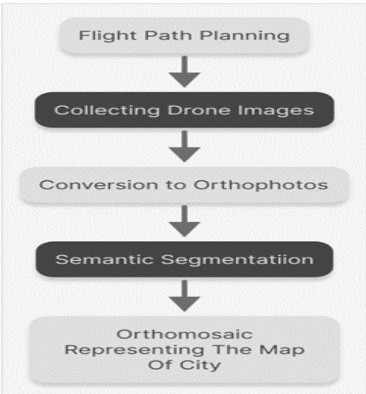

Fig-1: Block diagram of the Mapping Process

To convert central perspective images into orthographic photos

1. **To specify UAV trajectory**
   a. The map used here is obtained from Unreal Engine, i.e., US City Block scene, the waypoints can be selected using world frame of the scene [5].
   b. Considering intersection 1, intersection 6, intersection 7 and intersection 8 as takeoff point, flight point a, flight point b and landing point respectively, creating a flight path for the UAV by specifying it with the waypoints in the order of:
      - A takeoff point: [-185 105] with 0 meters of elevation.
      - Two flight waypoints, a and b in between takeoff and landing: [-115 105] and [-15 105] respectively.
      - A landing point: [-15 -5] with 0 meters of elevation.
   c. Specify elevations of 150 meters, for the waypoints a and b which will be maintained for the entire flight by the UAV.
   d. Compute and Visualize the flight path of the UAV.

2. **Run Simulation and Obtain Filtered Flight Data**
   a. Capturing data using an unreal simulation, then storing the Simulink signal data that was obtained in an out-MAT file that comprises logs of picture, label, and depth data.

b. Indicate the UAV's goal pitch in degrees. This pitch value is in the coordinate system used by Unreal Engine.
c. For the UAV elevation and UAV pitch, set the tolerance values that maintain projection at the designated elevation and eliminate noise. The simulation determines the time steps where the UAV is inside the target elevation and pitch tolerance limits. Data for only those time steps is then logged. This method eliminates noisy data while keeping the primary perspective projection at the appropriate elevation.
d. Filter out every Nth frame, set the value to 16 to create a map that is made of image frames which has overlapping regions between them.
e. Turn on the output semantic segmentation under ground truth tab of Simulation 3D camera.
f. Open and run the Simulink model.

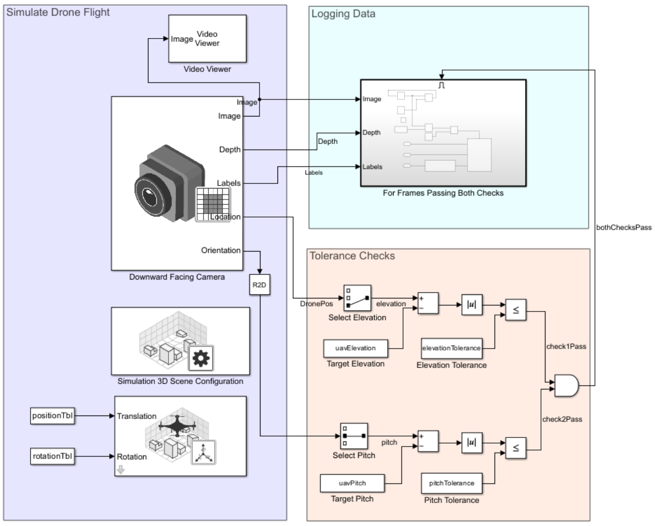

Fig-2: MATLAB Simulink Model

3. Loading, filtering and saving captured data

Determining the additional parameters needed for the computation of orthophotos:

- Focal Length in meters
- Meter To Pixel: The ratio between the screen to 1 meter in the real world/Simulink space.
- Reduction Factor: Setting the reduction factor of 800 for the orthophoto.

3.1 Saving the image, depth information, and extra orthophoto parameters into a MAT file.

The central perspective images should be converted to orthophotos following the modelling of a UAV flying over the US City Block area and capturing central perspective images as in objective 1. The cameras, similar to those found in UAVs, can only record perspective photos. Yet, orthographic images are needed for applications like aerial photogrammetry city mapping. The main reason for converting UAV-taken aerial pictures into orthophotos is to get the ground plane needed for image stitching.

1. Setup the file
2. Convert Perspective Images into Orthophotos
   a. Obtain the image resolution of the camera to capture the central perspective images.
   b. Create a folder to store orthophotos
   c. Count all of the frames, then make an empty cell array to hold the orthophotos for computation.
   d. Use the example helper get ortho from Pers helper function to turn each frame into an orthophoto, then store each orthophoto in the orthophotos folder.
3. Visualize Computed Orthophoto
   a. Get the depth map and perspective image for frame 30.
   b. Visualize the normalized depth map of the perspective image.
   c. Show the same frame's computed orthophoto.

3.2 Depth and Semantic segmentation Visualization

A grayscale representation of a camera sensor's output is called a depth map. Grayscale camera images are represented on these maps, with brighter pixels denoting items that are further away from the sensor.

Semantic segmentation is the process of assigning a class label to each pixel in an image, such as a road, structure, or traffic sign. You create fake semantic segmentation data in the 3D simulation environment using a label classification system. After that, you may use these labels to train a neural network for applications like road segmentation in automatic driving. The semantic segmentation data can be shown, which allows you to check your categorization strategy.

3.3 To obtain a map through an ortho mosaic of orthographic photos and classify the same using semantic segmentation feature in Simulation 3D Camera

After obtaining orthophotos from previous objective, the labels obtained from the semantic segmentation output are used to classify the orthophotos obtained by overlaying the labels on the orthophotos. The color map and class names are specified for showing color bar for classified pixels

1. Setup the files.
2. Visualize the computed orthophoto with labels overlaid for frame 10.
3. Visualize the montage of orthophotos.
4. Visualize the montage of orthophotos with overlaid labels.
5. Create the ortho mosaic
   a. The orthophoto pairs should be registered.
   b. Set the ortho mosaic to zero.
   c. Compute the orthophotos after transformation. - visualize the montage of transformed orthophotos and the same with overlaid transformed ortho labels
   d. Create, save and visualize the stitched ortho mosaic and the same with labels overlaid using stitching algorithm.
6. Use selective smoothing to remove artifacts due to automated stitching.
7. Visualize smoothed ortho mosaic and the same with labels overlaid

4. Result And Discussion

4.1 To convert central perspective images into orthographic photos

After running the Simulink model, the UAV flies through the city following the waypoints specified and captures aerial images using a camera and other sensor data to map the environment. By using the video viewer, the camera feed can be visualized. The perspective image and its normalized depth map is visualized. The computed orthophoto for the same frame is visualized.

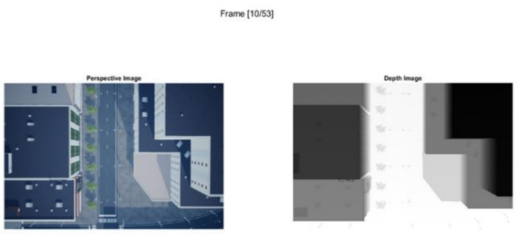

Fig-3: visualization of Perspective Image and its normalized depth map.

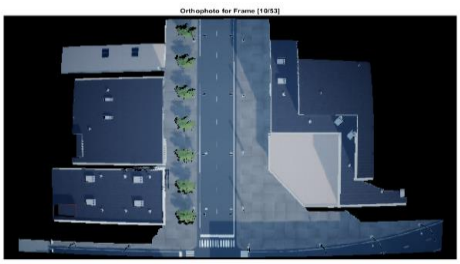

Fig-4: Visualization of computed orthophoto for the same frame

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4.2 To obtain a map through an ortho mosaic of orthographic photos and classify the same using semantic segmentation feature in Simulation 3D Camera

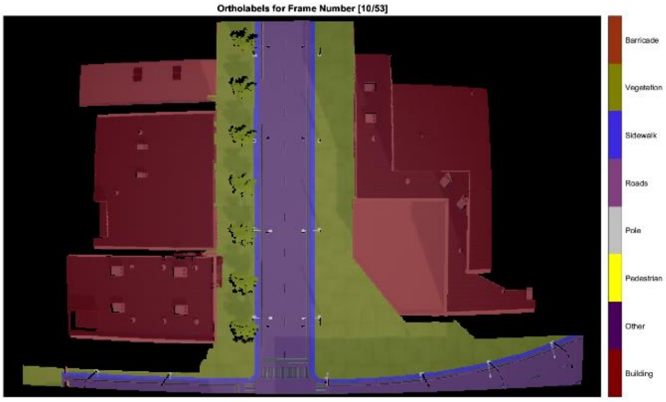

Fig-5: The orthophoto of frame 10 is visualized with labels overlaid

The montage of transformed orthophotos and the same with overlaid transformed ortho labels are visualized. The stitched ortho mosaic and the same with labels overlaid is visualized. The line artifacts are visible. The smoothed ortho mosaic and the same with labels overlaid is visualized. Hence a classified map of the desired environment is obtained.

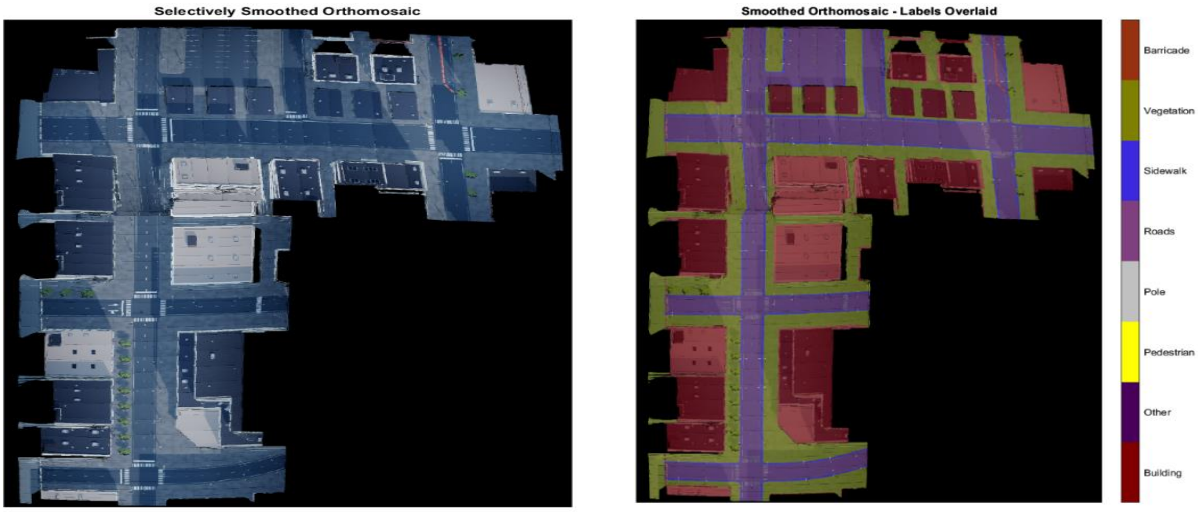

Fig-6: Visualization of smoothed ortho mosaic and the same with labels overlaid

5. Conclusion

The data is captured by creating the flight path by specifying the waypoints and other required parameters. After modelling a UAV trajectory, the central perspective images captured through UAV camera is converted into orthophotos.

After visualizing the computed orthophotos, each pixel of the image is assigned with a class label. This process is known as Semantic Segmentation.

The color map and class names are specified for showing color bar for classified pixels. Selective smoothing is used to remove artifacts due to automated stitching. At the end smoothed ortho mosaic with overlaid labels is visualized.

Semantic segmentation feature in simulation 3D camera can be used to analyze the classification scheme used for generating synthetic semantic segmentation data from the Unreal Engine environment like generating urban city map for numerous applications such as, Forest cover, infrastructure cover, Wildfire fighting, City planning, Navigation etc. Also, can be used to test various techniques, algorithms that requires classified map through semantic segmentation.

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