STATS 402 - Interdisciplinary Data Analysis <Building Change Detection using CNN Model on Aerial Images: A Comparative Analysis of 2012 and 2016 Datasets> Milestone Report: Stage 1

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***Abstract*—This project aims to develop a robust and accurate system for detecting and quantifying changes in the built environment using satellite imagery, focusing on both construction and demolition activities. Our innovative approach will provide urban planners with valuable insights into the dynamics of urban growth and decline, facilitating data-driven decision-making and the development of sustainable, resilient urban environments. To achieve this, we will employ semantic segmentation techniques and supervised machine learning algorithms, such as fully convolutional networks (FCN) and U-Net based convolutional neural networks (CNN) [1], to effectively detect buildings in satellite images taken at different time periods. The proposed system will address critical scientific challenges, including minimizing false positives, satellite image alignment, and scalability and adaptability to various satellite images and time periods. Our research and experimental methods involve rigorous dataset division, iterative model refinement, and the evaluation of model performance on unseen data. By incorporating innovative techniques and addressing key challenges, this project is expected to deliver an effective tool for detecting changes in urban landscapes and quantifying urbanization rates, ultimately contributing to better urban planning and policy-making.**

I. The Project Rational

A. Motivation

The ability to accurately detect changes in the built environment, such as construction and demolition activities, is crucial for urban planners seeking insights into the dynamic growth and development of cities. By monitoring these changes, planners can make well-informed decisions regarding land use, infrastructure development, and resource allocation, ultimately contributing to sustainable urbanization. Satellite image analysis offers a transformative approach to this challenge, providing real-time, precise, and comprehensive data on urban transformation. Unlike traditional manual methods, which are time-consuming and prone to inaccuracies, satellite image detection enables urban planners to track and quantify changes in the built environment at any given moment. This powerful tool has the potential to greatly enhance the efficiency and effectiveness of urban planning processes, enabling planners to identify trends, monitor progress, and implement data-driven policies that respond to the evolving needs of cities and their inhabitants. By leveraging satellite image detection, we can create more resilient and adaptive urban landscapes for a rapidly changing world.

The dataset we will use for this project covers an area where a 6.3-magnitude earthquake occurred in February 2011 and rebuilt in the following years. This dataset consists of aerial images obtained in April 2012 that contain 12796 buildings in 20.5 km^2 (16077 buildings in the same area in 2016 dataset).

Fig. 1. Illustration of the building change dataset we will use in this project (the changed parts are white) [2].

B. Development Trend of Related Fields & Commonly Used Method

learning techniques and more sophisticated algorithms for identifying changes in land cover, land use, and other phenomena over time. This evolution reflects the growing trend of adopting data-driven approaches to solve complex problems in diverse fields.

One popular approach for building change detection is image differencing, which involves subtracting two or more images of the same area to highlight regions where changes have occurred. This technique is intuitive and straightforward, but may require extensive preprocessing to align the images and adjust for differences in illumination or sensor characteristics.

Change detection is closely related to semantic segmentation. Semantic segmentation categorizes each pixel in an image into a class or object, while for change detection we are only interested in the change between the two images. Machine learning algorithms, particularly convolutional neural networks (CNNs), have become the basis for semantic segmentation tasks [3]. CNNs turn fully connected layers into fully convolutional layers so that we can classify images pixel by pixel using a 2-D heatmap, enabling the identification of changes based on differences in these features. This approach has proven effective in various applications, from identifying urban growth to monitoring deforestation.

Recent advancements have seen the integration of more complex methodologies, such as siamese neural networks [4], which simultaneously process pairs of images to extract representative features. These networks can then map the differences in pixel-wise features back to the original pixel space using another deep learning network, resulting in a difference image (DI) that highlights the changes. This approach can be combined with other advanced techniques, including U-net architectures, attention mechanisms, transformers, and transfer learning, to further enhance the performance of change detection models.

C. Application Prospects

The proposed project aims to develop a highly accurate system for building extraction and change detection, which can be effectively applied to various sectors. In urban planning, the system will enable the calculation of urbanization rates by identifying and tracking the growth and transformation of urban structures. In disaster response, it will facilitate the detection of demolished buildings following natural disasters such as earthquakes and tsunamis or human-induced catastrophes like warfare, enabling more efficient allocation of resources and support. Furthermore, with potential applications beyond building analysis, the system could contribute to environmental monitoring by detecting changes in the extent of lakes, glaciers, and forests. This comprehensive, versatile approach will provide critical insights and tools for addressing diverse challenges across urban planning, disaster response, and environmental preservation, all within a single, sophisticated system.

II. The Research Content/Objectives of This Project and Critical Scientific Problems to be Solved

A. Research Content/Objectives

The primary objective of this project is to develop a robust and accurate system for detecting and quantifying changes in the built environment using satellite imagery, with a focus on both construction and demolition activities. The research content includes the following key aspects:

1. Develop an effective and efficient semantic segmentation model to accurately extract building structures from satellite images.

2. Design a change detection algorithm capable of identifying new and demolished buildings between two different time periods.

3. Establish a methodology for quantifying urbanization rates, based on the insights gained from the change detection model.

4. Ensure the developed model and methodology are adaptable to various satellite images and time periods, making it a versatile tool for urban planning and other applications.

B. Critical Scientific Problems to be Solved

To achieve the project objectives, we must address several critical scientific challenges:

1. Minimizing false positives: To ensure the accuracy of our model, it is crucial to minimize false positives, such as misidentifying vehicles or other objects as buildings. Developing techniques that account for these common errors will improve the precision of our change detection system.

2. Satellite image alignment: Accurate change detection requires the effective handling of images taken from different angles or with slight misalignments. We must develop algorithms capable of aligning images for precise comparison and quantification of changes in the built environment.

3. Scalability and adaptability: Our proposed system must be scalable and adaptable to various satellite images and time periods, ensuring its applicability across different urban environments and diverse applications.

III. The Proposed Research Plan and Feasibility Analysis (Including Research Methods, Technical Routes, Experimental Methods, Key Technologies, etc.)

In this project, we aim to utilize semantic segmentation techniques to effectively detect buildings in satellite images taken in 2012 and 2016, allowing us to analyze and quantify changes in urban landscapes. By implementing a change detection algorithm, we hope to uncover insights into the rate of construction and demolition, which will ultimately aid urban planners in making informed decisions regarding city growth and development.

To achieve our goals, we will employ supervised machine learning, leveraging a dataset that includes both satellite images and corresponding labels. As our baseline model, we will utilize fully convolutional networks (FCN) for image segmentation, which will be specifically trained to detect buildings within the provided satellite images. In order to improve the accuracy and efficiency of our model, we will explore the use of U-Net based convolutional neural networks (CNNs). Additionally, we will undertake necessary image preprocessing steps, such as data transformation, feature engineering, and k-fold cross-validation, to ensure optimal model performance. In comparing the segmented images from the two time periods, we will employ a pixel-wise subtraction method as the most straightforward approach to change detection. Beyond that, we will also apply a Siamese network with shared weights to learn different images (DI) based on different features using another deep learning network (as shallow FCN in figure 2).

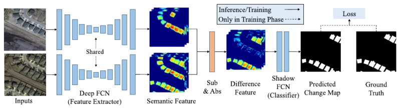

Fig. 2. Illustration of Deep Learning Network with Siamese network for Change Detection [5].

For the research and experimental methods, we will begin by dividing the dataset into training, validation, and testing subsets. This will allow us to iteratively refine our model and evaluate its performance on unseen data. We will then train our baseline FCN model and compare it with the U-Net based CNN model to determine the most effective architecture for our specific task. Furthermore, we will investigate the impact of various preprocessing techniques on model performance, ensuring the selection of the most suitable methods. By employing a rigorous experimental process and employing cutting-edge techniques, our research aims to develop an innovative, reliable, and efficient method for detecting changes in urban environments using satellite imagery.

IV. Features and Innovations of This Project and the Expected Results

A. *Innovations of This Project*

Our project distinguishes itself from other change detection studies by focusing not only on newly constructed buildings but also on those that have been demolished, providing a comprehensive understanding of urban transformations. To improve the precision of our model, we will incorporate techniques that minimize false positives, such as misidentifying vehicles or other objects as buildings. Additionally, we will address challenges associated with satellite image alignment by implementing algorithms that can effectively handle images of the same buildings taken from different angles. This is crucial for accurately quantifying changes in the built environment. Furthermore, we aim to develop an innovative tool for quantifying urbanization rates, leveraging the insights gained from our building change detection model to inform urban planning and policy-making.

B. *Expected Results*

The anticipated outcomes of this project include the accurate detection and quantification of changes in the built environment over a specified time period. We aim to identify locations where new buildings have been constructed and old ones demolished, contributing to a deeper understanding of urban development patterns. Additionally, we expect to establish a robust methodology for detecting changes in building structures, adaptable to various satellite images taken at different times. By successfully achieving these outcomes, our project will provide urban planners and policymakers with valuable insights into the dynamics of urban growth and decline, facilitating data-driven decision-making and the development of more sustainable, resilient urban environments.

References

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