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Generating Analysis-Ready Geospatial Products from National Historical Air Photos

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Abstract:

The Canadian National Air Photo Library (NAPL) contains millions of historical aerial photographs, spanning over a century, that provide valuable geospatial records of Canada's landscape across both spatial and temporal dimensions. Historical photographs can be utilized to create long-term time series and support various analyses, such as tracking the expansion or contraction of urban areas, measuring changes in forest structure, monitoring the impacts of mine abandonment and reclamation on surrounding environments, assessing the thinning and retreating rates of glaciers, and determining coastal erosion rates. In our presentation, we will discuss the solutions being developed at Natural Resources Canada (NRCan) to produce analysis-ready mapping products from NAPL that include workflows for 1) the photogrammetric processing of historical photos with an emphasis on the more challenging automated georeferencing component and 2) enhancing interpretability through generative artificial intelligence (AI) models for super-resolution and deep colorization, and generating foundational layers (e.g., building outlines) via semantic segmentation.

The photogrammetric processing of NAPL data begins with a self-calibration process which includes two main steps. First, tie points are extracted and used to determine the relative orientation of images within an aerial survey. Bundle block adjustment (BBA) is performed to estimate the intrinsic camera calibration parameters, along with the images' exterior orientation parameters (EOPs), which are tied to an approximate coordinate system based on the roughly known positions of the image centers derived from the flight information. The second step, which involves the absolute orientation in a common coordinate reference system, requires the collection of reference observations, such as ground control points (GCP). These observations are essential to ensure the accurate spatial alignment of historical and modern mapping products, which in turn is a critical requirement for creating time series and performing multi-temporal change analyses. The state of the art to address this problem is to create virtual GCPs by finding common features that have remained unchanged between the historical photos and a modern data source, e.g. optical geo-referenced imagery and digital elevation models (Zhang et al., 2021). This approach, however, necessitates robust inter-epoch feature extraction and matching which can be considerably challenging given the significant visual differences between historical and modern data sources.

Accordingly, in our workflow, we investigated multiple state-of-the-art learning-based methods to automatically identify reliable correspondences between cross-temporal and multi-modal optical imagery, i.e. between grayscale scanned historical photos and multi-spectral modern satellite imagery. We were inspired by the fact that learning-based approaches have demonstrated better potential for finding reliable matches in challenging scenarios, e.g. between multi-temporal images (Morelli et al., 2022), daytime and night-time images (Dusmanu et al., 2019), and poorly textured images (Sun et al., 2021). After the initial putative correspondences are computed, RANSAC or one of its derivatives (e.g. USAC) is used to filter out outliers that do not conform to a homographic transformation between the images. In our presentation, we will discuss the findings of a thorough comparison of different learning-based approaches that rely on various architectures, including convolutional neural networks (CNN) (Dusmanu et al., 2019), transformers (Lindenberger et al., 2023) and hybrid CNN-transformer architectures (Sun et al., 2021) that may also incorporate the large-scale contextual understanding of foundation models (Edstedt et al., 2024). The performance of these methods was tested on our benchmark comprised of 60 historical-modern photo pairs. It was shown that learning-based approaches like RoMa and LoFTR had over 90% success rate while the traditional SIFT matching only succeeded in about 30% of the cases (Figure 1). The verified virtual GCPs are then used in a second round of BBA, where EOPs are refined, followed by dense matching and generation of digital surface models and ortho-rectified mosaics using conventional photogrammetric approaches. These solutions are implemented using our in-house libraries as well as MicMac open-source software. In our presentation, we will also demonstrate examples of the intermediate and final products and will discuss their qualities.

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Figure 1. Example of identifying homologous points between a historical and a modern photo using: a learning-based algorithm (LightGlue – Left), and a traditional approach (RootSIFT with kNN matching – Right).

AI-based solutions can enhance the visual appeal and interpretability of historical photographs, bridging the gap between NAPL's grayscale images and modern color imagery. This advancement also enables the application of our existing in-house models for semantic segmentation and the extraction of foundational layers, such as buildings, roads, forests, and surface water. To this end, we have been developing and testing fully automated methods to colorize historical mosaics using deep image-to-image translation models (Figure 2). In this presentation, we will compare the performance of various solutions, including conditional generative adversarial networks (GAN), encoder-decoder networks, and transformers, and discuss their impact on the realistic colorization of historical data. We show that structural similarity index measures of higher than 0.96 and peak signal-to-noise ratios higher than 30 could be achieved, both indicating high quality of colorization. Furthermore, we have achieved significant improvements in the spatial resolution of historical images scanned at low resolution from printed photos using a customized GAN, which renders them comparable to photos scanned directly from film rolls at high resolution (Figure 3). In this presentation, we will discuss how these visual enhancements impact the analysis-ready mapping products.

Figure 2. Example of using deep colorization for Photo enhancement. Left to right: NAPL original, NAPL Colorized, Modern Image.

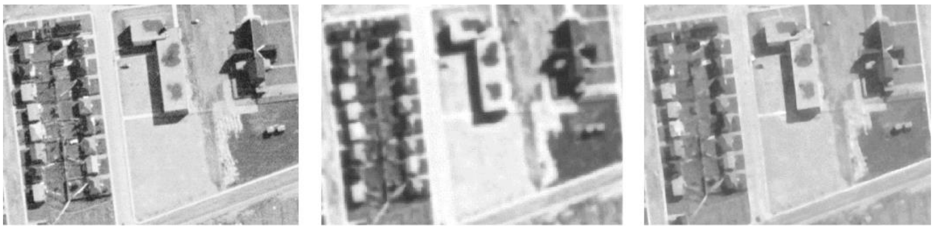

Figure 3. Example of using generative AI for Photo enhancement. From left to right: Photo region scanned from film roll at 2000 dpi; Scanned from paper at 800 dpi; Super-resolved product from 800 to 1600 dpi.

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