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AN OPEN API FOR 3D-GEOREFERENCED HISTORICAL PICTURES

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ABSTRACT:

In this article we describe the possibilities and opportunities of the utilization of 3D georeferenced historical images in different contexts. In the frame of an ongoing research project that aims at establishing a national infrastructure for georeferenced pictures, we have created an open API that allows researchers and developers to access and interact with an existing database containing 200'000 3D-georeferenced images. In this database images have been georeferenced by volunteers in 3D using monoplotting. The new API allows for instance to extract the 3D geolocation of images and their footprints as well as to upload new images. It is as far as possible based on existing standards in the fields of archive management, 3D image standards and web-services. This work is of interest for researchers who want to utilize and analyze 3D georeferenced historical imagery and for people who want to establish open API's to give access to data that is relevant for research.

1. INTRODUCTION

Historical images have a high potential for the analysis of different landscape features over time such as the analysis of melting glaciers in the context of climate change, the effects of urbanization or natural hazards. Moreover, historical photographs have a higher temporal and spatial resolution than for instance satellite imagery and therefore allow for analyzes that go farther back in time.

The 3D georeferencing of historical imagery adds several opportunities for archive managers, researchers and developers of geospatial applications. We hereby cite some examples:

A 3D georeferenced image can be combined with a digital terrain model (DTM) and other reference data to calculate the exact footprint (i.e the 2D area that is visible in the image) and to generate a list of visible toponyms. These toponyms can on the one hand be displayed on the image or be added to an image's metadata in order to be used to find pictures of a specific place or region within a database.

3D georeferenced imagery can be overlaid on top of recent imagery to illustrate the changing landscape and to allow a layman to compare the impacts of urbanization, climate change etc.

Methods coming from the fields of photogrammetry, remote sensing and machine learning can be used with 3D georefenced imagery, to for instance digitally recreate buildings that have been destroyed a long time ago (Soto-Martin et al., 2020) or to automatically detect and analyze landscape features such as fields, mountains, lakes, etc.

The utilization of historical images is unfortunately still difficult due to the following reasons:

1. Historical images need to be digitized, stored and made accessible. This process is often time-consuming and includes many manual tasks, such as scanning or entering metadata that is written on the original images.
2. Image collections are often spread across several places in different archives and institutions.
3. Metadata is often not available or incomplete (e.g. visible places, date, photographer, etc).
4. The vast majority of historical images are oblique images taken from balloons, airplanes or from natural points of view. In order to use this data with automated tools (e.g. as compared to 2D satellite imagery) a precise georeferencing is needed.
5. Few specific standards exist for sharing historical images along with their geolocation.

Fortunately several archives around the world are in the process of digitizing their image archives. This opens historical picture collection to a much larger public and prevents the contents from decay.

In the ongoing open-source project Smapshot (Produit et al., 2018, Produit and Ingensand, 2018) (https://smapshot.heig-vd.ch/) over 200'000 digitized historical images have been georeferenced in 3D by more than 800 participants. In the web-platform a participant can georeference an image using monoplotting (Bayr, 2021, Bozzini et al., 2012) - ground-control-points (GCP) are digitized both in a historical image and in a virtual globe that displays recent data (aerial imagery draped on top of a terrain model DTM along with 3D buildings). These GCP allow for the calculation of the exact position from where the image has been taken or painted (3D point) and

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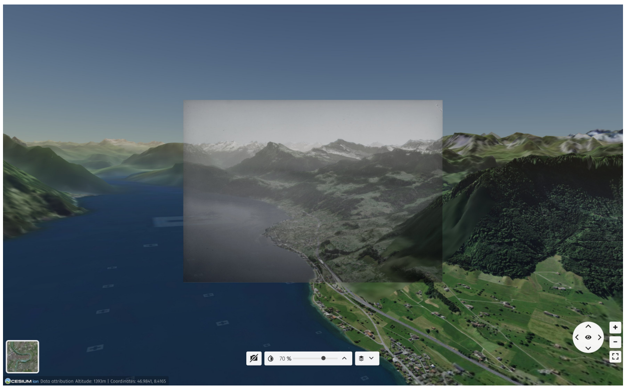

Figure 1. A historical image in Smapshot, displayed on top of a virtual globe, https://smapshot.heig-vd.ch/

the three angles that define the direction of view: roll, pitch and yaw. For the calculation of an approximate position four GCP are necessary, but at least six GCP are required to obtain a more precise position.

Once the position and the direction of view has been calculated, a footprint (i.e. the area that is visible in the image in 2D) is generated by calculating the viewshed around the photographer's position using a DTM and by clipping the obtained viewshed using the image parameters and the direction of view. This footprint allows for the calculation of visible toponyms which can thereafter be utilized for a more precise description of the features that are visible in the picture. The calculation of toponyms however requires to take into account the distance between the virtual camera and the toponym due to the fact that a toponym might be far in the background and thus not relevant for the image. The calculated toponyms can thereafter help in identifying pictures that for instance display a specific place and are valuable metadata for the archives who provided the pictures.

Due to the fact that georeferencing is created by volunteers, the data needs to be validated. In Smapshot administrators validate the data using pre-calculated indicators such as the number of GCP, the computed error or the surface covered by the GCP.

2. AN OPEN API FOR GEOREFERENCED HISTORICAL PICTURES

Within the field of Digital Humanities there are several initiatives to georeference historical contents. (Luft and Schiewe, 2021) for instance have developed a method to automatically georeference historical 2D maps using openstreetmap data as reference data. Another project that uses crowdsourcing for the 2D georeferencing of historical maps is Georeferencer, (https://www.georeferencer.com/) It is today used by several libraries around the world.

Another trend in science that has been utilized for several years is the parsing and georeferencing of text data. In the Venice Time Machine project (Abbott, 2017) researchers combined data from several archives and sources to build a database of georeferenced historical contents that allows researchers to analyze events in the past.

For the 3D georeferencing using monoplotting there are also some tools available. We can for instance cite the WSL-monoplotting tool (https://www.wsl.ch/en/) by (Bozzini et al., 2012) and a QGIS-Plugin Pic2Map (https://plugins.qgis.org/plugins/Pic2Map/). These tools however allow for the manual georeferencing by expert users and are less adapted for producing large quantities of 3D georeferencings.

In the frame of a Swiss National project for the development of national geodata-infrastructures, the goal is to create a national infrastructure for 3D georeferenced historical images that includes historical pictures as well as historical paintings reaching even further back in time. The opportunities of such an infrastructure are multiple:

- The search for historical images for specific regions and periods of time is facilitated due to the calculation of visible toponyms and footprints.
- Images from several data-sources can be combined and analyzed.
- Above-mentioned research analyzes involving large amounts of data (e.g. melting glaciers, natural hazards, etc) are made possible.
- The development of third-party applications that use and include the data is facilitated.

A first step was thus to make the pictures and the metadata from the Smapshot platform available to the public and to build an open API that can allow researchers, developers and the public to interact with the available data in both directions and that can also be utilized by others to add metadata. Another goal was to allow for other projects to implement the same type of API and to thereby build other bricks in the frame of a future national infrastructure for georeferenced images.

3. IMPLEMENTATION

In order to offer easy access to all the data in the Smapshot database and to allow for different types of queries such as retrieving the footprints of the photos, fetching metadata of a picture (e.g. owner, title, date, x/y/z position and roll, pitch, yaw angles) or retrieving images that are within a certain range from a specific point we wanted to create an API that would serve and use existing and established standards as far as possible. We therefore investigated existing standards both in the fields of archive management, within image management and within the field of geographic data.

For the definition of metadata in documents there are several well-established standards such as the Dublin-Core (https://www.dublincore.org/) or the ISAD(G) (https://www.ica.org/) standards. Both standards are frequently used in the context of archive management, but are neither optimized for image metadata nor for geospatial information. Wikidata (https://www.wikidata.org/) has also specified a structure for documents that considers image metadata and WGS84 coordinates in 2D.

For the definition of technical metadata in images the EXIF-extension (commonly used with file formats such as jpeg, tiff or png) stores technical details of an image such as for example the shooting date and time and the focal length. It has some support for geographic data: position and azimuth data can be transmitted. For the distribution of images and their metadata using API's there is also a more recent standard called IIIF (International Image Interoperability Framework, https://iiif.io/).

Today the IIIF standard has very limited support for geospatial information, but discussions are ongoing in the IIIF community to integrate geospatial metadata.

On the side of geospatial data standards there is relatively poor support for pictures that are oriented in 3D. The binary glTF (Graphics Language Transmission Format) standard (https://www.khronos.org/gltf/) is one such example that is today used and supported by a variety of software projects. There is also a recent initiative from the Open Geospatial Consortium (OGC) called GeoPose (https://www.ogc.org/projects/groups/geoposeswg) which formalizes a standard to define a 6DoF pose everywhere on Earth.

To increase the flexibility of the API and the possibilities to interact with the data we decided to focus on the IIIF standard for the integration of image contents (e.g. pushing and retrieving the IIIF link to an image). Moreover IIIF allows for storing and accessing metadata of the images as well as some functionalities such as for instance deep zoom, rotating, cropping and tiling images.

Regarding the pose of an image we decided to define a minimal set of attributes (see figure 2).

```
pose:
  altitude:    4352.568197699614
  latitude:    45.97507029984338
  longitude:   7.349208588815669
  azimuth:     436.5489879519721
  tilt:        -9.67549393401211
  roll:        -4.156134444814597
  focal:       1932.5935599887157
```

Figure 2. The definition of a 3D pose in the API: the 3D position from where the image has been taken or painted, the three angles that define the direction along the optical axis and the focal length.

Figure 3. A footprint of a historical image: the 2D area that is visible in the image

The API was implemented using common modern web technologies, in particular NodeJS (https://nodejs.org/) with a PostgreSQL/PostGIS (https://www.postgresql.org/, https://postgis.net/) database and Python code for the georeferencing algorithm. The API is a REST API fully documented using the OpenAPI specification (see figure 4) The source code of the API and the georeferencing algorithm have been released using the 3-clause BSD open source licence. (Fürhoff et al., 2021, Produit, 2021) Specific test-suites have been put in place to ensure quality and to allow community contributions with confidence.

Some examples for operations that have been implemented are:

- Retrieve the 3D geolocation of an image
- Get the footprint of an image (see figure 3)
- Submit an observation related to an image
- Submit a new image (via a IIIF link)
- List and retrieve image collections

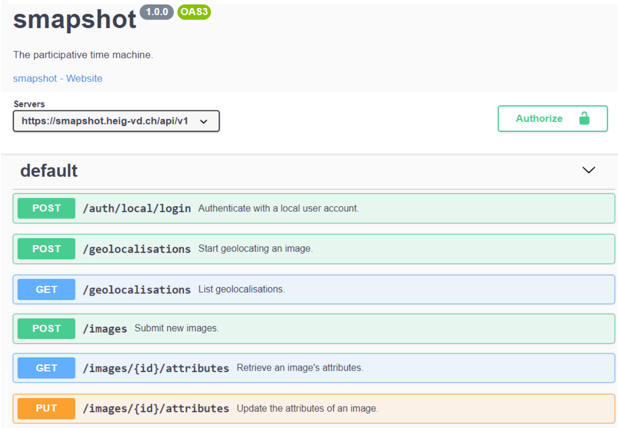

Figure 4. Extract of the Smapshot API documentation (https://smapshot.heig-vd.ch/api/v1/docs/#/default)

In the following sections we will illustrate some use-cases which make use of the API.

4. USE CASES

4.1 Bilder der Schweiz Online

A first use case that uses the API is an ongoing research project at the University of Zurich called Bilder der Schweiz Online (BSO) - Images of Switzerland Online (https://www.bilder-der-schweiz.online). BSO is a public portal which publishes a large amount of images from three Swiss collections of historical photographs and paintings. One goal of the research project is to build a knowledge graph of the image contents that includes the position(s) of the painter / photographer, the time an image has been established as well as the annotated contents of the image. The knowledge graph enables for instance researchers among others to retrace the historic journey of painters across Switzerland and to analyze which objects have been depicted and from which positions.

A key in this use case was the integration of the IIIF standard in the API: the images are hosted on an external server and therefore only the IIIF link to an image is pushed through the API. This procedures also solves the problem of the copyrights to an image - the entity that hosts the image is responsible for the image copyright. Moreover the image is only hosted on specific place and data is not duplicated.

In the frame of the project we adapted the API to be able to manage IIIF regions. BSO can therefore use the API to retrieve annotations and their corresponding image area created by the volunteers, and display the information on its own platform. New IIIF images with its metadata can also be added to the platform via the API, and regions corresponding to crop areas of the original scan can be updated.

4.2 ImagineRio

Another use case taking advantage of IIIF integration to facilitate import of images into smapshot is the imagineRio project (https://www.imaginerio.org/). A collection of historical images from Rio de Janeiro has been integrated into Smapshot.

https://doi.org/10.5194/isprs-archives-XLVIII-4-W1-2022-217-2022

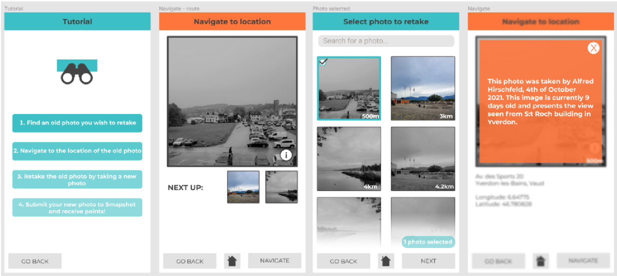

Figure 5. Prototype of a mobile application to retake a historical photograph - the application guides a user to the exact position from where a photo has been taken. (Karlsson, C and Hirschfeld, A, 2022)

The API is later used by imagineRio to integrate the footprints into the project's platform. A specific feature of this use case is the integration of different historical terrain-models that are used for the calculation of the position and the footprints: due to the fact that the landscape in Rio de Janeiro has dramatically changed over the last 100 years it was necessary to select a terrain model for the exact period when a photo had been taken.

4.3 Input for machine learning algorithms

Another use-case that has been initiated as a student project is the training of a machine-learning algorithm to recognize georeferenced features. The algorithm can be trained using available pictures and corresponding geo-data retrieved through the Smaphsot API . With a trained algorithm it becomes possible to calculate an absolute position only using imagery (e.g. through the detection of several features). This process can be used to direct an unmanned aerial vehicle (UAV) with the imagery of a camera, but without the utilization of a GPS.

4.4 UAV rephotography

A further scenario is the utilization of the exact positioning of a historical aerial georeferenced picture to automatically position an UAV with an installed camera to retake the photo from the exact historical position. The automated positioning of UAV is however very manufacturer-dependent and lacks standardization. This use-case makes it possible to illustrate the precise change in the landscape that occurred in the time between the date of the historical photograph and today.

4.5 Mobile rephotography

A similar use-case is the creation of a mobile application that enables the user to retake a terrestrial photo using a smartphone or tablet-computer. The idea is to direct a user to the exact position from where a terrestrial photo has been taken using a mobile application and then to show the user in which direction to point the device. The results of a prototype implementation have been described by (Karlsson, C and Hirschfeld, A, 2022), see figure 5

5. CONCLUSIONS AND PERSPECTIVES

In this article we have described the establishment of an open API for 3D georeferenced historical imagery. The context of 3D-georeferenced historical pictures opens many possibilities and perspectives, and we can also see the georeferencing of pictures in a larger context.

5.1 Further use-cases

3D georeferenced images are increasingly used by several projects that document change over time. With the development of the open API that allows a bi-directional interaction with 3D georeferenced imagery we have created a platform that can be used in a variety of other scenarios.

In the open-source project Smapshot volunteers are georeferencing historical imagery using the manual clicking of ground-control points and thus generating content that is served through the API. However there are other methods that enable the 3D referencing of pictures: 1. If the camera position and angles are known through different sensors, the geolocation information can be stored with the picture. 2. If there are several pictures of the same object or region, but taken from different positions it is possible to calculate a relative position. If the absolute position of one picture is known, it becomes possible to calculate the absolute position of all pictures. This approach has been implemented and described by (Blanc et al., 2018). The latter methods can also benefit from a standardized API in order to update an underlying database with more data, e.g. with machine-learning algorithms that automatically georeference new images based on already georeferenced imagery.

Within the field of digital humanities even paintings can be considered for 3D georeferencing and differences between the real world and the painted world can give room for analysis and interpretation (e.g. vertical exaggeration to make mountains look more dramatic or the adding or deleting of objects to improve the aesthetics of a painting.) see figure 6.

Figure 6. Example of artistic distortion. The height of the mountains is exaggerated. Bilder der Schweiz Online. Zentralbibliothek Zürich. Available at: https://resource.swissartresearch.net/artwork/nb-480044 Accessed 07.06.2022

The referencing of paintings is in some cases a challenge. When a camera obscura had been used, a painting has a geometry comparable to a photograph and can easily be georeferenced, but if the painter used for instance several points of view for one painting (e.g. to make the painting look more dramatic) (Besse, M, 2022), or if the painting is a panorama, monoplotting does not work anymore since the algorithm is unable to identify a single point of view. One solution to this problem is to cut the painting into several parts and to georeference each part separately. In this context the IIIF standard is of use since it allows for cropping and rotating parts of an image. The same process can be used for panoramic images made of stitched photos.

Another scenario are photographic observatories. The concept behind such observatories is that a picture is taken from exactly the same point in space, but at several points of time. Such photographic observatories document the change in the landscape and are for instance used in the fields of land use planning and environmental research. (Gutiérrez et al., 2022) For photographic observatories the metadata of the images depends very much on the context and can be very exhaustive. The developed API can be of use for photographic observatories and allow for uploading and downloading new contents and helping a photographer to find the exact spot to retake a picture.

A further use-case is the creation of geovisualization-applications that show the contents of historical pictures in 3D and that enable a user to compare it to the real world (e.g. augmented or virtual reality applications). A possibility would be for instance to create a mobile application that allows a user to virtually visit a city or a landscape from 50 years ago while walking through today's landscape. Furthermore it would be possible to drape the 3D-contents of a picture collection on top of a digital terrain model in order to recreate a virtual globe of the past.

The open API for 3D georeferenced historical pictures makes several types of analyses easier and opens the data for a larger public. It also becomes possible to implement other solutions that utilize the data directly - e.g. for displaying historical pictures in a 3rd party web page or for implementing machine-learning processes that automatically download pictures and metadata in order to recognize features and places.

In addition to the use cases made possible by such an API, the results of the project are also an important input for standardization activities that aim at establishing standards in the context of georeferenced pictures and their metadata.

The developed API represents a first step in the establishment of a decentralized infrastructure for 3D-georeferenced pictures that can be deployed on a national or international level and that also offers the possibility to push new data (i.e. pictures or their metadata) to a database.

5.2 Beyond the 3D georeferencing of historical imagery

3D georefenced historical imagery is one very interesting source of information for research and the general public, but it is also necessary to see this data in a larger context. In order to do research it is often required to combine information that comes from different sources and in different formats. For a future development of the open API we therefore aim at investigating the links with other georeferenced data such as 2D georeferenced imagery (satellite, historical maps, etc) or vector data. Recently the OGC has published new specifications and standards in the context of the OGC-API (https://ogcapi.ogc.org/) series. This series of standards is also based on the Open API specifications. A compatibility with these standards and specifications is therefore desirable.

In 1895 the Lumière brothers made the world's first film in Paris - since that time there is also an increasing number of films that could theoretically be georeferenced in 3D. Of course the georeferencing of a film needs more resources and techniques, but one possibility could be to georeference specific frames of a film and to interpolate the position in between the frames. In this context machine learning algorithms could be of use to find relative positions. In the field of forensic sciences the 3D georeferencing of films allows for the analysis of different situations - e.g. through the 3D modelling of buildings, places and people at different points in time. (Carew et al., 2021)

Moreover in the context of digital humanities the concept of linked data is increasingly used to combine data from very different sources. An interesting perspective in the context of such a national data infrastructure is an extension for linked data: Linked data interfaces can link several types of data and sources together and thereby build new knowledge. We therefore also want to implement a way of communicating with the API using RDF tools.

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