Ubiquitous Digital Storytelling with Local and Dynamic Georeferencing of Analog Maps

Masatoshi Arikawa and Min Lu

Abstract Maps are important vehicles for storytelling. Although the ubiquity of current web-mapping services has contributed greatly to the creation of map-based content, these services have also imposed restrictions on map representation. Conventional analog maps are still being created and remain widely used. Some of the most well-designed analog maps are highly contextual, and they are as such more suitable for storytelling with related backgrounds. To utilize analog maps in location-aware mobile environments for storytelling, local and dynamic georeferencing, which attaches geospatial information to analog map images without distorting the maps or destroying their artistic designs, is introduced. A data format, extended from a popular GIS data standard, was designed for creating and sharing storytelling content more easily by permitting the attachment of multimedia resources to georeferenced map images. In cooperation with local communities, prototype applications were developed and tested in walking tours to assist in the creation and browsing of map-based storytelling content.

Keywords Map-based storytelling · Location-based audio tours · User-generated content · Analog maps · Georeferencing · Data standard

1 Introduction

Storytelling is a common and efficient way of sharing knowledge. Indeed, people have used stories to convey information, cultural values, and experiences for as long as modern humans have existed (Gershon and Page 2001). Storytelling was once regarded informally, and its capacity for knowledge sharing was greeted with much skepticism, but it is now recognized as a valuable resource in knowledge sharing environments (Mitchell 2005). It has been suggested that sharing experiences through

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storytelling has various benefits, such as building trust, cultivating norms, transferring tacit knowledge, facilitating unlearning, and generating emotional connections (Sole and Wilson 1999; Ohler 2006). Maps are important vehicles for spatial communication, and they have been used for visual storytelling in human society since ancient times. With the technological development of maps and mapping in the digital era, map-based storytelling is no longer restricted by static media or limited by difficulties in mapmaking. People can use web-mapping services to create their own stories more easily by deploying point and line features linked to multimedia resources. At the same time, map-based and location-based mobile services have become popular in assisting with and enhancing people's real-world experiences.

However, although the ubiquity and convenience of current web-mapping services have great advantages, they also have drawbacks (Muehlenhaus 2014), like lack of diversity and freedom in map communication and aesthetic designs. On the other hand, conventional paper-based maps, such as tourist maps in leaflets of local communities, illustrated maps in guidebooks and magazines, signboard maps, and hand-drawn maps, continue to be created and widely used. Although the functions of such maps are limited by static media, they have the advantage of representing highly specified and contextual information with well-designed map representations.

This research aimed to provide users with a platform and tools for map-based storytelling that is free from the limitations of web mapping but can include all kinds of maps collected or created by the users. Users can employ the platform to position multimedia content on the maps and attach georeferences easily. This user-generated, map-based storytelling content can be shared with and experienced by other users with location-aware mobile devices in real-world settings. For this purpose, studies have focused on local and dynamic georeferencing techniques, data formats for georeferenced map-based storytelling and content sharing, and the development of prototypes of content editing tools and mobile browsing applications.

2 Cartographic Fundamentals of Human-Centered Mapping

The geographic visualization and graphic communication functions of maps, especially for conveying spatial knowledge, have been clarified in the past decades. By reviewing the lexical and functional traditions of conventional mapmaking, the current research revealed that map communication is essential to human-centered mapmaking, while the functionality, storytelling capacity, aesthetics, and potential inconsistency of such maps can be considered as some of their most important characteristics. The bird's-eye-view maps produced by the great Japanese cartographic artist, Hatsusaburo Yoshida (吉田初三郎, 1884–1955), are introduced in this work as examples of well-designed, human-centered maps to demonstrate their functional deformations.

The lexical and functional traditions of conventional mapmaking have been interlaced throughout the evolution of maps. As shown in Fig. 1, the media applications and functions of maps have shifted many times due to the emergence of new technologies. Among them, modern surveying has made maps more accurate and earth-centered, while information technologies have separated the storage and representation functions of maps. Although current digital maps appear to be primarily computer-centered, increased opportunities to focus more on their essential function—that is, communication—have clearly emerged.

The rapid development of web-mapping services has had a measurable impact on cartography and has changed mapmaking and map usage. New features of maps, including hypermedia, dynamics, interactivity, and accessibility, have extended the capabilities of map communication. However, such potential has not been well explored for human-centered maps. The drawbacks of current web-mapping services include *Googlization* in map design (Muehlenhaus 2014), restrictions on the creation of mash-up mappings, and a lack of diversity in map usage. As shown in Fig. 2, there is a hierarchy of maps, from computer-centered data maps to human-centered story maps. Current web mapping mainly focuses on the level of base maps. Mash-up maps based on digital base maps can be considered as a preliminary realization of digital thematic maps. At higher levels, which was the target of this research, maps are

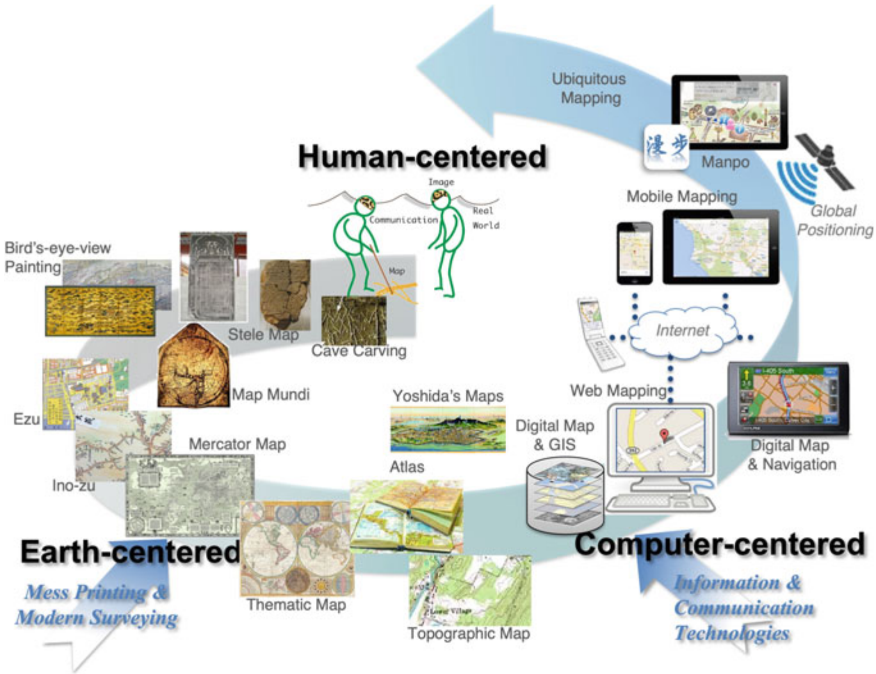

Fig. 1 Evolution in the appearance, media applications, and functions of maps with respect to the impacts of new theories and technologies

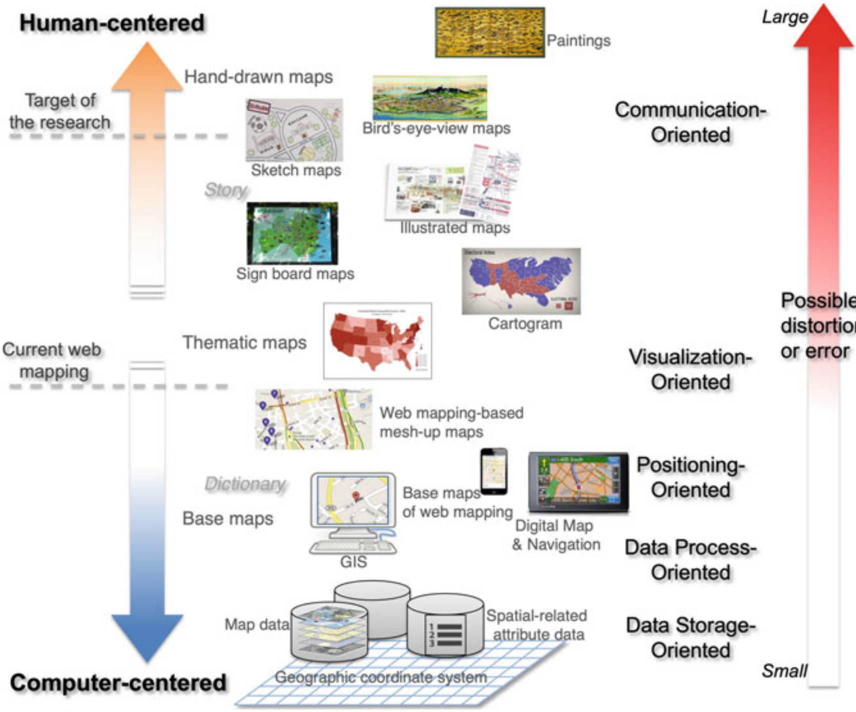

Fig. 2 Hierarchy from computer-centered maps to human-centered maps

more communication-oriented, but they are still deficient in terms of current mobile mapping.

In our study, a survey was distributed to young users of mobile mapping, with the results revealing that current web mapping does not take the place of conventional printed maps when used for specific purposes, such as sightseeing (Lu and Arikawa 2015). This further indicates that well-designed, conventional maps made by humans are preferred when such maps permit the integration of the advantages of mobile devices, especially GPS positioning. Examples of existing mobile applications that use maps other than web mapping have been investigated, and their limitations have been highlighted.

3 Maps and Storytelling

Before computers and Geographic Information Systems (GIS) came into being, maps were static. They told stories through static map images, illustrated figures, and texts, and they had to present all information, including map symbols, titles, legends, illustrations, and texts, at the same time. The tradition of integrating cartographers' stories (knowledge, notions, beliefs, etc.) with maps has existed since ancient times, when maps had additional functions beyond presenting visual representations of the real world. These functions included promoting worldviews, religious beliefs, and royal authority against the backdrop of culture-specific aesthetics and norms. In such maps, inconsistent scales, projections, symbols, etc., that were created with intentions, can often be found. Some may argue that such inconsistency was caused simply by undeveloped survey technologies. In fact, in the modern age, numerous examples of story maps simultaneously occurring alongside well-surveyed maps can still be found. However, as mapmaking is a professional activity, it is usually very difficult for ordinary users to create map-based storytelling on their own.

The development of web mapping and mobile mapping services has changed this situation, as these technologies provide accurate and detailed global base maps and data with interactive and customizable functions. Storytellers can, for instance, link story events to their relevant locations on the base map. They can also illustrate their stories with different maps, each showing locations and areas related to story events. This makes map-based storytelling much more convenient, as there is no need to create the base maps. At the same time, location-aware devices with mapping services make it possible to easily generate location-related content and intuitively browse map-based stories based on the user's current location. At present, one of the simplest ways to share a story is to tweet a location (Papacharissi and Oliveira 2012).

However, as current web-mapping services typically generate maps from the latest data for multiple purposes, they are often not the best choice for telling a story comprising specific backgrounds, topics, times, and places. For example, using only modern maps as the background for a historical story would likely overlook the circumstances in which the story events occurred. Also, the projections, map symbols, and generalizations of a web-mapping service are determined solely by the service, which means these features cannot be modified according to story specifics. Likewise, the aesthetic designs of map representations cannot be chosen by the storytellers according to the story topics, as multipurpose-oriented web mapping tends to use universal designs. In contrast, in the analog world, a wide range of map designs can be found. These highly contextual and purpose-specific map designs are quite suitable for stories that share the same context. For example, when tourists want to tell stories about their trips, tourist maps of the places they visited can be very suitable base maps.

4 Local and Dynamic Georeferencing for Analog Maps with Inconsistencies

Map-based storytelling in real places can be a good experience, as it can evoke intuitive feelings about the places among users, who can then compare the maps and the associated stories with their current realities. When using analog maps, however, the experience can be limited by the relative ability of users to read maps as well as by variations in spatial cognition. One practical way to assist users in overcoming difficulties with locating their positions on analog maps and connecting the maps with the real world is to directly apply the benefits of the latest multimedia and location-aware platforms. For this purpose, the application of georeferencing to analog maps is a promising approach.

Analog maps, such as hand-drawn maps, illustrated maps, and bird's-eye-view maps, often contain irregular deformations and geometric and semantic inconsistencies. Examples of geometric inconsistencies include inconsistent map projections, scales, and directions, whereas semantic inconsistencies include different depictions of objects of the same type and size. Such inconsistencies are the result of multiple factors, such as selective depictions of objects and exaggerations or simplifications of different regions. When a mapmaker is trying to achieve functionality, aesthetics, and effective storytelling in a map, accuracy and consistency are often compromised. However, without addressing inconsistency, mapmakers cannot directly incorporate location-based services (LBS) or location-aware devices into their maps.

Appending additional georeference data to analog maps and adjusting the maps to certain projections are common methods for aligning old, often inaccurate maps and sketch maps with far more accurate modern web mapping (Fleet et al. 2012). However, doing so can sometimes distort the original maps and destroy their original designs, even rendering them unreadable after corrections. As map design and representation are salient aspects of map-based storytelling, georeferencing methods that do not change the appearance of maps are required.

For this purpose, the present research proposes the application of local and dynamic georeferencing to accurately map geographic information (e.g., user location information obtained from a mobile device) onto the graphic space of analog maps without changing—or damaging—their appearance. The primary methodology in this regard is to dynamically search nearby georeferences and use them to make local corrections. Such corrections are not processed onto the map image but instead onto the inputted geographic information (e.g., the user's current location). This research used experimentation to realize the following local and dynamic georeferencing method.

Three-point-based georeferencing is a georeferencing method based on control points, which are pairs of corresponding coordinates on the geographic coordinate system (e.g., in latitude and longitude) and the graphic coordinate system of a map image (e.g., in x and y). The deployment of the control points over the maps does not require the control points to be evenly distributed, but they should sufficiently cover the area that the map users intend to visit. The points of interest (POIs) on the map can be utilized as natural control points. Additionally, places and objects that can be clearly confirmed on the map image and geographic information source (e.g., web mapping) can be chosen as control points. For example, road intersections and corners are suitable control points. The control points are preprocessed to form a triangulated irregular network (TIN). Consider a triangle Eq. (1) on the graphic coordinate system ($G_{a_i}\left(lon_{a_i}, lat_{a_i}\right)$ means the coordinates of a vertex in *longitude* and *latitude*) and its corresponding triangle Eq. (2) on the geographic coordinate system ($P_{a_i}(x_{a_i}, y_{a_i})$ means the coordinates of a vertex in x and y):

$$TG_i = \left(G_{a_i}\left(lon_{a_i}, lat_{a_i}\right), G_{b_i}\left(lon_{b_i}, lat_{b_i}\right), G_{c_i}\left(lon_{c_i}, lat_{c_i}\right)\right) \tag{1}$$

$$TP_i = \left(P_{a_i}\left(x_{a_i}, y_{a_i}\right), P_{b_i}\left(x_{b_i}, y_{b_i}\right), P_{c_i}\left(x_{c_i}, y_{c_i}\right)\right) \tag{2}$$

$$f_{v_i} = \begin{cases} x_{v_i} = m_{1i} \cdot lon_{v_i} + m_{2i} \cdot lat_{v_i} + m_{3i} \\ y_{v_i} = m_{4i} \cdot lon_{v_i} + m_{5i} \cdot lat_{v_i} + m_{6i} \end{cases}, v_i \in \{a_i, b_i, c_i\} \tag{3}$$

$$\begin{cases} m_{1i} = \frac{(x_{c_i} - x_{a_i}) - m_{2i}(lat_{c_i} - lat_{a_i})}{lon_{c_i} - lon_{a_i}}, lon_{c_i} \neq lon_{a_i} \\ or: m_{1i} = \frac{(x_{b_i} - x_{a_i}) - m_{2i}(lat_{b_i} - lat_{a_i})}{lon_{b_i} - lon_{a_i}}, lon_{b_i} \neq lon_{a_i} \\ m_{2i} = \frac{(x_{b_i} - x_{a_i})(lon_{c_i} - lon_{a_i}) - (x_{c_i} - x_{a_i})(lon_{b_i} - lon_{a_i})}{(lat_{b_i} - lat_{a_i})(lon_{c_i} - lon_{a_i}) - (lat_{c_i} - lat_{a_i})(lon_{b_i} - lon_{a_i})} \\ m_{3i} = x_{a_i} - m_{1i} \cdot lon_{a_i} - m_{2i} \cdot lat_{a_i} \\ m_{4i} = \frac{(y_{c_i} - y_{a_i}) - m_{5i}(lat_{c_i} - lat_{a_i})}{lon_{c_i} - lon_{a_i}}, lon_{c_i} \neq lon_{a_i} \\ or: m_{4i} = \frac{(y_{b_i} - y_{a_i}) - m_{5i}(lat_{b_i} - lat_{a_i})}{lon_{b_i} - lon_{a_i}}, lon_{b_i} \neq lon_{a_i} \\ m_{5i} = \frac{(y_{b_i} - y_{a_i})(lon_{c_i} - lon_{a_i}) - (y_{c_i} - y_{a_i})(lon_{b_i} - lon_{a_i})}{(lat_{b_i} - lat_{a_i})(lon_{c_i} - lon_{a_i}) - (lat_{c_i} - lat_{a_i})(lon_{b_i} - lon_{a_i})} \\ m_{6i} = y_{a_i} - m_{4i} \cdot lon_{a_i} - m_{5i} \cdot lat_{a_i} \end{cases} \tag{4}$$

TP_i is transformed from TG_i through *affine transformation* Eq. (3). Therefore, each pair of triangles can drive a group of six parameters Eq. (4) for the transformation.

As shown in Fig. 3, for mapping a geographic location onto a map image, this method will first search for the triangle that contains the location on the geographic coordinate system; when there is no such triangle, then the closest one is chosen. Hence, the affine transformation parameters of this triangle are used to calculate the corresponding graphic coordinates of the location onto the map image with Eq. (3).

Limitations in current story map applications include external sources, such as the deficient functions of human-centered mapmaking tools, as well as internal defects of human-centered maps, especially positioning difficulties due to immeasurable distortions. From both the author's and the user's viewpoints, this research studied use cases to clarify the requirements of the proposed approach. A human-centered mobile mapping framework, including both authoring tools and user applications, has been proposed (as shown in Fig. 4). The framework is designed to import conventional human-centered maps to mobile devices, after which the maps can be converted into interactive and geo-enabled mobile maps by integrating geo-metadata and multimedia content with originally static maps. Geo-metadata are designed to be the key to geo-enabling the printed human-centered maps. The concept model of geo-metadata is introduced in detail in the next section, which includes the model's graphic components and their associated georeference patterns. Frequently used geo-events and geo-interactions are also enumerated and discussed.

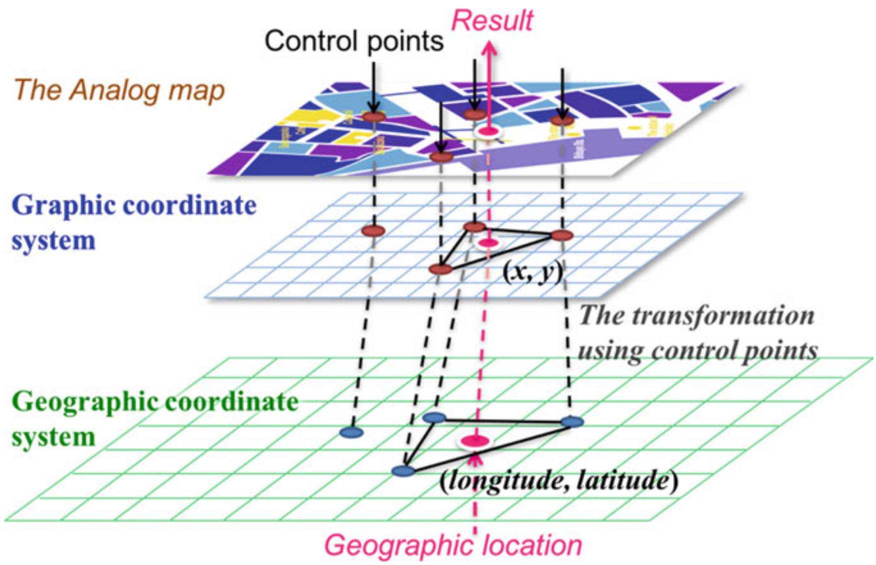

Fig. 3 Process for mapping a geographic location onto an analog map image with triangle-based affine transform

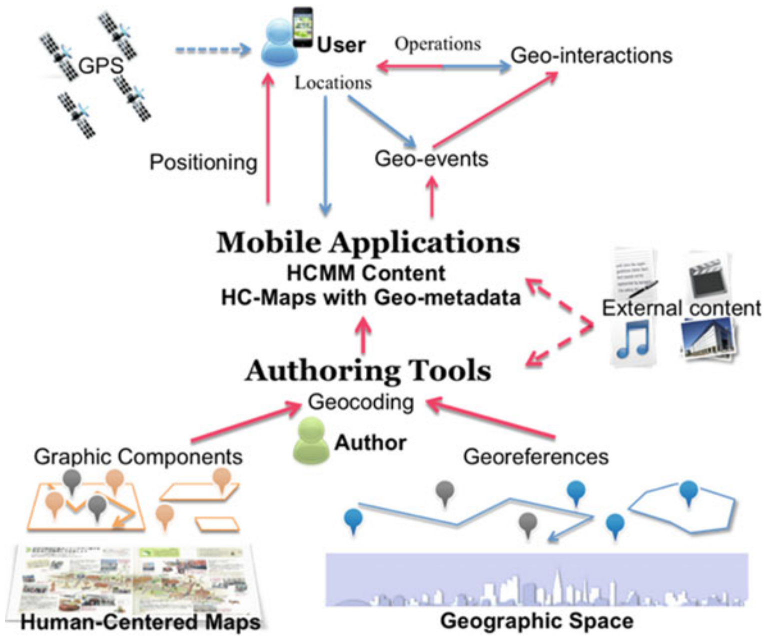

Fig. 4 Structure of the framework of the human-centered mobile mapping (HCMM) platform

5 Data Format for Sharing Analog Map-Based Storytelling Content

For describing, storing, and distributing map-based storytelling content via georeferences, a suitable data format is required. Apart from the descriptions of the geographic features, which can be the same as the existing GIS data standards, the data format should also include definitions of the graphic features in the analog map images, the georeferences, and the multimedia resources linked to the maps for storytelling. To match the context of geospatial data infrastructures and existing GIS tools and services, this research proposes the ManpoJSON format, which is based on an extension of GeoJSON (Butler et al. 2016). Manpo (漫歩), our original software, is a smartphone application for creating and experiencing location-based walking tours. Figure 5 shows the basic structure of a ManpoJSON object.

- **Features**: The geometric description of a feature in a map image for map-based storytelling consists of two corresponding components: a geographic description and a graphic description. As GeoJSON has already defined the format of geographic features, like points, lines, and polygons, ManpoJSON inherited the GeoJSON format for the geographic description. At the same time, ManpoJSON extends the format for the graphic description by adding definitions of the corresponding graphic coordinates of the features in a map image. In corresponding to the key geometry for providing a geographic definition of a feature in GeoJSON, ManpoJSON adds a key reference to define the feature in the map image. A reference needs to contain the following keys and values:
  - **type**: This key is usually the same as the type defined in the geometry, which is typically Point, LineString or Polygon.
  - **coordinates**: The value contains an array of graphic coordinates that describe the shape of the feature in the analog map image.
- **Georeferences**: Although the features in a map image can act as georeferences as they have corresponding geographic and graphic definitions, the map often needs additional georeferences to refine the results of mapping. ManpoJSON adds a key georeference, which contains keys and values:
  - **type:** As the georeference contains multiple points and lines, its type should be FeatureCollection.
  - **features**: The georeference usually contains one or two features, namely control points and/or polylines. Each feature should have the following keys and values:
    - *type*: The type should be Feature.
    - *geometry*: The value for type should be MultiPoints or MultiLineString; the value for coordinates is the array of geographic coordinates of the control points or polylines, using the same GeoJSON format.

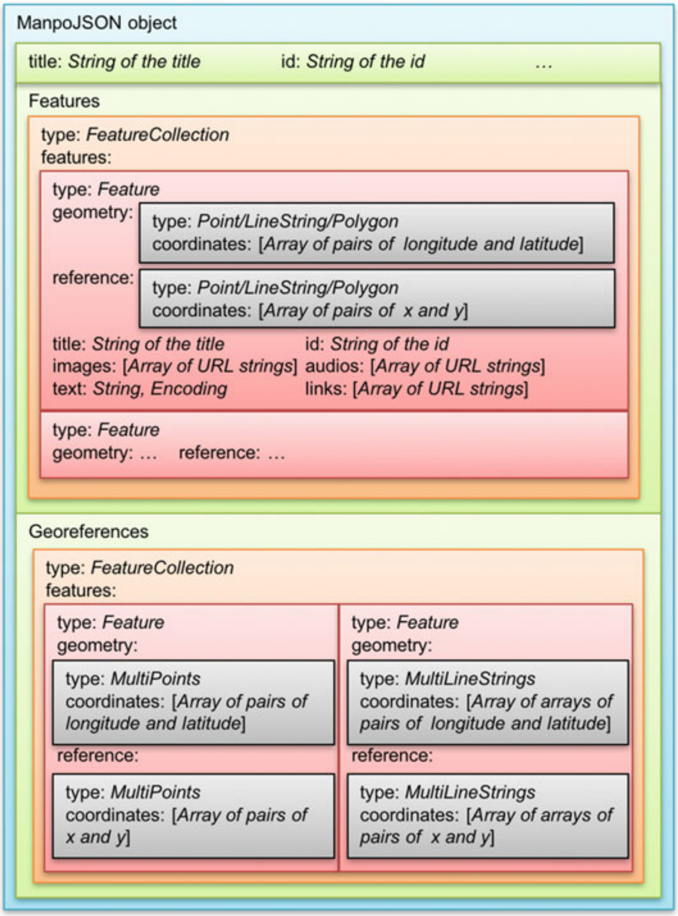

Fig. 5 Structure of a ManpoJSON object

- *reference*: This is defined by ManpoJSON. The value for type should be MultiPoints or MultiLineString, the same as in the geometry. The value for coordinates is the array of image coordinates of the control points or polylines, which should be in the same order, i.e., correspond to, the array in geometry.

- **Foreign Members for Storytelling**: As GeoJSON mainly defines the geospatial data, foreign members are needed to describe the multimedia resources linked to the features on the map images for storytelling.
  - **title**: This key can be a member of a feature or feature collection that has a string value of the title for the feature or feature collection.

- **id**: This key can be a member of a feature or feature collection with a value of the number. The id can be used for setting the order of features for storytelling.
- **images**: It can be a member of a feature, which contains an array of images, which have the key image, which contains a necessary member URL, whose value is a web URL or a file path.
- **audios**: It can be a member of a feature, which contains an array of audio resources, which have the key audio, which contains a necessary member URL, whose value is a web URL or a file path.
- **text**: It can be a member of a feature, which contains the following members:
  - *type*: The value can be a string or URL.
  - *value*: The value can be a string for the URL of the text file, or a string as the content.
  - *encoding*: The value can be a string that indicates the encoding of the text, such as ASCII and UTF8.
- **links**: It can be a member of a feature or feature collection, which contains an array of strings, which are web URLs.

6 Prototype Development

To realize the proposed approach of analog map-based storytelling with local and dynamic georeferencing, prototypes were developed, including editing tools for creating storytelling content and mobile applications for appreciating the content in real places. This research succeeded in developing and applying the following prototype for the purpose of evaluating the method in different application scenarios.

Manpo is an iOS application originally designed for location-based digital guides of walking tours with multimedia storytelling based on analog maps. Manpo makes use of analog walking-tour maps, such as the paper tourist maps provided by local tourism organizations and hand-drawn maps created by designers, in the digital mobile environment by enhancing the maps with georeferencing and multimedia interactions (Lu and Arikawa 2014). Figure 6 shows the main interface for viewing the georeferenced and multimedia-enhanced analog maps. When using the application in the places covered by the map, users can view their current locations on the analog map image. Their moving trajectories are recorded when they are moving, which will be shown on the map image as well. The users can view the content embedded on the maps by interacting with their content. For example, by clicking the POIs on the map image, a view with detailed information, including photos, text, and audio, will be shown to the users, as shown in Fig. 7. Lines with arrows show the recommended walking routes, in which audio guidance or narrations are embedded to be listened to along the way. The storytelling content can interact with the user's location. For example, when the user is nearing a POI or the start point of a line with audio, its icon will begin blinking. The recorded user trajectories and actions can be played back as a memorial of the trip.

Fig. 6 User interface of *Manpo* for viewing georeferenced and multimedia-enhanced analog maps

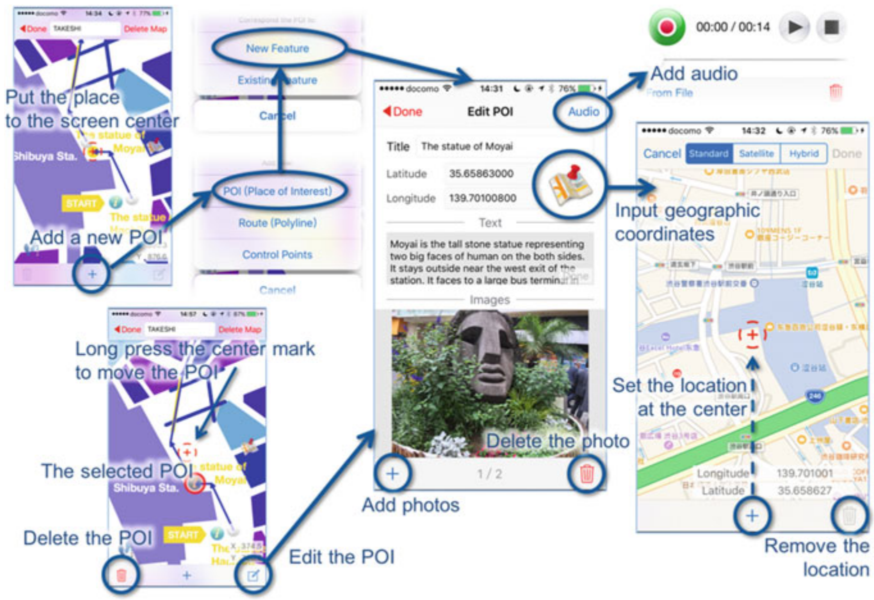

Fig. 7 User interfaces and procedures for creating a POI on the analog map image with text information, photos, and an audio clip using Manpo

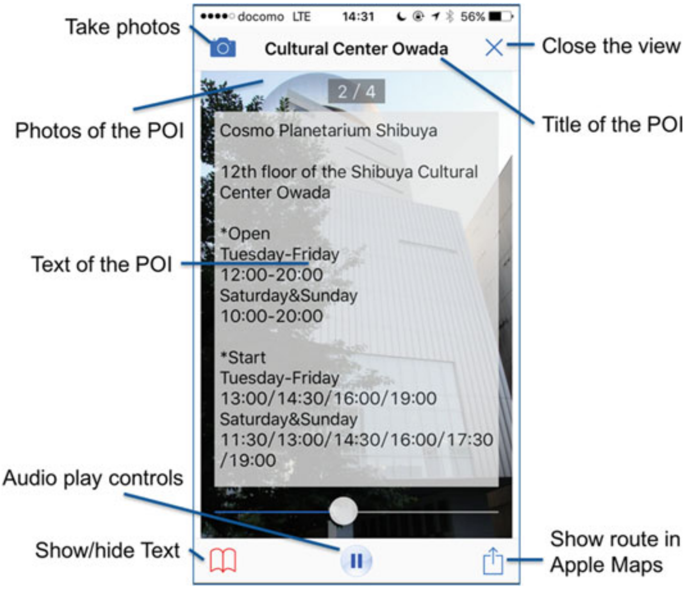

Fig. 8 The user interface for viewing the text, photos and playing the audio of a POI in Manpo

Manpo includes a tool for importing map images onto mobile devices and for inputting POIs, route lines, and control points onto the images. Storytelling content, such as images, text, and audio, can be bound to the points and routes. Figure 8 shows the user interfaces and procedures for creating a POI with text information, photos, and an audio clip. The way in which graphic coordinates are inputted is by simply pinning the correct position of the image on the center of the device screen. For inputting the geographic coordinates, Manpo provides an interface to pin the point on commercial web mapping (Apple Maps is used in Fig. 8). Manpo mainly applies *point-based georeferencing*. An interface of two split views showing the analog map image and the web mapping at the same time was developed for inputting the control points, as shown in Fig. 9. The user only needs to pan and zoom the maps, pin the corresponding points at the center of both views, and then tap the add button, after which the coordinates will be picked up and recorded by the application.

Manpo has been used by university students to create hand-drawn maps of areas near their campus in order to introduce others to local POIs and stories (Lu and Arikawa 2015). The students recorded audio guides about and took photos of the POIs and then organized them on their hand-drawn maps. Their outstanding work was then incorporated into an iOS application and published in the App Store. The Manpo approach is also used to develop mobile applications for university campuses and local tourism organizations, as explained in detail in the next section.

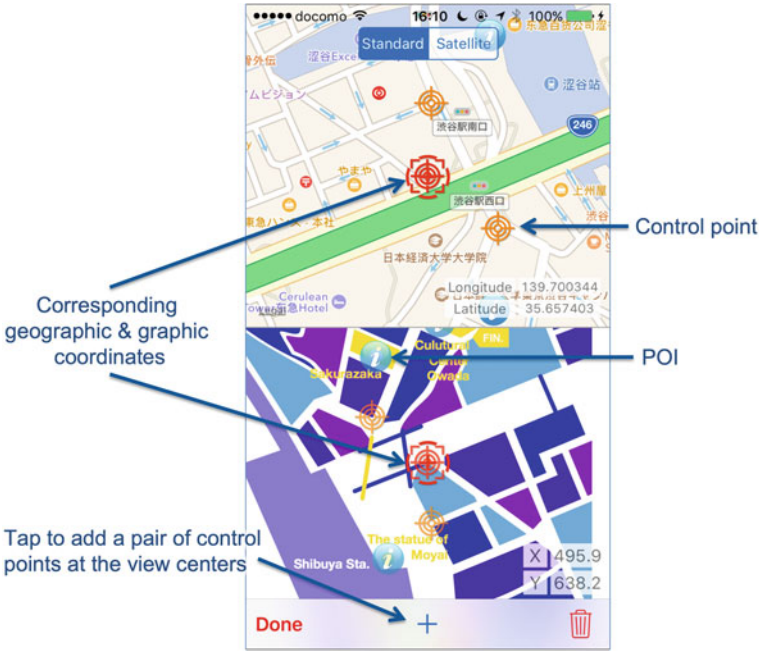

Fig. 9 User interface of Manpo for inputting the geographic coordinates and graphic coordinates of a control point from the maps

7 Experimental Applications

In cooperation with college students, university campuses, and local tourism organizations, experimental applications were developed to test the functionality and usability of the proposed mobile mapping application, as well as the feasibility of the proposed local tourist map ecosystem (Lu et al. 2018). Some of these applications have already been published for ordinary users. Two of the published applications are briefly introduced here.

7.1 Applications for Open Campus Events

Every October, from 2012 to 2017, an iOS application was introduced at a university's open campus events. The targeted users were participants at the open campus events, usually local residents and young students. The application was designed for the participants to freely move about the whole campus, visiting all of the institutes that were holding events or exhibitions, and being provided with brief introductions to the institutes and information about their events. The interfaces of this application are shown in Fig. 10.

(a) List of the stamps (POIs), showing their status and distances

(b) Displaying current location and trajectory on the campus map, with a POI invoked

(c) Main icons and buttons of the map view

(d) A checkpoint (POI) invoked by the current location, with a stamp to be obtained

(e) Event information of the POI during the open campus

Fig. 10 Application interfaces and instructions for open campus events: **a** list of the stamps (POIs), showing their status and distances; **b** display of current location and trajectory on the campus map, with a POI invoked; **c** main icons and buttons of the map view; **d** a checkpoint (POI) invoked by the current location, with a stamp to be obtained; **e** event information on the POIs during the open campus events. *Source* The maps and other image resources were provided by Kashiwa Campus, University of Tokyo

The application uses the official illustrated campus map, which was originally printed in leaflets and distributed to the participants. The institutes introduced in the leaflets were converted into POIs in the application. These POIs were also designed as checkpoints for a stamp rally activity. When the participants were close to a checkpoint (POI), they would be alerted by a blinking button in the map view, which would guide them to information about the POI, and a stamp could then be obtained by tapping the screen. When the participants viewed the map and its content, their location (longitude and latitude data from the smartphone) was recorded every 10 s; and when they obtained a stamp or took a photo, an additional location was recorded. Participants were encouraged to donate their trajectory data for research after finishing the stamp rally.

Analyses were conducted on the donated data, the results of which are shown in Figs. 11 and 12. In these figures, the official campus map is the one used in the mobile application, although it was processed to a much lower contrast in order to display the analysis results. In Fig. 11, which shows all of the donated movement trajectories in 2015 and 2016, we can see that the users tended to visit the western part of the campus (left part of the map) first, and then the eastern part. It seems that some users tended to follow the order of the POI numbers, but this is likely because the bus stop and general information center for the open campus events were closer to the western part. From these trajectories, heat maps presenting popular places on the campus, as shown in Fig. 12, were generated by setting a buffer range (20 m) to each location of a trajectory and then counting the number of different users in each pixel of the map. In the heat maps, the row of buildings at the center of the campus map was visited by most of the users, while buildings in the northern part, as well as gardens with woods and ponds in the southern part, were less visited.

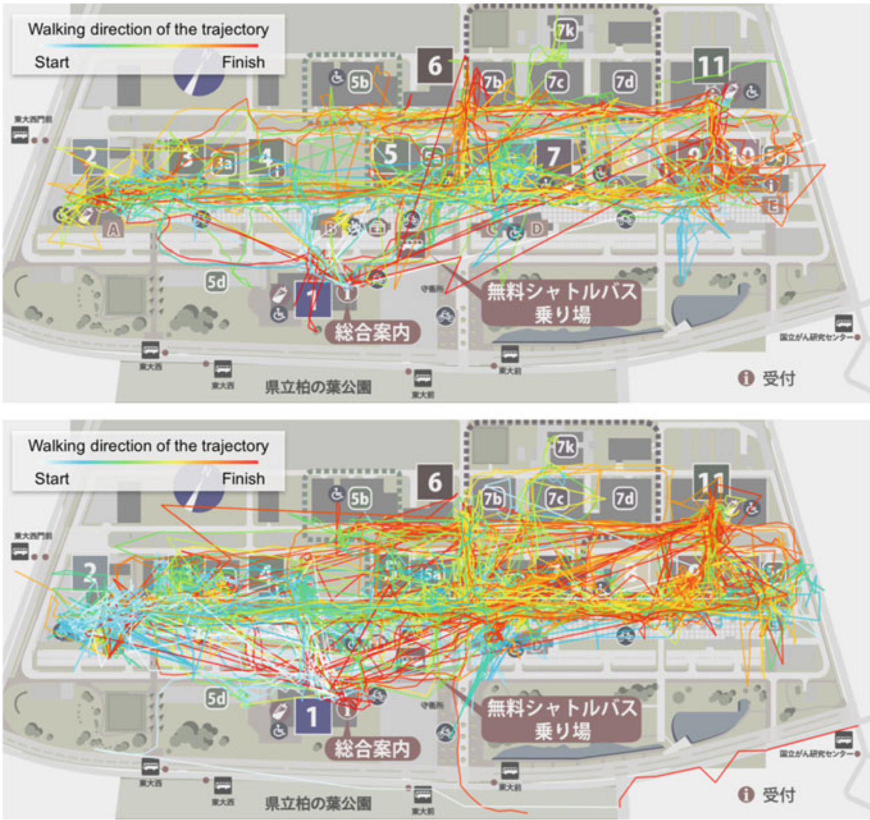

Fig. 11 Movement trajectories donated by the users of the application in the open campus events of 2015 (top) and 2016 (bottom). *Source* The map was provided by Kashiwa Campus, University of Tokyo

7.2 Applications for a Local Tourism Association

In 2015, the authors proposed solutions for utilizing existing paper-based tourist maps for mobile tourism applications to a tourism association in a district of Tokyo, Japan, and has been collaborating with this association ever since. The district includes many famous sightseeing spots, like gardens and temples. However, these spots are mostly known only to locals, with foreign visitors being rare. Therefore, there has been strong demand to improve awareness about these sightseeing spots, as well as knowledge about other places that tourists might be interested in. There have also been calls to improve the district's services and facilities. Toward this end, the district has already created free map leaflets, comprising base maps and data sources for the mobile application, in different foreign languages.

Via joint research, an iOS application was developed and published in Apple Inc.'s App Store. The application contains the English versions of three tourist maps: one

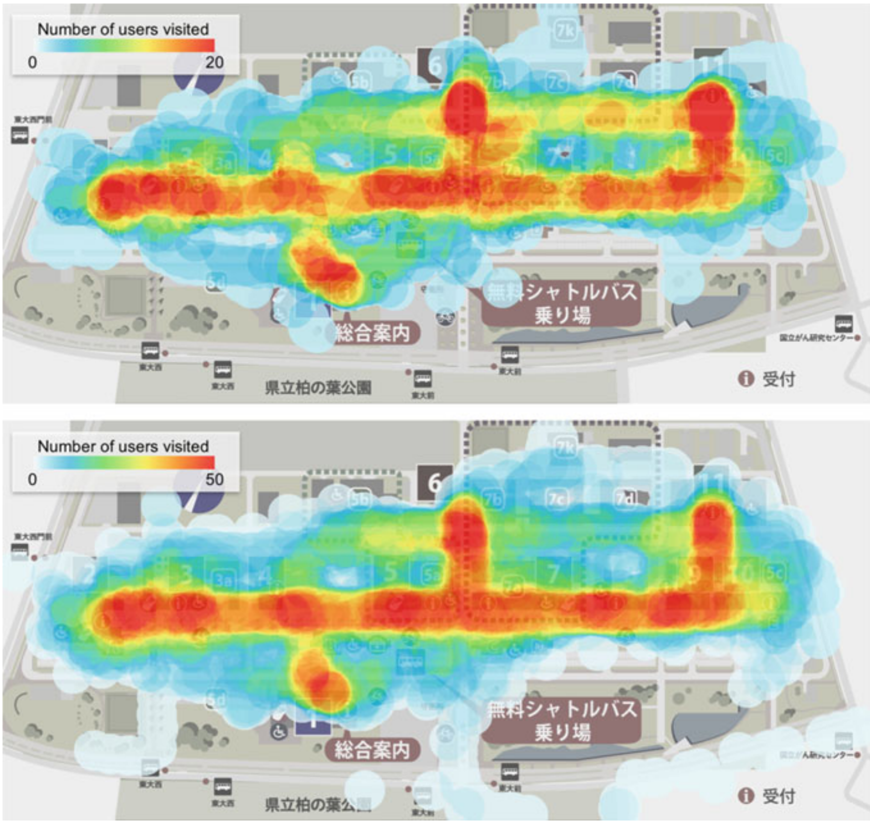

Fig. 12 Heat maps of popular places during the open campus events of 2015 (top) and 2016 (bottom), generated from the data in Fig. 11. *Source* The map was provided by Kashiwa Campus, University of Tokyo

tourist map of the whole district, and two maps of two famous gardens in the district. All three maps, which were originally printed on free leaflets, were georeferenced and attached with POI information originally printed on the leaflets. Apart from the functions of browsing the maps and obtaining POI information with positioning functions, comments, personal memos, and feedback with photos were also incorporated into the maps. Users can donate their comments, feedback, photos, and movement trajectories to the tourism association via a simple questionnaire accessible in the application.

Experiments involving the application were conducted in Tokyo with 12 international students, who were asked to take a walking tour independently with the application and to make comments with photos at any place and time they preferred. The movement trajectories and comment bubbles created by the participants are shown in Fig. 13. The results cannot be considered comprehensive because of the small number of users, and they may additionally have been biased as all of the

Fig. 13 Interfaces of the application for a local tourism association with user-generated comments and trajectories displayed (three on the top) and examples of user comments with photos (two on the bottom). *Source* The map was provided by the Bunkyo City Tourism Association, Tokyo, Japan

participants were young college students. However, the results have already made positive contributions—for example, the comments show that some historical places were interesting to foreigners but lacked information in foreign languages. In other example, the trajectory of one participant, who was near a garden, shows that he/she had been confused and took additional time to enter the garden, as the entrances were not clearly indicated on the map. Based on this feedback, the tourism association resolved the issue in the latest version of the map (2016–2018).

8 Conclusions

Map-based storytelling requires base maps with related backgrounds and context. Although current web mapping has the great advantages of ubiquity and convenience, the latest map data and multipurpose map representations are not always suitable for the topics and backgrounds of the stories. By introducing local and dynamic georeferencing, conventional paper-based maps can be utilized in location-aware mobile environments. Novel editing tools with a data format extended from a popular GIS data standard make it possible for mapmakers, designers, and even ordinary users to easily create storytelling content by attaching multimedia resources to georeferenced map images. Prototypes developed in this research have been tested and applied in cooperation with local communities, governments, and university students, and the map-based storytelling content created by them has been published as smartphone applications. These results have thus demonstrated the feasibility of the proposed approach.

In future work, the proposed georeferencing methods will be compared and refined to achieve better accuracy and stability. The characteristics of different georeferencing methods must be analyzed in order to determine the suitable map types of the different methods. On the other hand, input from the control points gathered by the prototype applications also introduced errors into the final georeferencing results. Therefore, better user interfaces and workflows for inputting georeferences must be designed. Furthermore, automatic or semi-automatic detection of suitable georeferences from analog maps using technologies such as image recognition and machine learning must be considered for longer-term development.

Currently, this research has focused on methodologies and prototypes for analog map-based content creation; thus, tools and applications were developed mainly for standalone use. In the next stage, this research will focus on constructing a platform for sharing the map-based storytelling content, one in which the effectiveness of the proposed data exchange format, ManpoJSON, will be tested and refined. This platform will be used for sharing created content, resources, and knowledge for creating the content, which may include maps, georeference data, georeferencing techniques, user data and feedback, and all kinds of multimedia resources. Finally, this research aims to establish a new mapmaking ecosystem and enhance local knowledge sharing, involving both ordinary users and specialists of different areas.

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