THIN PLATE SPLINE IN DETERMINING 500 YEARS MORPHOLOGY EVOLUTION OF HISTORICAL CITY OF MELAKA

[1]Marina Mohd Nor, [2]Norzailawati Mohd Noor and [3]Sadayuki Shimoda
[1,2] International Islamic University of Malaysia, 53100, Selangor, Malaysia,
Email: marina.mn@gmx.com, norzailawati@iium.edu.my
[3]Kumamoto National College of Technology, Yatsushiro City, Kumamoto, Japan,
Email: shimo@kumamoto-nct.ac.jp

KEYWORDS: Thin plate spline, GIS, urban morphology, historical city, old maps

ABSTRACT: Morphological urban studies have often been discussed in geographical literature, especially regarding geographical-historical settlement studies. Old maps are crucial for comparing spatial relationships of past phenomena and their evolution over time and permitting qualitative and quantitative analysis. However, most of the old maps were hand-drawn, unscaled and recorded by traveller or historian lead. Therefore, the spatial information of the old maps needs to extract and analysed. This paper will demonstrate old maps to study urban morphology in Melaka with the scientific geo-referenced approach by using thin-plate spline projection. Thin plate spline is a global elastic transformation that maintains the assigned map coordinates of all control point locations but applies smoothly varying transformations between control points. This transformation is capable of geo-referenced low quality or less-precise historical maps. Multiple old maps from different years are used; 1515,1830,1960 to integrate with SPOT satellite images from 1993, 2005 and 2015. The results show that the Thin Plate Spline technique is accurate and able to coefficients once-and-for-all. Simultaneously, the GIS software with relevant geo-referencing techniques can provide accurate spatial geo-information to study historical morphology. Moreover, the geo-referenced historical maps open up new opportunities for a broad spectrum of historical analysis extracted from flat maps.

1. INTRODUCTION

Old maps are a great source of information, especially on documentation of the city's history. It has been long as the centre of geography discourse and usually implies a search of geographical features. Moreover, maps can be portrayed as a powerful political message linked via maps, especially in colonial history (Cajthaml, 2011; Harley, 1988). Besides, old maps were frequently used in environmental management and land use construction (Forejt et al., 2018). The constraint on the formats of maps comes with assortment data types such as hand-drawn, analogue print, or digital data (Fuchs et al., 2015). Today, the old maps are easier to access than before and have been digitally restored via the scanned process. Due to the city's morphological study, it is crucial to obtain and examine the old maps to monitor the city's development. Moreover, old maps are part of cultural heritage and provide valuable information for a broad range of applications, including architecture, planning, historical and territorial research.

However, the old maps need to be pre-processed before they can be used in GIS to analyse. The old maps were produced at different times and reading the map to adjust with the current time. Thus, advancing technology in geography using GIS can allow old maps to apply the geoprocessing method (Brovelli & Minghini, 2012). Geo-referencing and spatial overlay with a standard coordinate system is essential to compare old maps from distinct eras to monitor the city's morph. It is affected by many factors such as; scales and resolutions of maps and the number of control points. Meanwhile, the oldest version of maps was measured astronomically (Cajthaml, 2011), which measured on the ground and not using accurate cartographic projection. Therefore, the crucial issue is to transform old maps into well-defined systems. The geo-referencing process converts the image coordinates form (x,y) into (x,y), in which the coordinates from distorted images are expressed by (x,y) and the input image coordinates from the actual geo-referencing image given by (x,y). The distorted images were automatically corrected from internal and external distortion without using ground truth. The old maps concerned should be properly geo-rectified by using appropriate methods of transformation which available for rectification (Beyhan & Ergenoğlu, 2018)

Hence, this study shows geo-referencing of early maps of Melaka city by using the thin-plate spline transformation approach. The Thin Plate Spline model is a global elastic transformation that maintains the assigned map coordinates of all control point locations but applies smoothly varying transformations between control points (Bazen & Gerez, 2003); MicroImage, 2013). The transformation from image to map coordinates is modelled mathematically as a thin elastic plate's deformation using the input control points. This transformation approach is an effective tool for modelling the coordinate transformation, successfully applied in numerous computer vision applications (Donato & Belongie, 2002). In geo-rectification operation, a one-to-one correspondence is established between two sets of GCPs lying on two different plane surfaces to rectify the historical map with the reference map. This paper aims to demonstrate old maps to study urban morphology in Melaka with the scientific geo-referenced approach by using thin-plate spline projection. It is crucial in historical study, especially where most of the historical cartography was an analogue version. Therefore, it can be extended use by historians, planners, architects and archaeologists as a source for broader application. Moreover, it provides technical solutions to ensure an accurate geo-referenced and continuously navigated in a geo-referenced framework.

2. STUDY AREA

Malacca state is next to the Straits of Malacca, at the coordinate location of 2.200844 latitudes and 102.240143 longitudes (Figure 1), known as the longest international route through a strait and linked with the straits of Singapore. The Malacca Straits have long been an important trade route linking the Indian Ocean to the South China Sea and the Pacific Ocean. Due to the strategic location, Malacca became an important port during the 15th century and was influenced by British settlement during British colonisation. This historic city centre has been listed as a UNESCO World Heritage since July 7 2008. The centre historic of Melaka city comprises two-zone: Core zone and Buffer Zone, including Sungai Melaka that passes through the site. The core zone, which encompasses St Paul's Civic Zone and Historic Residential and Commercial Zone (JPBD,2011), is defined as the most protected area which compromises every aspect of biological diversity, maintenance, and services in terms of provisioning, regulating, and cultural services. Meanwhile, buffer zones are created to enhance specific areas. It surrounds the core areas and helps to reduce the impact of human activity at the core area.

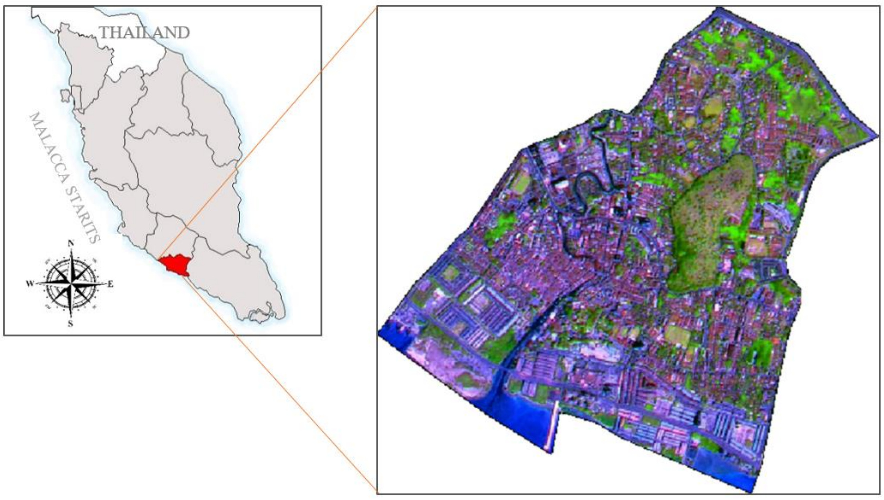


Figure 1 Location of the study area

3. MATERIAL AND METHOD

3.1. Materials and Software

In this study, several old maps and SPOT satellite imagery were used to analyse the morphology of Melaka. The detail on the data used in this study as in Table 1.

Table 1Data type in this study

Data Type	Year	Provider	Process	Output
Archived Data				
Melaka Land Use Archived Data	1515,1830,1960	• Internet Sources • Published Journal • National Archive	• Geo-referenced Process • Digitisation	• Time-series analysis data
Satellite Images				
SPOT 2-XS	1993	MYSA	• Geometric Correction • Image Enhancement • Clipping and subset • Supervised Classification • Accuracy Assessment	• Street Network Morphology
SPOT 5 Pansharp	2005			
SPOT 6 MS Pansharp	2015			

3.2. Methodology

City's morphology requires multitemporal data sets covering urban areas across an extended period. The merging of the dataset from historical maps, starting from 1511 to 1900 and satellite images from 1993 to 2015, will evaluate the spatial morphology of the 500 years of Melaka.

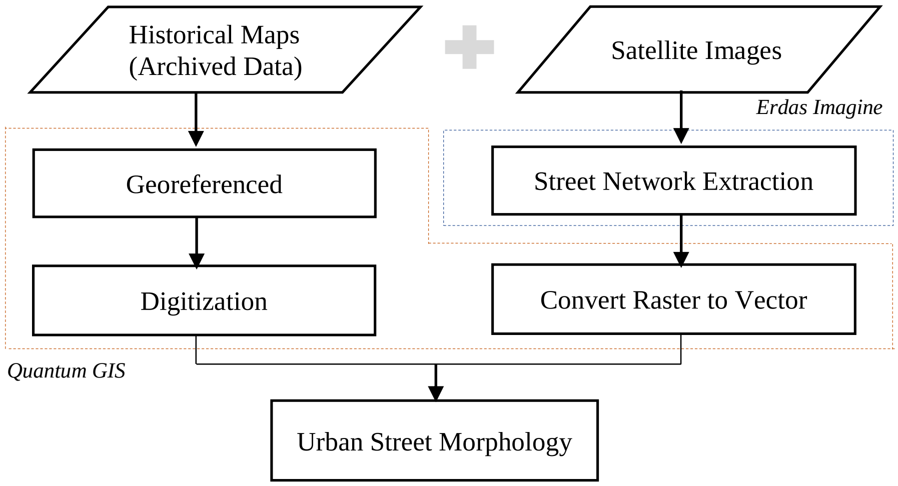


Figure 2 Flowchart of methodology for this study

In this study, there are two types of approaches with a different software applications. First, historical maps are using Quantum GIS (QGIS) software, where a thin-plate spline is selected as the main geo-rectification for transforming the historical maps. This transformation is capable of geo-referenced low quality or less-precise historical maps. It helps maintain the assigned map coordinates for all GCP and smoothly applies varying transformations of data deformations. However, it needs plentiful GCP all over the historical maps. In this process, approximately 30 GCP was applied on both maps (historical map and reference map) and projected in EPSG: 3857- WGS 84 / Pseudo-Mercator.

Meanwhile, for satellite images, using ERDAS Images software where image-to map technique applied to rectify the raw images that are non-systematic distort Thirteen control ground points (GCP) are used to pinpoint the exact coordinate in the images. The coordinate for every GCP in the site can be obtained from Google Earth Pro and referred to as image-to-map registration. These images using the standard coordinate system, World Geodetic System 84 (WGS 84). Point of Interest (POI) was the label on the reference map as an indicator of geographic features which constantly static despite changing times.

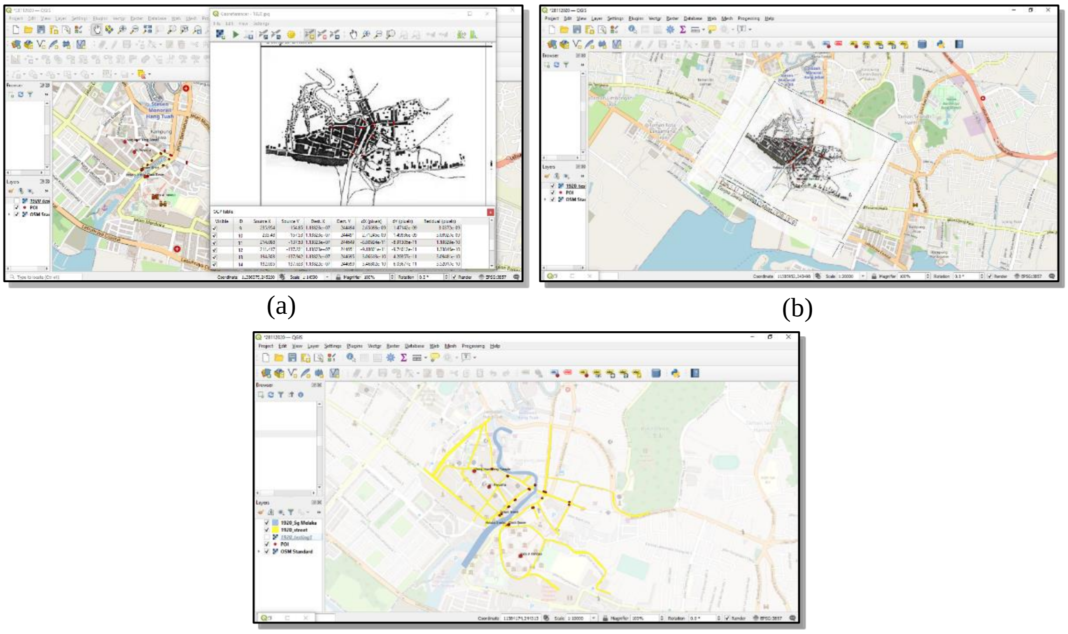
The root means square error (RMSE) is used to measure the precision of the map's transformation. It is the difference between the desired output coordinate for a GCP and actual (Franczyk, 2007; Moses & Devadas, 2012. Beyhan & Ergenoğlu (2018) agreed that RMSE is the most significant global statistic used to evaluate the deformations characterising the historical maps. The formula of RMSE is:

$$\mathrm{RMSE} = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2}$$

Where:

x_i *and* y_i are the input source coordinates.
x_r and y_r are the retransformed coordinates.

The RMSE values for each historical map are varied. This is because the maps obtained are not geodetic networks; no latitude or longitude indications, but the maps satisfy the reference map's primary topological conditions. Thus, the RMSE values are satisfied.



(a) (b) (c)

Figure 3: (a, b) Geo-referencing process; Thin Plate Spline transformation was applied on historical maps with at least 30 GCP and OSM as a reference map to locate into real-world location. (c) the digitisation process proceeds to all historical maps.

4. Result and Discussion

The street network's spatial distribution was plotted in the scatter graph (Figure 5) for each map to examine the street's spatial pattern and morphology. The street network's overall distribution shows that a newer street network was developed from time to time. The streets' development concentrated around the constant point of Kota A Famosa, Clock Tower, Temple Sri Poyyatha and Jonker Street. In the year 1515, the importance of the street is not yet aware. As time passed, the number of streets increasingly and expanded outwards from the Kota A Famosa. Street network development evolved from a constant point from the visual mapping of time series analysis (Figure 4). It stretched out to Sungai Melaka from time to time, especially during Dutch colonisation. The establishment of the street network system occurred mainly along Sungai Melaka, where it has become the central transportation hub for the city. It assumes that the street network pattern was expanding from the existence of the Malacca during Sultanate Malacca until the present.

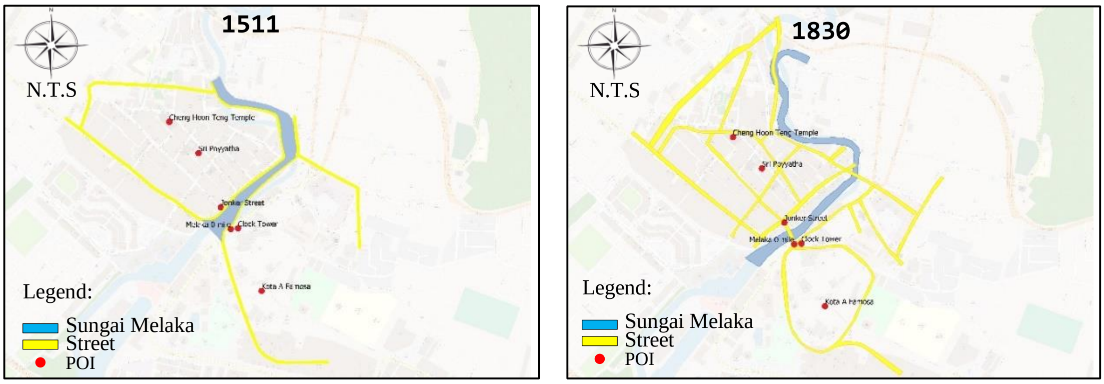
In this study, there are three phases of the era; colonial, post-colonial and modern era. This morphology phase shows the development of streets from the Sultanate of Melaka era until the present day. The settlement started along Sungai Melaka, as in Figure 4 in the year 1515, where the influx of migrants reflected the growth of the trading port. As a result, the streets began to exist, including Heeren Street, Jonker Street, Blacksmith Street, Goldsmith Street, and Temple Street, with few historical buildings such as Cheng Hoon Temple and Sri Poyyatha. In the 1990s, the streets became significant to the city as they helped people commute and drive economic and social activities. In addition, most surrounding streets are surrounded by historic and prominent cultural values (Marina & Mohd Noor, 2018). Therefore, the street network that has existed for a century adjacent to the heritage and cultural value plays a role in developing the city's morphology.

Moreover, the Malacca streets were named based on the nature of the area. As Rahman et al. (2014) mentioned, the street's character differs depending on the purpose and function of the location, physical form, and presence and including the cultural characteristics of the user. The development of Melaka city diverts to a new area in the north, such as Jalan Bunga Raya. Upon this development, the arrangement of Melaka city does not depend on the river anymore. Land reclamation took place to build new areas in Melaka. New streets and road networks were established and became the primary transportation mode rather than a river. After obtained Independence in 1957, Melaka was free from colonisation, and thus, the development of Melaka was not static and moved forward freely.

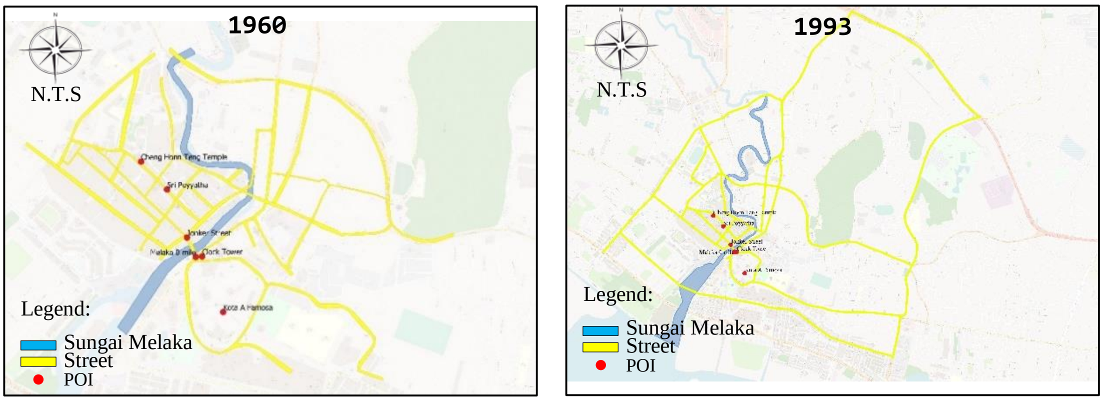
The study of the city's morph shows that historical city development conveys the shapes and identity of the city's identity. Melaka is renowned as a historical city with various aspects of heritage and cultural exchanges due to the international trading activities Align with SDG agenda; it embodies a juncture that explicitly considers natural and cultural heritage sustainability. The thin-plate spline approach shows that the current geo-referenced framework incorporates the spatial component, providing a comprehensive and sophisticated understanding of the data. It enables the interpretation of the analogue data by digitisation into vector format and classifies data attributes. This operation helps to minimise and simplified the operation queue. Moreover, the pros of this method fit the surface by distributing control ground points with exact coordinates information; for horizontal and vertical dimensions. Therefore, the surface of maps passes from the user control points and contains fewer residuals.

Furthermore, the function of Thin Plate Spline is described as distances between control points used in interpolation. Thus, the distance of control points on the elevations (historical map) of new interpolation points decrease. Therefore, a very successful solution can be achieved in the interpolation area using a thin-plate spline. In this context, urban morphology analysis can be conducted quantitative rather than rely on qualitative techniques. Therefore, primarily, historians can use GIS and remote sensing technologies to analyse a more relevant city's morphology. Besides that, digitisation and geo-referencing practices in historical projects can provide higher spatial consistency, regardless of the cost of intensive human labour (Lan & Longley, 2019). Moreover, with the advancement and enablement of technology and innovation, GIS application as a geospatial database in monitoring the city's urban process (Marina & Mohd Noor, 2014) (Mohd Noor, N., Mohd Nor, 2020) will help control the development to ensure the resilience and sustainability of a city.

COLONIAL ERA (1511-19000



POST-COLONIAL ERA (19000-2000)



MODERN ERA (2000-2015)

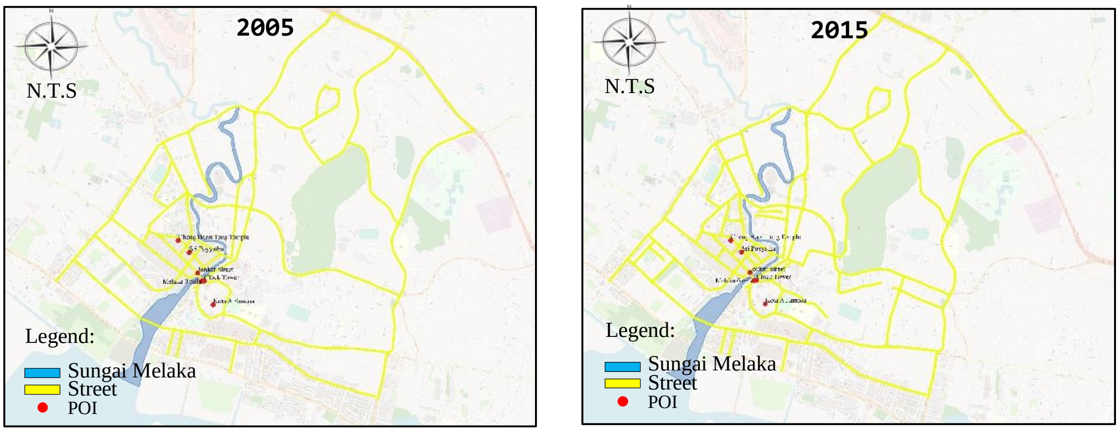


Figure 4 The digitisation of Melaka city from the historical map using QGIS. The maps were arranged according to the morphological phase; colonial era, post-colonial and modern era.

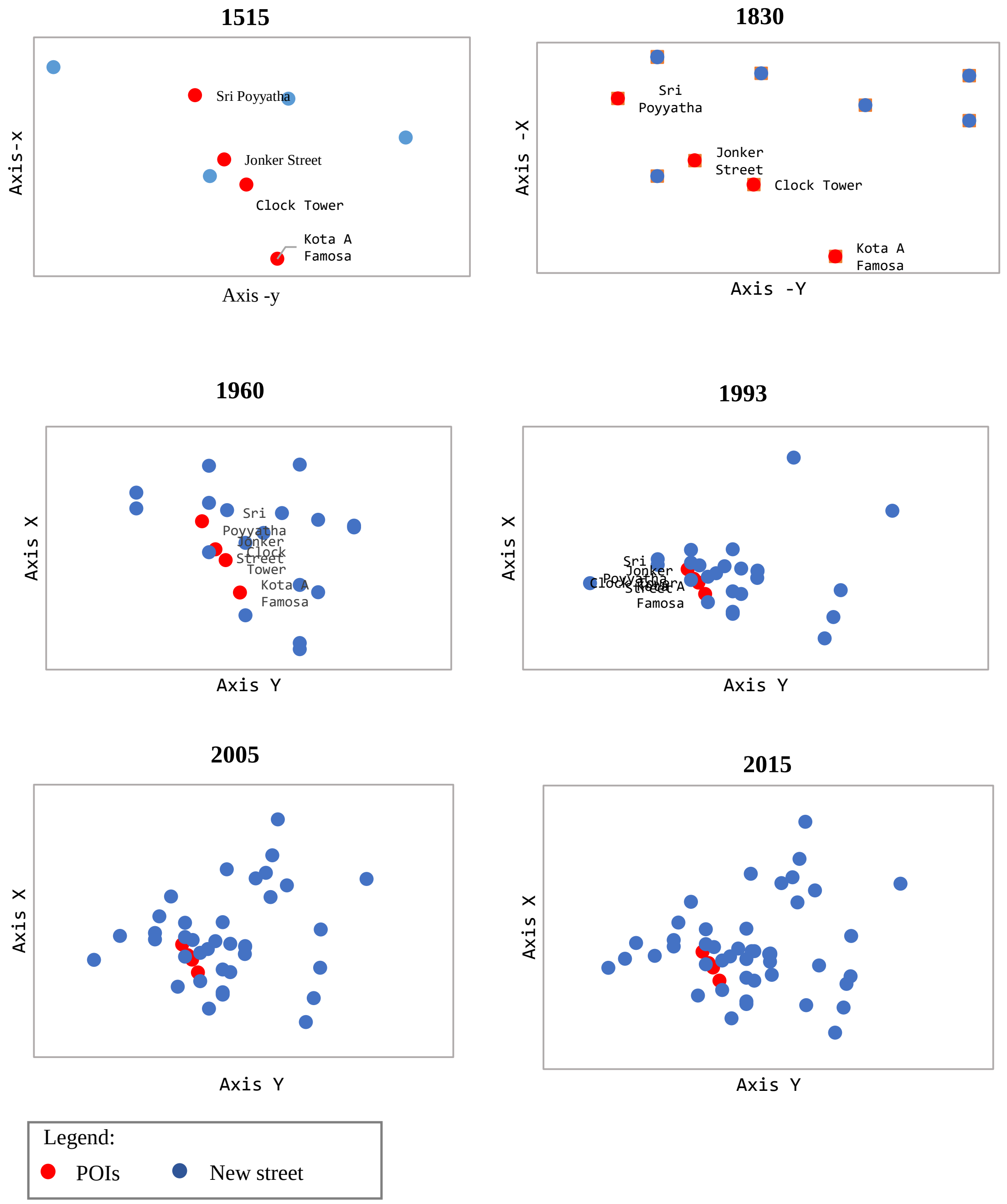


Figure 5: Spatial distribution of the street network. The constant points or POIs indicate in the red bullet; meanwhile, the blue bullet indicates the newer street that develops from time to time.

5. CONCLUSION

The advancement of geospatial technology in studying urban morphology was significant, especially in the geo-referencing process of old maps to the coordinate system. The transformation approach of geo-rectification opens more solutions and gives a new perspective of GIS capability in analysing the analogue map and converting it into a digital map. Thin plate spline can be advantageous in improving the coordinate system to improve the coordinate system on map and accuracy of the map geo-referencing. Furthermore, this method can support increasing levels of complexity and numerous information coming from different archive sources. With the appropriate technique and method, the city's morph can be examined using old maps / archived data produced for the most extended human settlement period and structured as databases. Besides, it will help in dealing with spatial problems such as urban planning and management issues. The study of historical roots is essential to evaluate the urban growth in terms of form, pattern and structure and improve the weakest area to become a more urban dynamic area.

REFERENCES

References from Journals:

Bazen, A. M., & Gerez, S. H. (2003). Fingerprint matching by thin-plate spline modelling of elastic deformations. *Pattern Recognition*, *36*(8), 1859–1867. https://doi.org/10.1016/S0031-3203(03)00036-0

Beyhan, B., & Ergenoğlu, M. (2018). Revival of the Collective Memory With the Help of Cartographic Materials and Gis. *7th International Conference on Cartography and GIS, 18-23 June 2018, Sozopol, Bulgaria*, *June*, 18–23.

Cajthaml, J. (2011). Methods of geo-referencing old maps on the example of Czech early maps. *Proceedings of the 25th International Cartographic Conference*, *January*, 1–6.

Donato, G., & Belongie, S. (2002). Approximate thin plate spline mappings. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *2352*, 21–31. https://doi.org/10.1007/3-540-47977-5_2

Forejt, M., Dolejš, M., & Raška, P. (2018). How reliable is my historical land-use reconstruction? Assessing uncertainties in old cadastral maps. *Ecological Indicators*, *94*(June), 237–245. https://doi.org/10.1016/j.ecolind.2018.06.053

Fuchs, R., Verburg, P. H., Clevers, J. G. P. W., & Herold, M. (2015). The potential of old maps and encyclopaedias for reconstructing historic European land cover/use change. *Applied Geography*, *59*, 43–55. https://doi.org/10.1016/j.apgeog.2015.02.013

Lan, & Longley. (2019). Geo-Referencing and Mapping 1901 Census Addresses for England and Wales. *ISPRS International Journal of Geo-Information*, *8*(8), 320. https://doi.org/10.3390/ijgi8080320

Marina, M. N., & Mohd Noor, N. (2014). Urban morphology analysis by remote sensing and GIS technique, case study: Georgetown, Penang. *35th Asian Conference on Remote Sensing 2014, ACRS 2014: Sensing for Reintegration of Societies*.

Marina, M. N., & Mohd Noor, N. (2018). Integrating satellite temporal analysis for urban morphology study in Melaka. *IOP Conference Series: Earth and Environmental Science*, *169*(1). https://doi.org/10.1088/1755-1315/169/1/012028

Mohd Noor, N., Mohd Nor, M. (2020). Geospatial Technology and Innovation Enablement for Physical Planning.Space and Process. *International Congress of Architecture and Planning (ICONARCH IV)*, 77–86.

Rohr, K., Stiehl, H. S., Sprengel, R., Buzug, T. M., Weese, J., & Kuhn, M. H., 2001. Landmark-based elastic registration using approximating thin-plate splines. *IEEE Transactions on Medical Imaging*, *20*(6), 526–534. https://doi.org/10.1109/42.929618

Wood, S. N., 2003. Thin plate regression splines. *Journal of the Royal Statistical Society. Series B: Statistical Methodology*, *65*(1), 95–114. https://doi.org/10.1111/1467-9868.00374

References from websites:

MicroImages, 2013. Reproject Using Thin Plate Spline Model, Retrieved September 15, 2020, from https://www.microimages.com/