

A MOBILE GIS APPLICATION FOR HEAVILY RESOURCE-CONSTRAINED DEVICES

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ABSTRACT

GIS applications for mobile devices are becoming increasingly popular, utilizing a diverse range of devices. Many of these devices suffer from serious constraints in three main areas: processor speed, memory space, and screen size. This paper presents a GIS application, called “MacauMap”, that is intended for heavily resource-constrained handheld devices. MacauMap is a tourism-oriented map application of the Macau territory for PalmOS and Pocket PC personal digital assistants. It was designed to perform satisfactorily on devices with as little as 16 MHz processor speed, and requires only 500 KB available memory for the GIS application and all GIS data. Memory requirements are kept low through a specially designed data format. The main challenge of satisfactory map drawing speed is addressed through a variety of techniques that were developed for this application. The paper describes the application’s data format, outlines the map drawing techniques, and points to areas for future development.

KEYWORDS: personal digital assistant, mobile GIS, map drawing, GPS.

1 INTRODUCTION

GIS applications are software applications that process large amounts of geospatial data, involving heavy computations. Traditionally, these applications have resided on high-performance workstations and servers equipped with the necessary resources: large amounts of primary and secondary memory, fast CPUs and graphics processors, and large screens for displaying the data.

The recent decade, however, has seen a move of GIS applications onto smaller platforms, including mobile platforms such as personal digital assistants (PDAs). These platforms offer a number of attractive features, primary among which is their extreme mobility: because of its small size, a PDA can be carried and used practically anywhere.

Driven by the need to promote tourism in the Macau territory, the development of a tourist-oriented mobile GIS application was initiated. Since the Macau government declared Macau as a ‘city of tourism’ in 1961 (Maruya 1999), the tourism industry in the territory has experienced a rapid and continuous growth, becoming the leading economic sector in Macau (Chan 2000). In 2001, around 10 million visitor arrivals to the territory

were recorded (Direcção dos Serviços de Estatística e Censos 2001), the majority of whom came to Macau for holiday purposes. Given this background, the promotion and continuous development of tourism is an important issue for the local economy.

The Macau territory is a place with unique characteristics: it consists of the Macau peninsula and two islands, Taipa and Coloane, which have recently been merged into one through land reclamation. The total land area measures only approximately 25 square kilometres, while it has a population of about 450,000. This makes it one of the most densely populated places in the world. The consequence is that most of Macau, and particularly Macau peninsula, is fully and densely covered with buildings and streets.

To provide information about the Macau territory to tourists, a mobile GIS application, designated “MacauMap”, was developed at the University of Macau between 2001 and 2003, while development of improvements as well as versions on different platforms continues now and into the future. The main objectives of MacauMap are:

1. To provide basic geographic information about the Macau territory, such as coastal outlines and the network of streets.
2. To provide information about places that are of interest to tourists.
3. To provide information about public transport facilities in Macau.
4. To provide information about hotels and restaurants in Macau.

The aim of MacauMap can thus be summarized as facilitating and thereby making more enjoyable the stay of tourists in the Macau territory. However, it was also realized that local residents would have use for a GIS application like MacauMap, and from the outset this was considered in its development.

The rest of the paper is structured as follows: Section 2 presents an overview of the functions provided by the MacauMap application. This is followed in Section 3 with a description of important design considerations in the development of MacauMap. Finally, conclusions are presented in Section 4.

2 OVERVIEW OF MACAUMAP

MacauMap is a PDA-based tourism-oriented GIS application. Two versions exist, one for PDAs running PalmOS, the other one for PDAs running the Pocket PC operating system, thereby covering approximately 75% of the PDA market. Both versions are practically identical in function and differ only slightly in their user interface due to platform dependencies. All screenshots shown in this paper are of the PalmOS version of MacauMap.

The MacauMap user interface is shown in Figure 1. It consists of a map display area that occupies the majority of the screen, and a toolbar for accessing frequently used functions located at the bottom of the screen. Buttons in the toolbar allow the user to manipulate the map, traverse the navigation history, and to locate information. The main functions are listed below:

1. *Map manipulation*: zooming in/out, panning, navigation history (previous/next map view).
2. *Search*: searching for streets or places and displaying their location on the map.

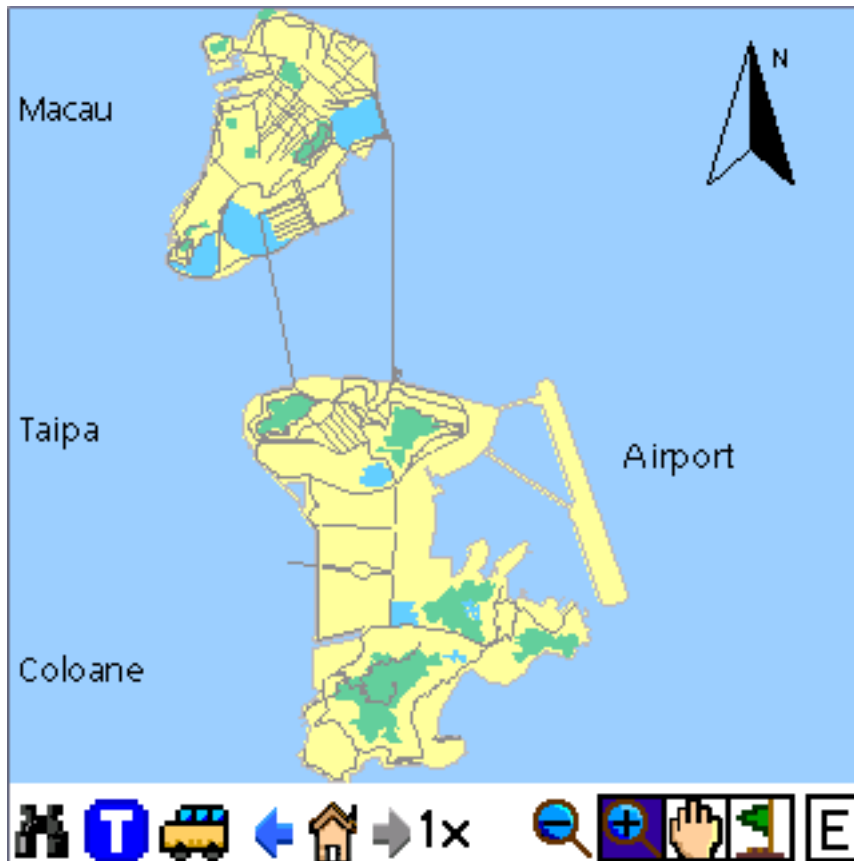
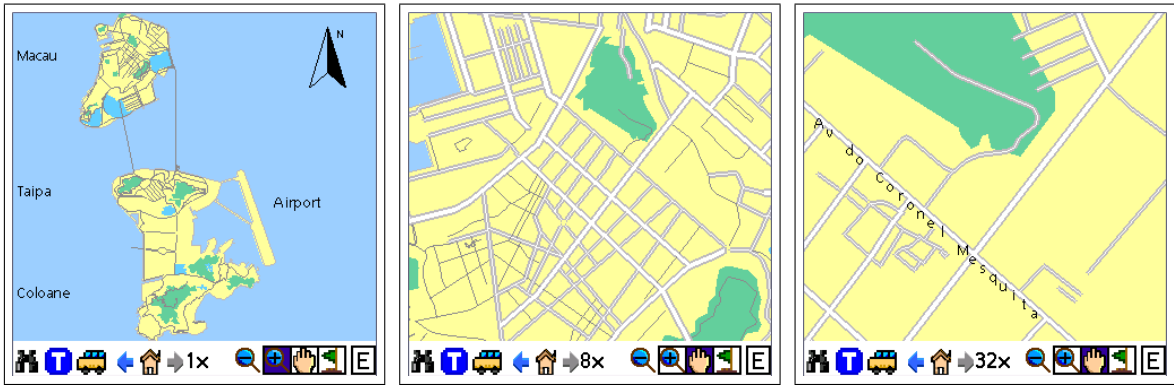


Figure 1: MacauMap user interface showing a map at 1x zoom level

3. *Bilingual information*: switching of language of text labels in the map between English and Chinese.
4. *GPS*: display of the user's current location using a reading obtained from a connected GPS device.
5. *Bus information*: browsing of public bus information, and bus guide for calculating an optimal bus route from a starting bus stop to a destination bus stop.
6. *Sightseeing guide*: providing information about museums, churches, temples, and other places of interest, as well as their location on the map.
7. *Hotel and restaurant guide*: providing a choice of restaurants and hotels matching criteria of location, class and style, and displaying the location of selected hotels and restaurants on the map.

Some of the main functions are illustrated in the following figures. Map zooming is shown in Figure 2. Figure 3 shows the bus routing function, where MacauMap finds the optimal route from the bus stop "Terminal Maritimo" to the bus stop "Almeida Ribeiro". The switching of the language with which information in the map is displayed is illustrated in Figure 4.

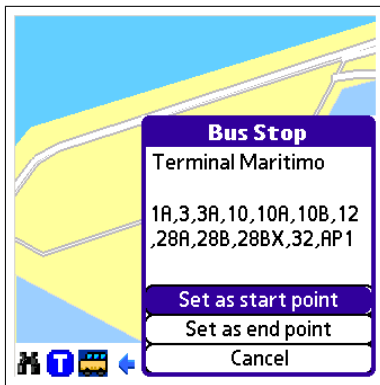


(a) 1x zoom level

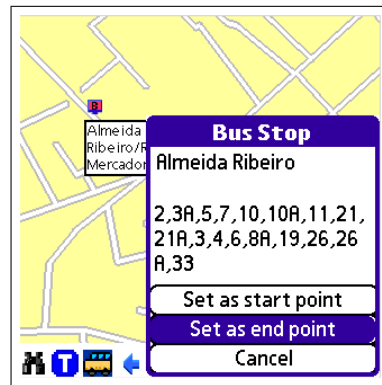
(b) 8x zoom level

(c) 32x zoom level

Figure 2: Zooming into a map



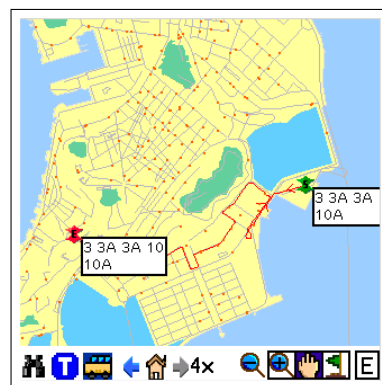
(a) Setting a starting bus stop



(b) Setting a destination bus stop



(c) Setting search options



(d) Display of the shortest route

Figure 3: Finding the shortest bus route from a given start to a given end bus stop

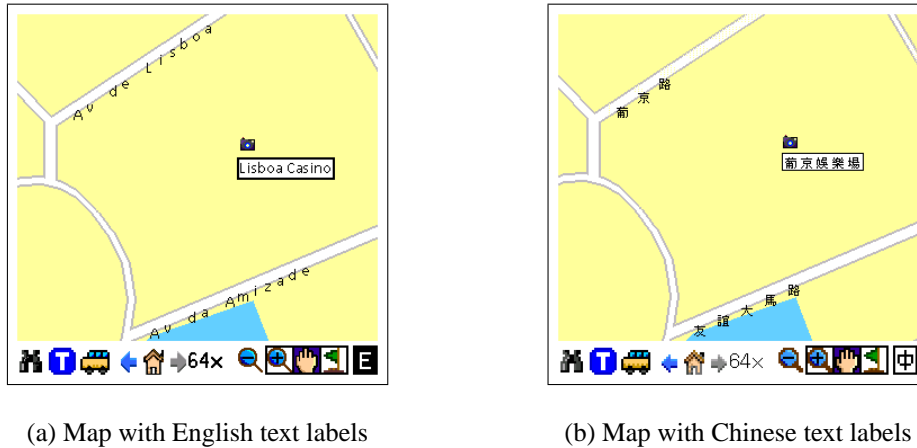


Figure 4: Switching the language of text labels in the map

3 DESIGN CONSIDERATIONS

MacauMap runs on a computing platform which has serious limitations, when compared to desktop GIS workstations: the main limitations are the slow processor speed, the small memory, and the small screen. For example, MacauMap was designed to perform satisfactorily on any PalmOS device operating under at least PalmOS v3.5. This includes devices that have a main processor running at a clock speed of only 16 MHz, with memory (both primary and secondary memory combined) of only 2 MB, and a screen measuring less than 3 inches diagonally. To achieve satisfactory performance on such a heavily resource-constrained device requires careful design, which is elaborated on in this section.

When developing MacauMap, certain performance targets were defined: for the majority of map views, map operations should complete within one second, with only a small number of map views allowed to take up to two seconds. The latter are those maps consisting of particularly many objects, which is generally only the case for maps at the zoom levels between 1x and 4x (where the 1x zoom level shows the entire map of Macau, Taipa and Coloane).

Achieving these performance goals necessitated certain sacrifices in terms of map detail and functionality, as compared to desktop GIS applications. These are discussed in the following subsections.

3.1 Data Format

Data used by the MacauMap application was provided by two departments of the Macau S.A.R. government: basic map data, including information on street centrelines, coastal outlines, green areas, lakes, and places of interest, were provided by the Cartography and Cadastre Bureau; these were in ESRI Shapefile format (ESRI 1998). Bus route data were provided by the Lands, Public Works and Transportation Bureau; these were in AutoCAD format.

Given that the source data was partly in ESRI Shapefile and partly in AutoCAD formats, two challenges existed: firstly, how to use data in two different data formats; and secondly, how to reduce its size. The ESRI Shapefiles of the basic map data have a combined size of around 1.5 MB, while the AutoCAD files of the bus route data measure about 30 MB. The target platform, however, and in particular older PalmOS PDAs, has only a

small amount of memory available, as little as 2 MB of memory. Because of the organization of memory on PDAs, this amount of memory is used as both primary (i.e. working) and secondary (i.e. storage) memory. It has to accommodate the operating system and all user applications, while leaving enough available memory for running applications.

Moreover, the original source data was designed for use on a desktop workstation with a large screen, and does therefore contain a high level of detail. The screen of a PDA, however, is comparatively much smaller, which makes it impossible to display the same amount of data in any legible form. As an illustration, Figure 5 shows a map of Macau peninsula as viewed in a desktop workstation through the ArcView GIS application. This map contains a great amount of detail. On the other hand, the map display that is required on the PDA needs to be much simpler, as in the images of actual MacauMap screens shown in Figure 6 (two images are shown, one taken from an older low-resolution black-and-white Palm device, the other from a newer higher-resolution colour Palm device).

The first step to tackle these two challenges was to manually convert the bus route information to ESRI shapefile format. This solved the problem of having to deal with different data formats. It also greatly reduced the data size, from nearly 30 MB to under 200 KB, a reduction by a factor of 150. This was possible by omitting much of the information contained in the AutoCAD files, such as street layout and building information.

However, even after converting the AutoCAD data files to ESRI Shapefile format, it was still evident that the data size was too large, measuring about 1.7 MB. A further reduction in the data's size was achieved by map data generalization. This had the advantage of simplifying the map data for drawing (benefiting the performance of map drawing, discussed in the following subsection), while simultaneously resulting in a reduction in size. The generalized map data measured only about 1.4 MB.

The generalized map data, however, was still too large to fit on PDAs with small amounts of memory, therefore it was decided to create a custom data format for the MacauMap application which would only consist of the essential data elements. A conversion program was developed to convert from ESRI Shapefile format to MacauMap data format. The conversion process is illustrated in Figure 7. The conversion produces a PalmOS database file, which is a simple record database for storing data for a PalmOS application. Internally, records in the database are structured according to the MacauMap data format. This format separates different data elements into separate records which are cross-linked through pointers. The result is efficient data storage as well as efficient data access.

An example of this is shown in Figure 8 for road centreline data. The road centreline data is divided into seven separate records, to allow for the most efficient data access. The records contain the following data:

1. Record 0: Count of the total number of road centrelines.
2. Record 1: Road centreline index; this records a number of attributes of a road, such as its bounding area, length, offsets to other parts of the road data contained in other records, number of segments, number of points, and the road's width level used for determining how wide to draw the road in the map.
3. Record 2: Road name data; the names of all roads are recorded, in English and Chinese, as null-terminated strings. The starting offset of a given road's English or Chinese name is recorded in record 1.

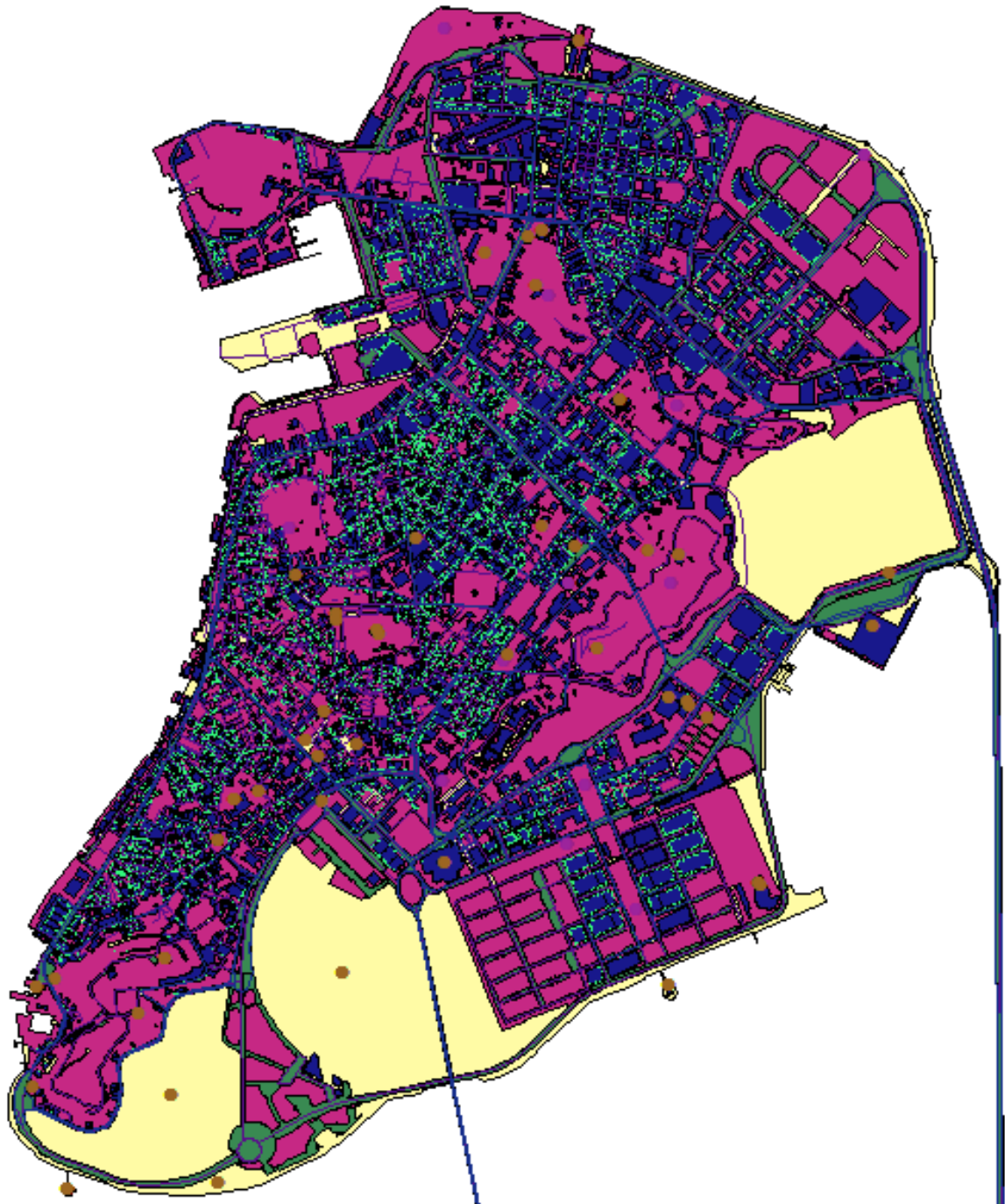


Figure 5: Map of Macau peninsula in ArcView GIS application on a desktop workstation



(a) Black-and-white map display, resolution 160 x 160 pixels, on a Palm Vx device



(b) Colour map display, resolution 320 x 320 pixels, on a Palm Tungsten T device

Figure 6: Map of Macau peninsula on black-and-white and colour PDAs

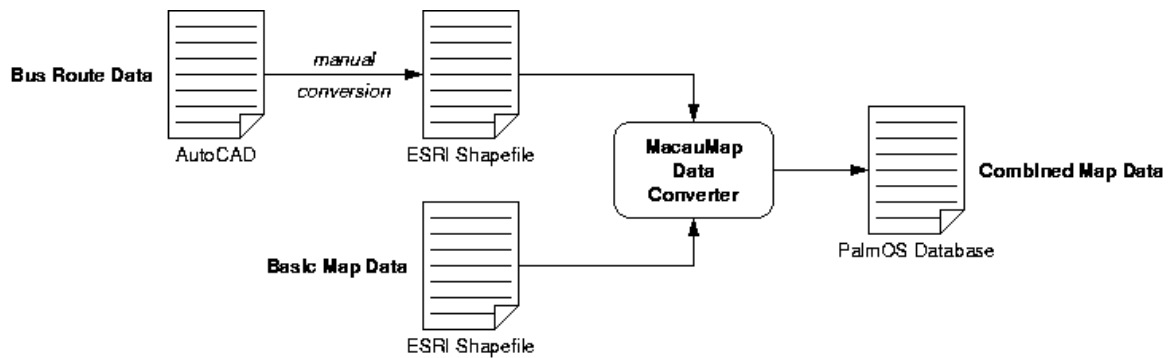


Figure 7: MacauMap data conversion process

Record 0: Number of Road Centrelines

1168

Record 1: Road Centreline Index

minX	minY	maxX	maxY	streetLength	engStrOffset	chiStrOffset	pointOffset	slopeOffset	numSlope	level	numPoints	...
1074645665	144663484	1243295721	296195506	1000	200	220	20	19	3	1	4	...

Record 2: Road Name Data

T r a v d a R e p u b l i c a \0	...
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Record 3: Road Centreline Coordinates

X	Y	X	Y	X	Y	X	Y	...
556644778	123456789	846287464	956374850	936472637	930478274	456294505	782374930	...

Record 4: English Road Name Index

637	25	146	5	963	67	734	9	...
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Record 5: Chinese Road Name Index

18	409	95	563	176	3	290	367	...
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Record 6: Slope Index

V	H	H	V	H	H	V	H	V	V	H	H	...
---	---	---	---	---	---	---	---	---	---	---	---	-----

Figure 8: MacauMap road centreline data structures

- Record 3: Road centreline coordinates; x/y coordinates of all road centrelines are recorded. For adjacent road segments, only one set of coordinates is recorded in order to save storage space. The starting offset of a given road's first coordinate is recorded in record 1, which also records the number of points in the polyline representing the road.
- Record 4: English road name index; stores an index number for each road, arranged in alphabetical order of the road's English name. The index is used to locate the road's centreline index in record 1, from where the road's name can be obtained by following the offset into record 2 that is recorded there.
- Record 5: Chinese road name index; stores an index number for each road, arranged in order of the road's Chinese name's internal code (Big5 code). The index is used to locate the road's centreline index in record 1, from where the road's name can be obtained by following the offset into record 2 that is recorded there.
- Record 6: Slope index; each road segment is drawn in the map at a certain slope. In order to simplify map drawing, the slope is pre-calculated and classified as a horizontal (between -1 and 1) or vertical (less than -1 or more than 1) slope. The slope is stored in this record to avoid the slope calculation to have to be performed on the device at runtime.

The structure chosen is somewhat more complex than a simple sequence of records, each containing all data related to a given road, would have been. However, this structure has the advantage that road data can be quickly located using an index of the road, as each road's set of data in record 1 is of the same length. This is utilized, for instance, for the indexing of the English and Chinese road names.

Other data, such as those related to bus routes, coastal outlines, green areas, lakes, etc. is structured in a similar fashion. The resulting data is stored in an efficient format that

only occupies a total of 250 KB, while at the same time facilitating efficient processing. The MacauMap application measures an additional 250 KB, for a total memory consumption of application and data of only 500 KB.

3.2 Map Drawing

The major design challenge in the development of MacauMap was achieving satisfactory performance. As data retrieval could be performed efficiently, thanks to the data structures employed which were discussed above, the major remaining performance bottleneck was map drawing. Initial prototypes required up to ten seconds for drawing a map. As mentioned earlier, performance targets of 1–2 seconds had been set, so it was essential to bring map drawing time down.

The main reason for the slowness of map drawing is the large number of objects (points and lines) that need to be drawn on the screen. All maps are drawn as vector graphics, therefore the coordinates for each screen object need to be calculated for each map view. The PalmOS API is extremely simple and has no provision for advanced graphics beyond drawing points and lines. For instance, there is no flood fill API function. Therefore nearly all graphics functions had to be implemented in MacauMap.

A number of steps were taken to improve map drawing performance:

1. *Filtering*: Macau has a total of 1188 streets in an area of just 25 square kilometres. Many of these streets are tightly packed together in a small area. Therefore, some areas appear cluttered on the screen, particularly at low zoom levels. To overcome this problem, *filtering* is applied to eliminate small streets from the map view at low zoom levels. To make this possible, a “street level” field is saved along with the data for each street to indicate whether it is a major, intermediate, or minor street. At different zoom levels, only some groups of streets are shown, e.g. only major, or only major and intermediate streets. This has the desirable effect of reducing the number of lines that need to be drawn on the screen, and thus improving map drawing performance.
2. *Converting map data to integer*: The original source map data stored map coordinates as real numbers. However, calculations involving real numbers are slow, and this is particularly noticeable on a computing device with heavily constrained computing resources such as older Palm PDAs. For this reason, all map coordinates were converted to integer, and all calculations involving these coordinates were carried out as integer calculations. However, because calculations such as integer division involve some loss of accuracy because of the rounding that takes place on the result, the map coordinates of the source data were first converted to large integers, in this case 32-bit integers, so that the loss of accuracy involved in the calculation of these numbers would be insignificant. In this way, a performance improvement of about 100% was achieved.
3. *Different map display modes*: To accommodate the large variety of PDAs with different performance characteristics, MacauMap allows the user to control the amount of detail displayed in the map. This is done by offering three different *map display modes*: (1) Simple map display, with streets represented by centre line only; (2) Intermediate-detail map display, with streets represented by centre line, and filling of map background with different colours for land, sea, parks, etc.; (3) Detailed map display, with streets drawn with left and right border, and filling of map background with different colours. Each of these display modes requires a different number of objects to be

drawn, with the simple map display requiring the fewest and the detailed map display requiring the most objects. Different users may choose the amount of detail they desire: those with a slow device may choose a simple map display, whereas those with a faster device may choose the detailed map display to get a better-quality map.

Through the above means, map drawing performance was greatly improved, so that now even older devices are able to achieve the map drawing performance targets of 1–2 seconds.

4 CONCLUSIONS

This paper has outlined the development of the MacauMap mobile GIS application. The development of the first version of MacauMap was completed in May 2003, at which time it was released to the public. In July 2003 a second version corresponding to the one reported on in this paper was released to the public. MacauMap is presently available for free download from the Macau Government Tourist Office's website at www.macautourism.gov.mo. In the first three months since its public release, some 15,000 copies of MacauMap were downloaded. Of these, approximately two thirds were of the PalmOS version, with the remainder being of the Pocket PC version. MacauMap has proven to be popular with both tourists and local residents alike, and comments received from tourists using MacauMap indicate that it has been of value in their visit to Macau.

At present, the development of versions of MacauMap on different platforms are underway. One of these is of a mobile phone version of MacauMap, to run under J2ME (Java 2 Mobile Edition), as well as a version for Symbian mobile phones. Given that these devices are even more heavily constrained than PDAs, in terms of memory and computing resources as well as screen size, the development of efficient storage and map drawing techniques is crucial. Moreover, given the much more primitive forms of user input possible on mobile phones, the design of the user interface to achieve acceptable usability will be a challenge.

Another version of MacauMap that is being planned is a web-based version. This will be of benefit to those who do not possess a PDA or a mobile phone capable of having software installed into. It also has the advantage of not being as heavily resource-constrained as PDAs, while allowing a much larger map display.

Given the current developments, we anticipate that in future significantly more tourists and Macau residents will be able to benefit from the availability of MacauMap.

ACKNOWLEDGMENTS

The work reported on in this paper was supported by the Research Committee of the University of Macau. The support is gratefully acknowledged. Special thanks are due to Kass Ian, José Choi, Victor Lam, Samuel Chiu, Henry Lam, and Anthony Lam, whose hard work and determination have helped make MacauMap a reality.

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