Chapter 11
A Web-Based GIS for Crime Mapping and Decision Support

Guiyun Zhou, Jiayuan Lin, and Xiujun Ma

Abstract Timely mapping of crime locations and accurate detection of spatial concentrations of crime help to identify where crimes concentrate in space and time and thus provide important information for crime reduction efforts of law enforcement. The main objective of this chapter is to design and implement a Web-based GIS for crime mapping and decision support. The prototype system allows users to detect and view crime hotspots in a Web environment in the form of thematic layers overlaid on background data. Four hotspot mapping techniques, i.e., choropleth mapping, grid mapping, spatial ellipse mapping, and kernel density mapping, are implemented. The system can be used for mapping crime hotspots, predicting the locations of future crime, and optimizing crime reduction efforts. It is a rich Internet application and is much more efficient than script-based clients in hotspot detection, map manipulation, and rendering. It is entirely based on open-source software, making it affordable for many small- and medium-sized police departments in developing countries. Results from the prototype development demonstrate that for a Web-based crime mapping and decision support system, rich Internet application technology in combination with open-source software is an effective solution in terms of both system performance and financial cost.

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11.1 Introduction

Crime has an inherent geographic component, and the locations of crime are not randomly distributed (Phillips and Lee 2011). Many police departments map crime data as a part of their routine strategic and tactical activities (Levine 2006). Optimizing the spatial and temporal allocation of law enforcement resources can contribute significantly to crime reduction and prevention. Timely mapping of crime locations and accurate detection of spatial concentrations or clusters of crime help to identify where crime tends to concentrate in space and time and thus provide important information for law enforcement resource allocation. Crime mapping can be used for responding to incidents, generating intelligence products, reassurance policing, performance monitoring, and information sharing and partnership working (Chainey and Ratcliffe 2005; Home Office 2005). Much of a crime mapping effort is devoted to the identification of crime hotspots. The areas of concentrations or clusters of crime are referred to as hotspots. Hotspots are scale-dependent (Wu and Grubesic 2010). Various hotspot mapping techniques such as choropleth mapping and kernel density mapping are available to provide different insights into the spatial patterns of crime occurrences. Hotspots are of particular interests to law enforcement agencies since they can be used to help predict the locations of future crime and to optimize crime reduction efforts (Chainey et al. 2008).

Various software products are available for crime mapping and analysis, and a selected list of them is given in Table 11.1. Among them, ArcGIS for Desktop Basic, previously called ArcView, is a generic GIS software whereas other products are mainly developed for dedicated purposes such as spatial modeling and crime mapping. Many commonly used crime mapping tools such as CrimeStat, ArcView, and GeoDa (Eck et al. 2005) are desktop applications. A Web-based system offers many advantages over desktop applications. The availability of a Web-based crime mapping and decision support system helps law enforcement agencies to conduct timely crime mapping and hotspot detection and to facilitate decision support in a crime crackdown. It delivers mapping tools to a wide range of police staff more easily and faster. It ensures that the most up-to-date crime data are used for mapping and analysis by accessing a centralized and regularly updated crime database. A Web-based system can easily be integrated with other police systems such as command and control centers for responding to incidents much more efficiently. Some Web-based crime mapping systems are available to the public. The website operated by the British government utilizes Google Maps and offers public access to monthly updated street level crime data in England and Wales (Police UK 2013). All crime incidents reported to the police are expected to be shown on the website. The Omega Group has a Web-based product which can be used through a police department's intranet. A version of the product is up and running on the Internet, helping law

Table 11.1 Selected applications used for crime mapping and analysis

Software	URL	Application type	Based on commercial products?	Functionalities
CrimeStat	http://www.icpsr.umich.edu/CrimeStat/	Desktop	No	Spatial distribution, hotspot analysis, interpolation statistics
GeoDa	http://geodacenter.asu.edu/	Desktop	No	Statistical graphics, spatial autocorrelation, spatial regression
ArcGIS for Desktop Basic[a]	http://www.esri.com/software/arcgis/arcgis-for-desktop	Desktop	Yes	Choropleth mapping, density mapping
Hotspot Detective	http://jratcliffe.net/hsd/	Desktop plug-in	Yes, MapInfo	Hotspot surface mapping, timeline graphs, repeat location finder
Police, UK	http://www.police.uk	Web	Yes, Google Maps	Crime location mapping
CrimeMapping	http://www.crimemapping.com/	Web	Yes, ArcGIS Server	Crime location mapping, trend report
CrimeReports	https://www.crimereports.com/	Web	Yes, Google Maps	Crime location mapping
Oakland Crimespotting	http://oakland.crimespotting.org/	Web	Unknown	Crime location mapping
WebCAT	http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1242424	Web	No	Kernel density mapping, choropleth mapping

[a]ArcGIS for Desktop Basic is the new name given by ESRI. Previously it was called ArcView

enforcement agencies throughout North America to provide the public with valuable information about recent crime activities in their neighborhoods (Crime Mapping 2013). The application is based on ESRI mapping engine and maps crime locations based on their types. CrimeReports runs a similar crime mapping service as the Omega Group on the Internet, with crime data coverage extended outside North America (CrimeReports 2013). Its mapping service is based on Google Maps. Oakland Crimespotting is an interactive map of crimes in Oakland and a tool for mapping crime locations (Oakland Crimespotting 2013). Its client side is based on Adobe Flash, a rich Internet application technology that will be discussed in more detail in the latter part of the chapter. WebCAT is a Web-based crime analysis toolkit available to all Virginia crime agencies (Hawkins et al. 2003; Calhoun et al. 2008). It uses open-source MapServer as its GIS Web server (MapServer 2013). In terms of crime mapping, it implements choropleth mapping and kernel density mapping functionalities on the server side.

Law enforcement agencies generally require a Web-based mapping application on their intranets, which makes public mapping services such as Google Maps unavailable. Compared with the development and maintaining costs of crime mapping applications, commercial Web-based mapping products such as ArcGIS Server are generally expensive and add to total financial costs significantly, which makes their wide use impractical for many small- and medium-sized police departments, particularly in developing countries. In addition, most current Web-based GIS applications for crime mapping primarily use JavaScript-based technology for rendering point, line, or polygon dynamic data on the client side, which is efficient only when the amount of dynamic data is limited, as is often the case with public mapping services on the Internet. However, for crime hotspot mapping the amount of dynamic data is relatively large, which may comprise hundreds or thousands of polygons. In order to effectively process these dynamic data on the client side, the client side will need to use rich Internet applications (RIAs). An RIA is a Web-based application that has the typical characteristics of desktop applications. Platforms that support RIAs include Adobe Flash, Microsoft SilverLight, and JavaFX. RIAs can shift a large part of processing burdens from the server to the client, allowing the server to provide services to more clients. RIAs provide efficient client-side rendering mechanisms that can present responsive and graphically rich user interfaces, lowering the amount of traffic between the client and the server, as compared to the HTML-based client–server architecture (O'Rourke 2004; Li et al. 2011). For a Web-based GIS for crime mapping and decision support, RIAs can implement computation-intensive algorithms on the client side and present the mapping output in an efficient and responsive way, allowing the Web system to respond to more user requests very quickly.

This chapter aims to present the design and implementation of a Web-based GIS for efficient crime mapping and decision support, which is based on open-source software and rich Internet client. The remainder of the chapter is organized as follows. The next section reviews some commonly used hotspot mapping techniques. Section 11.3 gives an overview of Web-based GIS techniques and compares the performances of various techniques for client side rendering of geospatial data. The architecture and development of a prototype system of the Web-based crime mapping and decision support system is introduced in Sect. 11.4. Section 11.5 presents some example application results of the system. Section 11.6 concludes the chapter with a discussion on future improvements.

11.2 Hotspot Mapping Methods

Many researchers have reviewed crime hotspot mapping techniques (Eck et al. 2005; Chainey et al. 2008). In this section, we give a review of four hotspot mapping techniques commonly used by law enforcement agencies and researchers. Figure 11.1 shows some commonly used methods for crime hotspot mapping.

11.2.1 Choropleth Mapping

Choropleth mapping techniques are widely used to represent spatial distributions of geographic phenomena, and it is no exception with crime data (Harries 1999; Home Office 2005). To create a choropleth map, the study area is divided into various geographic areal units, and each areal unit is shaded based on the number of crimes committed within it. The commonly used geographic areal units for crime mapping are administrative regions and police districts such as census tracts and police precincts. Areal units are classified based on its crime count using a classification scheme such as equal interval and natural breaks (Dent et al. 2008) and shaded using a coloring scheme. Choropleth maps help to identify areal units of high crime concentration and can be used to detect areal units of abnormal changes in crime occurrences by mapping the difference in crime counts of comparable time periods. Figure 11.2 shows the flowchart to generate a choropleth crime map, and an example of choropleth maps for crime mapping is shown in Fig. 11.1b.

11.2.2 Grid Mapping

One salient problem with choropleth maps for crime mapping is the varying sizes and shapes of the geographic areal units. In order to overcome this problem, equally sized grids can be generated across the study area and be shaded depending on the number of crimes falling within each of them (Bowers et al. 2001; LeBeau 2001). The uniform size of grids facilitates the identification and comparison of hotspots. The main issue with grid mapping is the determination of grid sizes. In addition, grid mapping output is often not aesthetically appealing. An example of grid thematic maps is shown in Fig. 11.1c.

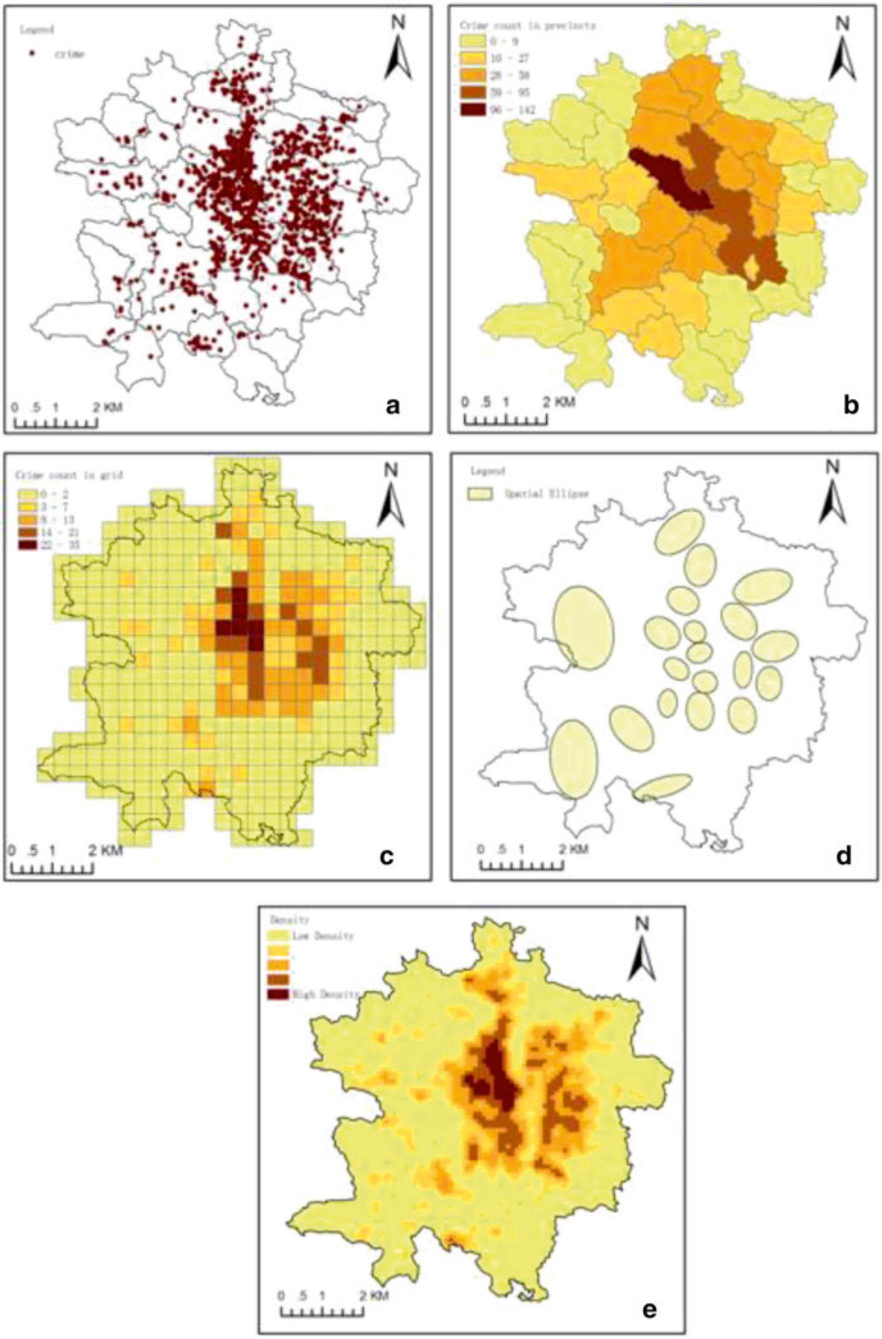

Fig. 11.1 Common crime mapping techniques: (**a**) discrete point mapping, (**b**) choropleth mapping, (**c**) grid thematic mapping, (**d**) spatial ellipse mapping, and (**e**) kernel density mapping

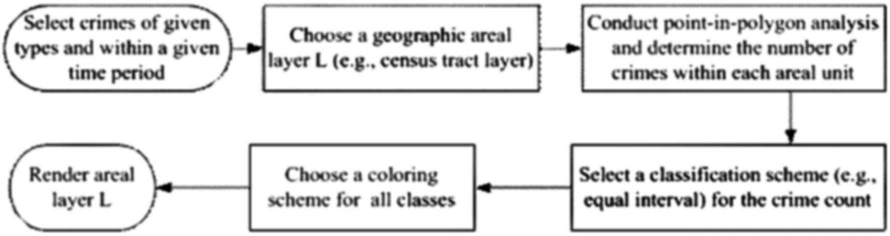

Fig. 11.2 Flowchart of choropleth crime mapping

11.2.3 Spatial Ellipses

In this hotspot mapping method, points are grouped into clusters based on their proximity and a standard deviational ellipse is fitted to each cluster to indicate the dispersion of crime points in the cluster through the ellipse's size and alignment (Cromley 1992). Figure 11.1d shows an example of spatial ellipse maps.

The K-means clustering algorithm is one of the most commonly used clustering methods for generating spatial ellipse maps (Levine 2010). Users specify the number of clusters to be grouped and a separation value between initial seed locations. The algorithm makes initial estimates of seed locations for a specified number of clusters, assigns each crime to its nearest seed, recalculates a new seed for each cluster, and repeats the procedure. The procedure stops when there are no or few changes to each cluster.

The derivation of spatial ellipses depends only on the spatial positions of crimes in a cluster and does not rely on geographic boundaries, as is the case with choropleth mapping and grid mapping (Martin et al. 1998).

11.2.4 Kernel Density Mapping

Kernel density is probably the most commonly used hotspot mapping technique for visualizing hotspots and has higher prediction abilities than other techniques (Chainey et al. 2008; Levine 2010). Its popularity is partly due to its ability to produce aesthetically appealing maps. The flowchart to create a kernel density surface is shown in Fig. 11.3. To create a kernel density map, a grid is generated to cover the study area, then a kernel function is centered on each crime point, and density values are calculated for each grid cell by aggregating contributions from all crimes. Two commonly used kernel functions are normal distribution function and triangular function.

For kernel functions, the bandwidth and grid dimensions (or grid cell size) are specified by the users. For novice users, guidelines exist for choosing the bandwidth and grid dimensions (Williamson et al. 1999; Eck et al. 2005). For experienced users, changing these parameters allows them to investigate the spatial effects of these parameters on the density patterns.

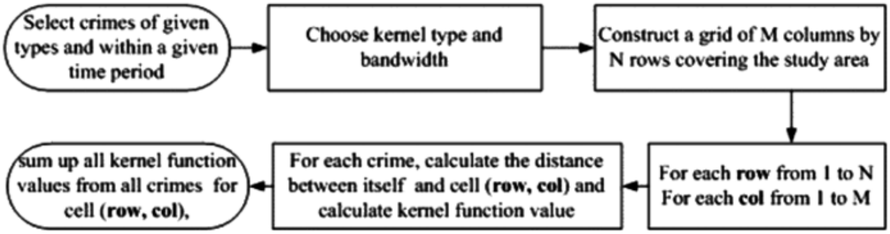

Fig. 11.3 Flowchart to construct a kernel density surface

The resulting density surface represents the point density of crime in the study area and can be rendered using some classification and coloring schemes, as with choropleth mapping and grid mapping. An example of kernel density map is presented in Fig. 11.1e. Examples demonstrating the use of kernel density mapping techniques can be found in the work of many researchers and governmental reports (Chainey and Ratcliffe 2005; Eck et al. 2005).

11.3 Web-Based GIS Techniques

11.3.1 An Overview of Web-Based GIS Techniques

Depending on the requirements of individual systems, different architectures of Web-based GIS have been presented in the literature. Many early Web GIS systems are based on the widely used commercial product ESRI ArcIMS (Su et al. 2000; Chang and Park 2004; Sugumaran et al. 2004; Tsou 2004; Kontoes et al. 2005; Rao et al. 2007), and some are based on open-source platforms such as MapServer and GeoServer (Tuama and Hamre 2007; Kruger et al. 2007). These systems, which are usually implemented in Dynamic HyperText Markup Language (DHTML) and have limited interactive capabilities, deliver dynamically generated maps to the clients. Generating maps dynamically on the server posts a huge load demand, resulting in long response time and limited number of concurrent requests. Using cached tiles or pre-generated tiles has become a common practice to improve system response in various public mapping services such as Google Maps and Microsoft Bing Maps. Intranet applications have also started adopting such techniques (Kulawiak et al. 2010), and open-source script-based libraries such as OpenLayers provide efficient tile rendering mechanisms. Caching or pre-generating tiles is a technique appropriate for background maps and images which do not need frequent updates, and other more dynamic data such as points and lines are rendered on the client using DHTML techniques. DHTML is suitable for rendering limited amount of data, which is usually the case in public mapping services. We have been developing Web GIS applications for crime mapping for nearly a decade for many municipal police departments across China, and the applications have followed similar technological routes as described above.

The above described architectures use thin-client script-based technology, which rely heavily on the server for processing and do not take advantage fully of client-side computing capabilities. To overcome this problem, in early systems, rich clients use technologies such as Java Applet or custom-made browser plug-ins (Al-Sabhan et al. 2003). Custom-made browser plug-ins are rarely used in today's applications because of such issues as compatibility, security, and initial downloading and installation. Java Applet, for various reasons, is seldom used as well. On the other hand, Adobe Flash, previously called Adobe Flex, is compatible with Windows, Macintosh, and Unix browsers; additionally, Flash starts much faster than Java Applet, and Flash can easily add animation, video, and interactivity to Web pages. It has extensive features and consistent appearance in major browsers. Flash comes with a variety of built-in user interface and other components. For Web GIS systems, Flash provides effective vector and raster manipulation and rendering operations. More importantly, since popular Internet video-sharing websites such as YouTube prefer Flash to display video contents, the Flash plug-in is the world's most pervasive software reaching 99 % of Internet-enabled desktops in major western countries (Adobe Flash 2011), which Microsoft SilverLight cannot compete with. Commercial products like ArcGIS Server Flash APIs are commonly used to build Flash-based Web mapping systems (Li et al. 2011; Defne et al. 2012).

11.3.2 Comparison of Client-Side Rendering Mechanisms

A Web-based GIS for crime mapping and decision support requires an efficient client side rendering mechanism to support the presentation of large number of crime points, polygonal features, and other spatial data types. In this section, DHTML-rendering methods and rich-client methods are compared in terms of their performances.

There are three methods in DHTML to render geographic features in a browser. The three methods are scalable vector graphics (SVG), vector markup language (VML), and HTML5. SVG is a standard proposed by the World Wide Web Consortium supported by major browsers, such as Mozilla Firefox, Internet Explorer 9, Google Chrome, Opera, and Safari, to render two-dimensional vector graphics. VML is an XML-based language to render vector graphics and has been supported by Internet Explorer between versions 5 and 9. Before Internet Explorer 9, VML was the only available method to render vector graphics in Internet Explorer. Microsoft has encouraged the use of SVG over VML in Internet Explorer 9. Despite that, VML is still widely used in many websites because of the large number of legacy users of Internet Explorer 6 and Internet Explorer 8. HTML5 is a new version of HTML that supports rendering graphics using the Canvas tag. HTML5 graphics rendering capability is supported in all mobile browsers and latest versions of desktop browsers.

Flash is the most popular rich-client technology compared with SilverLight and JavaFX and is chosen to compare with DHTML. To compare the performances of DHTML and RIA for mapping geospatial features, two commonly used mapping

Table 11.2 Test vector datasets

	Dataset name	No. of polygons	No. of vertices	Sources
DS1	Countries – 100 m	177	10,589	Natural Earth http://www.naturalearthdata.com/downloads/110m-cultural-vectors/110 m-admin-0-countries/
DS2	Countries – 50 m	242	99,606	Natural Earth http://www.naturalearthdata.com/downloads/50m-cultural-vectors/50m-admin-0-countries-2/
DS3	Countries – 10 m	253	536,399	Natural Earth http://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-admin-0-countries/

Table 11.3 Time (in milliseconds) used from zooming 20 times

		Browsers		
Dataset	Rendering methods	IE9	Chrome	Firefox
DS1	SVG	1,345	858	1,622
	HTML5	1,909	1,277	1,598
	VML	9,156	N/A	N/A
	Flash	71	72	74
DS2	SVG	10,331	5,342	12,441
	HTML5	13,606	8,813	10,318
	VML	120,588	N/A	N/A
	Flash	371	379	372
DS3	SVG	55,730	21,734	60,480
	HTML5	115,048	58,959	67,665
	VML	No response[a]	N/A	N/A
	Flash	1,831	1,890	1,887

[a]More than 10 min for the operation to be completed

operations, i.e., zooming and panning, are compared. Two open-source mapping frameworks, OpenLayers and OpenScales, are used to conduct the comparison. OpenLayers is an open-source JavaScript-based client-side mapping library that supports SVG, VML, and HTML5. OpenScales is an open-source Flash-based mapping library. Three browsers, Internet Explorer 9, Google Chrome, and Mozilla Firefox, are used for the experiments. The experiments are conducted on a Windows 7 system, with 4GB of RAM and an I3 3.30 GHz processor. In all experiments, the entire dataset is loaded before the operations are conducted. Table 11.2 lists three datasets of various sizes used for the comparison. Tables 11.3 and 11.4 list the time used for zooming and panning 20 times, respectively.

For panning operations, all rendering methods take a negligible amount of time. This is due to the fact that the entire dataset is preloaded and the panning operations involve the relocation of the previously generated images, which can be done in an efficient way by translating the container's location only. For the zooming operations, the performance of each rendering method varies considerably. Flash is basically independent of the browsers and it takes no more than one tenth of the time used by the three DHTML methods. As an RIA technology, the performance

Table 11.4 Time (in milliseconds) used from panning 20 times

		Browsers		
Dataset	Rendering methods	IE9	Chrome	Firefox
DS1	SVG	1	2	4
	HTML5	1	5	8
	VML	6	N/A	N/A
	Flash	3	3	3
DS2	SVG	2	3	4
	HTML5	3	5	8
	VML	6	N/A	N/A
	Flash	3	3	2
DS3	SVG	3	6	8
	HTML5	3	5	4
	VML	10	N/A	N/A
	Flash	3	3	1

of Flash depends on its internal rendering mechanism, and the browsers it runs within have little effect. Among the three DHTML methods, SVG takes the least amount of time and VML takes largest amount of time for all three browsers when applicable. The poor performance of VML is possibly partly due to the fact that Microsoft is on the way to phase it out. Among the three browsers, Chrome performs the best for all rendering methods, and the efficient V8 JavaScript Engine used by Chrome contributes to its excellent performances. As the volume of the dataset increases, the time used increases. For the largest dataset (DS3) which contains 253 polygons and 536,999 vertices, SVG takes at least 21 s, HTML5 58 s, and VML 10 min, while Flash takes around 2 s.

A Web-based crime mapping and decision support system needs to render large amount of dynamic data, particularly line and polygon features. The excellent performance of Flash, particularly for zooming operations, makes it a good choice for client-side geographic feature rendering.

11.4 Prototype Design and Development

11.4.1 Users and System Requirements

The Web-based crime mapping and decision support system primarily targets law enforcement agencies. The system can be deployed on their proprietary intranets. Law enforcement staff can perform sophisticated hotspot analysis and mapping using various methods. We are particularly concerned with small and medium-sized police departments in developing countries, which cannot afford expensive commercial GIS software in addition to the development and maintenance costs of the system. The system can also be useful to the public when deployed on the Internet, enabling them to view, browse, and search crime points of different types and time periods.

Drawing upon our previous requirement analyses with many law enforcement agencies, we conclude that the Web-based GIS system for crime mapping and decision support should implement such fundamental requirements as basic mapping operations and hotspot mapping. Basic mapping operations should enable users to zoom and pan to areas of interest; manage layer properties such as visibility, opacity, and display order; retrieve spatial data through Open Geospatial Consortium (OGC) protocols such as Web Feature Service (WFS) and Web Mapping Service (WMS); and display tiled maps for background display through Web Map Tile Service (TMS). Hotspot mapping functions should enable users to specify mapping methods and related parameters, define classification and coloring schemes, etc. In addition, crime database should be kept up to date with original master dataset within a reasonable time lag. Existing and incoming crime records should be geocoded accurately and stored in the spatial database before being mapped for hotspot analysis.

11.4.2 Choice of Open-Source Products

Since one objective of this study is to make the Web-based GIS system affordable for small- and medium-sized police departments in developing countries, we choose to use open-source products instead of commercial GIS systems. Open-source software products such as OpenLayers and MapServer have been widely used in Web mapping and Web-based GIS systems (Tuama and Hamre 2007; Kulawiak et al. 2010; Rinner et al. 2011). On the server side, we choose PostgreSQL as the database server, PostGIS as the spatial database engine, and GeoServer as the GIS server. PostgreSQL is a powerful, open-source object-relational database system and runs on all major operating systems. It has a proven architecture that has earned a strong reputation for reliability, data integrity, and consistency. PostGIS is an open-source software product that adds support for geographic objects to the PostgreSQL object-relational database. GeoServer is an open-source Java-based software server that allows users to share and edit geospatial data. Designed for interoperability, it publishes data from major spatial data sources such as Shapefile, PostGIS, GeoTIFF, ArcSDE, GML, MySQL, Oracle, etc. It supports standard protocols including WFS, WMS, and WCS (Web Coverage Service) and can be configured through its user-friendly Web administration interface, which enables the rapid and easy publishing of spatial data.

On the client side, OpenScales is chosen as the mapping engine. OpenScales is an open-source mapping framework based on Adobe Flash and used for building rich Internet mapping applications. It is a pure client-side product and can work with a suite of open-source and commercial products through standard protocols and supports different types of layers such as tiled map layers, common OGC protocols like WFS and WMS, efficient and fast vector rendering capabilities, powerful style APIs, popup support, and XML runtime configuration. It comes with a range of controls and components including essential map control, layer manager control, zoom/pan control, overview map, and scale bar. Together with good

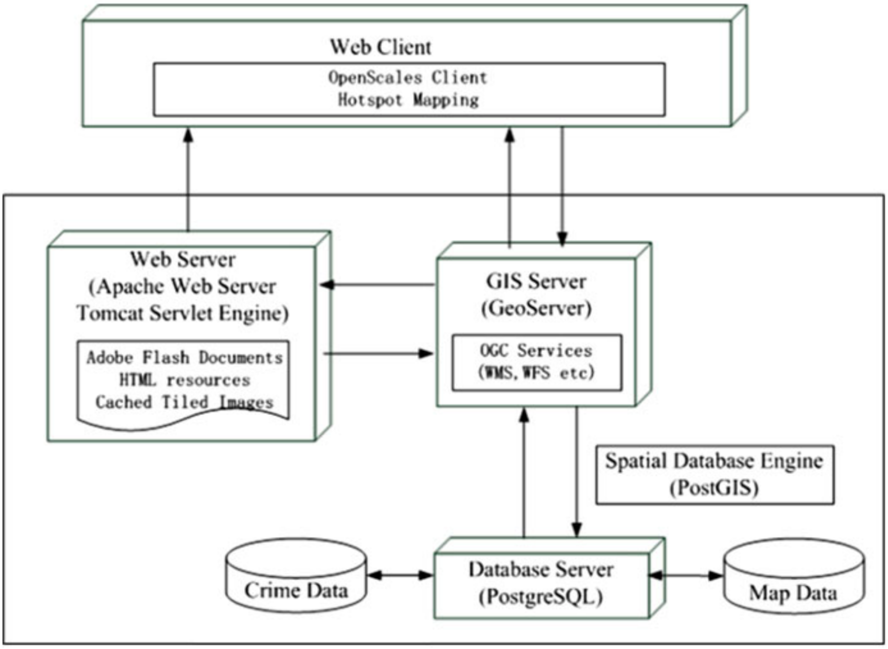

Fig. 11.4 Architecture of Web-based crime mapping and decision support system

documentation and a vast library of examples and tutorials, these controls and components enable the rapid and easy development of mapping clients with advanced features. As an open-source framework, OpenScales can be easily extended to accommodate custom requirements by allowing developers to delve into the source codes and to better understand the inner mechanisms of the framework.

11.4.3 System Architecture

Figure 11.4 illustrates the architecture of the Web-based crime mapping and decision support system. This multi-tier, client-server architecture is composed of a database server, a GIS server, a spatial database engine, a Web server, and a Web client. All server-side software is open-source products. The database server hosts crime data and other map data such as administrative boundaries and police precincts. The database server is spatially enabled through the spatial database engine. The GIS server publishes such OGC services as WFS and WMS for mapping, querying, and updating the spatial database through the spatial database engine. The Web server hosts OpenScales documents, custom-made Flash controls, HTML resources, and the cached tiled images.

The Web client is installed with Adobe Flash Player and accesses the Web resources on the Web server and GIS functionalities through the GIS server. The

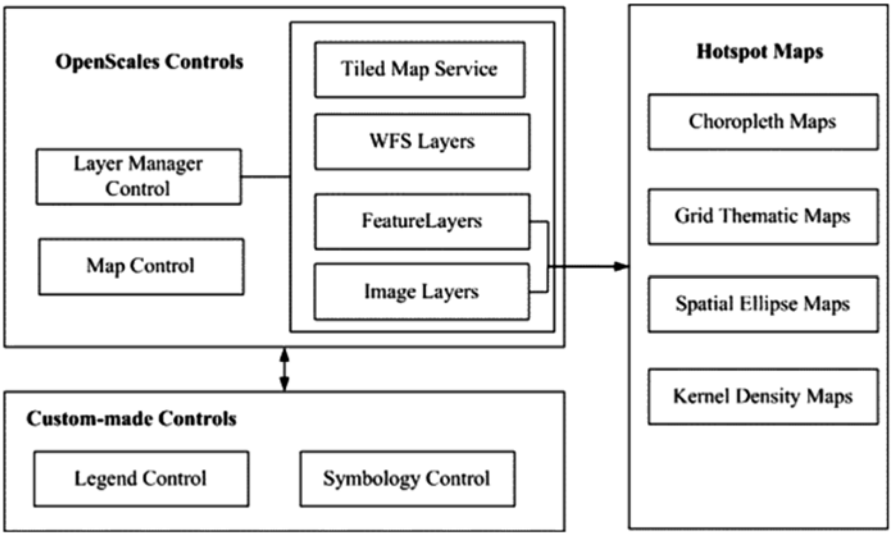

Fig. 11.5 Client-side architecture of the system

Web client provides basic GIS functionalities through OpenScales framework and various crime hotspot mapping options. The architecture of the client side is shown in Fig. 11.5. The application uses OpenScales controls such as map control and layer manager control for basic presentation and manipulation operations. The layer manager control manages such layers as tiled map service, WFS layers, feature layers, and image layers. The tiled map service is for the presentation of cached background data. WFS layers are used to retrieve spatial data such as crime points and administrative boundaries from the GIS server. Feature and image layers are used to render hotspot maps. In addition, custom controls including legend and symbology controls are implemented. The legend control shows the legend of the current hotspot map. The symbology control allows users to define classification schemes, color ramps, and symbology properties for each class.

11.4.4 Prototype Development

A prototype of the Web-based GIS for crime mapping and decision support has been developed according to the requirements and design described in the previous sections. The prototype serves to demonstrate that open-source software can meet the requirements of Web-based GIS systems for crime mapping and rich Internet applications give users more freedom than thin-client applications to manipulate hotspot mapping options. The prototype also serves to refine the requirements of law enforcement agencies.

The main user interface of the prototype system is shown in Fig. 11.6. Spatial data are retrieved and rendered by using OpenScales built-in feature layers and

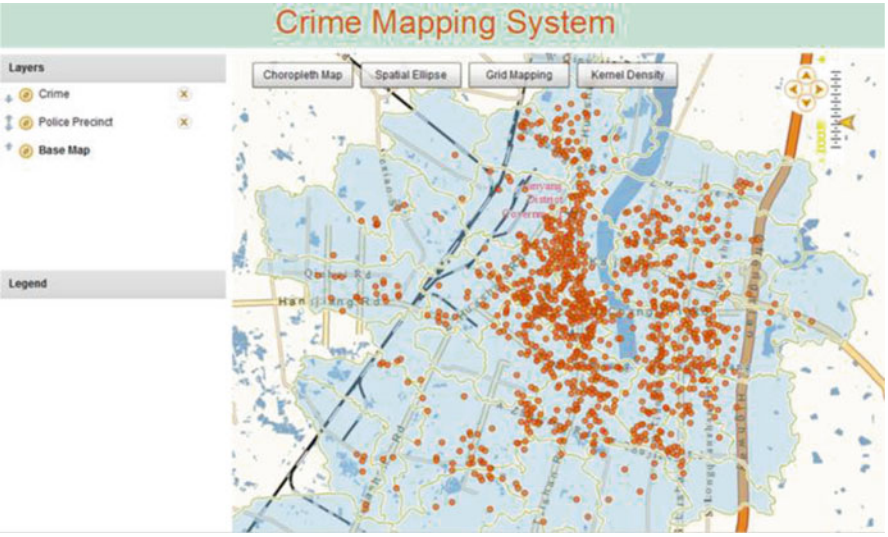

Fig. 11.6 The user interface of the system prototype

OGC layers. Hotspot map generation methods are implemented in ActionScript on the client side. Hotspots are arranged in thematic layers, whose properties such as opacity, visibility, and display order can be changed in the layer manager control. Spatial data are published from GeoServer using standard OGC protocols.

Background maps provide important reference information such as roads, buildings, rivers, parks, and recreational locations for the spatial distribution of crime, and they are an inherent part of a crime mapping and decision support system. Background maps generally do not change frequently and can be cached at different scales in tiled images to provide efficient Web mapping, which is a common practice in Internet mapping. As compared with on-the-fly map generation, cached images provide an additional benefit, i.e., visually more aesthetic maps. This is because cached images are usually prepared with a lot of effort at each display scale, sometimes with proprietary tools, whereas on-the-fly map generation generally does not satisfactorily deal with such factors as feature selection and text labeling.

11.5 Example Application Results

In this section, we demonstrate the application results of the prototype system. In the examples, the spatial data are originally obtained from a police department we worked with before and used here for demonstration purpose only. The crime dataset include such information as address, crime type, crime time, etc. Police precinct boundaries are used for choropleth mapping. Other spatial data are used primarily for background reference data. At each display scale, our background maps are prepared with care and tiled images are generated with a proprietary tool built on ArcEngine. The background tiled images are published through the Web server. All data are processed to be in a local projected coordinate system to facilitate the calculation of geometric measures such as distance.

For many police departments, geocoding crime records is the first step toward building a spatial database for crime mapping. Various geocoding methods and tools are available to provide satisfactory positional accuracy for the majority of records in western countries such as the United States (Zandbergen 2008). This is not the case for developing countries such as China (Li et al. 2010). In China, geocoding existing crime records is a daunting issue. This is due to the huge number of historical crime records to be processed and the lack of satisfactory automatic geocoding methods. Because of historical, cultural, and other reasons, Chinese addresses lack uniform formats, and the street numbers do not provide information on the relative positions of addresses in many cases (Li et al. 2010). Automatic tools generally yield address matching with an accuracy of less than 70 % according to our experiences with many Chinese police departments. The remaining unmatched addresses are geocoded manually. For our example crime dataset, the majority of the crime points are already geocoded previously, and the remaining addresses are geocoded manually. For daily operational application of the system, incoming crime records should be geocoded and stored in the spatial database using a dedicated tool. The dedicated tool should provide an automatic tool to geocode incoming crime locations and provide functionalities to manually adjust wrongfully geocoded addresses.

11.5.1 Hotspot Mapping Implementation

Figure 11.7 exemplifies choropleth mapping in the prototype system using all crimes for the year of 2010. As a rich-client application, the prototype needs to conduct point-in-polygon algorithm, which is implemented by OpenScales, in order to determine the number of crimes falling within each areal unit. Different classification and coloring schemes are provided to facilitate rendering.

Figure 11.8 exemplifies grid mapping in the prototype system. The grid mapping function allows users to specify an area of interest and grid size and number of grids along the horizontal and vertical directions. Once the grid dimensions are defined, the number of crimes falling inside each grid cell can be easily calculated, and then it becomes choropleth mapping with all necessary functions available to users.

Figure 11.9 shows an example of spatial ellipse mapping in the prototype system. The spatial ellipse function requires spatial clustering of crime points. The system implements K-means clustering method. Once the clusters are defined, a standard deviational ellipse is calculated for each cluster and displayed to users.

Figure 11.10 shows an example of kernel density mapping in the prototype system. With the kernel density mapping function, users can specify the dimensions of the grid to be generated for holding the kernel density value at each point in the

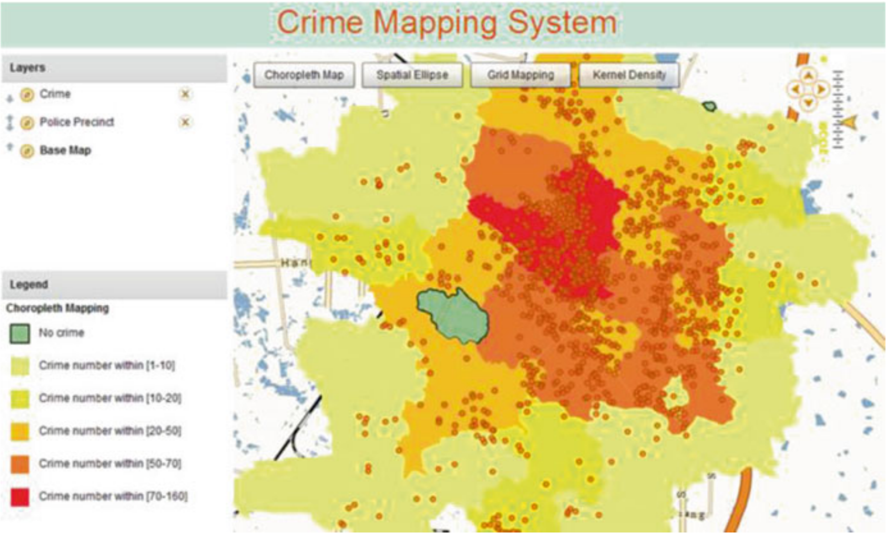

Fig. 11.7 Choropleth mapping overlaid with crime points

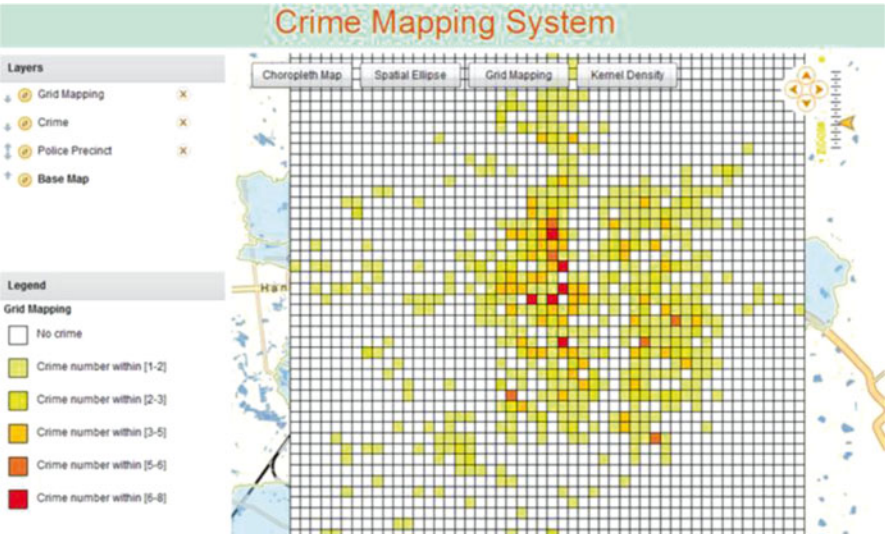

Fig. 11.8 Grid thematic mapping for crime hotspots

study area. Kernel functions such as the normal distribution function and triangular function can be specified and kernel density values contributed from all crime points are summed up for each grid cell. The bandwidth of the kernel function is defined by users. Once each grid cell receives its kernel density, the grid can be rendered in a way similar to choropleth mapping.

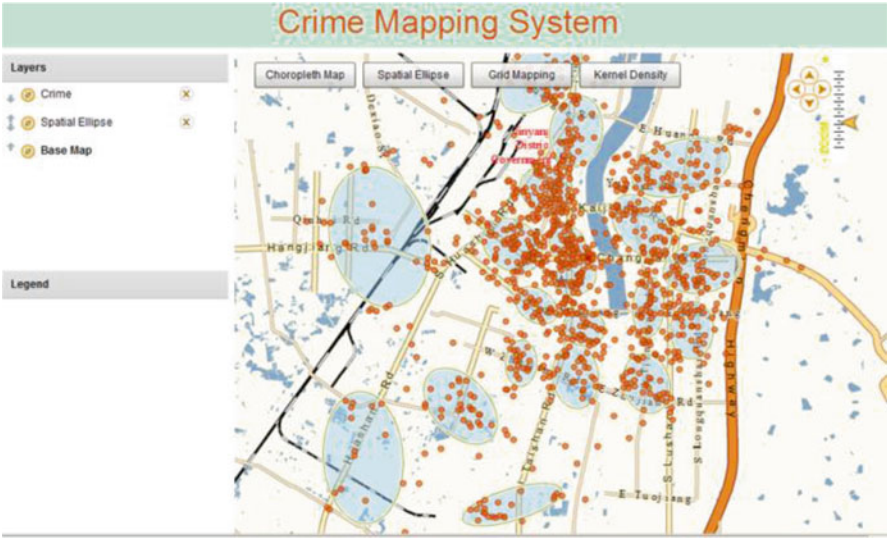

Fig. 11.9 Spatial hotspot ellipses overlaid with crime points

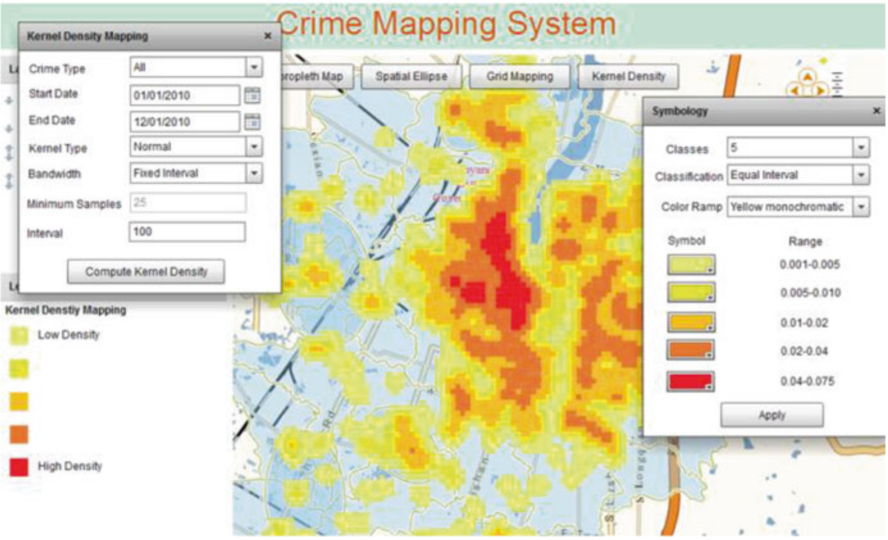

Fig. 11.10 Kernel density hotspot mapping

11.5.2 Spatial and Temporal Scale Effects

Spatial and temporal scales are key factors in many geographical phenomena, and crime hotspot detection is no exception (Wu and Grubesic 2010). To explore the spatial scale effects on hotspot detection and mapping, users can vary geographical

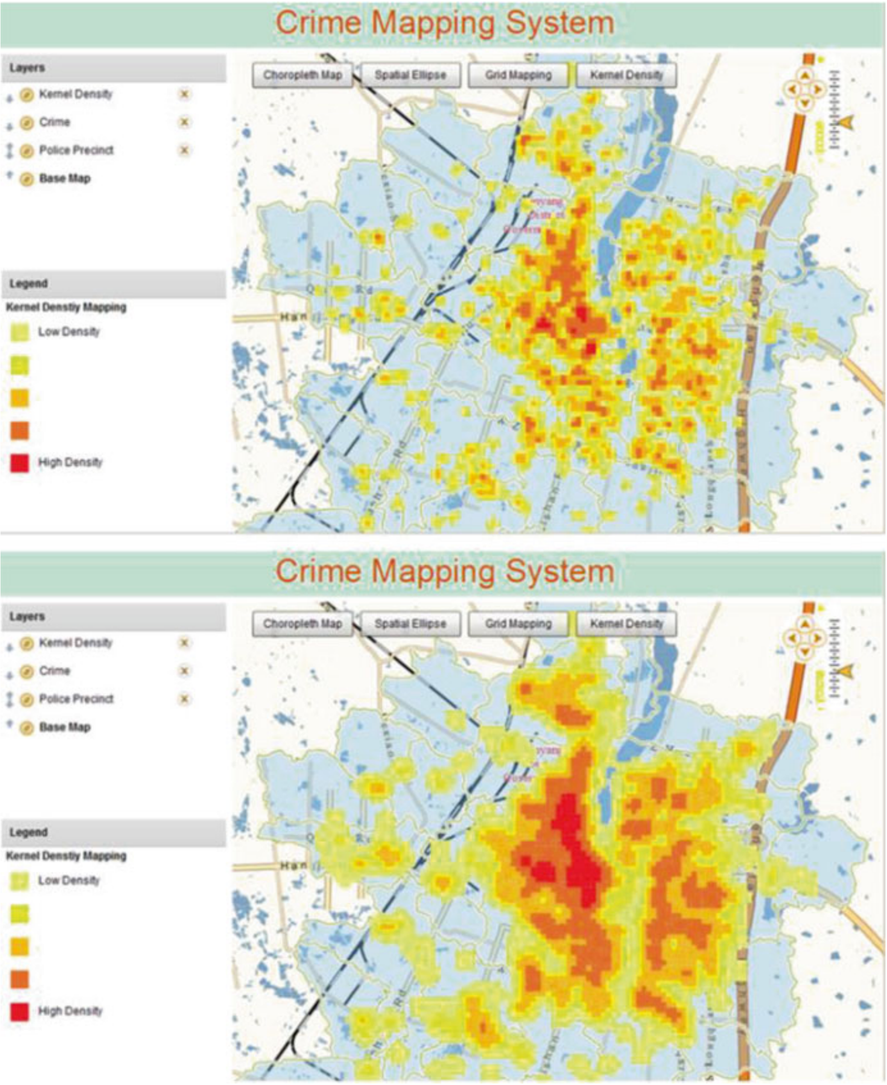

Fig. 11.11 Spatial scale effects on kernel density mapping. *Top*: normal kernel function with a bandwidth of 50 m. *Bottom*: normal kernel function with a bandwidth of 100 m. These two maps use the same classification and coloring schemes

areal units in choropleth mapping, grid size in grid mapping, the number of clusters to be grouped in spatial ellipse mapping, and the bandwidth of kernel function in kernel density mapping. In all four mapping methods, users can also vary the time span of crime to study the effect of various temporal scales. Users can study a subset of crime points by filtering the crime type as well. Figure 11.11 shows two kernel density maps generated using normal kernel function with a bandwidth of 50 m and 100 m, respectively. These two maps show distinct hotspot patterns at two spatial scales.

11.6 Summary and Conclusion

Existing applications for crime mapping and decision support are either desktop applications or based on commercial GIS products. The main objective of this research is to design and implement a crime mapping and decision support system based on open-source software packages. The prototype allows users to detect and view crime hotspots in the form of thematic layers overlaid on background data in a Web environment. The system is designed to be a part of a comprehensive police GIS system which basically encapsulates major aspects of routine police operations and can be effectively used for decision making. The prototype utilizes four hotspot mapping techniques, i.e., choropleth mapping, grid mapping, spatial ellipse mapping, and kernel density mapping. Hotspots are arranged in thematic layers, whose properties such as opacity, visibility, and display order can be changed in the layer manager control. The prototype can be used to map crime hotspots, predict the locations of future crime, and optimize crime reduction efforts for law enforcement agencies. The prototype allows users to specify various options for each hotspot mapping technique and to apply different classification and coloring schemes. Users can also study the spatial and temporal effects on crime hotspot patterns through the prototype.

The prototype is a rich Internet application, making it much more efficient than script-based clients in hotspot detection, map manipulation, and rendering. Large number of polygons such as police precincts and grid cells can be easily manipulated within a Flash client, whereas a script-based client is extremely cumbersome to handle a decent number of polygons. The prototype is entirely based on open-source software, making it affordable for many small- and medium-sized police departments in developing countries. GeoServer is used as the GIS server to publish crime data and other spatial data through standard protocols like WFS and WMS. Spatial data are stored in PostgreSQL and spatially enabled through spatial database engine PostGIS. The rich-client mapping framework OpenScales, as an open-source product, can be easily extended to meet custom requirements by allowing developers to delve into the source codes and to better understand the inner mechanisms of the software.

Although the prototype system has been tested and used for mapping property theft on public transit systems in Beijing metropolitan area, it is still in preliminary development stage. For future improvements, classification and coloring schemes may be saved on the server to allow users to retrieve and reapply them easily. Statistical charts such as bar charts and pie charts may be made available for better visualization and comparison. Other clustering methods such as hierarchical nearest neighbor clustering will be implemented to offer different options for clustering and to generate spatial ellipses for hotspots. More kernel types will be made available for kernel density mapping. Default bandwidth will be calculated for novice users.

Issues such as geocoding accuracy of addresses in China have broader implications, and advances in solving them will greatly benefit GIS-based crime mapping systems.

The prototype focuses on hotspot mapping. Other common GIS functionalities can be added to it to provide forensic cues for law enforcement agencies. One direction is to map hotel check-in records of suspects of motorcycle theft. Law enforcement agencies in many nations like China have all the check-in records of all hotel guests. Geospatial analytic tools can be applied to find those motorcycle theft suspects who have hotel check-in records outside their regular living areas during the period of the theft. A rule of thumb is that those suspects are more likely to have committed the crimes. Web-based GIS rich Internet applications can provide such functionalities on the client side more efficiently than script-based GIS applications.

Despite the fact that the prototype still needs further refinements, results obtained from the system development and testing stages demonstrate that rich Internet application technology, in combination with open-source software, is an effective solution for a Web-based GIS crime mapping and decision support system in terms of both system performance and financial cost.

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