SDImobile: Open Source Geo-Webservices for Mobile Data Capture in Cadastral Applications

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Abstract. Nowadays mobile devices equipped with GPS receivers are being used worldwide for field data collection. Cadastre information systems can benefit from using mobile device technology where both spatial and non-spatial data can be collected in the field. However, mobile devices suffer from technological limitations such as small screen size, small memory and processing power, and furthermore they use wireless networks for communication, which compared to wired networks are unreliable and costly. Therefore, the design of a mobile data collection system requires special attention. In this research we designed a system for mobile cadastral data collection that contains two components, a mobile capturing client and an SDI node supporting the mobile client, which we called *SDImobile*. In this research we focussed on the *SDImobile* node, and only used the mobile device to test capturing cadastral data in a very limited use case. *SDImobile* handles the communication of the mobile device with other SDI nodes that offer resources (data or services). Furthermore, *SDImobile* processes input data from the mobile device and sends them to other SDI nodes, in our case a cadastral one. Although the design is based on a cadastre use case, this research aimed at designing a *generic* and *interoperable* SDI node. For that purpose, we used a service orientation paradigm to design reusable and generic web services for the SDI node. By using open standards we aimed at designing the SDI node to be interoperable. A proof-of-concept prototype was implemented and tested, using free and open source software. We believe that the use of a mobile device, supported by a generic and interoperable SDI node, is very promising and offers great potential for field data collection applications.

Keywords. Mobile device, SDI node, generic, interoperability, open standards, cadastre

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1. Introduction

The development of Information Technology has influenced the evolvement of GIS technology from traditional GIS towards distributed GIS, part of which is mobile GIS (Peng & Tsou 2003). Nowadays, mobile GIS is widely used in field data collection, both in government and private enterprises. Cadastral application is one of the fields that can benefit from mobile GIS especially in developing countries where there are technical and financial difficulties in creating digital cadastral data acquisition systems (Mensah-Okantey & Köbben 2008). Mobile GIS has the potential to facilitate cadastral data collection by integrating spatial and attribute data collection directly in the field. However, mobile GISs suffer from some limitations. These are related to communication networks, low bandwidth (Farkas et al. 2006), and mobile device limitations such as small display screen, limited memory and power autonomy and limited processing capabilities (Brinkhoff 2008, Rabin & McCathieNevile 2008) All such limitations affect the design of a mobile system for cadastral data collection.

Our research aimed at designing an interoperable and platform-independent SDI node, a middel-ware which offers generic functionality for facilitating mobile cadastral data capture. The generic nature of the SDI node and its interoperability with other SDIs is achieved by using OGC-compliant geo-web services and open standards. Free and open source software (FOSS) was used to build a prototype of the SDI node. To test this SDI node we also made devised a matching mobile device client, albeit limited in functionality.

2. Related Work

The use of mobile GIS for field data collection has attracted many researchers. Casademont et al. (2004) presented an overview of the wireless technology and positioning technology that can be used in GIS. Hall and Gray (2004) developed a mobile system for field data collection with the main objective to facilitate collaboration and coordination of surveyors in large field surveys. CoMPASS is another mobile GIS application that offers the user GIS functionality such as navigation, spatial querying and manipulation of vector-based spatial data (Doyle et al. 2010). The authors were particularly concerned with the interaction methods between the user and the mobile device. Wagtendonk et al. (2004) developed a mobile GIS application for assisting the field surveyors in mapping crops in The Netherlands. Other researchers were focused on the format that can be used to display data in mobile GIS applications. An example is the MacauMap map application intended for tourism purposes (Biuk-Aghai 2004). The main concern of its design was the format used for map display in mobile devices with constrained. As a result the author proposed a custom data format for use in the MacauMap application. Brinkhoff and Weitkämper (2005) studied the Scalable Vector Graphics format for representation of vector data in maps. The authors proposed a format that is a restriction/extension of the SVG, which can fulfil GIS requirements for vector data representation in Location-Based Services (LBS). A prototype mobile application was created by Mensah-Okantey (2007) for cadastral data collection; here most effort was put on modelling the specific cadastral processes in Ghana.

3. A Cadastre Use Case

One of the main reasons for conducting a field survey is to delineate the boundaries of the properties, thus creating land parcels. We developed a use case scenario for field surveying using a mobile device. In this scenario, for simplicity reasons, we restricted the purpose of the system to measuring new land parcels.

Our system should allow the surveyor to measure a new land parcel, i.e., the boundaries will be measured for the first time and stored in a cadastral database. We are assuming that a cadastral database exists and the information can be stored and retrieved from it. The measurements of the parcel boundary points shall be done by means of GPS, either integrated in the mobile device or connected to it. For each measured parcel, the surveyor should be able to collect some descriptive information such as the administrative area, taxation value, et cetera. Besides, the system shall allow the surveyor to load the map of neighbouring properties (if any) from the cadastral database.

The system should be able to convert the measured points of the boundary into a parcel polygon and store it in the cadastral database. The newly created polygon should be checked for consistency with existing rules. Such rules could be about the allowed topological relationships between parcel polygons, the reference, inclusion of a unique identifier, and so on.

Furthermore, we are assuming that there is a utilities database that is accessible by cadastral surveyor in the field. The surveyor should use it to check if there is any overlay of the utility lines with the measured parcel. If so, the surveyor should be able to record a restriction/servitude on the property. In a similar way a municipal database should provide administrative information.

We assume that cadastral, utility, and address information is accessible through SDI (Spatial Data Infrastructure) nodes. The mobile device should be able to communicate with the SDIs. In absence of any communication network, the system should allow the surveyor to store the surveyed information locally in the mobile device and transfer the data at a later moment.

4. System Analysis and Design

We used the Unified Process (Hunt 2000) to guide an object-oriented analysis and design of the mobile data collection system. The Unified Modelling Language was used to draw the models derived during the Unified Process development. The requirements for the mobile data survey system, captured in the cadastre use case scenario, were put in context and analysed.

The use case we created leads to user requirements that are translated into steps to be performed by the surveyor. The technological restrictions of the mobile device and wireless network impose restrictions on the architecture of the system. To remedy this, we introduce another component in the system: The SDI node for mobile client – *SDImobile*. We believe that this new element will allow us to build a system that minimizes the usage of the mobile device resources. The *SDImobile* element will serve as a “bridge” between the mobile device and the other SDI nodes. It will handle the communication between them and run some of the activities in support of the use case. Therefore, we designed a logical architecture of the system including both a mobile device and the *SDImobile* component (Figure 1).

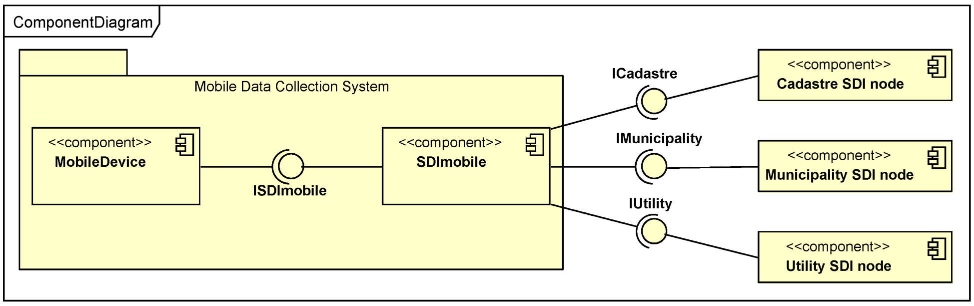

Figure 1. Logical Architecture of the Mobile Data Collection System.

Next, we identified the conceptual classes in the domain of interest using the noun/verb analysis (Arlow & Neustadt 2002). Futhermore, we identified the associations between classes and for some of the classes we have also identified attributes.

We proceeded by defining how the objects will collaborate to fulfil the user goals, as illustrated in the UML sequence diagrams in Figure 2.

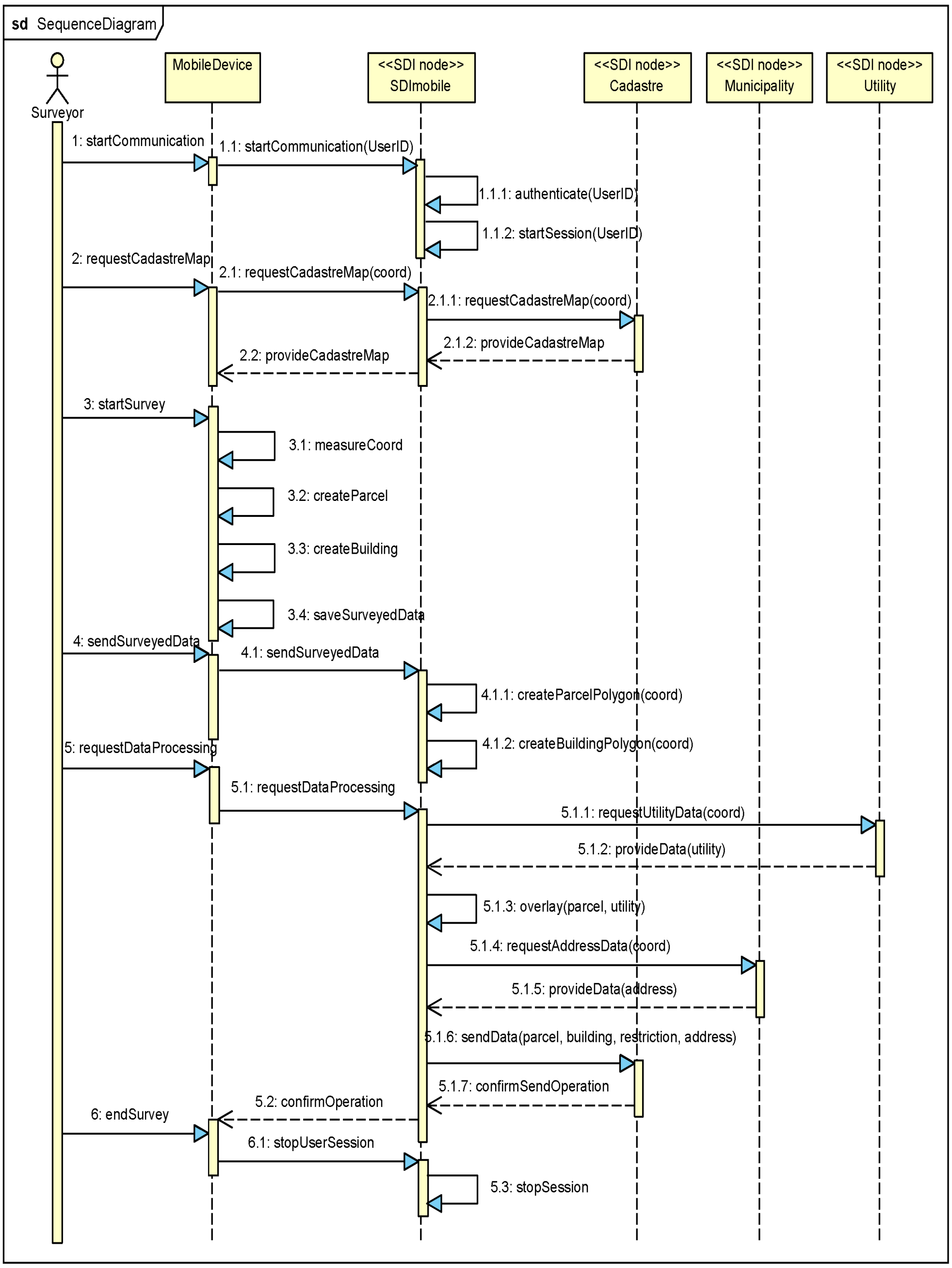

Figure 2. Sequence Diagram of the proposed system.

In the diagram, we can observe two communication models between the *MobileDevice* and *SDImobile* classes. The first situation is when one message sent from *MobileDevice* object invokes only one method in the *SDImobile*. For instance, if the message *requestCadastralMap* is sent to the *SDImobile*, then the method named *requestCadastralMap*() is triggered in the class. In the second situation, one message sent from *MobileDevice* invokes a group of methods in the *SDImobile* object. For instance, the *requestDataProcessing* message invokes several methods (5.1.1, 5.1.3, 5.1.4, and so on). The second communication model is especially useful in order to reduce the wireless communication between the mobile device and the *SDImobile* node.

The sequence diagram in Figure 2 reveals the responsibilities and importance of the *SDImobile* in the mobile system for field data collection. The *SDImobile* handles part of the communications between the mobile device and SDI nodes, which in its absence would have to be handled by the mobile device. Having this *SDImobile* component handling part of the communication creates, we believe, a more reliable and robust system.

In parallel with the creation of the sequence diagram we have created a class diagram that shows the objects, their attributes, methods, and relationships. The class diagram brings out the set of operations/methods that we defined in the *SDImobile* class. In the absence of that class, its operations would have to be provided by the *MobileDevice* class. We believe that having the *SDImobile* class to provide this set of operations improves the performance and reliability of the system.

4.1. SDI Node for Mobile Client – *SDImobile*

The *SDImobile* component, as the name suggests, is an SDI node that consumes services from other SDIs and also offers its own services for a specific group of devices with limited resources (Smartphones, PDAs, TabletPCs). De By et al. (2009) define an SDI node as “a moderately to highly complex information system with usually long lifetime expectancy, in which geospatial resources feature rather prominently”.

Our *SDImobile* “sits” in between the mobile device and other SDI nodes and acts as a mediator. In this role, it should have the functionality to search and find the SDI nodes that offer the proper services. Then it will bind to the services and if necessary will tailor them for the mobile device. For instance, the *SDImobile* can search for an SDI node that offers a Web Feature Service (WFS) and then a service tailored for consumation by the mobile device. This could be a WFS with appropriate filtering or simplification of features, or a WMS with appropriate (pre)tiling, etcetera, depending on the services needed, and the client set-up.

In this research we focused only on the design of the *SDImobile* node's functionality, expressed through services. We based the design of the *SDImobile* node on the requirements for the cadastral use scenario and aimed at making it as generic and reusable as possible. To achieve this, we divided the functionality of the *SDImobile* into two groups: generic functionality and specific functionality. In the first group we included functions that serve general purposes — which can also be reused in other situations. The specific functions are meant to fulfil the functional requirements of the specific use case such as *Survey Parcel*.

We based our design approach on the principle of separation of concerns (Morales et al. 2008), which helps managing the complexity of the design process by splitting it into phases that do not overlap. In the context of a service, there are three levels of concern: the *purpose* (what the service does); the *boundary* (the interface); and the *inside* (the internal structure of the service).

Here we followed service orientation principles for designing web services of the *SDImobile* node, which will encapsulate the required functionality. By using the service-orientation paradigm, we can design and implement a generic *SDImobile* node, i.e., reusable in situations other than our cadastral use case, and also interoperable with other SDIs. Services implemented using the service-orientation design paradigm encapsulate functionality that is not specific for any application, thus fostering reuse of the services (Erl 2007). Having reusable services in the *SDImobile* contributes towards a generic solution.

Following this approach we were able to identify a set of candidate web services and their operations for the *SDImobile* node. We aimed at refining them to be as generic and reusable as possible. However, these services are business-agnostic, meaning that they know nothing about the business process logic. Therefore, there is a need for some services that control and compose them according to a specific scenario. For this purpose, we added another service, *Cadastral Survey*, which is used to orchestrate candidate services identified earlier, and support the field cadastral data collection use case. The final services to be implemented are shown in Figure 3.

We proceed with the design of the service interfaces. This is in compliance with the separation of concerns as we separate the implementation of the services into three stages: service logic analysis, service interface design, and service logic implementation. For the design of the services interfaces we use a set of open web standards that foster interoperability regardless of the operating platform and/or programming language used for implementation (Fensel et al. 2007). This set of standards includes:

- eXtensible Markup Language (XML) and XML Schema Definition Language (XSD
- Hypertext Transfer Protocol (HTTP)
- Web Service Description Language (WSDL)
- Simple Object Access Protocol (SOAP)
- Web Services Business Process Execution Language (WS-BPEL)

Using XSD we were able to define schemas for the data types that will be exchanged between services. The service interfaces were defined using WSDL, HTTP, and SOAP standards.

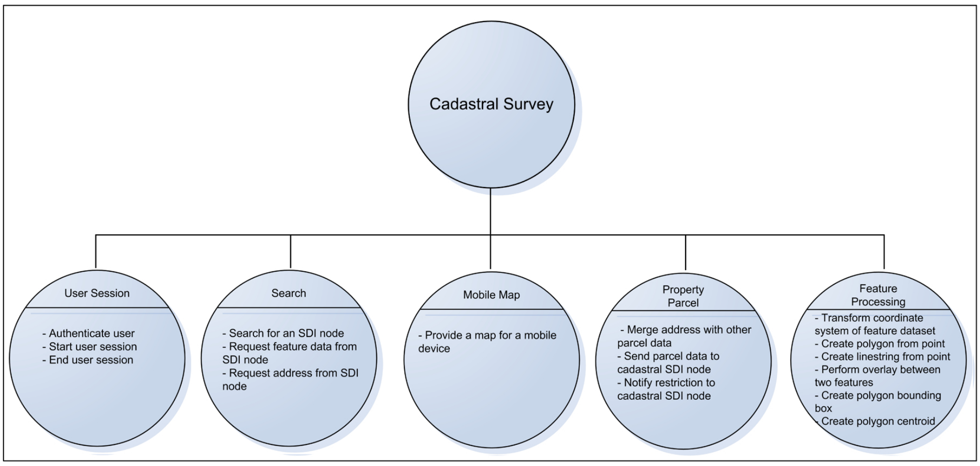

Figure 3. Service Composition Representing Cadastral Survey Process.

5. Prototype Implementation and Testing

A proof-of-concept prototype was implemented to finalize this research. The prototype contains some of the operations of *SDImobile* web services (the server side) as well as a very simple graphical user interface (GUI) for the mobile device (the client side).

We used the OpenLayers library (`www.openlayers.org`) and AJAX (Asynchronous JavaScript and XML) to implement a Graphical User Interface for the mobile device client, which can be used in any web browser. The client offers the user functionality to display a map and interact with it (zoom, pan) and to capture the location of the device. The latter functionality was built using the Geolocation API (Popescu 2010). Because our research was focussed on the *SDImobile* middle-ware, not on the client-side, we kept the set-up very simple and straightforward. For example, we did not investigate into the capability of the mobile client to work offline, something that modern HTML5 based browsers could easily offer.

After having been surveyed, the boundary points of the cadastral parcel can be sent to *SDImobile* in an asynchronous call. This means the *send* operation is done without disturbing the user experience and reloading the entire web page. The user will only see the response from the *SDImobile* component, displayed in a text box, and based on that may take other actions (for example, delete and re-measure the boundary points). If data processing in the *SDImobile* is successful and the measured parcel is stored in the cadastral database, then the user can see the new parcel displayed in the map.

To build the functionality of the *SDImobile* component we used different technologies. To create a Web Map Service (WMS) we used MapServer, with the cadastral data being stored in a PostgreSQL/PostGIS back-end database. The other functions of *SDImobile* are implemented using Python scripts in Active Server Pages. In ASP, the input data (boundary points) are retrieved from the client. We used the PROJ.4 library to implement a function that transforms the boundary points from the WGS84 reference system into the Dutch national reference system. Another function creates a polygon out of the transformed points, and also checks if it is a valid geometry, as defined by OGC (2010). Next, a WFS service of the utility lines is called. The result of the WFS call is used to test if the new measured cadastral polygon overlays with the utility lines. We have defined the overlay as: a.overlay(b) = a.Intersect(b) and not a.Touch(b), where both predicates are specified in the OGC implementation specification (OGC 2010). The output of the test is reported back to the mobile client and stored in the cadastral database.

We implemented a WFS-T (Transactional Web Feature Service) for storing the measured data into the cadastral database. WFS-T is a service that allows creating, updating, and deleting features from data stores. We used Geoserver for setting up the WFS-T. We created the utility lines WFS and cadastral data WFS-T services to prove that *SDImobile* is able to communicate with other SDI nodes through the use of open geo-webservices.

Finally we performed testing of the prototype by loading the client into the web browser of an Apple iPhone device and performing measurements in offline mode. We were able to work offline since the client is JavaScript-based and is cached by the web browser. The web browser is also able to cache the background map and the measured points. When measuring a point, the Geolocation API returns also the accuracy of the measurement. While at the start of the test the accuracy was low (about 200 meters) it kept improving and after 3-4 minutes proved stable. However, the API does not give information on which technology is used to capture the coordinates (it can be GPS, wireless positioning, cell tower positioning, etcetera). For that reason we switched of the wireless connection and removed the SIM card from the mobile device in order to force the Geolocation API to get coordinates from the GPS.

6. Conclusion

In this research we have proposed a middle-war SDI node for mobile data capture in the context of a cadastre application. We collected user requirements for cadastral data collection and created a use case where a mobile device could be used. Using appropriate analysis and design methods, we were able to design an OGC compliant, interoperable SDI node for supporting the field data collection. We used free and open source software to implement and test a proof-of-concept prototype. Using the prototype we were able to perform field data collection.

We believe that the combination of a mobile device, which is lightweight, practical, easy to use and equipped with a GPS receiver, and an SDI node that offers interoperable, platform independent and OGC compliant web services, is very promising and has great potential for mobile field data collection.

In general, an intermediate SDI node such as *SDImobile* is useful in mobile data capture applications because it can assist a mobile application in two ways. First, it will handle the communication with other SDI nodes and request the needed resources for the given application. The mobile device will communicate with only one SDI node instead of communicating with many of them. This reduces the communication of the mobile device, which is especially important in light of the unreliability of wireless networks. Secondly, in a mobile data collection application there may be a need for data processing tasks. An SDI node can handle such tasks far better then a resource-constraint mobile device.

Such an SDI node should be designed to be as generic and interoperable as possible. The generic nature of the SDI node can be achieved by designing reusable web services that are based on open web standards (in our example OGC web service standards). The use of open standards contributes towards achieving interoperability. Furthermore, free and open source software can be used to implement the client for the mobile device as well as the functionalities of the SDI node.

However, there is room for improvements. In our cadastral use case we only considered measuring new parcels. We suggest that the use case be extended to include update of the existing cadastral parcels as well. In the prototype we included functionality to only capture spatial information. It would be interesting to also provide functionality for capturing descriptive information. In such a case, it is important to investigate the possibilities for automatic generation of data entry forms from the schema definitions of the cadastral SDI nodes. This would contribute towards creating a more generic system for field data collection.

In our prototype we could only implement some of the functionalities of the *SDImobile*. It would be interesting to implement further functionalities into web services and test their interoperability with other SDI nodes. That way, *SDImobile* could be extended with more web services and operations.

Further research should also include more attention to the surveying software on the mobile device, for example looking into offline capabilities of the application as well as into accuracy and usability considerations.

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