Toward a Multi-Domain Platform for Live Sensor Data Visualisation and Collaborative Analysis

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***Abstract*—In this work, we present a web platform that seeks to tackle the challenges that come from the real-time visualisation of georeferenced sensor data in a multi-user, multi-touch environment. We introduce an input device agnostic user interface and the concept of realistic input reaction. We discuss the implemented components and the presentation system as a whole. The demonstrated platform also provides a set of building blocks to personalise the visualisation, easing its reuse in different monitoring scenarios. Finally, we show how the platform can be used to assist collaborative data visualisation and analysis.**

***Keywords*–environmental monitoring; real-time GIS data analysis; collaborative analysis; tabletops; natural user interfaces; multi touch.**

I. INTRODUCTION

In the recent years, sensor networks have been used to solve a variety of problems, ranging from environmental monitoring [1] to fine grained structural health monitoring [2]. Such deployed sensors might be used to ensure public safety and provide a steady flow of information to higher level decision makers, support systems and crisis first responders [3][4]. The amount of data collected by geographically distributed sensors, independently of their function, can be of a considerable volume and present a challenge to interactive visualisation. In this work, we present a platform for sensor data presentation and collaborative analysis. The platform aims to integrate and visualise in a clear and understandable way live data feeds coming from deployed sensors, geographical information systems and the result of higher level reasoning coming from data fusion engines or complex event processing. Moreover, it is designed to allow its use on Multi-Touch Tables (MTT), thus facilitating the collaboration and analysis through the means of natural user interfaces. Practical use cases of the system comprise real-time pollutant agents detection and warning system, nuclear waste monitoring and tracking or situation awareness and emergency monitoring in control rooms.

This paper is organized as follows. In Section II, we describe the previously proposed methods for web-based sensor data visualisation and discuss the limitations of these methods. In Section III, we describe the design elements and key principles we based our platform on. In Section IV, we describe our platform and explain how it tries to address the limitation of the approaches in the literature. Finally, in Section V, we present our conclusions and the direction of our future work.

II. RELATED WORK

In recent years, many largely different approaches have been proposed to interactively visualise considerable amounts of data coming from geographically distributed sensors. In this section, we introduce some of them, specifically focusing on web-based solutions. The SenseWeb project [5] demonstrates a web-based data gathering and visualisation infrastructure relying on Microsoft SensorMap for the visualisation, although not taking advantage of open geospatial standards. The National Oceanic and Atmospheric Administration's (NOAA) nowCOAST [6] aggregates heterogeneous informations, such as meteorological, oceanographic and hydrological data into a single, web-based visualisation platform, only partly based on open source technologies. Previous literature on multi-user, multi-touch interactions mainly focused on researching novel interaction techniques to mediate the issues involved in the collaborative interaction on a shared surface, such as content orientation, occlusion and reach [7]. The reacTable project demonstrated a multi-user, collaborative, electro-acoustic musical instrument on a multi-touch table [8]. In DTLens [9], a set of consistent interaction was investigated to allow multi-user exploration of geographical data on tabletops. In [10], a multi-touch system which allows multiple users to interact on a touch sensitive surface. Even though many sensor data visualisation systems have been demonstrated and implemented by the research community, they do not support multi-touch interactions out of the box thus not allowing collaborative multi-user touch interactions. The ones that support this kind of interaction lack real-time sensor live data integration with Geographic Information Systems (GIS). Moreover, an additional shortcoming of the aforementioned approaches is that their systems are tied to a specific domain or hardware platform and do not provide enough flexibility to be reused in different scenarios.

III. DESIGN PRINCIPLES

In this section, we describe the design principles we followed in the development of the platform.

A. *Easier deployment, scalability and easier maintainability*

Given the power of modern consumer hardware and the increasing efficiency of web browsing software, with the rise of emergent technologies like HTML5 and WebGL, a number of obstacles to the development of truly interactive web applications have been removed [11]. As a consequence, web applications can be considered as a feasible alternative to native applications for interactive software. Our platform (see Figure 1) is entirely based on state-of-the-art open technologies, exploiting the potential of the latest HTML5 draft [12] and the latest Javascript and WebGL [13] specifications. The strict adherence to open web standards and technologies allows to have a platform-independent software system which is:

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1) *simple to deploy*: the platform has to be deployed on a single machine and is automatically accessible to all the devices with a network connection;
2) *simple to maintain*: updates have to be delivered to a single machine;
3) *simple to scale*: a variety of open source, enterprise grade, components are already available for this purpose.

B. Multi-user, touch environment

The platform needs to exploit the potential benefits given by the use of MTTs. Each element of the platform has to react to touch inputs. The platform also has to abstract the user away from the challenges involved in the collaborative use of MTT including, but not limited to, content orientation, gestural interaction and group interaction [7]. Moreover, the platform has to provide support for legacy input devices like the mouse and be easily extensible to support new input paradigms (i.e., touch-less interaction).

C. Extensible widgets

The platform User Interface is made up by reusable modules called *widgets*. Each widget has to be replaceable. The developer has to be able to write new widget, either extending available ones or starting from scratch.

D. Standard communication protocols

Modules within the platform have to communicate using standard communication protocols and specifications. Since the platform works within a web browser, protocols like WebSocket [14], Server-Sent Events [15] and HTTP [16] are used. Geospatial data is delivered through the main protocols defined by the Open Geospatial Consortium (OGC): Web Feature Service (WFS), Web Coverage Service (WCS) and Web Map Service (WMS) protocols.

E. Open source stack

The platform has to integrate the most commonly used, widely tested, open source, third party libraries and encapsulate them into self-contained components, whenever this is possible. In our platform the jQuery [17] library, a small and fast Javascript library, is used to simplify web document manipulation. The platform also makes extensive use of the doT.js library [18] to provide template based presentation of live sensor data. The platform web pages are served through an instance of the Apache HTTP Server [19]. Furthermore, geospatial data is served using GeoServer [20], which implements the OGC standards. The OpenLayers [21] library is used to visualise data layers on bi-dimensional cartography while the CesiumJS [22] is used for data visualisation in a three-dimensional representation of the region of interest.

IV. PLATFORM OVERVIEW

Our platform allows geographically distributed sensor data visualisation. Its main strengths, which have been the focus of our research activities, are its flexibility and the multi-user, multi-touch capabilities. User interactions are characterized by the ability to use different input paradigms and devices, such as touch-based and mouse-based commands. Depending on the device used to access the platform, it can either be used completely through touch or mouse inputs, or both of them. Touch gestures are designed to maximize user action throughput when using the system: commands are triggered with the detection of a different number of touches or based on the kinematic parameters of the touch points. The platform user interface is designed as a desktop environment built within a web application, benefiting of the cross-device availability given by the latest web technologies. Furthermore, structuring the web application as desktop environment, helps reducing the learning time as the operator should be already familiar with native desktop environments which are commonly available on commodity personal computers.

A. Multi-touch, collaborative analysis

MTTs enable interaction with the hands and the fingers, providing each user in a multi-user scenario with the ability to manipulate virtual objects as if they were physical. Moreover, two-handed, multi-fingered input is more natural and flexible than mouse and stylus input devices [23]. The multiple points of contact in MTTs enable novel interaction flows, enhancing multiple user parallel reasoning and collaboration on the same interface. The multi-user interaction on a MTT can be used to exploit collaborative analysis and visualisation in different scenarios [24], as well as improve the decision making process in military [25] or clinical [26] settings. Due to the increasing use of mobile touch devices such as phones and tablets, interacting with touch surfaces has become a common practice, not dependent on the age of the user. As a result of this, the domain experts which are more resistant on using new software or technologies have a more positive attitude toward MTTs which aids the quicker learning of platform functionalities compared to the use of legacy devices. Furthermore, since a MTT allows a display to provide a common informative context as a shared workspace, parallel and collaborative analysis can be easily exploited. For example, if a user is examining the live data coming from sensors deployed on an extended geographical area detects an event of interest, he can send the relative data to another user on the MTT for further analysis. In another scenario, different users could concurrently analyse different sensor feeds coming from different geographical areas to resolve a common problem. The parallelism and the quick data/information exchange in face-to-face settings around a MTT may foster the collaboration among these individuals and consequently give an advantage during decision making processes and the analysis of emergency situations.

B. Widgets

A widget is a graphical user interface component which is part of the presentation platform, consisting of a title bar, a content area and input-reactive corners. To foster collaboration [27] among multiple users around a multi touch table, each widget in our platform can be repositioned and oriented freely, since a widget presented right-side up to one user might be upside-down for another. Widget repositioning is achieved by dragging the title bar with a single finger, the size can be varied by dragging its corners toward or away from each other while its orientation is changed by performing a clockwise or counter-clockwise rotation while holding down the two

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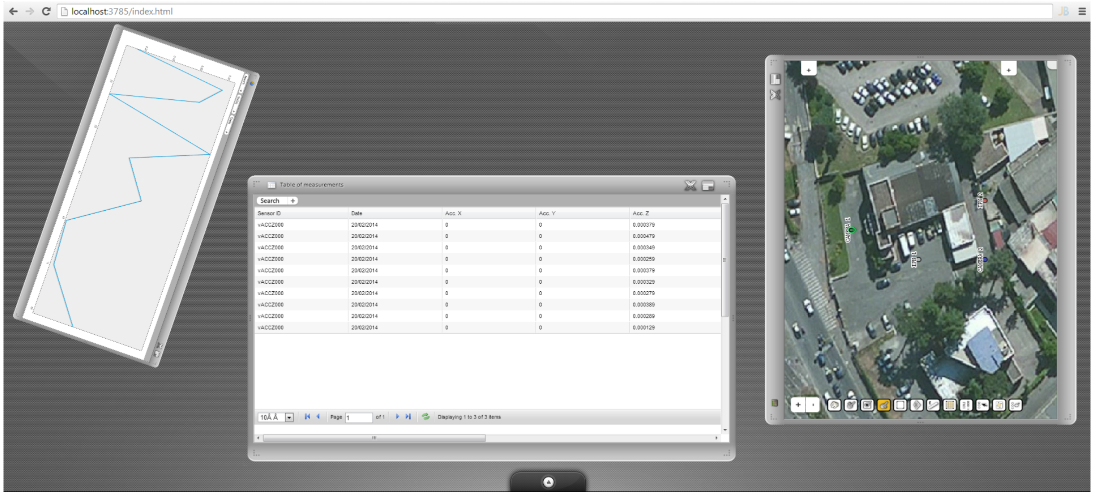

Figure 1: An overview of the sensor data presentation platform

fingers on the aforementioned corners, thus allowing users to organise the personal and group workspace on the table. In our platform, we introduced the concept realistic input reaction: the motion of a widget produced by user input is modelled by taking in consideration the laws of the motion of points and bodies or kinematics. Widgets behave as if they were physical objects reacting to an applied force. This feature makes touch manipulation of the widgets more natural and allows to transfer the motion of the fingers to the fingers, thus enabling users to drag widgets toward other users without moving around the table, simply by dragging it with the appropriate speed and then lifting the finger. We will briefly review the main widgets of the proposed platform.

1) Geospatial Data Widget: One of the components available within our platform is the *Geospatial Data Widget* (see figure 2). This component is completely built using Javascript, HTML5 and WebGL without relying on third party native software or closed source libraries. It does not require the installation of any browser plug-in as it is completely based on open web standards. The visualization component is integrated within platform and provides the seamless blend of geospatial data (aerial photographs, terrain elevation data) with live georeferenced sensor information about the monitored environment coming from the deployed sensors. Moreover, the geospatial data widget is also able to display both a bi-dimensional and a three-dimensional view of the monitored environment. When a bi-dimensional view is activated, aerial photographs of the region of interest are requested using the WMS protocol. If a three-dimensional visualization is requested, the terrain surface is built by exploiting aerial photographs and terrain elevation data for the region of interest. The visualisation is further augmented with additional data layers (buildings and 3D models) and real-time data collected from the sensors deployed on the field (GPS positions, measurements, video feeds, etc.). The style of each data feed can be personalized at deployment time or runtime, thus allowing to show different icons or models for different types of data coming from the sensors. Besides, each single data feed can be independently shown, hid or displayed with a particular opacity by interacting with the relative entry in the list of

Figure 2: The geospatial data widget

available sensors. A personalised HTML page can be shown when a sensor is selected in this widget. To ease the integration with different information systems and fusion engines, real-time information feeds can be streamed to the visualization component using different open formats and protocols: JSON, XML, GeoJSON and KML over WebSockets.

2) Common Alerting Protocol Widget: the Common Alerting Protocol [28] (CAP) is an emergency alert format which allows a consistent warning message to be disseminated over heterogeneous warning systems. Our platform supports CAP alerts visualisation and analysis through the CAP widget.

3) Data Table Widget: the data table widget displays the data coming from the deployed sensors in a tabular format. It can be either connected to a real-time sensor data feed or to a database storage system. Customised queries can be used to gather specific informations.

4) Graph Widget: this widget produces a graphical representation of the historical trend that a particular variable, coming from the deployed sensors or a database connection, assumes over time.

5) Video Streaming Widget: the video widget allows to display a video stream within the platform. The stream can come from a deployed sensor (i.e., a camera) or from a remote server.

6) Organiser Widget: when dealing with more than one widget on a single display, visual clutter might become an issue. This control enables users to reorder the widgets within the screen area by maximising the visibility of each widget's content area while spreading them around the empty areas of the display. Classical widgets reordering functions, such as widget tiling and cascading, are available as well. The organiser also serves a tool to easily locate desired opened widgets.

V. Conclusion and future work

In this work, a platform for the presentation and collaborative analysis of real-time data coming from geographically distributed sensor has been presented. Such system, which has been entirely written as a web software without any third party browser plug-in dependency, can be viewed in any browser supporting the latest HTML5, Javascript and WebGL specifications. Its presentation layer hides the heterogeneous nature of the real-time data coming from remote sensors, thus displaying data to the end user in a consistent and homogeneous way. Moreover, the presentation layer is optimised for displaying on different devices: MTTs, mobile tablets and personal computers. In particular, the platform is tailored to be used on MTTs enabling easier, collaborative data analysis. To further enhance the multi-touch collaborative experience, we introduced the realistic input reaction for widgets, to adhere to the user mental model of physical object movements. Future work will be focused on extending the collaborative interaction metaphors on multi-touch displays and adding support for touch-less interactions. Furthermore, given the increasing availability of augmented reality devices, additional research efforts will explore the use of the platform on such devices. Moreover, we will investigate how to describe the interface in abstract fashion thus enabling its auto adjustment depending on the used input device. Besides, an experimental campaign is scheduled to assess the potential advantage of using the platform, in a multi user environment, on a multi-touch table in a command and control room scenario.

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