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Flexible and Customizable Visualization of Data Generated within Intelligent Environments

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Abstract—**This paper outlines a tool for the visualization of data generated within Intelligent Environments. This tool has been designed with a focus on flexibility and customizability hence facilitating application to a range of areas including institutionalized or home-based healthcare monitoring. Through the use of an object toolbox, non-technical users can rapidly re-create a visual representation (aka a "Scene") of an intelligent environment and connect this scene to an active data repository. Data generated within the environment can be visualized in real-time, or summarized using a density ring visualization format that can be customized based on user defined rules to highlight events of particular interest. The tool was tested within a smart lab used as an active research environment. Collection of data over a one week period resulted in 3840 sensor activations. Visualization of this dataset illustrates the potential of the tool to highlight normal and abnormal activity trends within the environment.**

I. INTRODUCTION

Intelligent Environments (IEs) facilitate continual long-term pervasive data collection through the use of a range of sensor technologies. The sensor technologies employed are selected based on application scenario, research goals, stakeholder requirements, budget and availability. Such environments tend to be dynamic and evolve as constraints and requirements change. As a result, no standard IE hardware configuration exists, and the format of the data generated can vary significantly between environments, creating issues with comparison of results.

IEs can be used in a wide range of application scenarios, each presenting a diverse range of stakeholders with varying requirements and domain knowledge [1]. One popular area of research is the application of these environments to facilitate long term monitoring of health related metrics during institutionalized or home-based care provision [2]. A care home provides an example of a potential healthcare scenario in which an IE could be deployed. Stakeholders within a care home include: clinical staff members who are clinically trained and require detailed overviews of health metrics to aid the decision making process; patients and relatives who are not clinically or technically trained, however require insight into the progression of any health issues; and management staff who are not clinically trained and may be interested in clinical staff performance, space utilization and security issues.

Appropriate representation of data generated by IEs is necessary to facilitate optimal comprehension and usage. Visualization techniques can summarize vast amounts of data generated over extended periods of time, highlighting information of most importance and presenting it in a format that is considerate of a stakeholder's requirements and domain knowledge. Visualization of longitudinal trends in IE inhabitant activity aids identification of unexpected changes in behavior which may be indicative of decline in health. For example, a gradual increase in sedentary behavior may suggest the presence of an underlying issue that requires intervention. Data visualization can also facilitate abstraction from the underlying hardware architecture of an IE implementation, reducing the impact of hardware changes and facilitating direct comparison of heterogeneous data. Such visualization techniques must be flexible and customizable, allowing stakeholders to tailor visual outputs to meet their requirements.

This paper introduces a tool for the visualization of data generated within IEs. This tool is designed to be intuitive, flexible and customizable, suitable for use by non-technical stakeholders in a range of different use case scenarios. Section 2 provides an overview of related research into IE information visualization techniques and highlights areas for knowledge contribution. Section 3 provides an overview of the main components of the tool, with details of the implementation of these components provided in Section 4. Section 5 details the testing of the tool with user data and Section 6 provides concluding remarks.

II. RELATED RESEARCH

Existing research has employed a variety of approaches for the visualization of activity trends within IEs. Alexander *et al.* (2008) [3] developed a graph-based sensor data display technique capable of highlighting fluctuations in sensor activation levels of individual sensors over extended periods of time, with the potential of highlighting functional decline. A heuristic evaluation of the approach by clinical and non-clinical stakeholders rated the approach highly in terms of aesthetics and privacy, however, the evaluation suggested issues with ease of usage due to a lack of support for all users' skill levels. Wang and Skubic (2008) [4] developed a density map visualization technique capable of visualizing activity levels within an environment in relation to time of the day over a one month period and illustrated the ability of the approach to differentiate between active and sedentary living patterns. This approach, however, provides no

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additional contextual information relating to the distribution of activities within an IE, or the types of activities being performed.

The combination of spatial and temporal sensor activation information is necessary to provide additional context relating to activity performance within an IE. The floor-plan visualization approach is commonly employed to visualize real-time and simulated sensor data. Cook *et al.* (2010) [5] combined the density map and floor plan approaches, creating a technique capable of highlighting the spatial distribution of activity levels within an IE. This technique separates spatial and temporal data as the spread of activity levels over time is represented in a separate density map format. Thomas and Crandall (2011) [6] introduced PyViz, an interface primarily based on the floor-plan visualization method, capable of visualizing the location of sensor activations in real-time using sequential playback controls. An extended web-based version of this tool, CASASviz, was introduced by Chen and Dawadi (2011) [7]. In this approach, the frequency and location of sensor activations are represented on the floor plan using a heat map, and longitudinal information is represented in a separate activity graph.

The tool presented in this paper facilitates the representation of spatial and temporal data in a single intuitive format that can be customized through user defined rules. Flexibility and customizability is further provided through the ability to define customized objects, environments and rules through intuitive user interfaces without the need for extensive technical knowledge, maximizing the accessibility of the tool for stakeholders of various backgrounds.

III. The Proposed Approach

In order to provide a flexible and customizable visualization tool that can be used by stakeholders of mixed backgrounds, a number of key areas of functionality were identified. These were: Custom scene and object creation, real-time and longitudinal data visualization, and customization of data visualization. Each of these features should be accessible through an intuitive user interface. The proposed approach to facilitating this functionality includes the following series of related components:

- An *object manager* that provides a selection of pre-made objects and facilitates creation of custom user-created objects.
- A *database manager* that handles database connectivity, facilitating querying of the sensor database, providing real-time and longitudinal data for display within the scene.
- A *rule manager* that allows users to create and edit rules which tailor the way in which data is visualized.
- A *scene manager* that handles the placement and property management of objects placed within a scene.
- A *visualization manager* that handles scene rendering based on scene layout information and user-defined rules.

The relationship between these components is illustrated in Fig. 1.

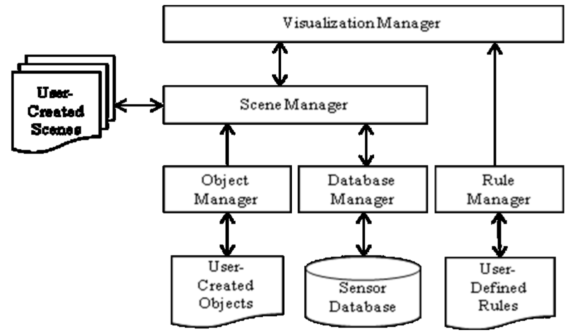

Figure 1. The relationship between the core components of the visualization tool.

The following describes each of these areas of functionality in further detail.

A. Scene and Object Creation

An object oriented approach is proposed in which all structures and sensors are considered to be objects with properties that can be adjusted by the user. By facilitating the creation of customized virtual environments (aka "Scenes") which represent the layout of a physical environment, users can create and modify such scenes to reflect changes within the physical environment. These scenes are constructed by populating a blank canvas with a selection of pre-made structural objects (such as walls and desks) and sensors which are associated with physical sensors. Users can expand the range of objects available for use within a scene through the creation of bespoke objects.

B. Real-time and Longitudinal Data Visualization

Real-time visualization of data is facilitated through the manipulation of a scene based on changes in physical sensor states. Virtual sensors will update in appearance to reflect the most recent state of the physical sensor with which it is associated. Users can establish these virtual-physical sensor associations through a properties menu. Longitudinal data can be visualized for individual sensors and summarized for an entire environment. To provide spatio-temporal context, this longitudinal visualization is superimposed within the scene.

C. Customization of Data Visualization

Customization of data visualization allows users to tailor output to meet the specific needs of the environment's stakeholders. This is facilitated through the creation of bespoke rules that define events of interest that may occur within the environment. Users can define which sensors the rule applies to, the criteria that form the rule and the method by which such events are visualized. For example, a user may specify that an alert should be generated if a specific sensor is activated after a certain time on a certain day and specify that an alert should be displayed within the real-time or longitudinal data visualization. This has potential application in patient wellbeing monitoring and security. Additionally, users can tailor the longitudinal visualization by specifying the metrics to be visualized and the represented time span.

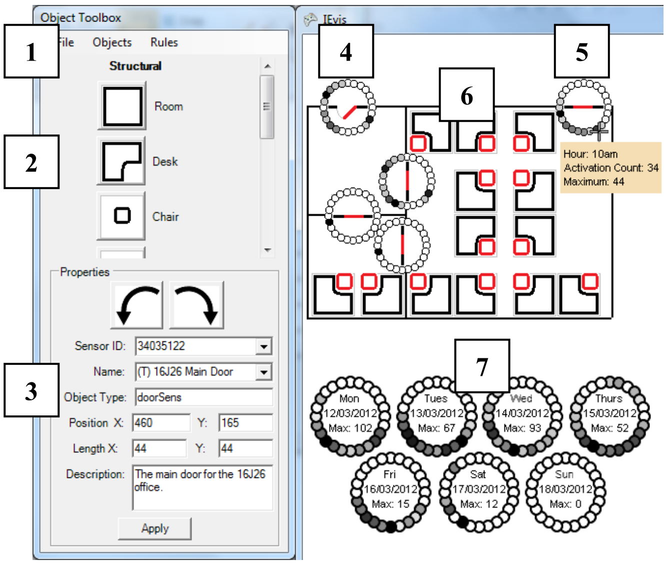

Figure 2. An overview of the main user interface of the visualization tool (1 - Customization Menu, 2 - Object List, 3 - Properties Menu, 4 - Open Door, 5 - Closed Door with Information Box, 6 - Current Scene, 7 - Week Summary).

IV. Implementation

The tool was implemented using C# with the Microsoft XNA Framework. Fig. 2 illustrates the main user interface of the tool, highlighting the layout and appearance of several of the main components. The following describes in detail the implementation of each of the system components.

A. The Object Manager

The Object Manager is presented to the user in the form of an object toolbox. This toolbox contains an object list (2) that presents a series of default structural and sensor objects that can be placed within the blank canvas area using a drag and drop interface. When an object in the scene is selected, the properties panel (3) updates to display the properties associated with that object, allowing the user to specify details such as the physical sensor the object represents, its orientation and a description. A dropdown list provides users with a list of all physical sensors found within the data repository. The customization menu (1) provides access to the bespoke object and rule creation wizards.

B. The Database Manager

The Database Manager contains all of the functionality required to connect to and query a live sensor database. The current version of this component has been designed to interact with a MySQL database with two tables: A 'Sensor' table, and an 'Event' table. The 'Sensor' table provides a description of each sensor in the test environment, and a unique ID. The 'Event' table is updated each time a sensor activation is detected, providing details including the ID of the activated sensor, an integer representing the type of event (e.g. Open/Close), and a timestamp. The 'Sensor' table is queried when using the object properties menu, providing the user with a list of available physical sensors that can be associated with a virtual sensor. Real-time and longitudinal visualization is facilitated through regular polling of the 'Event' table, providing information either about the most recent state of each sensor, or longitudinal metrics such as activity counts per hour for the previous 24 hour period.

C. The Rule Manager

The rule manager is presented as a Windows Form-based wizard that guides the user through the rule creation process. Users begin by specifying the sensors to which the rule applies. This may include all sensors, sensors of a specific type, or individually selected sensors. The rule criteria are then specified by selecting the condition (e.g. time activated), an operator (e.g. <, >, between) and a value threshold. The user can then specify the method by which the condition being met is visualized. This can be in the form of a customizable text message displayed in an alert box, or as an icon placed within the longitudinal visualization in the scene. Rules are stored in an XML format that records the name of the rule, the sensor the rule applies to (either an ID list of one or more sensors, a sensor type, or 'All'), the metric to assess (e.g. Activation Count), the operator (e.g. more than, less than, between), and a lower and upper (if applicable) threshold.

D. The Visualization Manager

The Visualization Manager provides the functionality associated with real-time and longitudinal data visualization. Real-time visualization is facilitated through regular polling of sensor states within the database. The visual representations of sensors within the scene are updated to reflect the most recent sensor state, an example of which can be seen in Fig. 2, where (4) is an example of a door which is currently open, and (5) is a door currently closed.

Longitudinal data associated with individual sensors is visualized in the form of density maps presented in a ring format around each sensor. The 'density rings' consist of a series of shaded segments that each represents a specified time interval. The shade of these segments is normalized based on the maximum value for the visualized time period. A white segment indicates a value of 0 and a black segment represents the maximum value for the time period. Shades of grey are calculated based on the percentage of the maximum value that the segment represents. The metric represented by each segment, the number of segments and the time interval represented by each segment are adjustable. This versatile approach allows the user to visualize information such as the number of activations per hour over 24 hours, or the total amount of time a pressure sensor in a bed has been activated per month over a period of one year. The approach can also be used to represent data from individual sensors or multiple sensors (7). One density ring may represent multiple sensors, providing a general overview of trends within the environment. By placing the mouse cursor over a segment, the user can view more detailed information about the represented metric, as shown in Fig. 2 (5).

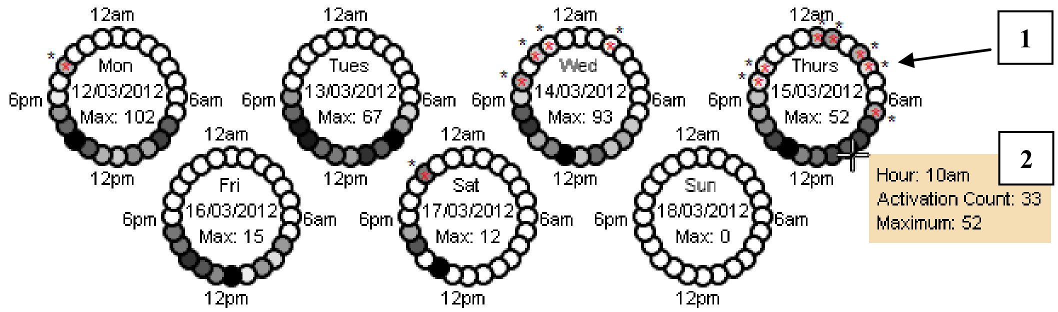

Figure 3. Visualization of one week of activity levels collected from all sensors in the smart lab. Asterisks have been repeated on the periphery of the density rings for the purpose of clarity in printed format. (1 - Asterisk indicating rule met, 2 - Information box)

E. The Scene Manager

The Scene Manager manages the placement of objects and elements of visualization within a scene. Scenes are presented in a 2D floor plan format for a number of reasons. Firstly, this technique allows users to view all sensors within an environment simultaneously, catering for rapid analysis and assessment. Secondly, when combined with longitudinal data visualization techniques, this approach can allow users to view both data in the spatial and temporal domain simultaneously. Created scenes can be saved in xml format for future use. Fig. 2 (6) provides an example of a scene representing a typical shared office environment.

V. Testing and Evaluation

The tool was tested in the University of Ulster's smart lab environment [8]. This environment consists of a series of single occupancy and shared research offices, a meeting room, a kitchen and a living room, all populated with a suite of sensor technology including PIR sensors, door sensors, floor pressure sensors and bed/chair occupancy sensors. The tool was capable of visualizing the real-time state of the environment and updating sensor icons to reflect changes in status. The longitudinal visualization technique was capable of highlighting trends in activity levels within the environment. Visualization of one week's activity levels (Fig. 3) summarized 3840 sensor activations collected from all sensors in the smart lab. This illustrates clear trends that would be expected in a typical office environment. It can be seen that the most active periods from Monday to Friday are typically 8am-6pm, with spikes in activity commonly occurring before and after the lunch period (12pm). Activities at the weekend do not follow this pattern, and activity levels can be seen to be much lower. For the purposes of testing, a rule was created that would highlight any activity during off-peak hours (between 8pm and 7am). Indeed, 12 such events were detected.

VI. Conclusion

This paper introduces a tool developed to facilitate the flexible, customizable visualization of data generated within IEs. The core components of the tool have been discussed, and the implementation of these components has been demonstrated. Testing of the tool was performed on real user data collected from a smart lab based in an active research office environment. The tool has been shown to be capable of facilitating the creation of a virtual environment, facilitating visualization of the real-time status of sensors within the environment and visualization of longitudinal trends in activity levels of individual sensors. Visualization of overall environment activity levels over extended periods of time has been demonstrated using a density ring format in addition to the use of a rule-based approach that facilitates highlighting of events of interest. This technique proved to be capable of illustrating trends that are expected within a typical office environment and was capable of highlighting unexpected behavior. These results suggest that this approach could be transferred to other areas such as long-term health monitoring, facilitating the illustration of trends in patient activity levels and alerting healthcare professionals to key events of interest. Future work will involve the testing of this approach in a clinical environment to assess the ability to identify changes in patient wellbeing, and evaluation of the software by users of various backgrounds to provide a detailed usability assessment.

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