The information visualization based on the sensor network: the survey

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Abstract——In this survey project, the data visualization and information visualization in the sensor network are the main topics. Base on the literature review in related topics, this project report will summarize some of the encoding methods with the framework they proposed. The main section of this paper will be separated into three sections: visualization in properties and problems on sensor network, visualization in health-care, tracking and position in indoor environment, visualization for environmental sensing and monitoring in city or region-scale. For each example for selected papers, "what" "why" "how" will be analyzed as well as the scale of each application. These analyses will be presented as a table and followed by the explanation. The evaluation of encoding methods and idioms which have been used in each example will be provided in the result section. The evaluations for different application scales will be provided in discussion section as well as the future work of this survey project. In the summary section, the works and contributions of this survey project will be illustrated.

1. Introduction

With the development of WSN (wireless sensor network) and IoT (Internet of things) in the recent decade, it indicates that the era of Big Data has approached. The sensor network is the infrastructures of these high-level applications regardless wired type or wireless type. Hence WSN has been applied in various fields, for example in small-scale, WSN applies on health-care, indoor monitoring, and positioning; in large-scale, the traffic tracking and environmental monitoring have been applied more attention. With the development of society and high-requirement for daily life, the demands of sensor network have reached an unexpected high-level in quality and quantity. The rapid increase in the number of various sensor networks generates even larger amount of "raw" data which are unstructured data from different sources globally. Data and information created by internet activities and expanding number of sensor networks [1]. With more information has emerged in our view, the decision-making process is more difficult than ever. Millions of data and uncountable information which may support decision-making progress have been produced every second. Hence the requirements for effective and reliable decision-making have been demanded based on the information in different sources. Therefore, the reliable and effective information or data visualization tools, frameworks and idioms are required. Indeed, the effective and reliable techniques can benefit the representation of information and data and help experts and analyst understand or manipulate data easily. This is the reasons and motivations for presenting this survey project. I want to explore these techniques which have been applied in the field of sensor network. Comprehension of how and why the idioms applied and understanding the task and data we faced are critical important for abstracting the useful information from the "raw" data, furthermore it can benefit the decision-making progress.

In [1] the authors give the definition for information visualization, "information that has been abstracted in some schematic form, including attributes or variables for the units of information." Data and information visualization are both an art and science. The approaching for visualization must be effective and reliable as far as it can be, such as limit information loss, prevent the distortion of data and present the useful information in more comprehensive way.

In paper [22], the author gives the definition for the sensor network, "the low-cost, low –power sensor devices make up hundreds or thousands of ad hoc tiny sensor nodes spread across a geographical area. These nodes collaborate among themselves to establish a sensor network. A sensor network that can provide access to information anytime, anywhere by collecting, processing analyzing and disseminating data. Thus, the network actively participates in creating a smart environment." Based on the definitions, the sensor networks consist of thousands of sensor nodes which can access and process information. The network without sensor nodes and the ability of processing information, it is not a sensor network.

In [1] the author also gives the definition of the sensor, "a device that receives a stimulus and responds with an electric signal whereby stimulus is the quantity, property or condition, that is sensed." Sensor network consists of a large number of sensor nodes. The Fig.1 below will show the overall structure of sensor network.

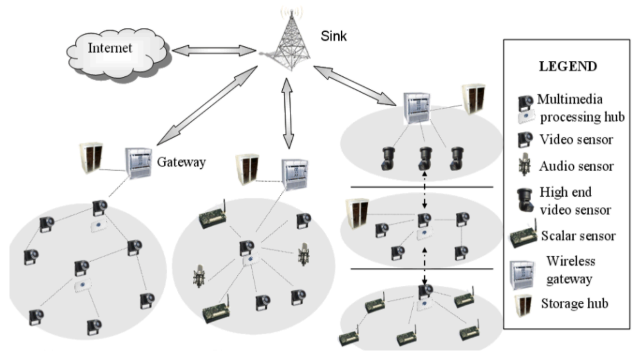

Fig.1. the overall structure of sensor network. [21]

As can been seen in Fig.1, there are three layers to construct the entire sensor network regardless of wireless type or wired type.

- First, the basic unit is sensor node which forms the first layer of the network. All kinds of sensors have been applied in the various fields, such as light sensor, humidity sensor, and temperature sensor. They provide environmental stimulus with the response of electric pulses, which indicate the state or the change of environmental condition.
- Then, the sink node/ base station would appeal in the view as the second layer of the network. This is a middle station between the sensor nodes (beginning place) and clinics/ users/ analyst (destination). All the sensor nodes forward all sensed data to the sink node via the network. It processes the "raw" or unstructured data into comprehensive content for the users and analyst. Some of the information visualization frameworks and tools can take place here for representing some basic information such as received signal strength for ZigBee [3] and the coverage/ energy consumption for sensor network or each sensor node. [12]
- Finally, it comes to internet/ application/ end user layer. This is the destination for sensed data. It is the interface which can provide the explorations and interactions of wanted data. Most of all the frameworks and tools are applied in information visualization fields. The derived data such as human emotion sensing based spatial location and activities [20]and adult and elder heathy tracking [2] [11] can provide more insights than original "raw" data. The encoding frameworks and idioms in this layer are the main content of this survey project.

In the following sections, the main body of this survey project will be revealed. The next section will illustrate the related works in this fields. The main body section will be separated into three parts based on the scale of applications about the information visualization, such as visualizations of properties and security problem of a sensor network, the home and indoor scale (small scale) applications and urban scale or region scale (large) applications. They will be introduced respectively in the body section. In the main section, for each example, the analysis table will be provided. The analysis table will contain several important analyses: what are the names of the encoding idioms or systems, what data has been encoded, what attributes have been derived, what tasks should be achieved, how the systems encode the data, how the system manipulate with data, how the facets look like, what is the scale of sensor network.
Then discussion and future work section will be provided next to result section, each section from the three result sections will be assessed and evaluated. The summary will be provided at the end of the survey project to summarize the overall structure of this survey project and the insights from each example.
The overall contributions of this survey project will be list below:

- Provide the overall review of state of art in information visualization in the various sensor network
- Analysis the encoding method/ idioms and task/data which have been applied in the fields
- Discuss the current methods which have been applied and evaluate the results for current applications

2. Related works

Based on the literature review I have done so far, there are not identical survey paper existed. However, there are some papers with relative topics existed, for example, "Visualization of Multidimensional Sensor Data in Industrial Engineering" [6] "Wireless Sensor Network Security Visualization" [8] and "Visualization of Data for Ambient Assisted Living Services" [17]. In paper [6], it provides the overall review of information visualization based on the sensor data in various applications in the industrial field. In this paper, authors provide multiple encoding methods such as a spiral shape with star glyph and circle views by facing temporal and temporal multidimensional data. The paper also illustrated tasks and requirements in information visualization, In the end of this paper, the author proposed a visualization environment/ interface for better comprehension and this interface will provide an overview of data as well as the detailed information simultaneously. In paper [8], it provides the overall review of security for the sensor network, it visualizes the whole network and emphasis the sensor node which may be in danger by visualizing the network traffic. It mentioned the power of visualization in the sensor network in term of network security. It provides the problems as well as the existing tools in the field. The research challenges have been mentioned at the end of the paper. Paper [17] provides the information visualization idioms for ambient assisted living (AAL) services in commercial and academic examples. This survey paper has clearly defined the users, roles for each participant and the examples. It also provides the case study in the end. These papers with relative topics provide the overall review on each field, but there are not providing the big picture of the sensor network on data and information visualization. There are more relative survey papers available with relative topics.

3. Sensor network property and problem visualization

For sensor network itself, there are many "raw" or unstructured data which may need information visualization to present the data. For example, the topologies of network and visualization of unworked sensor nodes in the network, they all prefer effective and reliable visualization for identifying the problems or overview of the network for specific need from industry.

3.1 Visualization of Wireless Sensor Network by A Java Framework For Security In Defense Surveillance

Paper [4] has demonstrated a framework for the proposes of security for a whole sensor network. In this paper, the author proposed a visualization for the topology of WSN as well as the sensor network deployment. The proposed framework is based on the sensor network deployment.

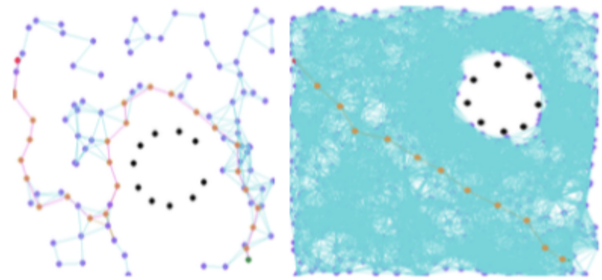

Fig.2 the visualization of sensor network from ring topology for 100 nodes and 1000 nodes in NetTopo simulation

In Fig.2, it presents the ring topology of the sensor network. It applies the node-link diagram to encode the ring topology in the sensor network. In my opinion, the node-link diagram is usually applied to encode the topology of the small sensor network. They use the different color hue (orange) to indicate the shortest path from source node to sink node. Blue has been used to encode the connection between each sensor node. In 100 sensor nodes (left), the connection and shortest path can be seen clearly. As the number of sensor node increases (right), this node-link diagram would not be the optimal solution.
As for the solution for visualizing the topology for a large sensor network, it could provide the 3D models which support the rotation of the model. It can provide the view in multiple directions. The topological fisheye [25] view would also be a good visualization idiom to choose. If more demands from the users have emerged, for example, visualization for different levels of the sensor network. As the most distinguishable encoding method, the different color hues can be applied to encode the different levels of a certain sensor network, rather than only encode the shortest path in the network.

System	NetTopo
What: data	the topology strategy
What: derived	One topology strategy per node-link diagram, shortest hopping path in the sensor network
Why: tasks	Display the different topologies for sensor networks, compare the different number of sensor nodes in topology, display the shortest path in sensor network topology
How: encode	Node-link diagram: the node has been used to indicate the sensor nodes, links between nodes to represent the connections in the sensor network, color hues have been applied to encode the sensor network: blue as usual sensor network, orange to indicate the shortest path among all the paths

Scale	100/1000 sensor nodes

Tab.1 visualization of topology for sensor network by NetTopo analysis table

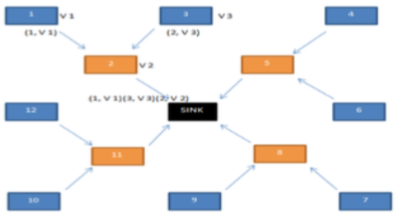

Fig.3 the visualization of sensor network layout for the proposed system

Fig.3 shows a small layout of the sensor network for the proposed system. The node-link diagram has been applied to encode this layout. The author presents the sensor node by using a rectangle rather than a dot. In each rectangle, the serial number of a certain sensor node has been provided as well as the label which indicates the level and position, for example (1,v1) indicates that it is first sensor node in the first level. Different color hues encode the different level of the sensor node. (blue as the first level of sensor network (source node), orange as second level (gateway) and black as terminal node or sink node)

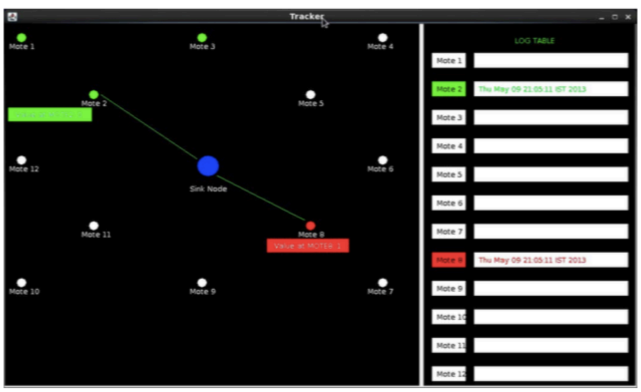

Fig.4 the visualization of sensor network deployment GUI (graphic user interface)

This interface in Fig.4 can view the topology of the sensor network, which is based on the layout from the Fig.3. The color hues have been applied to encode the state of the sensor network, blue node works as sink node, green one indicates the sensor node which received safe data from the source. The red node represents the node with danger data.

The node-link diagram has been applied to encode the topology strategy, dot mark indicates the sensor nodes, the rectangle below the dot marks show the label of the timestamp. The link indicates the commotion between nodes. The table on the right is the timestamp of each node. The level of the node can only be told by the links. For example, mote 2 has directed link with sink node, which indicates that it is single hop-distance from the sink node, as same for two hop-distance. The selection and navigation have been applied to the interaction. For each selected node, the detailed data it received can be seen in another window.

As for the improvement for this GUI, I do think they can provide more information from the sensor node rather than the simple timestamp for each node. It only supports the visualization of the small number of sensor nodes, which is the main limitation of this visualization. If the author wants to provide the visualization for the large sensor network. The original topology layout (Fig.3) should be reconsidered.

System	Java framework
What: data	Information from source node (timestamp), topology information (logical position)
What: derived	Network level in sensor network, sensor with danger information
Why: tasks	Display the topology and security states of sensor nodes
How: encode	Color hues: in GUI of java framework, blue encode the sink nodes, green indicate the node in safe state, red is in danger state. node-link diagram: the dot mark has been applied as node to represent each sensor, the rectangle below shows the timestamp, the line between each node indicate the connection for the sensor network
How: manipulate	Selection for each node and look the timestamp for them, navigation among the nodes
Scale	13 sensor nodes

Tab.2 Java framework analysis table

3.2 Wireless Sensor Network Security Visualization

Paper [8] present multiple visualization tools for security of sensor network. The Vis-alter has been applied in this paper to visualize the sensor network.

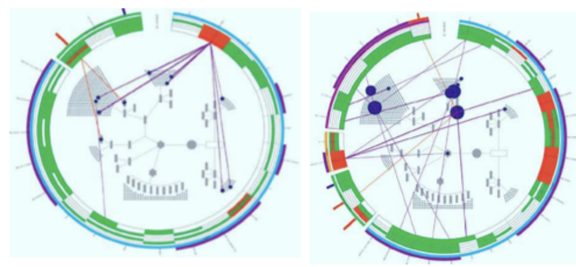

Fig.5 the visualization of sensor network by applying VisAlert

The visualization tool "VisAlert" has been applied for security detection. This VisAlert is based on the W3 concept: what, when and where. These attributes are capable of describing and comparing the heterogeneous events. As can be seen in Fig.5, the network topology map has been displayed in the center of surrounding ring. The ring width has been divided into several sections to represent the different time periods. The color hues in surrounding rings encode the secure events and danger events. The area of line mark on the ring encode the number of the alters, the area of the node also encodes the state of alters. The thicker lines show a higher number of single time alters and the larger node in topology map represent the unique alerts which may be at high risk. The node-link graph has been applied in this case. This idiom has been applied to encode the relationship between the specific sensor node and alerts events in this security problem visualization. The node inside the circle links the surrounding circle to indicate location, time and event for a certain sensor node.

The author of this paper did not provide more detailed information about this case. However, if the scale of the sensor network is enlarged, the visualization would be disordered. In my opinion, the inactions like navigation and selection should be considered. Then the detailed information for each node, date, and event can be displayed more clearly even in a larger sensor network.

System	VisAlerts

What: data	states of events, topology of the network, the time and duration of event
What: derived	the topology of network, the occurrence of events in time and logical location (not the spatial location, is the level or cluster location of sensor node)
Why: tasks	Display the relationship between time/logical location of event and events, show the topology
How: encode	Size of the marks: size of the line mark indicates the number of event, the size of dot mark indicates the uniqueness of events, color hues: red indicate nodes are in danger and green means safe state, node-link diagram represents the topology of the network, also encode the relationship for events and sensor nodes in time and in location

Tab.3 VisAlert visualization analysis table

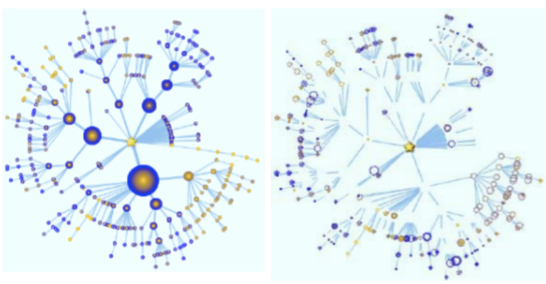

Fig.6 the visualization of sensor network topologies with flat TEM and flat TEM with anomaly ring

As one of the widely used idioms for node-link network layout, the force radial directed tree-map has been applied in Fig.6. This idiom has been applied to encode the topology of the sensor network. The author employs the traditional radial directed tree-map layout to visualization the distribution of sensor node. However, the exact spatial location does not encode any attributes. The anomaly changes in the sensor network have been encoded by different color hues: anomaly change has been encoded by the hollow circle with yellow ring, the node without change is in solid blue, as can be seen on the right of Fig.6. This radial directed tree-map can see the cluster and detailed layout of network topology in each cluster of nodes.

As the improvements for this visualization, the zoom-in and zoom-out or selection with popup window can be considered as improvements for better visualization results.

System	Radial directed tree map
What: data	Change of the event, topology of the sensor network
What: derived	the cluster of network, the change of the sensor node
Why: tasks	Display the topology of sensor network, indicate the change for each sensor node
How: encode	Different marks: the solid blue circle indicate the node with no anomaly change, the hollow circle with yellow rings indicate these have anomaly change. Node-link diagram: it applies the node as sensor nodes in sensor network and links indicate the connection between nodes

Tab.4 Radial directed tree map analysis table

3.3 Visualization of efficiency coverage and energy consumption of sensors in wireless sensor networks using heat map

This paper [12] mainly illustrates the visualization of coverage and energy consumption of sensor network. These two visualization problems are key concerns in the WSN field. The effective visualization for network coverage and for energy consumption will alleviate the works of WSN allocation and replacement. As can be seen from the title, the heat-map would be the main idiom for achieving the visualization of these two concerns. This paper proposed a CROWD structure to visualize these problems.

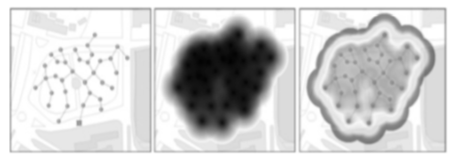

Fig.7 example of visualization of coverage by heat-map

In Fig,9 the GIS (geographic information system) has been used as the general geographic layout of visualization area. The first graph on the left presents topology layout of the sensor network. The color brightness encodes the coverage area. The second graph above shows the coverage area of sensor network; however, the topology layout is covered by the shadow of the mask. Hence the third figure has been set for better clearness. The boundary shows the edge of sensor network coverage, the color brightness indicates the strength of the signal and the node-link diagram shows the network topology.

Fig.8 example of GUI of CROWD

Fig.8 has demonstrated the interface of proposed CROWD. The map tools and node tools have been applied for interaction propose. The nodes from the sensor network can be selected and the detailed information such as ID and lifetime prediction will be presented. The attributions table for each selected sensor node has been displayed on the right of this interface. The event table has been listed at the bottom of the interface.

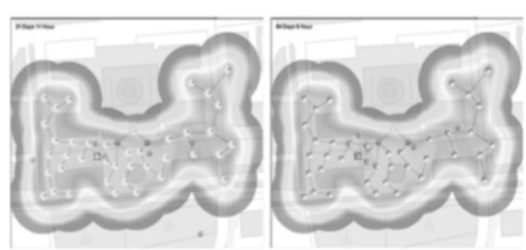

Fig.9 example of visualization in remaining energy of sensor network in pie chart.

The life-time prediction has also been shown in the overall geographic map. In Fig.9, it may not show very clear, each node is small pie chart to present the energy consumption and remaining battery life. Energy consumption and remaining energy have been encoded by the black and white respectively.

System	CRODW
What: data	Allocation of sensor node, coverage and battery life prediction of sensor node
Why: tasks	Display the topology of sensor network and physical allocation, display the coverage of each sensor node, compare the remaining energy and used energy
How: encode	Pie chart: for battery life prediction, white indicate the energy which has been consumed, grey indicate the remaining energy; color brightness: indicate the coverage area of sensor node, the brightness indicates the signal strength the boundary has been shown in dark grey; node-link diagram: display the allocation and topology for sensor network
How: manipulate	Selection: each node can be selected and detailed information for the sensor node will be display on the right; navigation among the network

Tab.5 CROWD analysis table

3.4 NetTopo: A framework of simulation and visualization for wireless sensor networks

Paper [15] introduce the NetTopo simulator for visualizing the topology of the sensor network. The limitations of this framework have been mention in previous section 3.1: not optimal for the large-scale sensor network. For a large number of sensor networks, the topology of sensor network will be ambiguous or even be chaotic.

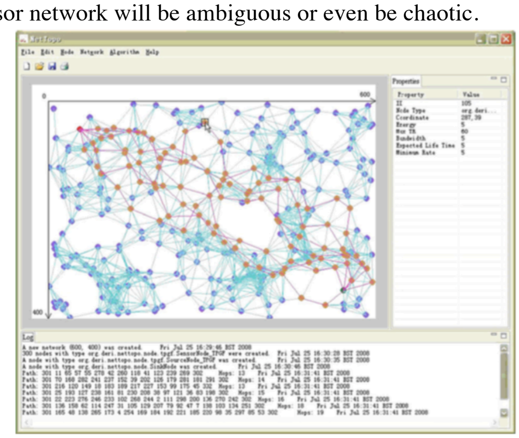

Fig.10 the example of NetTopo interface

The figure above provides the GUI (graphic user interface) of NetTopo simulator. The encoding method as section 3.1mention, the node-link diagram encodes the topology (dot as sensor node, line as the connection between each node) and the color hues have been applied to indicate the shortest path (orange) in the sensor network and normal link between nodes (blue). The properties table has been listed on the right of the topology graph. The information log is at the bottom of the interface. The selection can be performed as interaction in this interface. The properties menu can show the detailed information for each selected information.

System	NetTopo GUI
What: data	Connation between each node of sensor network
Why: tasks	Visualize the topology of sensor network
How: encode	Node-link diagram: dot mark indicates the sensor nodes and links indicates the connection between each node, color hues: orange indicate the shortest path, blue represent the normal link
How: manipulate	Selection: each node in the sensor network can be selected, the information for the node will be presented on the right

Tab.5 NetTopo GUI analysis table

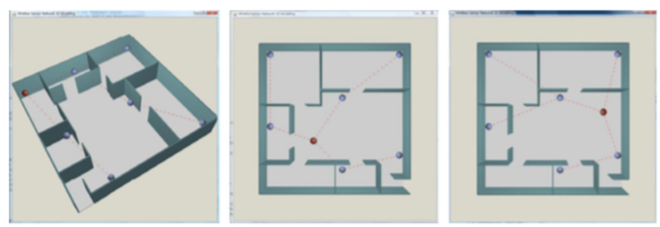

Fig.11 the crossbow example of 3D visualization in house model

The 3D visualization for allocation of sensor network. The different color hues have also been applied for the distinction of sink node (red) and source node/gateway (blue).

System	3D model
What: data	Allocation of sensor network, layout of the room, connection between sensors
Why: tasks	Visualize the geographic allocation and topology of sensor network
How: encode	Node-link diagram: dot marks as sensor node, line indicate the connection, color hues: red as source node, blue as gateway
Sacle	7 sensor nodes in a room

Tab.6 3D model analysis table

4. Small scale applications (Health care and indoor tracking/ positioning) visualization

With the development of IoT (internet of things), many applications (smart-home applications) in a domestic area have been paid more attention to. In last decade, many applications based on health-monitoring, indoor tracking and even human-activities predictions have been developed. These domestic applications of sensor network will provide packs of "raw" or unstructured data in the field, which may need a clear and comprehensive form of representing under the help of better data visualization. Especially in certain applications such as tracking/ positioning and activities prediction, the misrepresentations or unclearness of information visualization would lead to unnecessary and unexpected problems. Hence the data visualization would be crucially important in these applications. To prevent the unclearness and misrepresentation from happening, the literature review for domestic applications will be done in this section.

4.1 Visualization of Wireless Sensor Networks using ZigBee's Received Signal Strength Indicator (RSSI) for Indoor Localization and Tracking

Paper [3] has proposed a sensor cloud framework for ZigBee sensor network for indoor tracking and localization based on RSSI (received signal strength indicator). ZigBee is a specific communication protocol with a standard medium control (MAC) and the physical lay protocol for low-power devices. Hence it is suitable for the indoor WSN applications. Based on the RSSI for sensor modules, the visualization for localization and tracking would benefit the applications in the field of WSN. In this section, only the visualization and the encoding idioms will be explained.

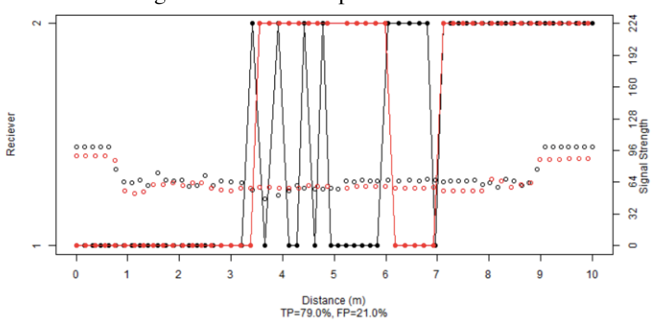

Fig.11 transmission of testing tag in two beacons

Fig.11 presents the signal availability and signal strength with respect to distance. Line plot, dots, and different color hues have been applied to encode the transmission of two beacons. The different color hues (black and red) encode the signal for two different beacons. Line plot idiom is used to encode the transmission between two beacons. The dot mark as signal strength reading has also been present in Fig.11. The summary for transmission have been presented under the figure, they provide true positive localization in 79%.

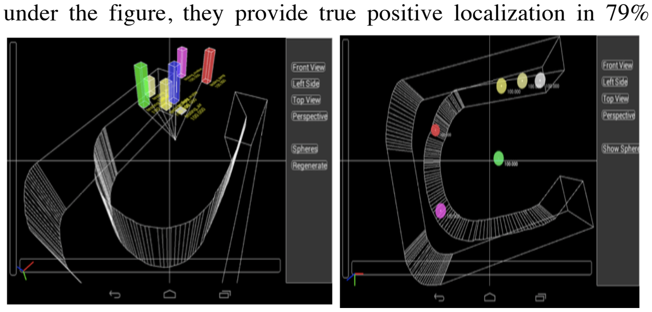

Fig.12 3D visualization for sensor network allocation and sensor data value by Envis

Fig.13 has applied 3D Model to visualize the indoor environment. Color hues represent different sensor node. bar chat and spheres have been applied to encode two attributes of the sensor network. The height of the bar chart or the size of the spheres is used to encode the volume of data for each sensor. However, the bar chart is focused on the comparison of the volume of data and the sphere mark is concentrated on the allocation of sensor network on the map. As can be seen in the left menu bar of 3D map, the different points of view (top view, front view and side view) can be selected as well as the bar chart and sphere mark. The rotation for this 3D map an available function in this 3D visualization. This visualization interface can also present sensor data at the different time. This visualization is suitable for multi-sensor monitoring applications.

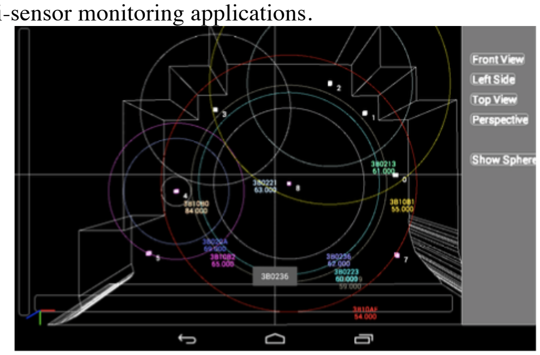

Fig.13 visualization for 3D sensor network allocation and RSSI by Envis GUI

The Fig.13 has indicated the signal strength on the 3D model from the top view. Each white dot with the number beside is then sensor node which has been placed in the room. Each circle with different colors and radius reflect the different estimated values of RSSI. The center of each circle is the coordinated beacon. The beacon in the center of the room can be located and tracked by the surrounding beacons.

GUI is relatively easy compared with GUI for other applications. To ensure the clearness of geographic map, the labels and parameter should not be placed on the map. As for the interaction, the selection for each sensor node should be considered. Each sensor node can be selected and viewed in detailed.

System	EnVis GUI
What: data	Spatial location, data volume
What: derived	Two attributes of sensor network: allocation (physical position) and RSSI
Why: tasks	Compare data volume, display the spatial location in 3D map, tracking the moving objects based on RSSI
How: encode	Color hues: side-view map, dot marks have been encoded by different color hues to indicate different sensor nodes, in top view map, different color hues have been applied to encode the different RSSI; Bar chart: height of bar chat encode data volume; dot mark: in side-view map, the size of dot mark encode the data volume. In top-view map, the white dot indicates the location of sensors. The large circles with different diameters encode the different RSSI value
How: manipulate	Selection for changing the view point, rotation for 3D model and navigation of the data in space and time
Scale	9 ZigBee modules

Tab.7 Envis framework analysis table

4.2 Visualization of movement of older adults within their homes based on PIR sensor data

For better understating of paper [11], PIR sensor stands for passive infra-red sensor. This paper has proposed a research of visualizing the activities and movement level for older adults. The sensor nodes have placed in each room for proceeding the better analysis results.

Fig.14 2D visualization for sensor network data in GNH apartment

As can be seen in Fig.14, the background apartment layout has been colored by different saturations of green color. The saturations of green have been applied to encode movements. The lighter green indicates the subtle movement, the darker green present less subtle or high-density movement. The half-circle in blue of Fig.13 is the sensor node location. It is an example of space-filling model in house model. However, there are several rooms have not been sensed by the sensor network. It does represent the movement density directly, however, when the various density has been applied in the map. Users are usually harder to tell the differences by using the different color saturations. Applying the sequential color hues would be a great improvement for higher differentiability.

System	2D visualization room model
What: data	Movement data
What: derived	The movement density
Why: tasks	Display the movement density in each location, find the activity pattern
How: encode	2D-space filling model by using saturation of color: dark green indicates the higher movement density, light green show lower density. Mark: blue half circle indicates the location of the sensor
Scale	3 motion sensors in a room

Tab.8 2D room visualization framework analysis table

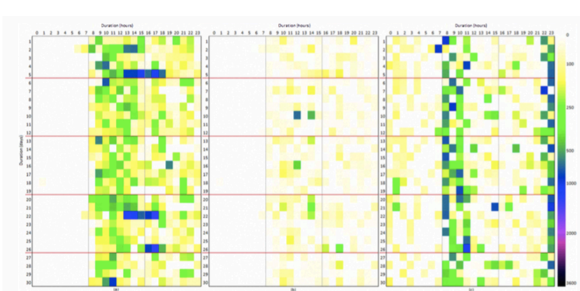

Fig.15 visualization for PIR motion sensor data in different location of apartment

In above figure, it presents a density map visualization to encode the movement for an older adult in different rooms, different date and the different time. The color bar on the right use sequential colors to encode the sensed movement in an hour. Black indicates the high-density movement in an hour (movements can be sensed in each second) and white indicate the no movement sensed in an hour. The other sequential colors in between indicate the middle density of movement. For each figure, it has been separated into 24 columns and 31 rows. Each row indicates the different date of the months, each column encodes the 24 hours a day. The first graph represents the movements, the second indicates the movement in the hallway and the last represents activities in the bedroom. This 2D space-filling model can directly display the activities pattern for a certain person. This visualization idiom presents great performances on visualizing the activities pattern in different date and locations.

System	Density map
What: data	Motion data
What: derived	The activities pattern of a person
Why: tasks	Visualize the movement pattern of different locations in an apartment in different date, find the activity pattern
How: encode	sequential color hues: indicate the different density of movement
Scale	Dozens of motion sensors in several rooms of an apartment

Tab.9 movement analysis framework analysis table

4.3 Visualizations of Human Activities in Sensor-enabled Ubiquitous Environments

Paper [13] present a structure of visualizing human activities based on the sensor network. The changes in human activities level should focus on visualizing the characteristics of the activities. However, the characteristic often present in non-pre-attentive element from the sensor data. In this section, their visualization will be explained and displayed below.

Fig.16 visualization in detail supporting pre-attentive and non-pre-attentive

In above figure, it presents the shape marks and line plot to encode the change from an activity to another. The x-axis indicates the time and Y-axis shows the accelerometer. The different colors indicate the different types of useful time-depend data. Based on the line plots, the superellipsoid based glyph has been created. In total, there three types of 3D glyphs: sphere, rectangle, and diamond. The glyphs with square-corners indicate non-violent, the rounded corner indicates the moderate activities and the pinched-corners represent violent activities. The three line plots indicate the three dimensions of the 3D glyphs. There are some shapes between the diamond, rectangle, and sphere, they indicate the middle state of activities. The shape sizes are based on the amplitude of three plot. The blue-spot indicates the average vector of all three plots. The visualization for human activities is not easily comprehensive with even less information in the paper. This visualization is difficult for people to understand the content without the background information for the data. In paper [19], it does not provide the information about the line graph. These three line plots can be thought of the body movement in three directions. They are generally thought as time-dependent variables with accelerations in three directions.

System	Human activities framework
What: data	Three time-dependent variables with accelerations in three dimensions (not mentioned in detail)
What: derived	The movement transition of human activities.
Why: tasks	Visualize the transition for each activity
How: encode	Line plots: present three time –dependent variables with accelerations; color hues: green, red, blue as three variables, shape of 3D marks: the X, Y and Z axis have been used to present the accelerations in three directions
How: facet	3D figures above the three line plots
Scale	Sensors network in ubiquitous environment (in the experiment of this paper, sensor network has been applied in a room)

Tab.9 visualization of transition for activities analysis table

4.4 Density map visualization from motion sensors for environment activity level [14]

Based on the sensor network, the author has proposed a visualization for elder care and motion monitoring. The density map model has been proposed as solutions for the activity visualization. Based on the visualization of allocation for sensor network, the algorithm for determining the "away" and "at home" states have been proposed in the paper. The visualization for sensor network allocation is a basic 2D layout graph for a certain apartment, which will not be mentioned in this survey.

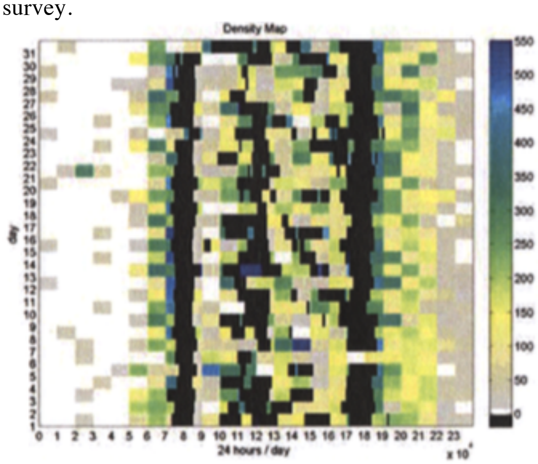

Fig.17 visualization for motion sensor network

Fig.17 and Fig.15 have almost the same encoding idiom, this figure shows the motion sensed data in a certain location of the apartment for an entire month. The x-axis indicates the 24-hour day and Y axis present days in a month. The main difference between Fig.15 and Fig.13 is the color hues as an encoding channel. Indeed, they all apply the sequential colors bar to indicate the different density of daily activities. However, the sensed data has been pre-processed to determine the different states of activities. The black represents the state of "away from home" and white represents that there are no activities happened in the room (no sensor fired). The color changes from grey to dark blue as the density of events per hour increased. However, the algorithm for pre-processing sensed data are vital for the correctness of this visualization. The algorithm is also an effect for the visualization.

Compared with the section 4.2, it provides the algorithm for determining the state of activities. In the content of the paper [14], the algorithm is not convinced, which may affect the behaviors of visualizations.

System	Density map
What: data	Motions in the room
What: derived	The state of activities for a person
Why: tasks	Visualize the motions in a room for certain day and time, find the activity patterns
How: encode	sequential color hues: the different color hue indicate the different motion states
Scale	In several rooms of an apartment

Tab.10 motion sensor network analysis table

4.5 Visualization of Data for Ambient Assisted Living Services

In this paper [17], the author has proposed visualizations for AAL (ambient assisted living) service. It illustrates an idea "explain how the visualizations convey the information across time and location" [17]. This citation from the paper holds the key propose of visualization in indoor tracking and motion sensing. The ALL service collects motion data for different uses, for example, it alerts an emergency incident, unexpected behaviour, and assists daily living activities. In this section, the main visualizations have been applied in the paper will be explained.

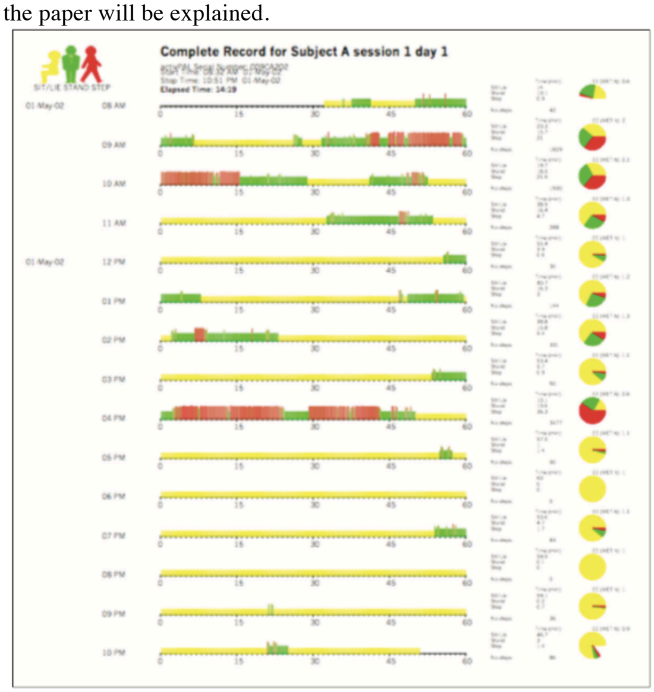

Fig.18 visualization for a 72-year-old object over 14 hours

The data is collected from activePal wearable sensor network in Fig.18 This figure mainly indicates the three states (sit/lie, stand and

step) over 14 hours when the object is awake. The different color hues have represented the different states of object: yellow indicates the sit or lie state, green represents stand state and red color indicates the walk. The bar chart and pie chart have also been employed for comparing for these three states. The height of bar chart indicates three states, the different portions of pie charts present the different states which occupied in an hour.
This visualization cannot provide the clear representation of an object in a day, for example, the exact behaviors have been taken in the day cannot be presented. This visualization is designed for special propose, it only emphasizes the states for the person in a certain period.

System	Mixed charts
What: data	Time data, movement states (sit/lie, stand and step) data
What: derived	The activities pattern in 14-hour for a centain person
Why: tasks	Display the duration for three states in 14 hours, find activity pattern and part-to-whole relationship
How: encode	Color hues: used to encode three states, yellow as sit or lie, green as stand and red as step. bar chart: the height of bar chart encodes the three states: highest bar as step, middle one as stand and lowest one as sit or lie. Pie chart: compare the time duration for three states in an hour
How: facet	The label for three states have been list on the top left, the bar chart stays in the middle of the figure, the pie chart display on the right
Scale	Wearable sensor network in a person

Tab.11 mixed charts visualization analysis table

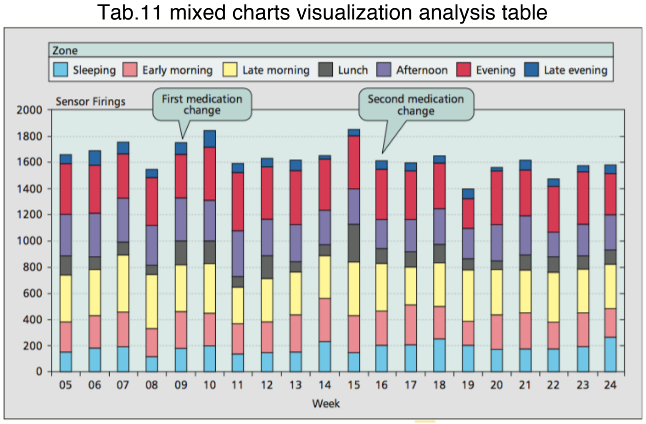

Fig.19 visualization for motion sensing data in a day for object

As can be seen in Fig.19 the stacked bar chart idiom has been applied in visualization for a better result for comparison. The x-axis indicates the date and Y-axis show the number of motion sensor fired. The different color hues illustrate the different period of a day. (blue for sleep, pink for early morning, yellow for late morning, grey for lunchtime, purple for the afternoon, red for evening and blue for late evening).

System	Stacked bar charts
What: data	Time data (duration),
What: derived	the number of sensor fired for specific time in days
Why: tasks	Visualize and compare the activities density for a person in days, show the part-to-whole relationship, find the trends
How: encode	Color hues: it used different color hues to indicate the different time period in a day, to be specific, the legend has been listed on the top of Fig.17. bar chart: the height for bar chart is used to encode the number of sensor fired for each time period in different color hues. X axis represent the different date
Scale	Wearable sensor network in a person

Tab.12 stacked bar chart visualization analysis table

Fig.20 visualization for wellbeing training in garden map

Fig.20 has presented an interesting visualization idiom called garden map. Rather than use simple colors or shape to encode the activities, it applies the different flowers to indicate the different trainings or exercises. The legends have been listed on the left of the garden map. The position of flower indicates the sequence of exercises which have been taken. The height of the flowers in indicates the duration of each exercise. The butterflies show the completion of exercises. It presents an easy understanding and interesting visualization idiom by the garden map.
Fig.18 indeed provides an attractive visualization idiom, however, without scales, it also presents information loss. In my opinion, the time scale for the garden map should be provided.

System	Garden map
What: data	Time data, activities recording
What: derived	The length of training and time order of activities
Why: tasks	Visual the duration of activities and show the completeness of each activities
How: encode	Mark: different types of flowers indicate the different training and butterflies indicate the completeness of activities

How: facet	The legends on the left and the garden map on the right
Scale	Wearable sensor network in a person

Tab.11 garden map visualization analysis table

Fig.21 interface for single sensor cell and data sensor in previous day

Fig.21 has introduced the overall view of sensor data and a detailed sensing data in each day. On the left-hand side of the interface, it represents data has been sensed in a single cell. On the right, the sensor in different cells and in different date can be viewed. Selection interaction can be applied. The different color hues have been used to indicate the different sensor cell. On the top of Fig.19, red has been used to indicate data from the PIR sensor. When PIR sensor fired, the time period (X-axis) will be printed to red otherwise it will be grey. The Y axis for this bar chart indicates the different sensor cell.

System	ALL service interface
What: data	Motion data with respect of time
What: derived	the activity pattern and motions in different sensor cells
Why: tasks	Display and visualize the time and location for number of sensor fired, find the part-to-whole relationship
How: encode	Color hues: bar chart on the bottom right, different color hues have been applied to encode different location, in other graph, the red indicates the number of sensor fired, black represents the sensors do not fired. bar chart: the height of each bar indicates the number of sensor fired
How: manipulate	Selection: number of sensor fired in specific date can be selected
How: facet	In the user interface, the detailed data in single sensor cell is on the left and the overview of data in different sensor cells and in different date
Scale	Multiple sensor cells in an apartment

Tab.12 ALL service analysis table

4.6 Visualization of Health Monitoring Data Acquired from Distributed Sensors for Multiple Patients

Paper [19] illustrated the visualization for health monitoring mainly focus on the heart pulse. The main features of this case are not required to visualized spatial location. It provides the visualization for health conditions for multiple patients, which is simpler task to achieved.

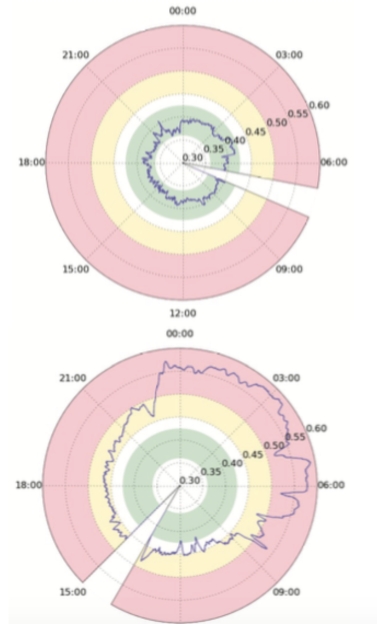

Fig.22 visualization of real-time data for the heart beats in a day for multiple patients

Fig.22 has presented a visualization for heart beats for two patients. The top figure indicates the health patient and the bottom one represents the patient with heart problem. This circle map indicates highest heart beats in each hour in 24-hour day. The different color hues within the circle indicate the different state zoom, the red one indicate the danger zoom, yellow zoom indicate the warning zoon which represent the potential dangers state and as for white and green means the safe zoom. The line plot in the circle indicates QTc value, the multiple circles indicates the different QTc value, which can determine the health condition of patients. The fluctuation of QTc values within the circle reflects the condition of patients.

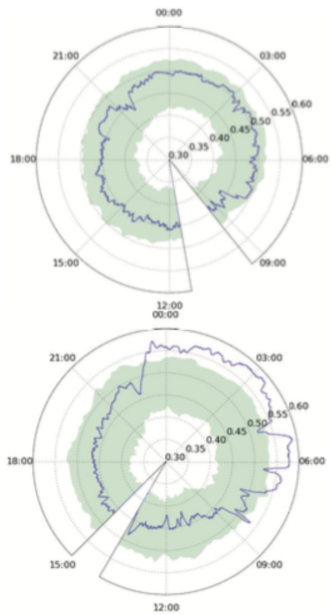

Fig.23 visualization of real-time data for the heart beats in a day for two male patients

In Fig.23, it presents almost the identical encoding idiom as Fig.22. However, the green zoom rather than indicating the state of heart condition, but it indicates superimposed averaged QTc value for the peer males. Hence it is not a circle shape. The other encoding method is the same. As can be seen in Fig.21, the bottom one shows the unstable condition compared with the peer average value.

System	QTc pie chart
What: data	QTc values (based on the heart beats value)
What: derived	The health condition: The average QTc in peer (Fig.21)
Why: tasks	Display the QTc value and comparison for QTc among the patients and peer
How: encode	Color hues: in Fig.20, different color hues indicate the different three states, red as danger state, yellow as warning and green as safe state. In Fig.21, green indicate the QTc value for peer male, circle map: use circles with different radius to indicate different QTc values, the outline of the circle indicate time. line graph: in each pie chart use to represent the QTc vale over time
Scale	Sensor data for multiple patients

Tab.13 QTc pie chart analysis table

5. AND CITY-SCALE/ REGION-SCALE ENVIRONMENT VISUALIZATION

City or region-scale applications have been mentioned and developed in recent years, such as tracking, environmental monitoring, and traffic estimation. These applications would bring the benefit to our daily life and improve the social services in many aspects. Hence the clear representation of the data or information will also be crucial for the users and analysts. The section will present some example applications on the city or region-scale, the literature review of relative topics and analysis will be done.

5.1 SWE FRAMEWORK WITH INFORMATION VISUALIZATION

In paper [2], it provides a certain framework which is called SWE (sensor web enablement) and based on the JSF (the James Cook University Sensor Federation). This framework provides all kinds of web services and standards based on the sensing data and measurement. In the article, the author displays web page and deployment page interface of 52' North SOS version 2.0 at the "SOS (sensor observation service) Design and implementation" section. This application has embedded Google map as the source of the geographic map. There are six attributes in the visualization framework: identification, capabilities, location, input, output, and component. Components have been considered as an embedded system for the system, such as Google map as the embedded system, which will not be taken into consideration as parts of information visualization. Identification and capability can be easily represented. The input/output and location should be paid more attention to. The input/ output has not been given as a certain parameter as temperature, humidity or something can be measured by the sensor network. Thus, the table data with a geographical location is the main data type which needs visualization. The visualization examples in this paper will be provided below.

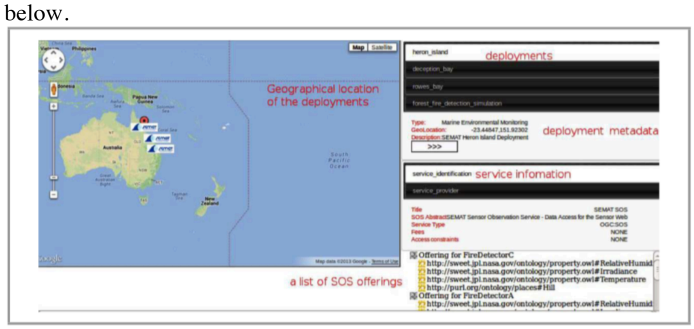

Fig.24 main web-page interface example [2]

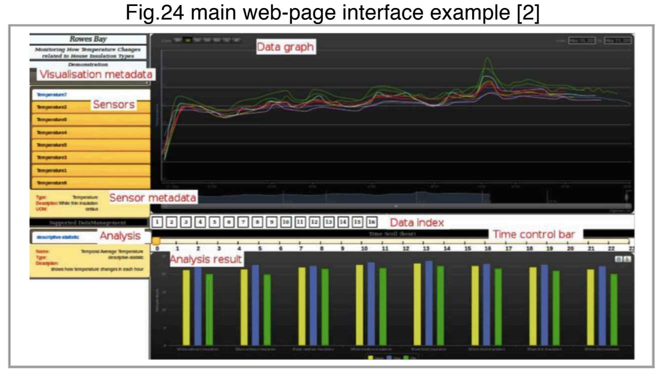

Fig.25 deployment-page example [2]

The Fig.24 and Fig.25 show the main web page and deployment page respectively. Tasks for visualization of sensor network data mainly aggregate the sensor data, make a comparison and list the distribution of desired parameters. In this case, they apply line graph and bar chart to demonstrate the data and analysis results in individual deployment page. In deployment page, the different color hues have been applied to encode the different types of data from the sensor network in the bar chart and line graph. Without much information which has been provided in the paper, the exact data types or attributes which have been encoded cannot be determined. The main web page applies the geographic map to indicate the distribution of the sensor network. As for the interaction of this framework, in the main web page, users can navigate the map and select the desired sensor network with some certain parameters. Then the individual deployment page will be loading. In deployment page, users can graphically visualize the sensor data and analysis result in each deployment page as well as export data into a file. The scale of this framework is limited to 100 sensor networks.

This framework support various interactions to explore data, it provides the overall geographic map to show the distribution of sensor network in web pages as well as the detailed information in deployment page. SWE framework provides the user-friendly GUI for visualization.

System	SWE (sensor web enablement) framework
What: data	geographical position, input/output from sensor network,
What: derived	Geographic distribution of sensor network, the sensed environmental data (has not been mentioned in the paper)
Why: tasks	Show distributions of sensor network, comparison of sensed data in various sensor networks
How: encode	Line graph and bar chart: they all apply the different color hue to encode different types of data or attributes. marks on the geographical map: the small rectangle marks in main page indicate the locations of sensor networks
How: manipulate	Select: in the main page, the different sensor network can be selected. In deployment page, the various data index can be selected as well as the different sensor. Navigate: the geographic map can be navigated as well as the data index from deployment page, control: the control for viewing the data in different time
How: facet	Web page: geographic map on the left with deployment choices on the right (service information and SOS offerings) deployment page: data graph on the top and analysis results in the bottom of the figure, the sensor selection menu in on the left.
Scale	Multiple sensors (at most 100)

Tab.14 SWE framework analysis table

5.2 From robots to human: visualization for robot sensor data

In paper [5], the author proposed visualization for sensor data in a robot. This article emphasizes three parameters from three different sensors in a robot: spatial position (laser scan), speed and touch sensors for the position of objectives (touch sensor); which are the important parameters for robots. The author provides this visualization to help developers quickly understand the pattern of receiving data for a robot. This visualization can also benefit programmers in improving or modifying the program. The examples of visualization for three sensing data will be shown below.

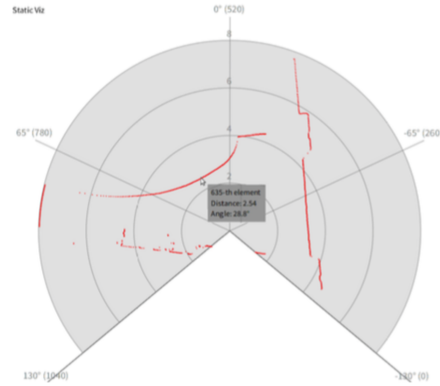

Fig.26 visualization of laser scan in 2D [5]

The Fig.26 has shown the visualization of laser-scan, it applies the circle map with multiple circles inside (like radar system). As can be seen, there is the angular scale around this circle map, it indicates the positions and direction based on the robot (origin of the circle map). Each inside circle indicates the distance. The red line in Fig. are consisted with thousands of red dots. When the laser sweeps the detection area, the outlines of surrounding environment are presented with multiple red dots. Based on the location of the red line, the users can comprehend the surrounding environment of the robot and the distance between the objective and outline of them.

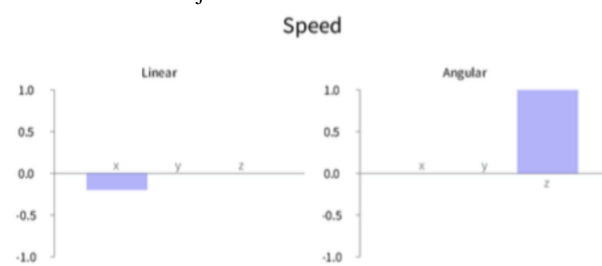

Fig.27 visualization of robot speed example

The visualization for robot speed has been provided in Fig. 27. The axis is most noticeable in this bar chart. Y-axis has shown the normalized speed, positive values and negative values in bar chart indicate the forward and backward movement respectively. The x-axis indicates the three directions surrounding environment, in other words, the angular and linear speed has been decomposed into three axes: X, Y, and Z. When the robot moves in a certain direction, the speed will be speared into three component speeds.

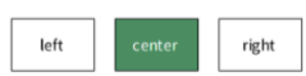

Fig.28 visualization example of touch sensor

In Fig.28, it illustrates the relative location/ position with respect to the front of the robot. It uses three square boxes to indicate the relative position of the object. When the desired objects are right in the center with respect to robot location, the “center box” will be painted as green. The same pattern will happen when the objects are in the right or left with respect of front of the robot.

Indeed, these visualization idioms provide the necessary information for sensor network in the robot. However, some of these idioms are too easy, which may cause the unnecessary mistakes and miscomprehension. As for the Fig.27, it rather than use bar chart to encode the angular speed, the circle view with the bar chart or line graph would be a better choice. It can show the magnitude as well as the directions. It can present the angular speed more directly and clearly.

As for Fig.28, the three rectangular boxes are too simple to indicate the relative position between objects and robot. In my opinion, the radar map with 2D plane visualization for the robot would be the better choice. The radar map can present the relative distance between objects and robot clearly. 2D plane visualization for the face of the robot would be helpful for visualizing the relative location between objectives and robot. Indeed, the radar map for laser scan is a good idiom for visualizing the surrounding environment.

System	Robot sensor network
What: data	spatial data, speed, "touch" data
What: derived	Relative location, relative distance, value of speed
Why: tasks	Visualize the surrounding environment, display the angular and linear speed, show the relative location between objectives and robot
How: encode	circle map (radar map): has been applied to present the surrounding environment of robot, the circle with different radius indicate the different distance, the red line show the outline of the surrounding environment, bar chart: use bar chart to present the angular and linear speed, the height of bar indicate the magnitude of speed, three box model: indicate the relative location between objective and robot
Scale	Several sensors in a certain robot

Tab.15 Robot sensor data analysis table

5.3 Visualization of Multidimensional Sensor Data in Industrial Engineering

This survey paper [6] is not only reviewing the visualization but also proposed a visualization in industrial application. Based on the nature of sensor data, the author has proposed an environment for visualization of multidimensional data in the industry. Before the explanations of the content, this paper proposed the visualization environment for multidimensional data, which means that the desired data may have multiple attributes, like weather data, can have multiple attributes: humidity, precipitation and so on. In larger scale application, this multiple-attribute data will occur more than they occur in the small-scale application. (like motion data only counts the number of sensors fired)

The proposed visualization environment is the combination of overall and detail of information. The overall is the visual-spatial map with detailed information in the table which is beside the map.

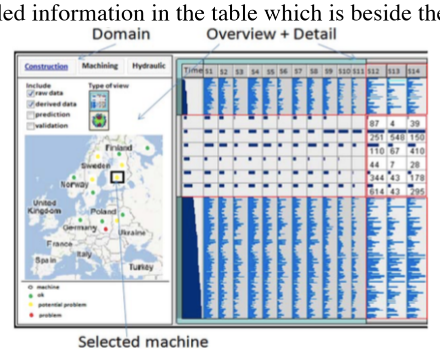

Fig.29 the proposed visualization example in table

Fig.29 shows the proposed visualization environment for many geographic locations of each sensor network on the left-hand side. For each selected data from each select application in the geographic map, the table in right-hand side provides the detailed data in form of bar chart. The data can be reordered by the desired properties of each data. The author also provides an alternative environment for visualizing the multidimensional data to overcome the limitation of the table with the bar chart.

System	TableLen
What: data	(In this case the exact type of data has not been mentioned,) the environmental data with multiple attributes
Why: tasks	Show overall distributions in geographic map, comparison for each attribute in detailed for data
How: encode	Table form with multiple bar chart: the height of the bar chart has been applied to encode the magnitude for the sensor data
How: manipulate	Selection: the sensor network in different locations can be selected, navigation: the location and data can be explored, filtering: the data can be viewed as the desired order or can be filtered by the choice zoom in/out In this environment, it supports derivations and manipulations of the "raw" data
How: facet	Overall geographic map on the left with detailed data beside on the right

Tab.16 TableLen example analysis table

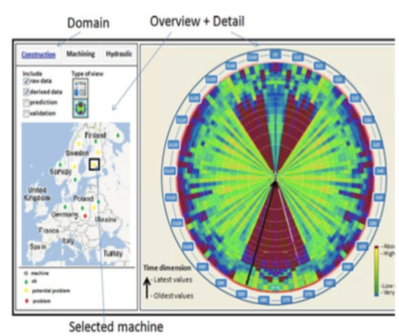

Fig.30 the proposed visualization example in circle view

In the alternative approach, they apply circle view instead of a table with multiple bar charts. The circle view can display characteristics for one parameter more directionally. It also can present the comparison for a data with multiple attributes or for a certain attribute which shared by multiple data. Indeed, I can provide the better comprehension in some way, but it does have its own limitations.

The proposed visualization environment support two main type interactions. Selection, filtering/zooming, navigation and all kinds of interactions in the interface are the first interaction. The second type is through the visualization and directly interact with "raw" data. The derivation and prediction for the data can be achieved by this type of interaction.

System	circle view
What: data	(In this case the exact type of data has not been mentioned,) the environmental data with multiple attributes
Why: tasks	Show overall distributions in geographic map, comparison for each attribute in detailed for data
How: encode	circle graph: it has been applied to encode the data with multiple attribute
How: manipulate	Selection: the sensor network in different locations can be selected, navigation: the location and data can be explored, filtering: the data can be viewed as the desired order or can be filtered by the choice zoom in/out In this environment, it supports derivations and manipulations of the "raw" data
How: facet	Overall geographic map on the left with detailed data beside on the right

Tab.17 Circle view example analysis table

5.4 Dynamic Annotation and Visualization of the South Esk Hydrological Sensor Web

Paper [7] has proposed a design and development of an adaptive tool for visualizing sensor network in South Esk. The coverage area of this sensor web is approximately 95km *220km area. The whole region was mapped as multiple gridded rectangle, each cell represents a 5*5km region. This sensor network is applied for investigating hydrological data such as wind speed, humidity, and precipitation. This design proposed the visualization for sensor distribution in spatial location, it also provides the visualization interface for specific data.

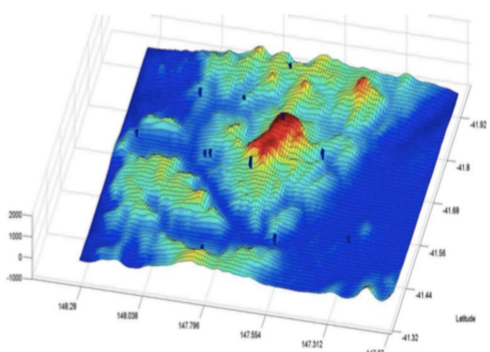

Fig.31 the visualization example of geographic map

Fig.31 has presented the 3D geographic map in a small 5*5km cell, the color hues indicate the height of spatial location. The color bar has not been provided, but, as can be seen, the dark color (red) indicates the maximum height and the light color (blue) indicate the lower height. As can be noticed, there are several dark blue dots on the map. They presented the sensor node in a map. This 3D map has shown the overall geographic condition in the cell and distribution of sensor node.

System	3D geographic map
What: data	Spatial location
What: derived	The allocation of the sensor node, the height of geographic location
Why: tasks	Display the geographic location of sensor node, the height of geographic location
How: encode	Mark: blue dots indicate the location of sensor node. Color hues: sequential color hues indicate the height of geographic location, blue as lowest points and red as the highest. The colors in between show the middle height
Scale	Several sensor nodes in 5*5km area

Tab.18 3D geographic map data analysis table

Fig.32 the visualization example of south Esk data service v1.0

Fig.32 provide the overall user interface for this proposed visualization system. The line graph in blue and in red both show the raindrop in different time-series. The line graph in red displays the refined line graph. The environmental variables can be chosen from the drop-down menu. The dot plot in the bottom right indicates the data availability. The detailed data can be explored by choosing the dots. The detailed graph will be explained below.

Fig.33 the visualization of precipitation with time-series

As can be seen in Fig.33, there some data missing in the blue line graph. The top line graph displays the actual sensor data. Red line graph has applied the prediction algorithm to enhance the integrity of data.

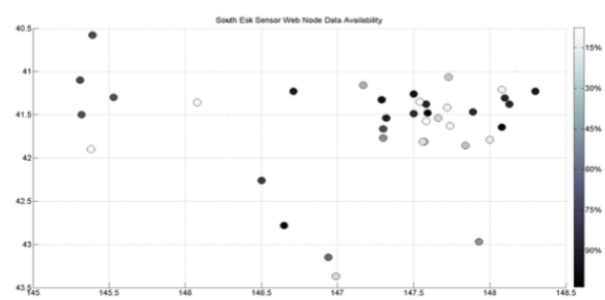

Fig.34 the visualization of data availability

Fig.34 has provided an interesting encoding idiom. It provides the color bar to show the availability of data: the dark color indicates the high availability and light color represents low availability. The X axis and Y axis represent longitude and latitude of a geographic map. The dots are the sensor nodes. In other words, this dot-map is the map which shows the distribution of sensor node. For each dot, it contains the detailed data of environmental variables which can be measured in the sensor network.

System	South Esk data service v1.0
What: data	Availability of data, rain-drop data
What: derived	Availability of sensed data, precipitation in different location
Why: tasks	Determine the data availability, display and complete the precipitation data
How: encode	Line graph: it has been applied to encode the precipitation of sensor cell. Dot plot: dot plot has been apply to encode the location of sensor node. Different color hues: blue as original data from the sensor, red line as the compensated data. Color saturations: in dot plot, the low saturation (white) indicates the low data availabilities, dark one (black) indicates the high availabilities
How: manipulate	Selection: the precipitation in different time can be selected and viewed. The different types of data can also be selected and viewed
How: facet	The result data can be seen on the top with dot plot in the bottom right
Scale	Sensor network in a sensor cell 5*5km

Tab.19 South Esk data service v1.0 analysis table

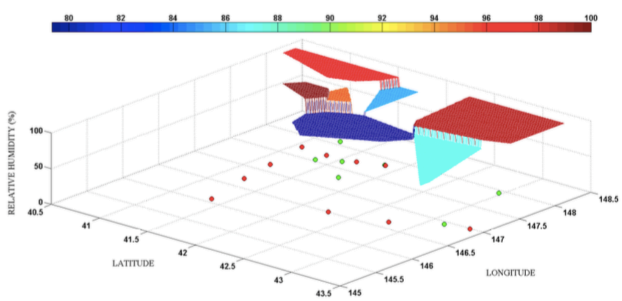

Fig.35 the 3D visualization of gridded humidity surface

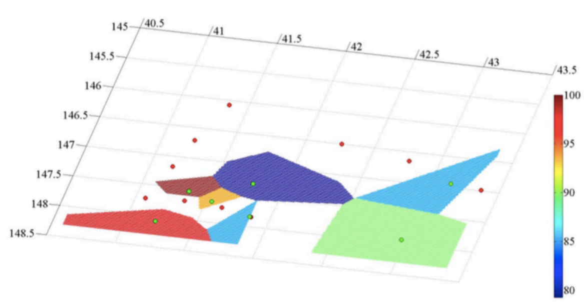

Fig.36 the 2D visualization of gridded humidity surface

The Fig.35 and Fig.36 show humidity distribution in 3D and 2D visualization modules. Dynamic data from 40 sensors are considered to construct these models based upon cubic interpolation. The red dots and green dots in each model indicate the reliability of the sensor data. The green dot means "reliable" and red dot indicates "unreliable". In these two models, color hues have been applied to encode the relative humidity. The color bar has been listed above these two models. The red color indicates high relative humidity and blue represent relative low humidity. In 3D model, the vertical axis also represents the relative humidity, which can provide better comprehend and visualization of relative humidity.

System	2D/3D visualization of gridded humidity surface
What: data	Sensed environmental data, location
What: derived	Relative humidity of each area, data availabilities, geographic location
Why: tasks	Visualize the relative humidity in sensor cell, data reliability of sensor node, geographic location
How: encode	Sequential color hues: it has been applied to encode the relative humidity of sensor cell. Red as highest one, blue as lowest one. The green dot on the map indicate the sensor which provide the reliable data, red indicate the unreliable one. 3D/2D map: indicates the geographic location dot plot: indicate the allocation of sensor node
Scale	Sensor network (40 sensor nodes) in a sensor cell 5*5km

Tab.20 2D/3D visualization of gridded humidity surface analysis table

5.5 Visualization for Anomaly Detection and Data Management by Leveraging Network, Sensor and GIS techniques

Paper [9] not only provides two case studies of abnormal detection of a sensor network and data management but also presented the frameworks for visualizing detection of abnormal data from sensor network in city-regions. Based on the distribution of sensor nodes in geographic location, the system provides the interface to visualize the distribution of each node and sensed information in each node.

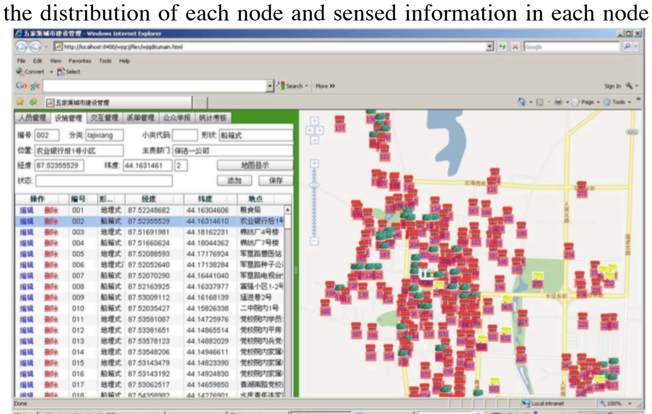

Fig.37 the visualization of abnormal data detection in web-interface

As can be seen in Fig.37, the web interface provides the detailed data on the left-hand side and the map with data location on the right. In detailed data view, it displays the geographic coordination, equipment attributes, staff and other information which can be selected by the users. The map-viewing frame displays the corresponding map of selected function from the data-viewing frame. This framework can perform the selection, navigation, and many other functions as interactions in this interface. It provides node-link diagram in the geographic map to encode route history for selected staff and selected date. In the future work, the author wants to propose a traffic prediction visualization based on the web interface.

System	Urban environmental management system
What: data	Static information in the table
Why: tasks	Present the route history and distribution of nodes (each node for each staff)
How: encode	Geographic map: indicate location of each staff, mark: the flag mark indicates each staff which has registered in the system
How: manipulate	Selection: the information for each selected user can be viewed, addition/delete: add and delete the users, navigation: users in the map can be explored and selected. Filtering: underside users can be filtered
How: facet	A detailed data viewing on the left with geographic map beside
Scale	City scale applications, the number of sensor determined by the number of registered users

Tab.21 Urban environmental management system example analysis table

5.6 City-Scale Traffic Estimation from a Roving Sensor Network

Paper [18] has proposed a design for traffic estimation from a roving sensor network. By applying the visualization for different types of data, the reliable algorithms for traffic estimation has been proposed in this paper. In this survey project, the data visualization patterns and the encoding methods which they have applied in the proposed work are the target for this survey project.

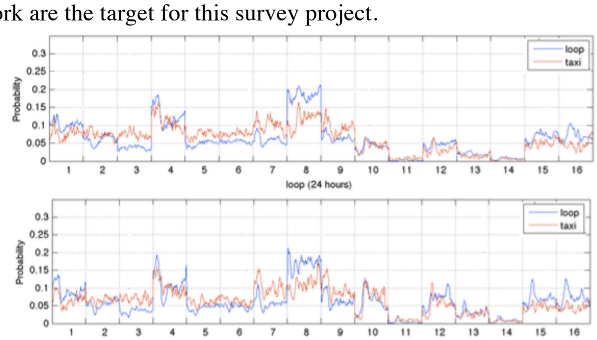

Fig.38 traffic condition for 16 road segments visualization for loop detector and sensors in the taxi

In Fig.38, the author uses the line graph to visualize and compare the traffic condition in the different date. The top figure shows the traffic condition in 1st of Aug and the bottom one display the data in next date. Y-axis presents the traffic in the certain segment in certain time. X axis has been divided into 16 parts to represent the 16 random selected road segments. Each one of 16 segments indicates a 24-hour day (there are 96 data points in each segment). They apply different color hues to encoding the data from the different source. Orange present the data from the sensor in the taxi and blue indicates the data from the loop detector. In this case, the author did not apply the usually encoding idioms (geographic map with dynamic navigation) to visualize the traffic conditions and compare the data from two different sources. The discussion and evolution will be mentioned in the discussion section.

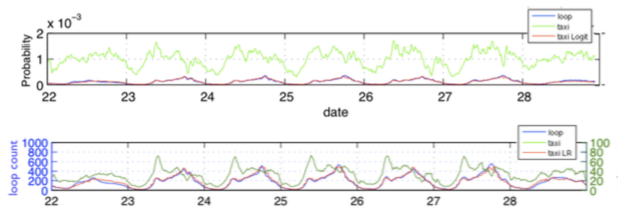

Fig.39 results of regression

The Fig.39 above apply the line graph to encode the traffic condition. The difference between Fig.37 and Fig.38 are the X-axis which encodes the date rather than the road segments. It also presents the 24-hour day in each section of X-axis. The two figures in Fig.39 have different scales in Y-axis, top one present traffic in certain time and the bottom one indicates the loop count for the blue and the red line, the taxi count for the green line. The different color hues have been applied to encode different data: blue for loop detector data, green for taxi sensor data and red for regression data.

System	Line graph
What: data	Counter for different traffic segments
Why: tasks	Visualize the sensor traffic data, compare the data from three different sources
How: encode	Line graph: it applies the line graph to encode the traffic conditions in 16 different road segments in 24-hour day Different color hues: in Fig.36, red indicates the data from taxi sensors, blue represent the loop counter. In Fig.37, red as regression data, blue for loop detector and green the data from the sensors in taxi
Scale	city scale application (thousands of sensor nodes)

Tab.22 line graph analysis table

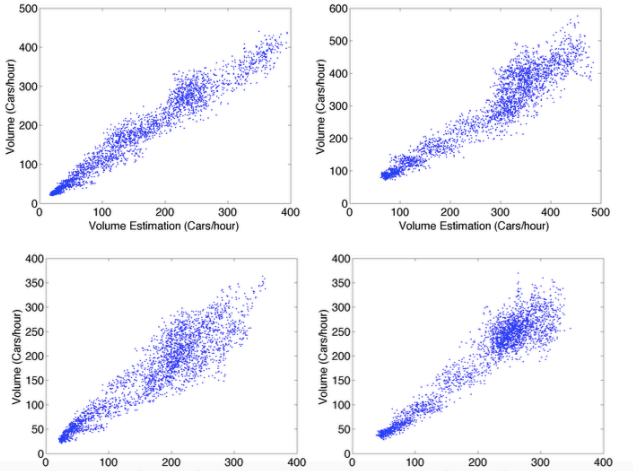

Fig.40 results of relationship between real value of car and estimation value

There are four graphs represent the four randomly selected roads. They apply the scatter plot to reveal the relationship between real values and estimation values. It can clearly present each sensor data with corresponding estimation data on the scatter plot. The perfect estimation match should be the linear relationship with a unity gradient (y=x). In the paper [18], the author also provides the histogram to encode correlation coefficient distribution, which reveals how reliable the estimation is.

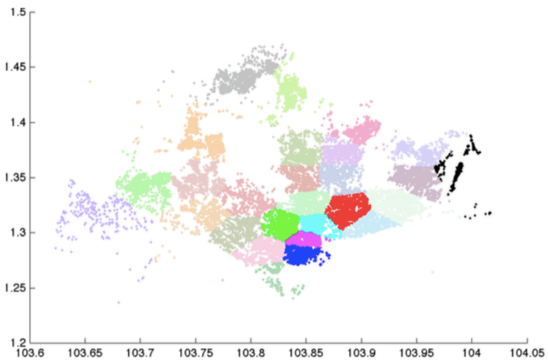
Fig.41 visualization of 27 Voronoi regions in Singapore

As except, the visualization for a geographic region is necessary for the city or region-scale application. The six highlighted regions represent the places of interest. The color hues have applied to separated regions.

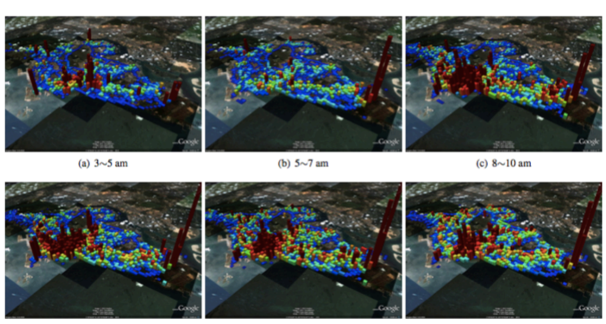

Fig.42 refined snapshot of traffic value based on the sensor network of taxi

In Fig.42, it provides the snapshot for visualizing the traffic value in regional scale. Based on the geographic map, color hues and bar chart has been applied to encode the traffic volume. The dark colors hues are used to encode high volume of traffic as well as the high bars on the map. The light colors and low bars have been applied to encode the relatively low traffic volume.

Fig.43 hotspots for visualizing traffic volume pattern

Fig.43 also presents the traffic volume in 2D form with hotspot idiom. The color luminance has been applied to encode the traffic volume.

The analysis and researches are based on the data visualization to abstract the valuable information and ensure the reliability of the algorithm.

System	Traffic estimation system
What: data	Geographic/spatial data, static data (number counter)
Why: tasks	Display the distribution of traffic volume in 3D map, present the traffic volume in city in different time
How: encode	Geographic map: 3D geographic map indicates the layout of sensor region, Bar chart: in Fig.40, the height of bar chart indicates the volume of traffic. Different color hues: the sequential color hues have been applied to indicate the traffic volume. In Fig.40, dark red indicates the highest traffic volume, the dark blue indicates the lowest one. Color luminance: in Fig.41, high red luminance indicates the high traffic volume, the low luminance indicates the low Mark : in Fig.41 red flag marks indicate the places of interesting
Scale	Thousands of sensors in regional scale

Tab.23 Traffic estimation analysis table

5.7 A new Approach in the Visualization of Georeferenced Sensor Data in Spatial Planning

In paper [20], the author proposed a visualization based on the sensor network which can provide human emotion assessment. Based on the sensor network in human and geographic map, GeoVisualizer as proposed tool for spatial planning has emerged.

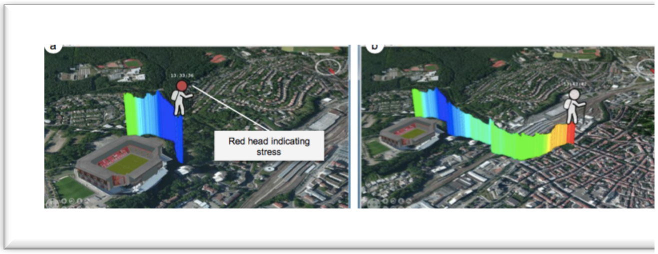

Fig.44 visualization for human emotion assessment

As can be seen in Fig.44, it provides GIS (geographic information system) as the background map. In this visualization idiom, the color hues encode the human emotion. It also uses the human symbol as a mark to encode the geographic location of the person under the measurement. The head of human symbol also uses color to encode the human emotion, for example, the "red-head' present high stress. The rainbow paths behind the human mark are the historical emotion data from the object. The various color hues have encoded different states of human emotions. The warm color such as red, orange and yellow indicate the high-stress saturation and cold colors such as green and blue present low-stress situation. The sensing data from the "rainbow path" perfect fit the expectation from the experiment.

System	GeoVisualizer
What: data	Spatial data, emotion data
Why: tasks	Visualize the path in 3D map, show the relationship between emotion data and the path choice
How: encode	Color hues: the sequential color hues have been applied to encode the emotion data, red indicate the highest stress condition for object, the lowest stress condition has been encoded by blue. The Red-head indicate the high-stress condition for object. marks: human-shape mark indicate the experiment object
Scale	Sensor network in a human

Tab.24 Geovisualizer analysis table

6. DISCUSSION AND FUTURE WORK

The discussion section will illustrate the improvements and evaluations based on three scales which have been mentioned in result section. Based on the literature review, there are several considerations I would like to mention. The challenges for visualization for data from sensor network are worth mentioning [23]. First, the isolation challenge. It means that the visualizations on sensor network are usually irrelevant, each application has own demands for visualizing data. There are not global optimal solutions available for all the visualization for sensor network. It demands the visualization for each field should be considered carefully and precisely based on the requirements from each application. The second challenge is evaluation capabilities. With the rapid increase of data, the visualization applications and tools should work more effectively. The last one is integrity challenges. In each domain there are specific demands, which indicate that visualization should focus on their own domains. Each domain should be independent from the concerns from other domain. Based on the challenges which has been mention in paper [23] and the literature reviews has been completed, the suggestions are worth mentioning.

First, the visualization framework should focus on data. The data type should be considered carefully. The single-attribute data like the data from motion sensor and multiple-attribute data (sensor network in industrial data) should be identified in the beginning. There are many frameworks or visualization idioms which fit them respectively. Then, the innovative visualization framework (garden map) is attractive and interesting, however, the information loss would not be negligible. To present the effective and efficient visualization frameworks or idioms, the way to present the information should be considered. Last but not least, the visualization idioms should be easily comprehensible. In example 4.3, it proposed a framework of indicating motion transition by using 3D figure. Without much background information provided, the models and the visualization idioms are difficult to follow.

As for the section.3, the sensor network properties and security problems, the topology for the sensor network are focused. How the security event connected with topology, how to present relationship between them clearly. These questions are worth considering. The example 3.2 are doing the better work among the examples. However, I do think more interactions functions in the GUI should be supported between the users and data, which can help the user explore and manipulate with data and provide the better comprehension. As for the section.4, it is about visualization on small-scale such as health care and motion sensing. They mainly focus on visualizing the state of the object. It requires more clear representation for the states of the object, which may not require any interaction functions. Example 4.2 and 4.5 do provide the great performances for visualizing activity pattern and motion states for the objects. As for the large-scale application in section.5, it often requires the presenting data with the geographic map. The clearness of representation has been listed in higher priority. By applying different color hues, it does provide best distinguishable performance. However, when color hues combine with the geographic map, it would lead the disorder in visualization idioms. Different color hues should be applied carefully. Hence many GUI in large-scale applications are provided different interfaces for presenting the geographic map and detailed data respectively. The interaction functions are also provided for the user to view and manipulate with data. In section.5, they all provide the great work for visualizing the geographic map and detailed data. besides the color hues, size of marks (the height of bar chart) is also been provided for encoding the data in the map, which also provides great performances.

7. CONCLUSION

In this survey project, the literature for information visualization based on sensor network has been reviewed. In introduction section, the definition for a sensor network, sensor, and information visualization have been given. With the rapid development of IoT (internet of thing), the sensor network has been deployed in many areas. It provides the motivation for this survey project. The different layers of the sensor network have also been illustrated in introduction section as well as the overall contributions for this survey project. In the result sections, it has been separated into three sections based on the application scale. In each section, the several examples have been explained and the improvement suggestions were also provided. The analysis tables have been provided. The first part is about sensor network properties and security problems, there are several visualization idioms and tools have been reviewed. The second part is for small-scale applications, generally, it is the applications for home or indoor applications. Papers in this part mainly talk about the indoor tracking and health monitoring. The last part is large scale applications, it mentioned the applications in city or region scale. The applications in this scale usually include environmental monitoring and industrial sensor network. The discussion section has demonstrated the improvements and insights from the result section as well as the future work for this survey project. As the conclusion, this survey project has provided several visualization idioms in different scale and area under the topic of information visualization based on the sensor network. They have been explained and analyzed. The improvements and evaluations are also provided. However, this survey project still has many improvements should be achieved in the future.

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