Spatial Redesign Method Based on Behavior Data Visualization System

UWB interior positioning technology based office space redesign method research

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There is a typical symbiotic relationship between behavior and space. Design and evaluation of space are also inseparable from people's behavioral needs. Therefore, the study of behavior patterns can be regarded as the process of exploring the relationship between human and space. Traditional behavioral research lacks precise micro-individual data and analytical tools to express complex environments, and is more inclined to macro and qualitative static analysis. With the maturity of indoor positioning technology, the use of big data as a medium to quantitatively study the laws of behavior has gradually penetrated into the micro-level of indoor space. This paper begins with a brief introduction of the behavioral performance research process in history. The paper then describes the method that constructs the observation, quantification and visualization process of behavior data by using UWB positioning technology and visualization implementation system through an on-site experiment of office space. The last part of this paper discusses the establishment of spatial redesign method by mining the behavior data, and translating the results into spatial attributes.

Keywords: *behavior data visualization, UWB interior positioning technology, data mining, spatial redesign method*

INTRODUCTION

The analysis of "behavior performance" is an important way to establish the quantitative relationship between human and architectural space. The purpose of behavior data extraction and analysis is to help people know better of the space. Over the past 50 years, research on design methods and evaluation systems based on human behavior has emerged. In the former digital age, the quantitative study of Space Syntax and Behavior Mapping has an advanced guidance in the era that digital technology has not yet been popularized. With the gradual maturity of interior positioning technology such as Wi-Fi, Bluetooth, ZigBee, RFID and UWB (Ultra-Wideband) , the accurate collection of behavior data is becoming much more feasible, which provide a larger amount of precise and effective data, laying the foundation for the establishment of behavior data visualization system. However, the common problem in all current behavior data visualization researches is that the study of behavior data is only limited in the stage of visualization and does not relate the mining results of behavior data to the design of a new space or the redesign of a existing space. In short, the establishment of the current visualization system does not include space design or redesign. In the early stage of this research, the behavior visualization system has been established using UWB interior positioning technology and JavaScript visual programming language. Based on the existing research results, this paper proposes a space redesign method for the existing spatial layout and establish a new visualization system combining interior behavior data characteristic and space layout result.

BACKGROUND

Traditional behavioral performance research

The term "behavioral sciences" was officially named in an interdisciplinary conference in Chicago, USA in 1949. At the same time, building related environmental behavior research also emerged. Some psychologists in that period explored the real environment layout and space arrangement had a significant impact on people's behavior. After 1960s, architects gradually joined this field of research. The most representative of these researches is Kevin Lynch's book 'The Image of City' which describes the cognitive style of environmental sites and behavior. This part was later summarized by Gary T. Moore and extended to an interdisciplinary research branch (Figure1). Moore pointed out that there is a large deviation between the behavioral cognition and the real situation of environments. The study of the behavior pattern and its characteristics would help architects to truly understand the specific demand of the behavior to the space.

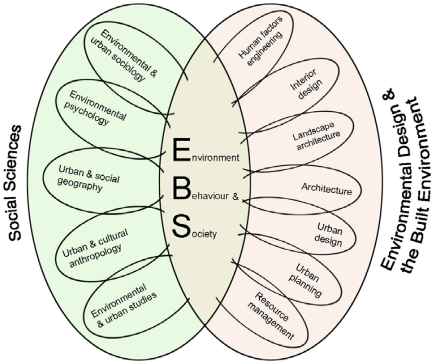


Figure 1
The interdisciplinary system based on the three elements of 'Environment Behavior Society'

Later on, the environmental analysis method and the building evaluation system based on the behavior pattern appeared in the public's vision. Bill Hillier established an analytical method and theory based on the behavioral visualization and the relative depth of space – 'Space Syntax'. It expresses the human visual perception behavior in the space through data visualization by showing the specific numerical range of the descriptive variables with different colors, and divides the space environment into a number of components (Figure 2). Based on environmental cognition behavior, Space Syntax defines a data language that measures the relationship between architectural space and behavior from the perspective of behavioral performance. However, Space Syntax cannot timely and accurately reflect the specific behavior data of the building users in the physical environment, so that their behavior characteristics and rules cannot be excavated correctly.

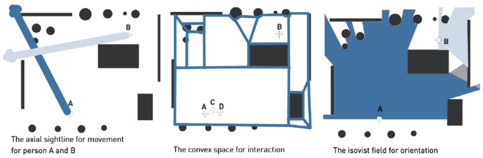


Figure 2
Three types of behavioral analysis methods in space syntax: axis, convex, sight

In 70s twentieth Century, William H. Ittelson first proposed the 'Behavior Mapping', from the perspective of behavior to space, using data statistics as a method to excavate the characteristics and laws of behavior. Subsequently, Ittelson summed up the behavior notation as 5 elements in the 1996 published article visual perception of makings, describes the subjective presentation of the behavior of space by the way of artificial observation and recording. Nilda Cosco, from the University of North Carolina College of design, used Behavior Mapping to study and analyze preschool children's physical activity in 2010. He regarded the Behavior Mapping as a means of direct observation of behavior. He collected the behavior data of children and the surrounding environment, and studied the degree of association between the two. It hoped to make some strategies to influence the design of architecture and environment with the help of this research in order to create an outdoor environment that is more conducive to children's activities (Figure 3).

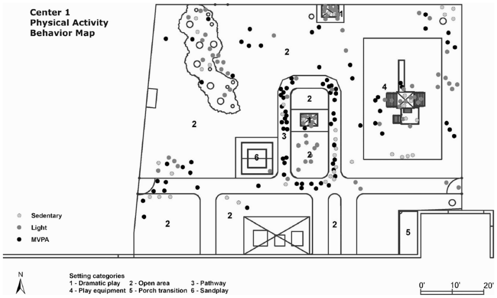


Figure 3
Physical activity Behavior Mapping of child center

However, with the abundance of behavioral activities and the complexity of the building environment, Space Syntax and Behavior Mapping are restricted by the number of samples and the precision of data. It is difficult to reflect the complex behavior characteristics of the new era. The behavior research in architecture needs to introduce more systematic tools and methods.

Behavioral performance research in digital age

With the rise of interdisciplinary and the development of digital technology, the quantitative research of behavior data observation system, big data mining and behavioral information dimension visualization make architects better understand the relationship between behavior and space. Behavioral performance research is no longer just a content of building evaluation, but has become a basic element to optimize and dominate the architectural space.

In the era of big data, human behavior data are gradually accumulated through the devices of Internet of things. Quantitative research on behavior can turn to a specific analysis of behavior data. Therefore, the acquisition and use of behavior data will be the key content in the process of behavior quantification. In the use of data, the statistical model represented by machine learning has been applied to the analysis of behavioral events, and a relatively good result is harvested. The specific ways of utilization include spatial analysis, computation model and behavior simulation. Generally speaking, the behavior data collected by the digital positioning device reflects the multi-layer characteristics of the behavior from time series, spatial distribution and individual information, which plays a guiding role in the layout and operation of the built environment. Data visualization is not only the result of behavior quantification, but also an important direction of space layout, especially of the redesign of an existing space.

Based on the above discussion, the space redesign method needs four parts: Taking the behavior data observation system as the framework; Using digital technology as a data collection tool; Mining the pattern of behavior characteristics through data visualization system; Translating the result of data visualization into guiding principle of space layout (Figure 4).

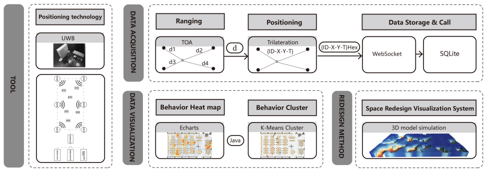


Figure 4
Behavior analysis & Space redesign process

BEHAVIOR DATA VISUALIZATION RESEARCH

Behavior data acquisition and storage based on UWB technology

In order to obtain behavioral data and information with a larger sample size, more variety, and more comprehensive behavioral characteristics, we need to use digital positioning equipment to complete the collection of behavioral data. Among the numerous positioning technologies, the author selected four types of devices commonly used in behavior research: RFID, Wi-Fi, Zigbee, and UWB, and conducted comparative studies from the perspectives of measurement range, accuracy, application scenarios and data characteristics (Figure 5).

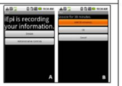
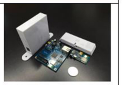
Positioning Technology	Site	Accuracy	Time	Stability	Application scenario	Equipment pictures
RFID	Small indoor space	1-30m	<1s	Medium	articles and equipment in hospitals and industrial production lines	
Wi-Fi	Large indoor space	2-15m	<3s	Medium	Personnel in shopping center and airport	
Zigbee	Network coverage area	3-5m	<1s	High	Personnel in hospital and mine	
UWB	Base station coverage area	<0.3m	Real-time	Very high	Personnel and articles in tunnel and industrial production line	

Figure 5
Specific performance of four types of positioning technology

In this research, the office space is chosen as the experimental space for behavior visualization and redesign of spatial research. As the area of office space is moderate, the type of behavior is relatively simple, the interference factor between behavior is small, so it is easier to judge the attribute of space. It is suitable to study the method of space rearrangement. Through the analysis of the four kinds of positioning equipment above and experiment site, the UWB positioning system is used to conduct the collection of behavioral data for office space.

A complete UWB positioning system requires at least 3 base stations to determine the location of label in the space. In addition, as the intersection node of the entire system set up, switchboards are connected to each base station reconciliation server through CAT6 cable. All the data information will be solved in the solution server. The behavioral data can be called and calculated in the visualization system and showed on the display terminal (Figure 6).

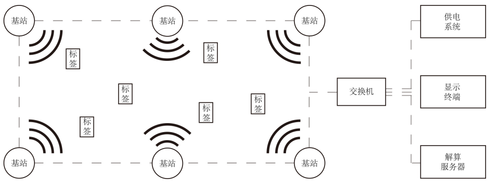


Figure 6
UWB positioning system

According to the TOA (Time of Arrival) location algorithm, the distance between each label to the base station could be measured. When more than three positioning base stations are arranged, we can make a rectangular coordinate system on the space plane and give each base station a position coordinates. To undertake the TOA calculation discussed above, the distance between each label and each base station will be solved by locating engine and server. In theory, the positioning system will automatically select the three sets of distance data of the best signal intensity, and use the Trilateration algorithm to transform the distance information between the label and the base station into the coordinate data. At this point, the positioning is completed.

When the system calculates the location data of the label by the Trilateration algorithm, the server will provide the four types of information: the label number, the current moment, the position abscissa X, the position ordinate Y. In data-calling phase, Websocket network protocol can ensure high frequency transmission of data communication, providing technical guarantee for real-time behavior of visual interface. In data-storing phase, the data is backed up into a SQLite database, stored on a computer's hard disk, which can be used to perform conditional queries, classification statistics, and data operations in the SQLite language. The coordinate data of high frequency outputs (including Tag_ID, Pos_x, Pos_y and

Time) are called by API interface in real time and provide technical support for the design of behavior visualization interface (Figure 7).

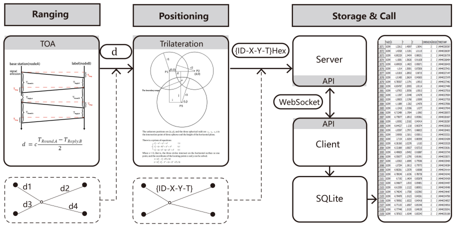


Figure 7
Behavior data acquisition and storage process

Data visualization interface

When the data acquisition and storage are completed, JavaScript visual programming language was used to write visualization interface. By invoking the API data, analyzing and mining the data information, it is translated into the behavioral elements of office staff including Behavior Heat map interface and Behavior Cluster interface.

The JavaScript language was used to build a real-time Behavior Heat map interface. The mathematical logic behind it is the kernel density estimation which is a function to estimate the unknown density in the probability theory. The specific estimation formula is as follows:

$$p(x) = \sum_{1}^{N} \frac{N(x - X_n, z)}{N} \tag{1}$$

Among them, N(x,y) It is the probability density function of the normal distribution. z is a set of parameters. The position coordinates of each tag at the current time are recorded and displayed as a dotted ribbon that radiates outward from the center of the circle, while the color corresponds to the cumulative heat value in the range of 0-1, gradually changing from warm colors to cool colors. The patches of different colors overlap with each other and the accumulated thermal values of some points change continuously. The heat map can describe the distribution, density and trend of the population in real time, to a certain extent, reflecting people's area preference (staying habits), areas with high crowd concentration (agglomeration areas), and the use of transportation corridors. Based on this series of behavior rules, the influencing factors can be dug out and fed back to design (Figure 8 (a)).

In addition, machine learning algorithm is introduced to perform K-Means Cluster on the past 400 tagged output points (one point per second). Firstly, K anchor points are selected randomly as the initial cluster center (the average distance from the cluster center to each scatter in the cluster is the smallest). Then the distance between each scatter and each cluster center are calculated, and then the scatters are assigned to their nearest cluster center. Clustering centers and the scatter points assigned to them are considered to be a cluster. Once all the scatter points have been assigned, the cluster centers of each cluster are recalculated based on the existing objects in this cluster. Iterative clustering operations will continue to run until the cluster center is no longer change. Through the process, scattered points with similar characteristics will be classified and self-organized intelligently under unsupervised learning, and we can judge the people belonging to the same group according to the division of the cluster, and the cluster center is very likely to be an important factor for the aggregation of individuals (Figure 8 (b)).

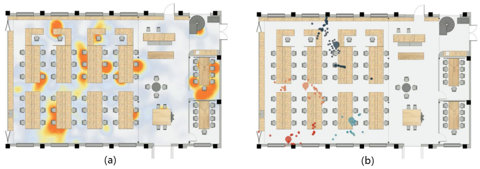


Figure 8
Behavior visualization interface

SPACE REDESIGN VISUALIZATION SYSTEM RESEARCH

On-site experiment of office space

Using the UWB positioning technology and behavioral visualization interface, we chose the architecture design company's office space for experimentation. The office space experiment was selected from 9:00 am to 6:30 pm as the execution time of this experiment (employee work time is from 9:00 am to 5:30 pm). The specific date was set for January 17, 2018. The author came to the lobby of the office at 8:30 in the morning and randomly distributed 15 positioning tags to the employees who were asked to remain wearing them to leave the company on the same day (Figure 9).

Figure 9
Base station arrangement and tag (label) distribution in office space

Through 9 hours of continuous data collection, more than 20000 behavior data were collected and recorded. According to the data visualization interface, the behavior rules of the whole office are presented. We can intuitively analyze some of the behavior information without the aid of computer algorithm analysis tools.

Through the behavior heat map, we can see that the employees' behavior is concentrated in some certain area. By comparing the spatial layout of the office, it can be found that most of the active orange area staff gathering easily is the area where the team leader is located, and the employees used to gather in these areas to discuss and communicate. These active areas should be the space to be emphasized in the follow-up space design update process. In other words, these areas are more influential factors for later spatial remolding.

In the clustering visualization process, the clustering center is where employees stay longer. Therefore, we speculate that the employees around the cluster center are occupied for a long time and work. This part of the staff may have a greater workload and will face overtime, which can be verified by comparing the behavioral heat map after work. The company manager can compare the seat arrangement and clustering results and exchange employees who need to communicate frequently and who need to communicate frequently to similar areas in order to reduce their communication costs and improve their work comfort (Figure 10).

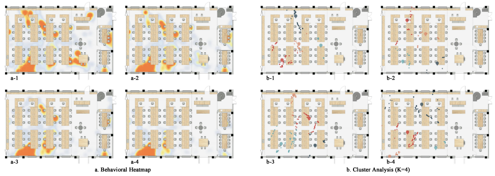


Figure 10
Data visualization interface

Space redesign method

The acquisition and visualization of behavioral data has helped us to solve the problem of how to quantify the invisible behavior characteristics in the process of spatial redesign, and the focus of this paper is on how to make a deeper mining of the quantitative behavior characteristics and establish a set of forming systems that determine the spatial distribution through the behavior characteristics. According to the traditional spatial graphic design method, furniture and partition are set by the designer's past design experience and behavior prediction in the built space. However these two points in the space redesign stage can not help designers make the correct judgments. Different from the traditional design methods based on experience and prediction, the spatial redesign study from the direct quantitative behavior attributes can provide a precise and convenient prototype for the designer.

In this research phase, we first analyze the spatial factors that affect behavioral characteristics. In the original layout of the office space, the pantry between the east and the west is a region with high activity in the original space, and we attribute it to a potential factor affecting the behavior. Based on the characteristics of behavioral data excavated from the previous step, we try to extract rules that affect spatial layout. From the label data stored in the database, we extract the time information of each behavior sample, defined as T, to be an important factor in the spatial layout. And then the degree of association between behavior and space is defined as a constant B. T is a variable, which is updated and stored in real time by the positioning system. B is based on the experience of the original space property and the specific behavior produced in this space. For example, there are more resting behaviors in office space while less active behaviors, then the correlation between primitive spatial form and triggering behavior is lower. Correspondingly, the value of B is reduced. At the same time, according to the characteristics of the original spatial layout, we further generalize the active degree of the original spatial characteristics to a constant S. The more active the original spatial attributes (such as the pantry and the discussion area), the more diversified the behavior is, and the larger the numerical value. In our space forming algorithm, T generalizes the behavior characteristics, S generalizes the original spatial characteristics, and B can be understood as the degree of correlation between T and S. The process of spatial redesign forming is shown as Figure 11.

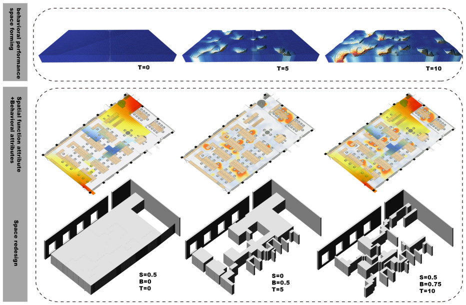


Figure 11
The process of spatial redesign forming

According to the above principles, we have established a space forming algorithm based on the existing spatial layout and spatial behavior characteristics. The initial space of the original space is defined as a complete cube, and the final space will be carve out according to the behavior characteristics and the law of spatial generation. In the algorithm, a reduction attribute is applied to the blue cube within the radiation range of the anchor point and its surrounding range. The farther the blue cube away from the anchor point, the lower its reduction attribute is. On the basis of this form, the entity is divided into many cubic blocks of 330mm by the minimum scale of space use function, which simulate furniture in the plane layout in the subsequent forming process. According to the algorithm, the solid block that are far away from the center of the active area are retained and are modeled as space partitions. Small cube blocks approaching the center point are reduced. We can control the magnitude of the cube reduction according to the size of the adjusted B value. In the experiment, we set the B value from 0.5 (50%) to 0.75 (75%). The correlation degree of the interaction between space and behavior becomes larger and the amplitude of the cube reduction becomes larger, indicating that the behavior property needs more space. When increasing the S value, it can be seen that the area of the original entity is gradually reduced to form a larger space, which indicates that the space utilization rate is not high due to the improper layout of the original plane in the course of the behavioral characteristics based forming, so these space should be paid more attention to and adjusted its function in the redesign stage.

CONCLUSION

From the perspective of behavior performance, this paper first combs the historical evolution process of behavior research, and points out that the development of behavior research needs to introduce systematic observation methods and more accurate data acquisition tools. Secondly, the performance and application scene of behavior data acquisition tools are discussed, and finally UWB positioning technology is selected. Then, by studying the working mode and data visualization system of UWB positioning technology, the development of the behavior visualization system is completed. Finally, a method of spatial redesign form is established, through it the behavioral data collection and analysis experiments were carried out on the office space. We hope that through this study, we can summarize and reflect on the past behavior research methods, and provide a complete and feasible visual analysis method for the future study of indoor space behavior in order to establish a scientific and efficient process for the redesign of existing space.

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