

An Improved Design of 3D Swept-Volume Volumetric Display

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Abstract—In this paper, we present a new design of a swept-volume 3D-360-degree display system with rotating LED panel. This system, which adopts the idea of modular design, is constituted of a mechanical part, a circuit part and a software part. The circuit part is mainly composed of synchronous control module, high speed data transmission module, display module and display control module, etc. The mechanical part includes a mounting platform, a carbon brush assembly, a slip ring assembly, a power mechanism, a synchronous belt mechanism, a rotation assembly, a top cover pressing mechanism, and an auxiliary support. The software part mainly realizes the 3D image data generation, simulation, transmission and display control function. The experimental results show that the SV3DD (swept volume 3D display) system can display 3D images and animations with 360-degree view angles.

Index Terms—Stereoscopic display, swept volume display, three dimensional (3D) display, volumetric display

I. INTRODUCTION

Many sophisticated and powerful techniques, such as perspective, shadowing, and texturing have been developed to display 3D information on flat, two-dimensional (2D) display [1-3]. 3D volumetric display technique, which can generate true volumetric 3D images by actually illuminating points in 3D space, is akin to viewing physical objects in the real world. Viewers can get depth perception to obtain a richer, more accurate understanding of the virtual 3D scene by their inherent physiological mechanism [4].

This display technology typically has a 360-degree field of view. Moreover, users do not need to wear hardware such as shutter glasses or head-trackers to view

3D images. Therefore, the 3D volumetric display technique is a very promising technology to replace the traditional 3D display systems, and has great potential applications in medical imaging, military visualization, computer aided design, and so on.

Volumetric display systems enable images to be formed within a transparent volume, and so the images are able to occupy a physically three-dimensional space [5]. This kind of displays may be characterized as follows [6]:

A volumetric display device permits the generation, absorption or scattering of visible radiation from a set of localized and specified regions within a physical volume. In some cases a volumetric system may support the controlled anisotropic propagation of this radiation from each localized region.

The 3D volumetric display can be divided into two categories including the static stereo 3D display (SS3DD) and the swept volume 3D display (SV3DD). SS3DD reproduces voxels on stationary regions in the image space, while SV3DD reproduces voxels through scanning a rotating two-dimensional display with high speed in real space [7].

The static-volume display places reliance on a 3D array of individually addressable light-emitting elements for image space formation. The previous works about static-volume display was carried out forming an image space include using mercury vapor[8], rubidium vapor[9], and ZBLAN (a fluoro-zirconate glass) as a host material doped with rare earth lanthanides such as praseodymium (Pr³⁺), erbium (Er³⁺), and thulium (Tm³⁺) [10, 11]. The DepthCube display[12, 13], which employs an image space formed from a stack of twenty liquid crystal panels, provides an effective approach to the implementation of a static-volume display.

The swept volume 3D display form the image space by means of the rapid cyclic movement of a “screen”, which is assumed to comprise a “surface of emission” (SOE)

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and any associated supporting structure[5]. The SOE is defined as [14]:

A planar or curved surface which cyclically sweeps out an image space and upon which voxels are generated. It may be passive (e.g., a light-scattering surface) or active (e.g., a matrix of individually addressable light emitting components). In the case of swept-volume displays, the SOE constitutes the voxel generation subsystem.

A frequently employed implementation approach of a volumetric display is to use a rapidly moving surface ('surface of emission' (SOE)), on which voxels are created in synchronism with the surface's motion [5]. The movement of the screen may be either rotational or translational. Fig.1 indicates approaches that may be adopted in the implementation of a swept-volume display.

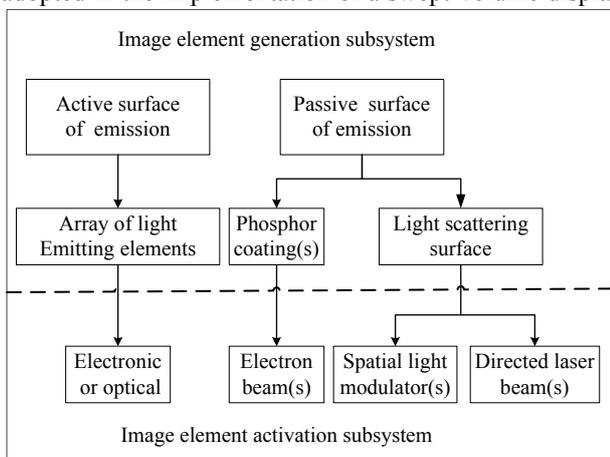


Figure1. Exemplar approaches that may be adopted in the implementation of the image element generation and activation subsystems for a swept-volume volumetric display[6].

Of the many and varied methods used for generating 3D displays [15]–[18], our display is based on the swept volume. Since the late 1970's, swept volume display has been carried out and has been a hotspot in the field of 3D display, for example, [19]–[21].

In this paper, a prototype of a new SV3DD is presented. The system has a 2D planar display panel containing LED arrays. Based on the prototype, the display of 3D still images and animations have been realized. Our contributions include:

- A novel data processing algorithm for processing the 3D data from acquiring to display.
- A novel software/hardware architecture that enables displaying 3D images and animations.

The rest of this paper is organized as follows: the related works is described in section II; the design technology for hardware of the SV3DD system is described in section III; the data acquisition and processing method of the SV3DD system is provided in section IV; the experimental results are discussed in section V; and finally, the conclusion is given in section VI.

II. RELATED WORKS

The surveys of three-dimensional display techniques can be found in [2,3,5]. Conclusions can be drawn from all kinds of existing prototype that the movement of the screen may be either rotational or translational. Translational motion is combined with a planar SOE. The planar SOE and helical forms of SOE are two kinds of widely researched display form for rotational motion swept-volume display.

The first active surface of swept volumetric display, which contains one rotating image panel covering one half of the cylindrical display, was developed by Berlin [19].

The work in [19] presented two display systems: a basic system and a modified system. The basic system is composed of a rotating 2D LED array. The modified system is composed of a rotating plasma display device and has more complex electronics in rotating parts than the basic one. This design cannot use the display space effectively. Since then, there have emerged many improved displays over the display in [19].

The display reported in [20] can provide 49152 voxels in a cylinder display space with a diameter of 144 mm and a height of 110 mm. The display is monochrome and the size of display space is finite.

The works reported in [21] include two display prototypes: a basic prototype and a modified one. The basic prototype can provide 3D images with 343-degree view angles, while the modified one with 360-degree view angles.

The display reported in [22] can provide 320*256*512 voxels in a cylinder display space, in which using wireless optical transmission realize the data transmitting form PC to the display system. The system has realized of dynamic display for large 3D scene by incremental transmission, and the whole dynamic scene display.

The display in [23] and [24] can be classified as a quasi-volumetric display by the parallax-barrier method to generate 3D images. The outer cylinder of this kind display is a parallax barrier spinning rapidly while the inner cylinder spins slower in the opposite direction. The two systems can only display the outer shell of a filled volume and cannot provide full 360 view angle of the object on display.

The Volumetric 3D Display in [25] uses the rotation of 1D LED arrays to display 3D images. The most essential difference is that the display can generate a real 3D imagery, while the display in [23] and [24] is quasi-volumetric. But the system can not display the volume close to the rotation axis.

The works reported in [26] and [27] are the recently developed SV3DD, the SV3DD is capable of rendering and displaying real time, full-motion 3D video. But the voxel space of the system is not distributed uniformly, since there has empty display space between the sub image units obviously.

In view of the above problems, the innovation of this

paper mainly include: (1) using the advanced electronic technology, realizing the continuous display of 3D animation smoothly; (2) realizing the uniform distribution of the display space; (3) realizing the development of practical commercial prototype.

Compared with the previous design, our design adopts modularization design method, compacted data structure, and multi-processing technique realizes displaying 3D images and animations with 360-degree view angles, and the image resolution can be up to 96*128*360 voxels at a refresh rate of 7200eFps.

III. SYSTEM HARDWARE

The mechanical components of the SV3DD system is composed of base mechanism component, transmission mechanism, display panel frame, and outer casing of safety protection. The block diagram of the system hardware is shown in Fig.2. The system hardware includes a wireless transceiver module, a synchronous control & data broadcast module (SC&DBM), a sub-display module, and a motor driver& control module [28].

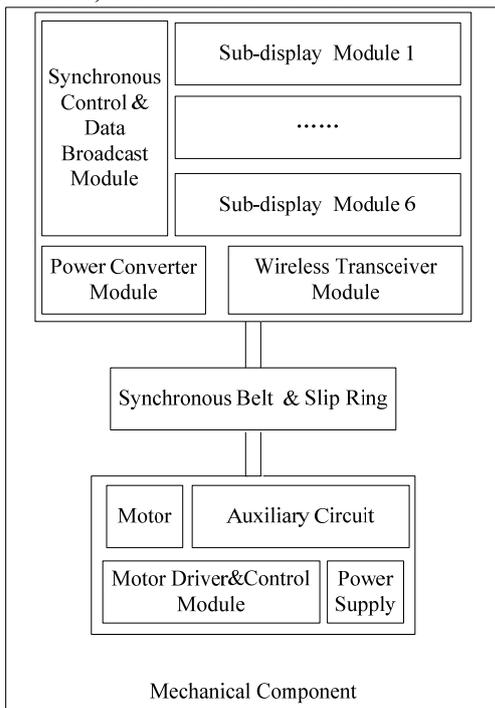


Figure2. System hardware block diagram of the SV3DD system

A. Wireless Transceiver Module

The function of the wireless transceiver module is realizing the transmission of 3D image data and control commands between three-dimensional display device and computer.

B. Synchronous Control & Data Broadcast Module (SC&DBM)

The SC&DBM module realize synchronous control signals' transmission and the 3D data broadcast.

The functions of SC&DBM module include: first, it can realize communication with the communication

module; second, it can realize the broadcast of 3D data as data is transmitted; third, it can realize the transmission of synchronization signal when the system is running.

C. Sub-display Module

Sub-display module includes data processing layer, display driver layer and LED display layer etc. The block diagram of Sub-display module is shown in Fig. 3.

Sub-display module includes data processing layer, display driver layer and LED display layer, etc.

Data processing layer's main function include two aspects: one is responsible for receiving and storing data into the memory card when SC&DBM broadcasts 3D data, another is responsible for the 3D data processing and transmission to display driver layer when the system is running.

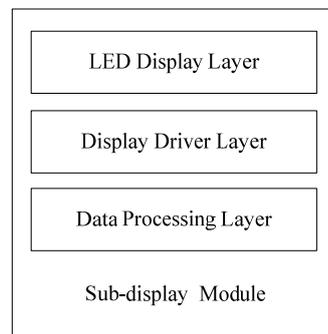


Figure3. Sub-display module

Display driver layer realizes the display's high speed driving and color display method.

LED panel is driven by FPGA chips through row and column scanning. A FPGA chip control LED array composed by 16*16 LED components. In a LED array, analog switch's one pin is connected with common anode pin of a line LED and the other pin is connected by one FPGA pin. And the same color LED's pins of the same column are connected with the other FPGA pin.

The LED panel is lighted by FPGA chip through row and column scanning mode. A FPGA chip controls a LED array composed by the 16*16 LED components.

Fig.4 shows SV3DD's photo and in operation displaying a static image of a HaiBao, respectively.



Figure4. ECNU's SV3DD (a) SV3DD (b) In operation

IV. DATA ACQUISITION & PROCESSING METHOD

The purpose of the data processing method is to obtain the correct data in order to display an object in the swept-volumetric display. This part describes the data acquisition, preprocessing method, and data rendering algorithm.

A. Data Acquisition Method

According to different data types, we adopt a different data acquisition method [29,30].

For a number of advertising, animation or science fiction and other virtual object, we use the mature 3D modeling software, such as 3DMAX, BLENDER, etc., to generate data file. The file contains vertex number of grid, grid coordinates, mesh texture vertex coordinates, the corresponding rendering map, grid vector coordinates, etc. We need to read the number of vertices of the grid from the file, and the grid vertex coordinates (x, y, z) were saved to memory; then according to the coordinates to find the mapping's RGB24 color data. Finally, we get the data with the form (x, y, z, r, g, b).

For the data obtained by scanning through the cross section, such as medical CT data, the coordinates (x, y) of each slice of CT picture remains the same and corresponding Z coordinate is given according to the relationship of multi-slice CT. A pixel's gray value assigned to the corresponding pixel's RGB24 color data. Then, we get the form of the data format (x, y, z, r, g, b).

For the real object, for example a teapot or a person, we can realize real-time data acquisition using camera networks, through data processing to obtain required final data [31-33].

B. Data Processing Method

Image data processing can be divided into the following three steps: data normalization, coordinate transformation data reduction, and data partitioning [30].

1) Data normalization

The purpose of data normalization is to select the proper parameters to fit the display.

Firstly, getting the maximum and minimum value of the data stored in the format (x, y, z, r, g, b) on the direction of X Y and Z, then obtaining the object center coordinates (x_{center}, y_{center}, z_{center}), which is computed using Eq.(1).

$$\begin{aligned} x_{center} &= (x_{max} + x_{min}) / 2 \\ y_{center} &= (y_{max} + y_{min}) / 2 \\ z_{center} &= (z_{max} + z_{min}) / 2 \end{aligned} \tag{1}$$

The center coordinates of the object moved to original coordinate, and the coordinate of the voxel changing to x', y' and z', which is computed using Eq.(2).

$$\begin{aligned} x' &= x - x_{center} \\ y' &= y - y_{center} \\ z' &= z - z_{center} \end{aligned} \tag{2}$$

Then adjust the object data scaling to the actual display screen resolution[23].

2) Coordinate transformation

The normalized data under the Descartes coordinates with the form (x, y, z, r, g, b) is converted to system coordinate with the form (h, w, θ, r, g, b). The implementation of the conversion requires two steps: 1) conversion the data from Descartes coordinates to cylindrical coordinates with the form (θ, ρ, z, r, g, b); 2) conversion the data from cylindrical coordinates to system coordinate with the form (h, w, θ, r, g, b).

3) Data reduction

After completion of coordinate transformation, we need to reduce the stored data. Data reduction process mainly includes: (1) saving the voxel data which will be activated; (2) using data reusing mechanism based on the system's character.

Based on the panel's coordinates of the 3D image inquiring the memory in which to store data, if the matching condition is satisfied at the termination of the query, color data in the memory gives corresponding color data of the 3D image, otherwise color data gives 0.

This algorithm can implement loops according to the slice from 0 to (N_{slice}/2-1), radius from 1 to 96, and with heights ranging from 1 to 256.

To reduce the data needed for swept-volumetric display, we adopt data reusing mechanism. The implementation of data reusing is to assign slices' data from (N_{slice}/2+1) to N_{slice} with from 0 to (N_{slice}/2-1).

4) Data partitioning

In this process, display data is divided into N equal size according to the size of the sub-display system [28]. Volumetric display space (VDS) and a longitudinal section of it are shown in Fig. 5.

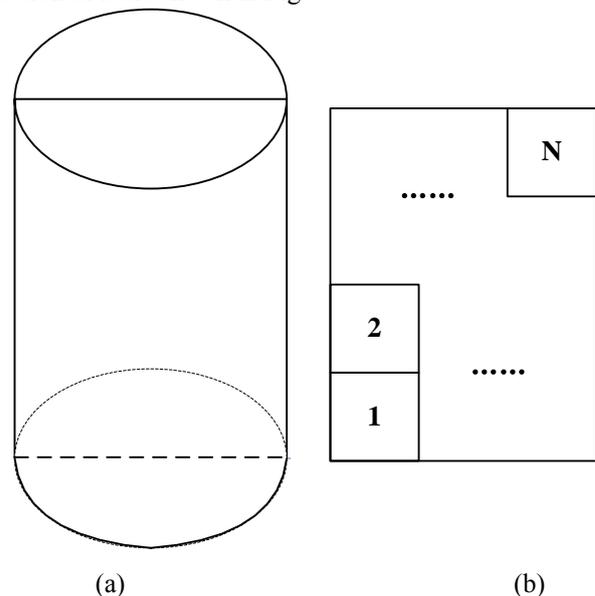


Figure5. Volumetric display space (VDS) and it's longitudinal section. (a)volumetric display space. (b) a longitudinal section of volumetric display space[28]

Fig. 6 presents the 3D data dividing process. The size of sub-3D data can be adjusted according to the processing ability of the sub-display system. Experiments proved that this data dividing algorithm has good

suitability, scalability, and acceptability.

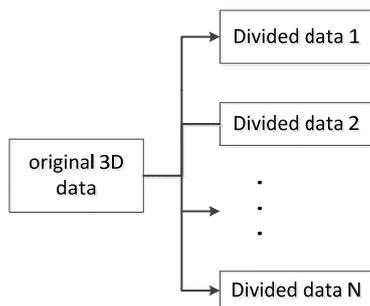


Figure6. 3D data dividing process

C. Data Rendering Algorithm

The purpose of the rendering algorithm is to compute the voxel locations in the cylindrical grid that require activation in order to display a polygon in 3D space.

So far, swept-volumetric 3D display system’s data rendering method emerging in literature are as follow: (1) saving, transmitting, and display raw voxel of 3D image[19],[23], (2) saving, transmitting, and display cross-sectional 2D images of the 3D image , by projecting 2D images onto a rotating screen or micro-mirrors to generate 3D image [23],[34-36], and (3) a streamline algorithm including edge intersection detection and polygon filling[26,27].

For the first method, the main disadvantage is the

communication bandwidth increasing with the size of a 3D image. The system will need complicated optical components for the second method. The algorithm of the third method is more computationally efficient than the first method. But the algorithm only employs basic functions for rendering colored polygons and can not render advanced lighting, shading and texture information of 3D objects. Increasing the number of activated voxels decreases the throughput of the display for the third method.

The improved data rendering algorithm is presented in Fig.7. This algorithm adopts the parallel processing method. In the process of rendering, all the sub-display modules synchronously receive the divided data and transmit the data to the display unit. This algorithm consists of three steps:

Step 1: 2D display frame detection. The purpose of this step is to find the proper planar SOE which will be activated.

Step 2: Data mapping. According to the planar SOE detected in step 1, finding proper display data for voxel activation is the main purpose of this step.

Step 3: Object’s voxels activation. This process is to activate needed LED on the SOE.

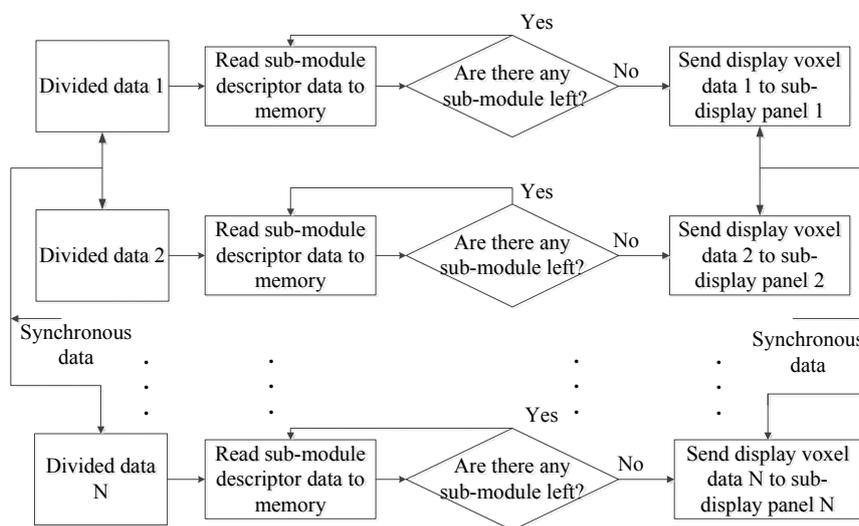


Figure7. Data Rendering Algorithm Overview

V. EXPERIMENTAL RESULTS AND DISCUSSION

This section presents the procedure of the verification process of the system and experimental results. The experiments include the following process: model generation, data processing and simulation, and on system testing.

Step 1: Model generation. In this process, we use the mature 3D modeling software 3DMAX to generate the

3D data of the model.

Step 2: Data processing and simulation. In this process, we process the generated data to fit the system’s character firstly, and then use our simulator to test the processed data which will be displayed on the prototype and show its results.

Step 3: On system testing. In this process, we test the processed data on ECNU’s SV3DD.

We tested the solution with 3D images and evaluated

its performance. The images were generated based on the method described in Section IV.

Fig.8 provides a 3D image generated from the 3DMAX.

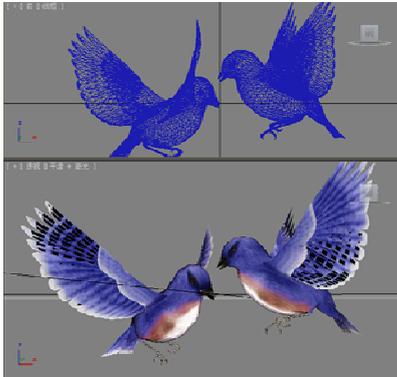


Figure8. Birds model

Fig.9 provides a simulation result of the reconstructed 3D model.

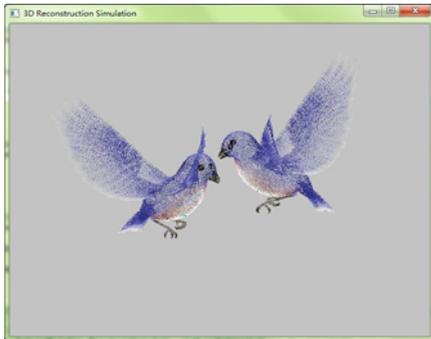
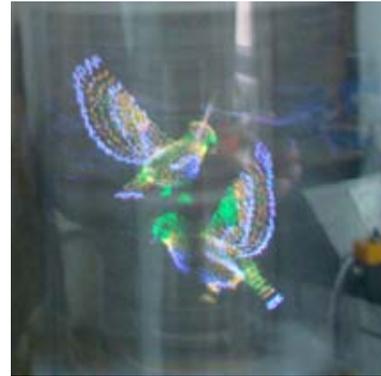


Figure9. Reconstructed Birds

In normal operations of the display, the display panel rotates at the speed of 900 rpm. It supports displaying 3D images at 7200 eFps. The actual displayed images from different view points are shown in Fig.10. The experimental results in Fig.10 show that the SV3DD (swept volume 3D display) system can display 3D images with 360-degree view angles.



(a)



(b)

Figure10. ECNU's SV3DD in operation from different view point

Table I summarizes the comparison result of characteristic for different display system. It is observed that the proposed solution consumes only 4bit per point (bpp) to store the whole data, while the one in [21] need 6 bit per point and the other one in [26,27] need 12 bit per point. Compared with the previous solutions [19-23] for SV3DD, the system's performance based on our solution greatly improved.

TABLE I.
CHARACTERISTIC COMPARISON OF DIFFERENT DISPLAY SYSTEM. DS=DISPLAY SPACE, RoLEDp=RESOLUTION OF THE LED PANEL, vNpvF=VOXEL NUMBER PER VOLUME FRAME, vDpvF=VOXEL DATA PER VOLUMETRIC FRAME, RS=ROTATE SPEED, CoD=CHARACTER OF DIODE RGB OR MONOCHROME

		DS(mm ³)	RoLEDp	vNpvF	vDpvF (Mb)	RS	CoD
The displays in [21]	small	φ 306*96	128*32	524288	8.388608	-	Monochrome
	large	φ 292*165	256*64	8388608	16.77722	-	Monochrome
The display in [22]		φ 800*640	320*256*3	62914560	251.658	900	RGB
The display in [26,27]		φ 712*-	64*64*3	6291456	50.332	1800	RGB
The improved displays	Large	φ 960*1440	128*96	2211840	17.695	1200	Monochrome
	middle	φ 480*640	192*256*3	26542080	70.779	900	RGB
	Small	φ 240*320	96*128*3	6635520	17.695	900	RGB

The rendering time of the display in [26,27] vary with the number of polygons of the same image, because of

the rendering overhead associated with reading polygon data and drawing polygon edges. The rendering time of

ECNU's SV3DD cannot increase with the number of the object's component. In general, since the improved method adopts color palette technology, the amount of data transmitted to sub-display model is compressed effectively.

VI. CONCLUSIONS

The display we present in this work is able to show small-sized scenes in 3D to any number of people gathered around to view its imagery. This paper presents a prototype of swept-volumetric display system based on LED arrays. This display can present 3D images without using special headgear or glasses, which has the advantage in displaying 3D opaque objects over other systems. We have designed an improved 3D image generation and displaying algorithm. With this method, the new display system can generate 3D images for display on a cylindrical display space, which effectively reduces the computational load on host PC and the required transmission bandwidth between PC and display.

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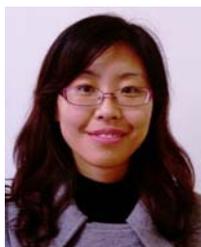
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