Multimedia Systems
DOI 10.1007/s00530-013-0333-1

REGULAR PAPER

Real-time panoramic video streaming system with overlaid interface concept for social media

Dongmahn Seo · Suhyun Kim · Hogun Park · Heedong Ko

Received: 17 August 2012 / Accepted: 9 August 2013
© Springer-Verlag Berlin Heidelberg 2013

Abstract In this paper, we propose a real-time panoramic video streaming system with overlaid interface concept for social media. The proposed system provides real-time panorama images for smart displays such as smart TVs, smart phones, and tablet PCs. Panorama images are collected at sporting events via panorama cameras. Contents thus collected are sent to servers and then provided to smart devices via live sports video streams. Users select a panorama camera and choose their viewing angle and zooming factor for the selected panorama camera. The proposed system provides immersive and realistic views of live sporting events on users' displays. Furthermore, an overlaid panoramic interface concept is proposed for immersive live baseball watching combined with tightly integrated social media experience.

Keywords TV · Panorama · Interface · SNS · Live · UGC · Smart TV · Smart phone · Streaming

1 Introduction

Advanced television systems have been developed to provide a better user experience, such as smart TV, interactive TV, internet protocol televisions (IPTV), social TV, stereoscopic three-dimensional (3D) TV and so on. However, these systems, except stereoscopic 3D TV, do not focus on providing immersive and realistic view of content. Especially for live sporting events, many users want to watch immersive and realistic images from their televisions. Full HD TVs provide high-resolution content, and stereoscopic 3D TVs support three dimensional images. However, full HD TVs do not provide interactive content, and as compared with legacy TVs they provide only higher resolution. Moreover, 3D TVs give users more immersive and realistic experience, but they tend to be inconvenient, requiring the use of glasses and sometimes making users feel dizzy.

In this paper, a real-time panoramic video streaming system with overlaid interface concept for social media is proposed to provide immersive live sports content on smart TVs and smart phones. Panoramic images from several panoramic cameras at a sports stadium are provided to users via servers. The proposed system offers $6{,}000 \times 3{,}000$ resolution panoramic views, moving left, right, up, and down and zooming in and out at the request of users. Using our panoramic video streaming system, users can watch not only the game but also spectators, cheerleaders, or other attractions in the stadium as they wish.

In research on social media in the interactive TV domain, many attempts have been made to provide a more socialized experience on TV. However, most existing social TV platforms aim to connect viewers with friends and families by providing a shared virtual space. Almost all current interactive TVs provide only TV content with bi-directional communication channels [1–4].

We propose a panoramic social media interface concept for immersive viewing of live baseball, soccer and so on with various types of content, including social media and

Communicated by: L. Böszörmenyi

D. Seo · S. Kim (✉) · H. Park · H. Ko
Imaging Media Research Center, Korea Institute of Science and Technology, Hwarangno 14-gil 5, Seongbuk, Seoul 136-791, Republic of Korea
e-mail: suhyun.kim@imrc.kist.re.kr

D. Seo
e-mail: sarum@imrc.kist.re.kr

H. Park
e-mail: hogun@imrc.kist.re.kr

H. Ko
e-mail: ko@imrc.kist.re.kr

user-generated content, on smart TVs and smart phones. It displays overlaid icons of the user-generated contents and social features over the high-definition panoramic live video.

The rest of this paper is organized as follows: Sect. 2 discusses related works. Section 3 details the architecture of the real-time panoramic video streaming system. In Sect. 4, an implementation of our system and its results are described. Section 5 proposes the concept of the panoramic interface concept for social media. In Sect. 6, user test and evaluation are discussed. Section 7 concludes the paper.

2 Related works

Related to panoramic images/videos, various concepts have been proposed [5–7]. Panoramic image creation technologies have been proposed in [5, 6]. However, panoramic services are not considered. The immersive panoramic video system has been proposed [7]. In immersive panoramic video, a user experiences the video by wearing a head-tracking display. The portion of the video in the direction of view is dynamically extracted and presented to the display in response to the user's head orientation. The related research explains camera subsystems, recording subsystems, hardware systems, a production process, live broadcasts, and playback applications. However, high-resolution panoramic images and TV environments are not considered. It is especially difficult to operate such a system in real environments, such as the panoramic cameras used during a live TV broadcast.

In one study [8], high-resolution panoramic views were proposed. The system discussed supporting ultra-HD (UHD) panoramic views in 3D environment. However, sequenced images or videos were not considered.

Another study [9] presented a unified approach to automatically build dynamic multi-resolution 360 panoramic (DMP) representations from sequences of images captured by hand-held cameras, mainly undertaking rotation and zooming for natural scenes with moving targets. However, neither real-time streaming nor live broadcasting was considered.

An adaptive strip compression for panorama video streaming was proposed in another study [10]. In this system, the panoramic images are fragmented vertically and streamed to clients for panoramic video streaming. However, the system concentrates only on strip images and compression. Also, images of 640 × 240 resolution are considered.

Region-of-interest (ROI)-based streaming has been proposed for peer-to-peer multicast live video streaming [11]. For distribution, the stanford peer-to-peer multicast (SPPM) protocol was applied. In this system, a thumbnail overview and slices are used for panoramic image streaming. A video conferencing streams at 3,584 × 512 resolution was used for the experiment.

A panoramic video coding based on multi-view video coding (MVC) has also been proposed [12]. In this approach, a MVC-coded panorama video stream and a down-sampled navigation video were applied for a panorama video stream format. Furthermore, a panorama video player was proposed to consider user interaction. However, since the MVC was applied, the system could not operate in a live broadcasting environment.

Supporting zoomable video stream with dynamic ROI cropping has been discussed [13]. In this research, the tiled streaming and the monolithic streaming were proposed, analyzed, and evaluated. However, since a pre-computed dependency information is used, this research is not suitable for real-time streaming and huge resolution panorama streaming.

End-user interfaces using panorama have been researched to provide a more immersive and interactive user experience (UX). In the FascinateE Project [14], a user interface (UI) for a mobile device and TV using UHD resolution panorama was proposed. The format-agnostic [15] concept was proposed to provide a UI which was an ROI-selectable interface using an adaptation of resolution, field-of-view, aspect ratio, frame rate, and color depth for the user environment [16]. However, since the proposed interface focused on ROI-transition for tracking a player or actor, it was limited to providing metadata abstraction for current ROI, visualization of summarized information, and mutual interaction between users. Furthermore, the segment recombination node (SRN), additional resources, was necessary for media streaming to end user devices.

As smart phones with GPS and digital compasses are widespread, various smart phone UIs for displaying location-based social media inputs have been proposed for social media consumption, creation, and interaction. The Sekai Camera provides a location-based augmented reality (AR) service on smart phones (http://sekaicamera.com/). In Sekai Camera, user-generated crowd tags are displayed over real-time recording video on a smart phone based on the video's location and direction. The Wikitude GIS provides visualized location information, such as nearby points of interest (POI) and direction via smart phones. However, such research has been limited to legacy 2D video and cannot display various ROIs and social media taking into account object distance and zooming factor.

3 Real-time panoramic video streaming

The proposed system encompasses not only the server side but also the client side. Servers in our system collect

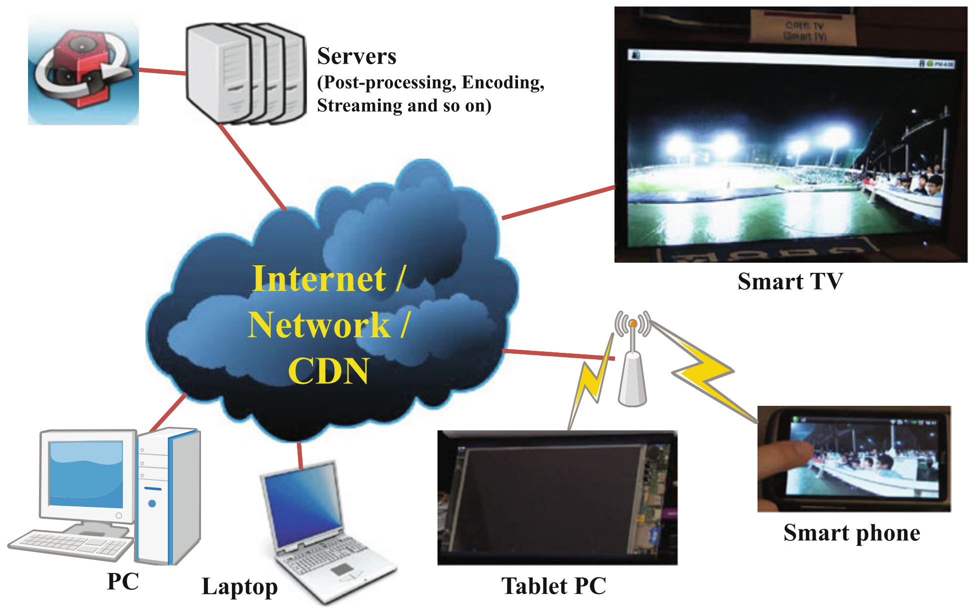

Fig. 1 The architecture of immersive panorama TV service system

panoramic images using panorama cameras at sports stadiums and provide streaming service to immersive panorama TV clients. Clients can be a smart TV, a smart phone, a tablet PC, a laptop, a PC and so on. Figure 1 shows the architecture of the immersive panorama TV service system.

3.1 Servers

As shown in Fig. 1, servers for the immersive panorama TV service consist of a post-processing module, an encoding module, and a streaming module. Each module can be an individual server or several software modules on the same server.

The post-processing module receives panoramic images from panorama cameras, decodes the images, and then adjusts them for contrast, brightness, and color. Such post-processing is essential: since the playing field of a stadium is quite bright and the stands of a stadium are relatively dark due to the stadium lights, it would otherwise be difficult to recognize objects, spectators, and players in the panoramic images. Since we deploy the Ladybug3 of Pointgrey as a panorama camera, the Ladybug SDK (http://www.ptgrey.com/products/ladybugSDK/index.asp) is applied for the post-processing module. After processing, the adjusted panoramic images are sent to the encoding module.

The encoding module encodes the adjusted panorama images sent from the post-processing module. At this point, the images are converted and encoded into more than three resolution levels to allow for effective play on various clients and to reduce network bandwidth consumption as shown in Fig. 2. The last example is a high-resolution image at the same resolution as that of the original, the first one is a low-resolution thumbnail for full-screen view, and the other is a moderate-resolution thumbnail. All of the panorama images are encoded in JPEG format. Since the actual viewing area on the client display is only a small part of the higher resolution images, the high-resolution image is divided into small slices and encoded. In this way, the network bandwidth consumption of the server is reduced significantly because clients receive slices of the high-resolution panoramic image rather than the entire image. An average size of an original source panorama image is approximately 1,564 kilobytes. If a 5,400 $\times$ 2,700 source image is divided into 40 slice images (10 $\times$ 4), one sliced image is 450 $\times$ 675. We assume that a sliced image size is the source image size / 40 slices (approximately 40 kilobytes). If a smart phone has a 1,280 $\times$ 720 display, maximum 12 sliced images (4 $\times$ 3) are needed to display panorama and a maximum bandwidth for one frame is 480 kilobytes in case of using sliced images. The method of dividing a high-resolution panoramic image into multiple slices is shown in Fig. 3. A source panorama image is 5,400 $\times$ 2,700; however, significant area is 5,400 $\times$ 2,000. We use four levels of panorama. The first one is a small thumbnail (1,080 $\times$ 400), the second one is a big thumbnail (1,728 $\times$ 640), the third one is a small sliced panorama (3,240 $\times$ 1,200), and the last one is a big sliced panorama (5,400 $\times$ 2,000). Small and big sliced panoramas are divided into 40 (10 $\times$ 4) slices. All encoded images for four levels are transmitted to the streaming module.

The streaming module receives the encoded images from the encoding module and provides panoramic live streams of the sporting event to clients according to user requests. While the low-resolution thumbnail image stream

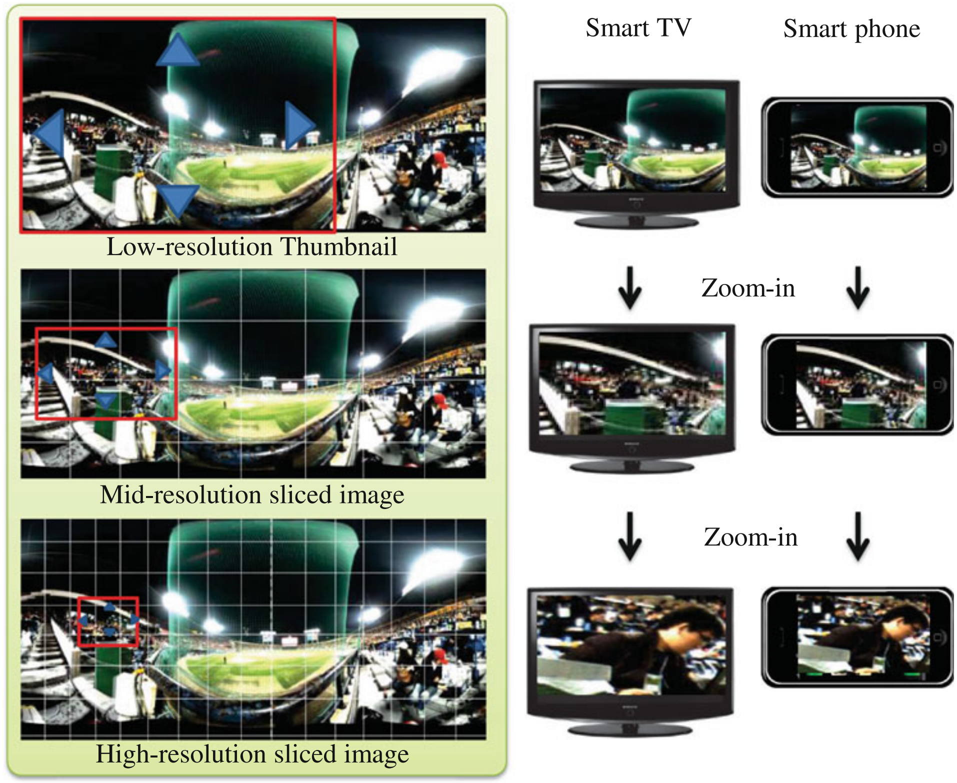

Fig. 2 Panorama images for streaming

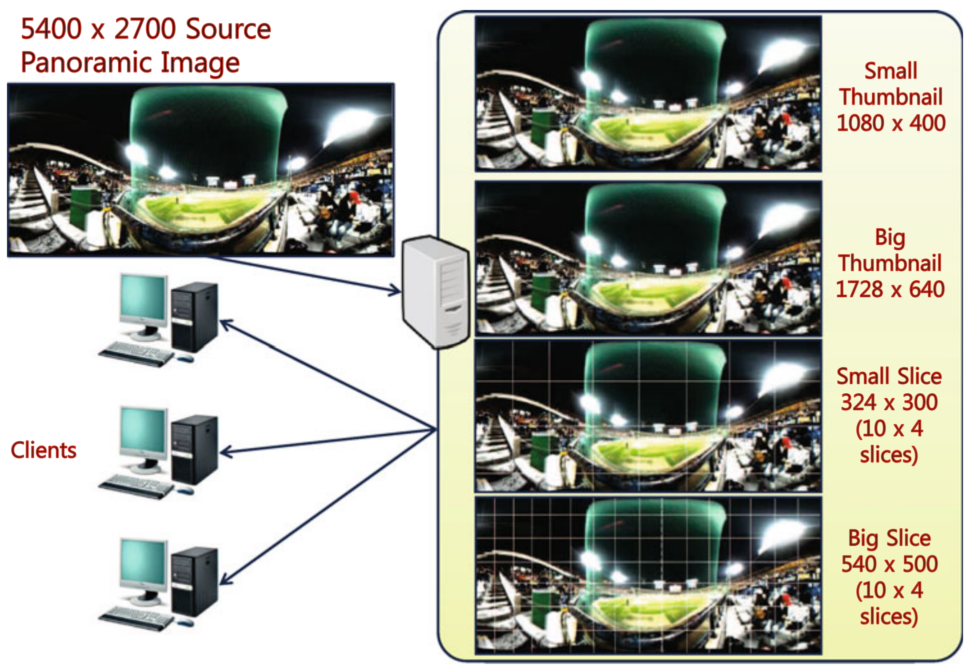

Fig. 3 Panorama resolution levels for streaming

is provided to clients watching the full-screen view of the entire panoramic image, sliced high-resolution image streams are served to the client watching a small portion of the high-resolution panoramic view. The server actively copes with the real-time requests of users and efficiently provides each stream.

3.2 Clients

A client can be a smart TV, a smart phone, a tablet PC, or a desktop or laptop computer. The client consists of a receiving module, a user interface module, and a display module. The receiving module manages buffers for panoramic images, stores the streams transmitted from servers, and sends them to the display module. When the display module requests images that are not in the buffers, the receiving module sends request packets to the servers to retrieve the requested images.

The user interface module collects user inputs for view changes such as moving left, right, up and down, and zooming in and out, and sends the view changing commands to the display module.

The display module receives view changing commands from the user interface module and shows panoramic images according to the received commands. The display module makes a virtual image space as large as the original panoramic image using the received low-resolution image in the buffer of the receiving module and shows the user the selected area of the panoramic image. When the user-selected area becomes smaller because of a zoom-in, the display module sends a request message for higher resolution images to the receiving module. When the display module is able to retrieve the higher resolution images, these are mapped to the virtual image space and are displayed on the client's screen.

4 Implementation and results

We implemented the proposed service system and tested it in a real environment. A commercial panorama camera (Ladybug 3) is deployed for our system. The panorama camera sends panoramic images to servers using an IEEE 1394B interface. Server modules were implemented in C#, C language, and a panorama API. The streaming module was developed in C#, and the post-processing module and the encoding module were implemented using C language and a panorama API.

Figure 4 shows the deployed real-time panorama streaming system. The panorama system was deployed at a baseball stadium to capture and stream live panoramic video.

The protocols for smart TVs and portable smart devices (smart phones, tablet PCs and so on) were developed on the open-source smart phone platform. The user interface module was implemented in Java, the post-processing module was developed in C language with JNI technology and the Ladybug SDK, and the display module was implemented in Java and C language using JNI technology. The PC-type client is developed using C on a general purpose operating system for personal computers.

On the used smart phone platform, memory lack problems emerged because a great deal of image buffering was needed to display the panoramic images. To solve this problem, we optimized display image size, memory usage, and buffer management of our client program on the

Fig. 4 Real-time panoramic video streaming system

platform via an experimental method. Since whole original panorama image is 5,400 × 2,000, over 30 megabytes are needed for a raw RGB data buffer per one frame. However, we use only 2.64 megabytes raw data buffer which is for display size 1,280 × 720. Furthermore, only two buffers are deployed for the proposed system. One is for display, and the other is for the next frame. To reduce CPU consumption of smart phone, display part of panorama images is decoded and written in a buffer.

We designed four kinds of user interfaces for the clients: the first used multi-touching and dragging, another employed a split-screen touch-based method, the third used keyboard and mouse, and the other used a TV remote controller. The method using multi-touching and dragging moves views of panoramic images according to drag direction and zooms in or out according to change in the distance between the touches. The split-screen touch-based method divides the screen into six areas. Four side areas are used for moving the panoramic image views, and the other two centered areas are for zooming in and out. The method using multi-touching and dragging and the split-screen touch-based method was applied to portable smart devices.

The method using keyboard and mouse is for desktop PCs or laptops. Input data from the keyboard and mouse are used for movement or zooming of panoramic views. The method using the remote controller is for smart TVs or IPTVs. According to the user's input with the remote controller, panoramic views are moved left, right, up, or down, and zoomed in or out.

Furthermore, we implemented a panoramic image recovery method. If some high-resolution slices are not found in the buffer when a user moves his or her high-resolution view, this method in the display module requests them from servers, and simultaneously creates non-

Fig. 5 Snapshots of smart TV

Fig. 6 Snapshots of smart phone

received part of a panoramic view from up-scaled low-resolution thumbnail until the requested slices arrive. Therefore, users are able to immediately navigate high-resolution panoramic view.

We deployed the system using three panorama cameras during the last game of the Korean Baseball Organization's Korean Series on October 19, 2010. The maximum number of concurrently served users was 15. Figures 5 and 6 show screenshots of the implemented immersive panorama TV service on a smart TV and a smart phone, respectively. The left upper picture of each figure explains the direction of the three panorama cameras at the stadium. Each of the cameras was located on a stand at the stadium in a given direction. When users selected a camera among the three locations, the panoramic stream of the selected camera was provided to the smart TV or the smart phone in real-time.

Table 1 shows the performance of the implemented system. The maximum resolution of the panoramic image was 6,000 $\times$ 3,000 which is the limitation of the deployed panorama camera (Ladybug 3), close to 3K UHD resolution. The service frame rate was one frame/sec, and the average transmission bit-rate was 250 KB/s. Table 2 shows server processing times for panorama images depending on panorama resolution. A server processing time consists of capturing and transmitting time from panorama camera and post-processing time and encoding time on the server. To

Table 1 Implemented service specification

Unit	Specification
Maximum panorama resolution	6,000 × 3,000
Applied panorama resolution	5,400 × 2,700
Significant panorama resolution	5,400 × 2,000
Frame rate	1 frame/s
Average bandwidth	Approx. 250 KB/s

Table 2 Panorama processing time in the propose server

Resolution	Maximum (s)	Minimum (s)	Average (s)
6,000 × 3,000	1.38	1.25	1.30
5,400 × 2,700	0.88	0.94	0.90

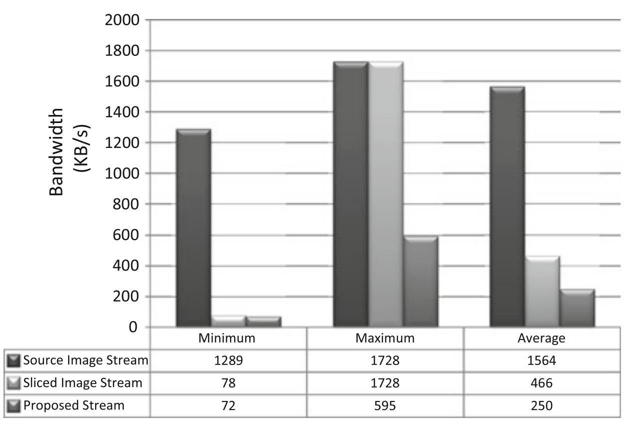

Fig. 7 Bandwidth consumption

provide 1 frame per second panorama streaming service, 5,400 × 2,700 panorama is applied for the implemented system. We remove unnecessary area (black area) in the captured panorama. Therefore, 5,400 × 2,000 significant panorama is applied for our system.

Figure 7 shows bandwidth consumption depending on streaming types. The source image stream is a streaming method with original source panorama images. The sliced image stream is a streaming method with big sliced images in our system. It is a similar method to SPPM [11] and/or the tiled streaming [13]. The minimum bandwidth of the sliced image stream and the proposed stream are very close. However, the maximum bandwidth of the sliced image stream is the same as the source image stream. Therefore, the average bandwidth of the proposed stream is the smallest among three streams. The average bandwidth has variation depending on user's ROI. A bandwidth requirement of the sliced image stream is as small as the proposed stream, in case of the highest zoom level. However, a bandwidth requirement of the sliced image stream is as big as the source image stream, in case of the lowest zoom level.

5 Panoramic interface with social media

5.1 Concept of the panoramic interface

Panoramic video provides immersive and 360 degree spatial information at the same time. When we compare panoramic video to a human being, views from the video directly correspond to ego-centric (self-to-object) observations on a point in space. Therefore, panoramic video can be regarded as a good spatial metaphor for perceiving targets and transiting to other placements [17]. In this paper, we propose a zooming-level-based panoramic interface for selecting geo-located media and changing its spatial orientation.

Figure 8 explains a concept of the panoramic interface. Since the panoramic interface displays real-time contents such as social media, user-generated content, pictures, and so on over UHD panorama live video, users can watch live sports in an immersive and interactive way, complete with social media and other related content. Users can select what they want to watch by moving up/down and left/right, and zooming in and out in a 360° panorama video of a stadium. Related content and social media are collected from various social networking services (SNS) and other mobile live streaming services. Therefore, users can consume various social media, video clips, pictures, and live video related to the sporting event being watched. Furthermore, live TV and additional multi-angle live video views are provided for more detail and to provide various scenes of the game, and a live scoreboard service is included.

Table 3 shows the display steps of the content depending on zoom level. Each content item has distinct display steps and scene changes for user recognition. Contents of the panoramic interface consist of live TV, a live scoreboard, other panorama views, HD or SD multi-angle views, user-generated content, information for each base event, and messages, pictures, and information inputted by friends. The implemented resolution levels for the streaming module is shown as Fig. 3 in Sect. 3 Each resolution level images is used for each zooming level of Table 3 for the panoramic interface.

Figures 9 and 10 show concepts of the proposed panoramic interface. We used three panorama video cameras in a baseball stadium for this interface. The panoramic interface for smart TVs is introduced in Fig. 9. Based on the zoom level as shown in Table 3, the panoramic interface for smart TVs changes. In level 1, summary icons and content counts are displayed at the right and top. Summary icons and counts are calculated and displayed form SNSes and other multimedia content in real time. When massive social media inputs are published in a specific area, that area and the social media counts are displayed over the

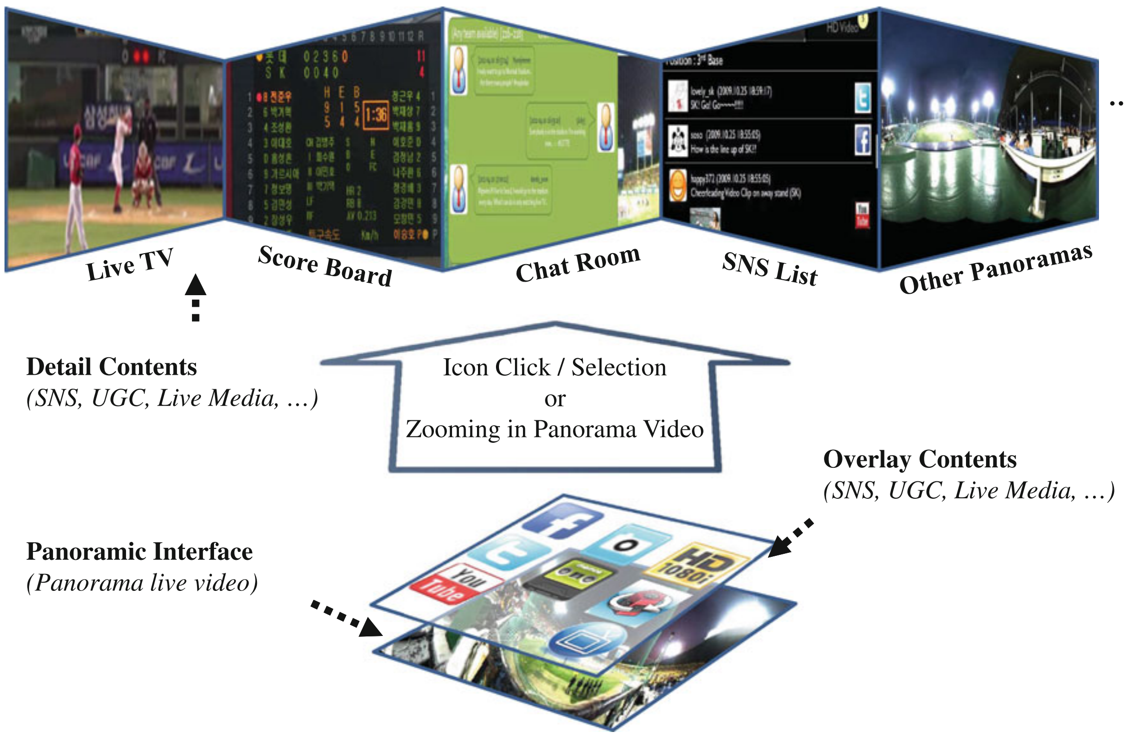

Fig. 8 Concept of the proposed panoramic interface

Table 3 Interface zooming levels

	Level 1	Level 2	Level 3	Level 4
Live TV	Icon	Thumbnail	Selection	Full screen TV
Score board	Icon	Icon	Selection	Live score board
Panorama	Icon	Icon and name	Icon and name	Selected panorama
HD and SD multi-angle view	Icon	HD or SD Icon	Thumbnail	Full screen
User-generated content	Icon	Icon	Thumbnail	Full screen
Information of each base	Icon	Icon and name	Icon and name	Full list and contents
Messages	Count	Icon	Icon, team and ID	Picture, team, ID, content and time
Pictures	Icon	Icon	Thumbnail	Full screen
Friends	Icon	Icon and name	Team, picture and name	Team, picture, name and summary

panoramic interface. Furthermore, locations of a user's friends are displayed for easy communication.

At level 2, more detailed information is displayed. Information for each social media outlet is displayed with more information for the published location over the panorama video. At level 3, interface selections are provided. As shown as the level 3 picture in Fig. 9, a selection interface between live TV content and a live scoreboard is displayed over the panoramic video.

Figure 10 shows the panoramic interface for smart phones. Since the display of the smart phone is small, summarized information and icons are displayed over the panorama video, and scene changes are minimized. Furthermore, since smart phones use wireless or 3G networks, the full-screen display of contents in the level 4 has no panorama background to reduce network bandwidth consumption. Only full-screen content is displayed.

5.2 Overlaid interface display for social media

In order to display location-based social media inputs over the panoramic video, depth information is needed. While objects are located in the same panorama view, distances between the camera's location and objects are quite different in the real world. Therefore, each object has a different distance when the same objects are located in different places in the panorama view. If distance information for the social media location is not considered when

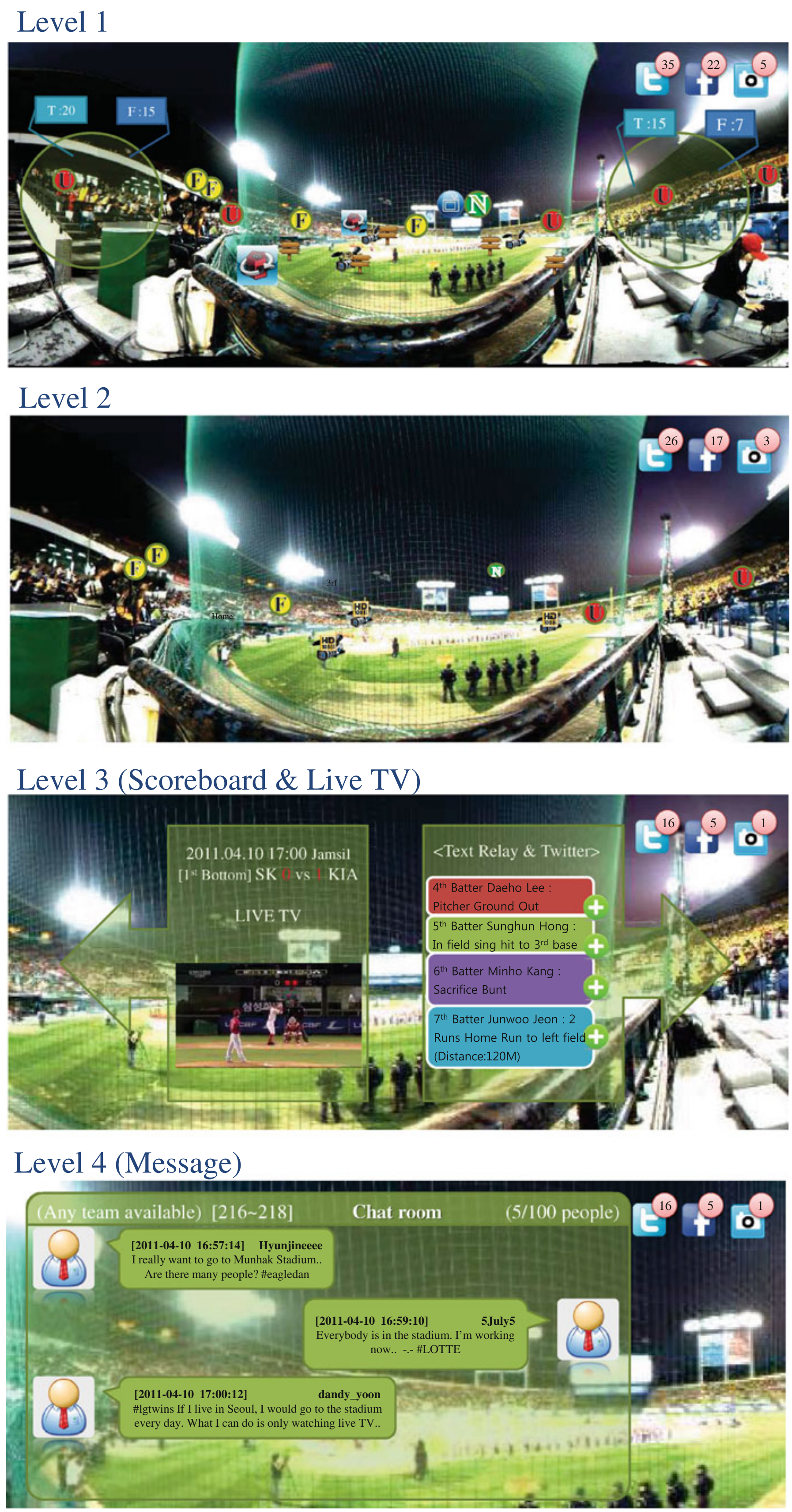

Fig. 9 Panoramic interface concept for smart TV

Fig. 10 Panoramic interface concept for smart phone

social media inputs are displayed on the panoramic view, users cannot recognize the location of social media inputs correctly. If every social media input is displayed via similarly sized icon in the panorama view, users may not have an adequate immersion experience. Therefore, different-sized social media displays depending on the location and distances of the social media are needed.

To solve these problems, we used a depth map for the panoramic video. The depth map has the same resolution as the video. In the depth map, each point has a depth value from 0 to 255. In displaying the social media inputs of the user's friends, we calculate relative distance from the user's viewpoint, the zoom level, and the location and depth values of the social media inputs. From the calculated relative distance of the social media inputs, the display size is determined according to the display size of the user device. Figure 11 shows the depth map image for panoramic video streaming. This depth map image is streamed to clients along with the panoramic video.

Figure 12 shows the implemented panoramic interface for smart phones. The implemented interface displayed various social media at the location where they were created, over the panoramic video using meta-data. In order to avoid information overload, the number of displayed social media inputs was limited as shown in the top-left snapshot of Fig. 12. If the number of retweets and/or replies for the social media inputs surpassed the threshold, the social media input was displayed. The implemented interface provided linkage with several services, such as a TV live service (top-right snapshot of Fig. 12), a SNS user profile view (bottom-left snapshot of Fig. 12), a user-generated content (UGC) streaming service (bottom-right snapshot of Fig. 12), and so on.

6 User test evaluation and discussion

6.1 Experimental setting

For the evaluation of our proposed interface, we conducted an experiment to investigate its immersiveness and informativeness for finding relevant media. In this experiment, a total of 38 participants (35 males, 3 females) participated, and their ages were ranged from 26 to 45 years old (Mean age = 33.44 years old, standard deviation (SD) = 4.44). The participants were recruited from baseball communities, online bulletin boards, and SNS. Their degrees of familiarity on a baseball game and social media services were (Mean = 2.92, SD = 1.53) and (Mean = 3.46, SD = 1.17), respectively.

In this experiment, our proposed panoramic interface was exposed to participants for 10 min, and a post-task questionnaire consisting of eight questions was sent to them via online, which the participants had to rate on a 5-point scale, indicating their level of agreement. As in Table 4, questions are grouped depending on immersiveness, informativeness, and comparison with existing social media services. The exact sentences for the questionnaire are described in Table 4.

6.2 Result and analysis

Table 5 shows results from evaluating immersiveness. When looking at question 1-1 and 1-2, it is observed that

Fig. 11 Panorama source image (*upper*) and depth map image (*downer*)

Fig. 12 Snapshots of panoramic interface on smart phone

their overall scores are promising in terms of providing immersive experience. In the question 1-1, participants felt that it could help to focus on the baseball game itself. According to our interview, some people thought that overlaid information on panorama video sometimes disrupted the important scenes at the baseball game. For example, when a Twitter message appeared at 1st base, the viewer may be able to miss an important judge to a runner at the 1st base while the Twitter message is visualized at the position of the base. In the question 1-2, most participants answered about four scores, and it indicates that ego-centric media interface was quite meaningful for enhancing immersiveness.

In these questions at Table 5, people were asked to answer how types of contents determine the immersiveness. As in scores of question 2-1 and 2-2, they indicate

Table 4 Questionnaire for evaluating a panoramic user interface

Group	No.	Question
Immersiveness	1-1	I could concentrate this baseball game
	1-2	I felt realistic that I've not felt with other services
Types of overlaid media	2-1	Linked live videos and UGCs in the service are helpful for me to concentrate a baseball game
	2-2	I felt that I'm in the stadium, from linked contents via overlaid icons
Informativeness	3-1	It is convenience for me to find various live videos and UGCs according to temporal and interest issues via panorama video
	3-2	It is convenience for me to get information according to location and time
Comparison with existing SNS	4-1	This service is easier interface to find information what I want than legacy SNS
	3-2	This service is more convenience to find people who have common interests than legacy SNS

Table 5 Results from evaluating immersiveness and immersiveness depending on types of overlaid contents

Question	Mean	SD
1-1	3.18	1.03
1-2	4.0	0.83
2-1	3.45	1.12
2-2	3.62	1.06

Table 6 Results from evaluating informativeness and comparison with existing social media services (Group A : familiarity on baseball game ≥ 3, Group B : familiarity on baseball game < 3)

Question	Groups of participants	Mean	SD
3-1	Group A	4.48	0.66
	Group B	3.75	0.97
	Overall	4.16	0.87
3-2	Group A	4.38	0.65
	Group B	4.19	0.53
	Overall	4.30	0.62
4-1	Group A	3.81	0.85
	Group B	3.44	0.70
	Overall	3.65	0.82
4-2	Group A	3.95	0.82
	Group B	3.69	0.98
	Overall	3.84	0.92

that both video and social media contents provide enough immersiveness for viewers. Thus, participants responded that immersiveness of the interface is almost equally influenced. They also answered that it was because those types of information were visualized using the same shapes of icons. Therefore, participants were likely to feel a little difference to discriminate a major factor for enhancing immersiveness.

In this set of questions, we sought to evaluate how the interface is informative for participants. As in Table 6, it shows high informativeness regarding temporal and spatial information retrieval. In particular, in Group A, participants, who have enough familiarity of a baseball game, experienced significantly high informativeness ($p < 0.01$ at t test). People responded that the proposed interface provided a good spatial metaphor, so it could help finding relevant information wherever they were needed.

In questionnaires on 4-1 and 4-2, participants were asked to compare our proposed interface with existing social media services. For example, Twitter often has been utilized for discovering and finding photos and information about a baseball game. However, in this proposed interface, it provides a region-based information visualization method for the same purpose. Therefore, we can compare it with the previous social media service for measuring its enhancement. According to the Table 6, people evaluated positively when it is compared, and it is also shown that Group A felt better usefulness on the two questions.

6.3 Subjective comments

In addition to the questionnaire above, we interviewed participant to list its pros and cons. As in Table 7, participants highly evaluated the spatial cognition from panoramic interface. For example, each live video, which is transmitting from 1st base, may convey different information depending on its pose and field-of-view. Therefore, users have great benefit in terms of selecting the best angle. Moreover, a participant expressed that transition using zooming factor was impressive. He answered that, in particular, summarization using icon and thumbnail at level 2 was useful for presenting pictures and videos. Meanwhile, for user-generated social media, he felt that it is needed to use different visualization interfaces, for instance, natural language-like summary. We also found it interesting that a participant preferred to use widget-type information visualization for frequently used types of information like scoreboard. Last, regarding the amount of time they spent, a participant answered that panoramic video was regarded as a transit media for selecting different geo-located social

Table 7 Summaries of subjective comments from participants

Responses
Good
It is intuitive to find messages and pictures, which are tagged by location
Seamless transition of each media is impressive!
This is my best experience ever tried! I can expect future view of video and become not to miss timely information
Bad
If the number of media is too large, it is needed to provide additional summarization or visualization tools
For some types of information like score-board, it seems like better to have a widget-type user interface
I stayed at the panoramic video for a while and spent my most time at other types of media

media. The response implies that relatively lower frame rate of panoramic video influences the pattern of usage.

7 Conclusion

In this paper, a real-time panoramic video streaming system was proposed to provide immersive and realistic content on TV and smart phone platforms. The proposed service was implemented for a live sports broadcast. The experiment confirmed that the implemented system provided users an immersive panoramic view. The implemented system supported a 5,400 x 2,000 resolution panoramic image of a live sporting event at one frame/s and immediately responded to user requests. The panoramic interface for the immersive baseball live broadcast has been proposed for various multimedia content and social media. Concepts of the proposed interface for smart TVs and smart phones have been introduced. With proposed interface, users can use SNS, communicate with friends, and obtain various information related to what they are watching.

In our future work, we plan to improve the frame rates of immersive panoramic images. The panoramic camera itself and the interface bandwidth between the panoramic camera and the server are bottlenecks for frame rate improvement. We plan to analyze more panoramic cameras and interfaces and thus address these problems.

Acknowledgments This research was supported by Korea Institute of Science and Technology under "Development of Tangible Social Media Platform."

References

1. Park, H., Lee, G. Y., Seo, D., Youn, S. B., Kim, S., and Ko, H.: N-Screen live baseball game watching system: novel interaction concepts within a public setting. In: Proceedings of Euro-ITV2011, pp. 13–14 (2011)
2. Mate, S., Curcio, D. D. I.: Mobile and interactive social television. IEEE Commun Magazine. **47**(12), 116–122 (2010)
3. Nathan, M., Harrison, C., Yarosh, S., Terveen, L., Stead, L., Amento, B.: CollaboraTV: making television viewing social again. In: Proceeding of the first international conference on designing interactive user experiences for TV and video, (2008)
4. Youn, S., Park, H., Lee, G. Y., Seo, D., Kim, S., and Ko, H.: Social Media-Based Three-Screen TV Service. In: Proceedings of 2011 IEEE International Conference on Consumer Electronics, pp. 920–921 (2011)
5. Kim, B. S., Lee, S. H., Cho, N. I.: Real-time panorama canvas of natural images. IEEE Trans. Consumer Electron. **57**(4), 1961–1968 (2011)
6. Xiong, Y., Pulli, K.: Fast panorama stitching for high-quality panoramic images on mobile phones. IEEE Trans. Consumer Electron. **56**(2), 298–306 (2010)
7. Neumann, U., Pintaric, T., Rizzo, A.: Immersive panoramic video. In: Proceeding of the eighth ACM International Conference on Multimedia, (2000)
8. Grunheit,C., Smolic, A., Wiegand, T.: Efficient representation and interactive streaming of high-resolution panoramic views. In: Proceeding of 2002 IEEE International conference on image processing, (2002)
9. Zhu, Z., Xu, G., Riseman, M. E., Hanson, R. A.: Fast construction of dynamic and multi-resolution 360 panoramas from video sequences. Image Vis. Comput. **24**(1), 13–26 (2006)
10. Kim, B.Y., Jang, K.H., Jung, S.K.: Adaptive strip compression for panorama video streaming. In: Proceeding of computer graphics international, (2004)
11. Mavlankar, A., Noh, J., Baccichet, P., Girod, B.: Peer-to-peer multicast live video streaming with interactive virtual pan/tilt/zoom functionality. In: Proceeding of 15th IEEE International conference on image processing, (2008)
12. Kimata, H., Shimizu, S., Kunita, Y., Isogai, M., Ohtani, Y.: Panorama video coding for user-driven interactive video application. In: Proceeding of IEEE 13th International Symposium on consumer electronics, (2009)
13. Khiem, N. Q. M., Ravindra, G., Carlier, A., Ooi, W. T.: Supporting zoomable video streams with dynamic region-of-interest cropping. In: Proceedings of the first annual ACM SIGMM conference on Multimedia systems, pp. 259-270 (2010)
14. Brandenburg, R. V., Niamut, O., Prins, M., Stokking, H.: Spatial Segmentation for Immersive Media Delivery. In: Proceeding of 2011 15th International Conference on intelligence in next generation networks, pp. 151–156 (2011)
15. Schafer, R., Kauff, P., Weissig, C.: Ultra high resolution video production and display as basis of a format agnostic production system. In: Proceedings of third annual international business conference, pp. 44–49 (2010)
16. Niamut, O., Prins, M., Brandenburg R.V., Havekes, A.: Spatial tiling and streaming in an immersive media delivery network. In: Proceeding of EuroITV2011, pp. 84–87 (2011)
17. Boonsuk, W., Gilbert, S., Kelly, J.: The impact of three interfaces for 360-degree video on spatial cognition. In: Proceedings of the SIGCHI conference on human factors in computing systems, pp. 2579–2588 (2012)