# Interacting with Smart Consumer Cameras: Exploring Gesture, Voice, and AI Control in Video Streaming

**Anonymous Author(s)***

## ABSTRACT

Livestreaming and video calls have grown in popularity due to the increased connectivity and advancements in mobile devices. Our interactions with these cameras are limited as the cameras are either fixed or manually remote controlled. Here we present a Wizard-of-Oz elicitation study to inform the design of interactions with smart 360° cameras or robotic mobile desk cameras for use in video-conferences and live-streaming situations. There was an overall preference for devices that can minimize distraction as well as preferences for devices that can show they demonstrate an understanding of video-meeting context. We find participants dynamically grow with regards to the complexity of interactions which illustrate the need for deeper event semantics within the Camera AI. Finally, we detail interaction techniques and design insights to inform the next generation of personal video cameras for streaming and collaboration.

**ACM Reference Format:**
Anonymous Author(s). 2018. Interacting with Smart Consumer Cameras: Exploring Gesture, Voice, and AI Control in Video Streaming. In *TVX '19: ACM International Conference on Interactive Experiences for Television and Online Video, June 05–07, 2019, Manchester, UK*. ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/1122445.1122456

## 1 INTRODUCTION

Personal media streaming has entered a new age [10] with the growth of Internet-enabled cameras and smartphones coupled with various streaming services and video calling applications. While in the past video-streaming was found in enterprise conference calls, it now also enables self-run Internet "TV" shows on YouTube, social media livestreams on Facebook, and personal broadcasts on Twitch. In many of these cases, people resort to holding a cameraphone, using a laptop screen mounted webcam, or even having installed setups with green screens, lighting, and picture in picture broadcasts. Consider the solo broadcaster or set of broadcasters trying to queue various cameras. Typically they would rely on a display camera zoomed into a fixed area so they could show a item and then have a second camera to capture themselves or the room. Cameras could be manually triggered or an articulating camera could be remote controlled. Both cases require various levels of interaction from the broadcaster.

Currently, we are faced with two recent advancements. First, cameras now have high resolution captures well beyond 1080p HD. Many consumer cameras shoot video in 4k or 6k and can capture wide or 360° fields of view, allowing one to crop out an HD frame. Second, artificial intelligence (AI) technologies have vastly improved in the areas of object detection, face identification, and voice recognition. Towards this, we ask how would one control such a high-resolution AI-enabled personal camera.

In this article, we present a Wizard-of-Oz elicitation study to understand how people would interact with a smart personal camera that could either (1) pick the person or objects to focus on automatically, (2) could be controlled by visual hand gestures like pointing, or (3) could be voice controlled to focus on a person or object. In the study, we not only surface what kind of visual or audio commands one would use to control such a personal video camera, but also how different cameras' interaction techniques can lead to the camera becoming a participant in the meeting and can facilitate deeper connections with remote participants. Finally, we illustrate how this research can inform the design of future enterprise or personal video cameras for meetings or livestreaming.

## 2 RELATED WORK

The broader research work in video conferencing, chat rooms, and livestreams is expansive. Telepresence systems have tried to connect people through extensive camera augmentation and registration [3] as well as simpler side-by-side [19] arrangements. Beyond work contexts, livestreaming on the Internet has grown [10] due to expanding connectivity and network-enabled cameras (and cameraphones). In this article, we focus less on improving image fidelity [21] and/or the mechanics of building an AI system for object recognition. Instead we focus on experiences, people, and behaviors.



*TVX '19, June 05–07, 2019, Manchester, UK*



ACM ISBN 978-1-4503-9999-9/18/06…$15.00
https://doi.org/10.1145/1122445.1122456

There has been some growth recently in video cameras for meetings, mostly in the enterprise sector. New devices like the Meeting Owl[1] and Sony Xperia Hello![2] provide tower-like single lens 360° cameras for video calling. The Meeting Owl has a top facing camera and is designed for boardroom use. The Xperia Hello! has a front skewed single lens camera for meetings or personal calling. Other devices, like the Amazon Echo Show and Spot, have a similar camera to that on a laptop of tablet device. Finally, the Google Snap camera is a device designed to be placed in vantage points where one might need photos or video marketed for non-enterprise environments.

### User Behaviors in Live Streams & Video Conferences

One common scenario for live streaming includes a conversation between individuals or a group of people who are sitting in a room or fixed location. However, as streaming becomes easier and more mobile, people may wish to view multiple streams from different perspectives, such as at a large public event [4]. Audience members may also interact with streamers in other ways such as through chat or voting mechanisms to influence what happens [6]. However, enabling presenters to easily share their perspectives and activities with viewers continues to be an important area of focus as well.

One issue that has emerged in single, or fixed-camera video streaming settings has to do with how people go beyond being "talking heads" to showing physical items or highlighting movements, as in a performance [14]. A study of how people share physical artifacts (whiteboards, notebooks, mobile phone screens) with remote meeting participants over video conferencing revealed that this behavior is difficult and can be disruptive to the flow of the meeting [11].

Other work [20] has looked at how multiple fixed cameras might be used to automatically switch between different views of people engaging in a distributed task. Initial explorations in this space suggest that automatically switching camera viewpoints could be a scalable solution when people are distributed across multiple sites; however, such a setup still requires that rooms be outfitted with several pieces of hardware that are not easily portable.

### Automatic Camera Operators

Another area of research is on the automatic camera operator. This includes proposing a set of rules for an automatic cameraperson [18] to learning where to focus a pan/tilt/zoom (PTZ) camera based on previous user interactions [8] to automatic positioning of multiple PTZ cameras to maximize the captured video information for passive viewers—providing the best close-up view with limited cameras [9]. Typically, when multiple cameras are in operation, camera selection is done via algorithm, such as a constraint satisfaction problem [5], or done via community cooperation [15]. More sophisticated controls create camera-sensing networks [13] or use a set of distributed smart cameras and with gesture sensing [7] to control the queuing.

### Interactions

Hand gestures have been a common interaction technique for video and for remote control [2]. This is of particular interest given the current advancements in AI and the availability of large scale, crowdsourced datasets for gesture recognition such as the 20BN-Jester Dataset V1. One question we wish to investigate is how people would interact through gestures for a personal desk robot. Bearing the most similarity to our work is the recent Wizard-of-Oz Human-Drone Interaction [1] experiment. While hand gestures have been explored before for remote controlling quadcopter drones [17], Cauchard et al.'s elicitation study showed how people would control a personal quadcopter through gesture and voice.

Also similar to our work is a recent observational lab study in which participants critiqued pairs of physical prototypes (prosthetic hands) for a face-to-face or remote collaborator. [12]. Here, details in physical prototypes were shared in two different contexts. The authors found that traditional media sharing experiences are optimized for an upwards gaze whereas tabletops focus downward; they suggest head-mounted displays to keep media spaces in peripheral vision while downward attention is focused on an artifact or object. They also suggest prioritizing the camera preview window as theirs was rendered too small in their experiment.

## 3 METHOD & EXPERIMENT

We present a Wizard-of-Oz elicitation study to understand the kind of interactions people would have with smart video cameras in a livestream or video-conference context. We used an office space with a table and a whiteboard and a set of printed material to simulate a conversation across two locations where two collocated participants shared materials and information with a remote attendee using four different camera setups and interaction modalities: (1) A stationary 4k 360° camera that automatically identifies the salient person or object and streams it. (2) A small moving camera-robot that pans on the table to automatically identify the salient person or object and streams it. (3) A small moving camera-robot that pans on the table and responds to visual gestures to turn to the salient person or object and stream it. (4) A small moving camera-robot that pans on the table and responds to voice commands to turn to the salient person or object and stream it. The 4k 360° camera was a Ricoh Theta V and the small moving camera-robot was an Anki Cozmo.Both cameras are consumer-level devices retailing for $400 and $180 respectively. An experimenter remote controlling the Cozmo over

[1] https://www.owllabs.com/
[2] http://www.sony.jp/xperia-smart-products/products/G1209/

WiFi was in an adjacent office with a confederate who was connected to the participants via a speakerphone to ask questions and comment. This setup mirrors a remote participant on a video call with no camera of their own (thus not drawing eye contact from the participants) which is also analogous to a typical livestream. The difference between the two scenarios is that the confederate can give audio feedback whereas a livestream would rely on text comments as feedback.

For each case, minimal instruction was given to the participants. For each condition this was:

- Condition 1: "The camera will use AI to automatically find and stream people and objects in the room relevant to the conversation."
- Condition 2: Same as Condition 1.
- Condition 3: "The robot-camera will respond to hand gestures to move."
- Condition 4: "The robot-camera will respond to voice commands if you first address it as 'hey robot'." This condition mimics modern voice appliances such as Amazon Alexa, Apple Siri.

We did not refer to either camera by brand or name to avoid anthropomorphism of the Cozmo robot and while the Cozmo has various expressive face/eye animations, we kept its expression in a neutral repose.

### Participants

For this study, we recruited 10 volunteers (2 females, 8 males) from our institution. All of the participants were college educated and were somewhat familiar with 360° or robot-articulating cameras. Additionally, all of the participants reported they generally felt comfortable around cameras in the room. There was also an even distribution of participants who said they were easily distracted or not easily distracted.

### Task

The basic task among each participant pair was to discuss various electronics or accessories to purchase for a company. We separated this into four tasks, one per category type: (a) laptop, (b) tablet, (c) phone, and (d) backpack/messenger bag. Two items from each task type were selected and printed out as technical specifications and prices from their associated web pages. The whiteboard contained a handwritten (but incomplete) table of regions, employee ranks, and budget prices. Conditions and tasks were matched randomly and counterbalanced for each pair (four in total). Each participant had one item assigned to them to explain and share with the remote participant. For example, for Condition 3 and task *phone*, one participant received printouts for an iPhone X and the other received printouts for a Google Pixel 2. Both participants were asked to discuss each device as it relates to a price point, region, or employee rank on the white board. The camera-robot was the only broadcasting feed and responded to visual gestures (Condition 3) to move.

### Procedure

An office equipped with a table, chairs, and a whiteboard was outfitted with several printouts. A small (GoPro) camera was mounted to the far corner of the whiteboard, opposite side of the experiment related whiteboard content, to record the experiment and participants were instructed to ignore it. Participants were first given 5 minutes to review all the printouts. Conditions and tasks were randomly assigned then, before each condition, an experimenter brought a camera device into the room, briefly explained its capabilities and discussed the task. The participants were told that an executive from corporate headquarters (the confederate) was connected via speakerphone.

The experimenter then left and the confederate prompted the session to begin. The confederate minimally prompted for information or visuals about the whiteboard and printouts if these were not spontaneously provided by the participants. As the Cozmo's resolution is rather low, the confederate had a copy of all the handouts but did not disclose this to the participants. This allowed the confederate to "play along" and overcome the current limitations with the camera-robot. Figure 2a shows an example of the camera's fidelity.

Upon completion of the condition-task pair, the experimenter returned, collected the device and handed the participants a short survey to fill out. Once completed, the surveys were collected, a device was returned to the room and the next condition-task pair started. There were four condition-task pairs in total and the full experimental session lasted around 30 minutes overall. At the end of the last condition-task pair, a final survey was completed by the participants, and they participated in a short interview/discussion with the two experimenters in order to collect additional comments about their reactions to the different conditions.

### Surveys and Exit Interview

After each condition-task pair, participants were handed a short survey. After the final pair, they were handed an additional overall survey. Once completed, the experimenters asked the participants if there was any additional feedback, comments, or questions. Each of the condition-task surveys asked questions (on a 5 point Likert scale from strongly disagree to strongly agree) related to the camera condition: was the camera useful, did they know what the camera was looking at during the meeting, did they want to control the camera/did they feel they could control the camera. Additionally, there were two open-ended questions asking participants what they liked and disliked about the technology they used in that condition.

The final survey gathered demographics (age, gender, education), experience with robotic or 360° cameras, how comfortable they are with being recorded, if the camera was distracting, and a self-reported assessment of whether they were easily distracted in general. We also asked if they wanted to be able to toggle the camera's recording state, and we asked them to rank the four conditions in order of preference. Finally we asked if there was any other way they would have liked to control the camera and if there was anything else aside from people, papers, and whiteboards that they would want the camera to know about.

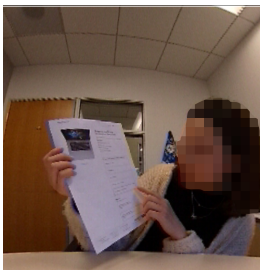
## 4 RESULTS

When asked to rate the four conditions in order of preference, the 360° degree camera was the favorite of 5/10 participants. The next most favored condition was the AI robot (3/10 participants), followed by voice control (2/10 participants). The gesture control condition was selected as the second favorite option by 4 out of 10 participants. To further unpack the variation in preferences between the different interaction methods, we now discuss behaviors observed during the experiment as well as open-ended comments provided by participants for the four different conditions. These provide some insights into the ways in which the different technological affordances of the 360° and robot cameras influenced the behaviors and attitudes of participants with regards to sharing their environments with the meeting viewer.

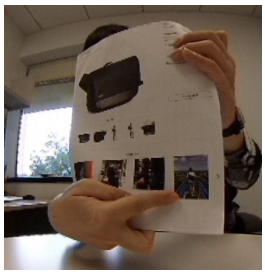
### 360°

During the 360° session, most participants were fairly comfortable with the technology even though not all of them had used such a device before. For this condition, 3 participants selected "Strongly Agree" with the statement that the camera was useful, 5 selected "Agree" and 2 were neutral. However, the 360-degree camera was rated significantly lower than the three robotic conditions in terms of agreement with the question "I knew what the camera was looking at." Participants brought up the point that the 360° camera required the least amount of input or interaction from the two presenters in the room (because the remote person could see everything and control what they focused on). The benefit of this setup was that it gave greater agency to the remote viewer: "The camera was for you [the remote participant], not for me . . . it's not my job." (P6) However, while this benefited the remote participant, the two co-located meeting participants lacked awareness of the remote party's focus. This was sometimes challenging because

> "it's always visible and the remote user can watch me. . . though I feel being monitored I also wonder whether the remote users have time and effort to monitor all the stuff in the 360° camera" (P9)



**(a) P8 discussing in a conversational style.**



**(b) P10 occluding himself from the view to discuss details.**

**Figure 1: Two participants on the 360° camera condition showing details on the printout. P8 (1a) discussed the paper in a conversational manner, showing herself with the document. P10 (1b) totally occluded himself from view and put the document forward as the sole artifact.**

In terms of presenting the documents, two participants (P3 and P4) left their documents flat on the table when discussing them. They had a general assumption that "It sees everything, I don't have to control it." (P3) despite the fact that there is a loss of legibility at a sharp angle—a case not considered by the participants. The rest of the participants would hold up the document to the camera to aid the remote in seeing the visuals (See Figure 1).

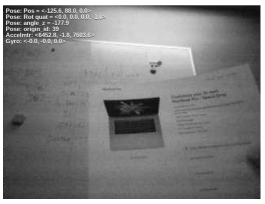
### AI Camera Robot

The AI Camera Robot began by doing a 360° sweep of the room. This took roughly 3 seconds and allowed the participants to feel as if the AI (actually WOZ) scanned the room so it could track the video session automatically. One participant was neutral to the usefulness of this condition, the rest Agreed (7) or Strongly Agreed (2) to the usefulness. Here we saw the AI plus Robot combination making a connection between the participant and remote confederate.

> "I felt the meeting person from the remote site listen to me when the robot camera turned towards me when I was talking." (P4)

Others felt the robot was a participant following along, "It's great that the robot could understand the conversation and get to know where he's supposed to turn towards." (P7) No other condition gathered such feedback about making a stronger connection with the (invisible) remote participant. One participant contrasted the AI robot condition with the 360° camera condition by saying:

> "It's fun and having a robot moving feels like you're interacting with a real user, real people. . . [the] 360° camera is just like a device, which is cold and doesn't feel very human" (P5).



**(a) The robot camera has been directed via gesture to look at the whiteboard.**

**(b) P5, unhappy with the response time of the robot, picks it up and points it at P6.**

**Figure 2: a A participant (P2) wanted to show a handout which he just put in the camera's field of vision instead of directing the robot camera back to him. (b) P5 and P6 gesture to the robot mostly out of field. Eventually, P5 just picks up the robot and points it to P6.**

### Gesture Driven Camera Robot

One participant (P8) disagreed that the Gesture-Driven Camera Robot was useful, while the rest agreed or strongly agreed. However, many participants cited there was a bad recognition lag time on the robot or that it was unclear to them what gestures they could actually use to make it work.

> "It seems gesture sensor is not so sensitive. And sometimes, feel confused how to make the right gesture to the robot to work well." (P7)

Also, "(I was) not sure how/what gestures can direct the robot." (P4).

Of the participants who made some gestures in the robots field of view, they still cited latency issues (likely partially due to the WiFi streaming rate of the robot). However, it was the case that most participants would gesture outside of the field of view of the camera and then slowly drop the gesture into the robots vision. Once the wizard could actually see the gesture from the robot's camera, it would be enacted. Two participants continually gestured outside of the robot's vision. Upon giving up, one participant just picked up the robot to turn it manually to the other person (Figure 2b). Four participants physically moved the robot in this condition (P7, P8, P9, and P10). One other participant asked if he was allowed to move the robot, but only did so after the sessions were completed. In this case, he thought "why am I using my hands [to gesture] when I can just do this? (*mimes picking up robot*)" (P8).

However, there were also some positive points made about gesture control being natural "It's like interacting with real people, natural." (P5) and not distracting "I don't have to stop talking to give it instructions, nice." (P7).

### Voice controlled Camera Robot

This condition had unanimous usefulness ratings: 4 with strongly agree and 6 with agree. We mimicked the interaction style of modern day speech interfaces by having the "hey robot" trigger. During the experiment, the robot (wizard) was rather flexible as many participants said "hello robot" or "hi robot." Many people enjoyed this interaction. "It's interesting to talk to the robot, it's like having a secretary." (P7), "(It's) easy to change views, flexible in conversation" (P5), and "I didn't need to learn a new control interface" (P8). Others cited difficulty: "Takes effort to describe orientation direction and how far to rotate." (P3) and "If within arms reach, easier to manually position or let remote person control it." (P6).

There were a few different interaction dynamics in this condition. A few participants (P3, P4, P5) gave relative-rotational instructions like *Turn* $\{n\}^\circ$ *to the* $\{d\}$. Others (P7, P8) would say the degrees of rotation with a logical object (like themselves) instead of clockwise or counterclockwise directive: e.g. "Turn 90° towards me". Some participants (P9, P10) would just say the trigger "hey robot" as the implicit *Turn to me* command. Finally some would give a logical object like "turn to the whiteboard" (P9) and others, noteably P4, stared with hard coordinate directions "Turn 70° to the left" but grew to say "Robot get the whiteboard, the whiteboard" by the end of the 10 minute condition session.

### Issues with the Camera Robot

There were some common issues with the Cozmo camera robot. First, many participants mentioned it was noisy (P3, P4, P5, P8). While not overwhelmingly loud, its motor driven tracks and head do make a grinding noise that is uncommon in most video sessions (different than the hum of a CPU or high-pitch sound of some electric devices). This is more so recognized next to the silent 360° camera. In the context of recording, it introduced some difficulties: "Made obvious noise when moving so i had to talk over it." (P8)

There was some small frustration with not knowing the vocabulary of commands, be them visual or audio, to give the robot (P3, P4, P6, P8) but this was the part of the exercise of this elicitation study. Also a few participants (P6, P8) asked what was the point of having the co-located presenters control the robot, as opposed to letting remote person just have control of the robot in the first place?

## 5 DISCUSSION

We investigated how people would interact with small smart camera devices and how would they change the experience. Three advancements motivate this work: more specialized devices are entering the consumer market, modern deep AI is driving advancements in gesture and voice interfaces, and finally, the growth of video communication (in teleconferences,

video calls, and livestreams). This study illustrates not the commands and manipulations people use with smart cameras. It points to an understanding of the context of use, not just the visual content in the scene. While the 360° camera was most often chosen as the most preferred when ranking the four conditions, most of the conditions were thought to be useful. We did find several social and environmental observations which should be considered for the future design of personal smart cameras.

First, we note that most of the participants asked for feedback from the device. No feedback was given from the Cozmo robot despite it having colored lights, text-to-speech, and can nod to say yes or shake in disagreement. This was to keep it close to the 360° camera which had no feedback capabilities. Further, many participants asked for a preview window of the devices and previous work has shown its value in media spaces [12] and livestream chats [16]. This was not in the study design as we wanted to focus on the interaction with the device and not self positioning in the preview frame.

In the cases where the robot had a gesture or voice control, many participants initially paused wondering what to gesture or say. Typically, when one participant would invent a command, the other would repeat a similar command. This dissipated over the course of each session as the participants started inventing newer commands, but was something to note. While most all the participants would generally control the camera for themselves, a few participants would give a command for the other participant. In one case, P5 gestured to move the camera to P6 (Figure 2). In another, P10 generally just moved the camera by hand for P9.

### Awareness

By withdrawing feedback, our experiment highlighted the importance of feedback delivery to the participants, especially with gesture control. Adding audio (tones or voice) output or visual displays showing what the robot is capturing could help alleviate these issues but also run the risk of distracting the video with sound or another screen in the frame. A screen would need to be on the camera-device as not to have someone look one direction to fix the camera in the other direction.

When it comes to voice commands, some participants directly addressed the robot by naming objects (e.g. "get the whiteboard", "back to me"). The robot needs to develop an awareness of its surroundings, remember its surroundings, or slowly build and remember the context to be fully operational as soon as possible. In particular, the AI will need to recognize common objects and their location given the context and task (meeting room, cooking show, family video call, etc.).

Overall, having a camera that knows where to look was seen as having value if one knows where it is looking. And while the 360° camera's silent omnicapture was preferred, the robot having a focus and attention brought it into the meeting as more of a participant. Conversely, the design of how a 360° camera could indicate its focus point merits exploration. In either case, there is a trade-off between awareness and interruption that must be taken into consideration.

### Camera Position

Most participants held papers up in front of the camera, both with the robot and the 360° camera. In some cases, they were holding the paper and still pointed at figures or paragraphs. If the 360° camera had instead been mounted above the table looking down, the users might have felt no need to hold their paper sheets. However, the aforementioned benefit of the robot on the desk makes it feel like more of a tool for engagement. This prompted several participants to pick it up and move it. A very portable and light-weight robot certainly encourages that kind of interaction. The physical design of a desk robot should have several view points. While many media spaces have conversations that are gaze-forward (to another) or gaze-down (to an object) [12], the design of such a desk camera robot should support both and possibly correct perspective. This is something that is lacking in common cameras on laptops and tablets and even more modern devices like the Meeting Owl.

### Laptops and Other Screens

While this experiment used papers and a whiteboard, many meetings and video sessions involve sharing screens from laptops, tablets, and smart phones—which are all part of the context of a video meeting. Indeed, half of our participants (P4, P7, P8, P9, P10) stated they would like the Cozmo to look at a laptop or device screen. This could be treated as any other media object or document where the participants turn their laptops toward the camera, like they did holding paper sheets. However, a small portable focused device could sit to the side of a user at the table's edge or even be positioned between a user and the device. Here, a device like a Cozmo could track a screen or hand-held device and, as our study elicited, keep users informed on what the camera is capturing. By contrast, placing a 360° camera between a device and a person could lead to some potentially unflattering vantage points for the participants. Even if the device has the AI smarts not to show faces from under ones nose, for example, users still might wonder if that is what it is capturing.

## 6 CONCLUSIONS

We describe insights from a Wizard-of-Oz elicitation study to inform the design of AI-powered interactions for smart cameras for video calling and livestreaming. While the silent, still 360° camera was preferred by the participants, it carried the understanding that it was auto-panning and cropping by itself; with that, participants still wondered where it was looking. Cameras that can "look" in a direction, such as the Cozmo,

provide such an indication of where it is pointed but introduce some distractions. Coupled with an auto-AI engine, participants considered the robot more of a meeting participant than the 360° camera—however this requires the AI modeling the event semantics (in this experiment, a teleconference) to facilitate meaningful interactions. However, most general purpose consumer devices are not well designed for these interactions and we have illustrated design and interaction techniques required for automated assisted cameras for streaming.

## REFERENCES


[1] Jessica R. Cauchard, Jane L. E, Kevin Y. Zhai, and James A. Landay. 2015. Drone & Me: An Exploration into Natural Human-drone Interaction. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '15)*. ACM, New York, NY, USA, 361–365. https://doi.org/10.1145/2750858.2805823

[2] Niloofar Dezfuli, Mohammadreza Khalilbeigi, Jochen Huber, Florian Müller, and Max Mühlhäuser. 2012. PalmRC: Imaginary Palm-based Remote Control for Eyes-free Television Interaction. In *Proceedings of the 10th European Conference on Interactive TV and Video (EuroITV '12)*. ACM, New York, NY, USA, 27–34. https://doi.org/10.1145/2325616.2325623

[3] Tony Dunnigan, John Doherty, Daniel Avrahami, Jacob Biehl, Patrick Chiu, Chelhwon Kim, Qiong Liu, Henry Tang, and Lynn Wilcox. 2015. Evolution of a Tabletop Telepresence System Through Art and Technology. In *Proceedings of the 23rd ACM International Conference on Multimedia (MM '15)*. ACM, New York, NY, USA, 775–776. https://doi.org/10.1145/2733373.2807400

[4] William A Hamilton, John Tang, Gina Venolia, Kori Inkpen, Jakob Zillner, and Derek Huang. 2016. Rivulet: Exploring participation in live events through multi-stream experiences. In *Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video*. ACM, 31–42.

[5] Michael Janzen, Michael Horsch, and Eric Neufeld. 2008. Camera Selection Using SCSPs. In *Proceedings of the 2008 Conference on Future Play: Research, Play, Share (Future Play '08)*. ACM, New York, NY, USA, 252–253. https://doi.org/10.1145/1496984.1497038

[6] Pascal Lessel, Michael Mauderer, Christian Wolff, and Antonio Krüger. 2017. Let's Play My Way: Investigating Audience Influence in User-Generated Gaming Live-Streams. In *Proceedings of the 2017 ACM International Conference on Interactive Experiences for TV and Online Video*. ACM, 51–63.

[7] Chang Hong Lin, Marilyn Wolf, Xenefon Koutsoukos, Sandeep Neema, and Janos Sztipanovits. 2010. System and Software Architectures of Distributed Smart Cameras. *ACM Trans. Embed. Comput. Syst.* 9, 4, Article 38 (April 2010), 30 pages. https://doi.org/10.1145/1721695.1721704

[8] Qiong Liu and Don Kimber. 2003. Learning automatic video capture from human's camera operations. In *Image Processing, 2003. ICIP 2003. Proceedings. 2003 International Conference on*, Vol. 2. IEEE, II–543.

[9] Qiong Liu, Xiaojin Shi, Don Kimber, Frank Zhao, and Frank Raab. 2005. An online video composition system. In *Multimedia and Expo, 2005. ICME 2005. IEEE International Conference on*. IEEE, 490–493.

[10] Danielle Lottridge, Frank Bentley, Matt Wheeler, Jason Lee, Janet Cheung, Katherine Ong, and Cristy Rowley. 2017. Third-wave Livestreaming: Teens' Long Form Selfie. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '17)*. ACM, New York, NY, USA, Article 20, 12 pages. https://doi.org/10.1145/3098279.3098540

[11] Jennifer Marlow, Scott Carter, Nathaniel Good, and Jung-Wei Chen. 2016. Beyond Talking Heads: Multimedia Artifact Creation, Use, and Sharing in Distributed Meetings. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16)*. ACM, New York, NY, USA, 1703–1715. https://doi.org/10.1145/2818048.2819958

[12] Terrance Mok and Lora Oehlberg. 2017. Critiquing Physical Prototypes for a Remote Audience. In *Proceedings of the 2017 Conference on Designing Interactive Systems (DIS '17)*. ACM, New York, NY, USA, 1295–1307. https://doi.org/10.1145/3064663.3064722

[13] Faisal Z. Qureshi. 2010. Collaborative Sensing via Local Negotiations in Ad Hoc Networks of Smart Cameras. In *Proceedings of the Fourth ACM/IEEE International Conference on Distributed Smart Cameras (ICDSC '10)*. ACM, New York, NY, USA, 190–197. https://doi.org/10.1145/1865987.1866017

[14] Stuart Reeves, Christian Greiffenhagen, Martin Flintham, Steve Benford, Matt Adams, Ju Row Farr, and Nicholas Tandavantij. 2015. I'd Hide You: Performing live broadcasting in public. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 2573–2582.

[15] Marco Sá, David A. Shamma, and Elizabeth F. Churchill. 2014. Live Mobile Collaboration for Video Production: Design, Guidelines, and Requirements. *Personal Ubiquitous Comput.* 18, 3 (March 2014), 693–707. https://doi.org/10.1007/s00779-013-0700-0

[16] David A. Shamma, Elizabeth F. Churchill, Nikhil Bobb, and Matt Fukuda. 2009. Spinning Online: A Case Study of Internet Broadcasting by DJs. In *Proceedings of the Fourth International Conference on Communities and Technologies (C&T '09)*. ACM, New York, NY, USA, 175–184. https://doi.org/10.1145/1556460.1556486

[17] Adrian Stoica, Federico Salvioli, and Caitlin Flowers. 2014. Remote Control of Quadrotor Teams, Using Hand Gestures. In *Proceedings of the 2014 ACM/IEEE International Conference on Human-robot Interaction (HRI '14)*. ACM, New York, NY, USA, 296–297. https://doi.org/10.1145/2559636.2559853

[18] Hugo Strubbe and Mi Suen Lee. 2001. UI for a Videoconference Camera. In *CHI '01 Extended Abstracts on Human Factors in Computing Systems (CHI EA '01)*. ACM, New York, NY, USA, 333–334. https://doi.org/10.1145/634067.634264

[19] Paul Tanner and Varnali Shah. 2010. Improving Remote Collaboration Through Side-by-side Telepresence. In *CHI '10 Extended Abstracts on Human Factors in Computing Systems (CHI EA '10)*. ACM, New York, NY, USA, 3493–3498. https://doi.org/10.1145/1753846.1754007

[20] Marian F Ursu, Manolis Falelakis, Martin Groen, Rene Kaiser, and Michael Frantzis. 2015. Experimental enquiry into automatically orchestrated live video communication in social settings. In *Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video*. ACM, 63–72.

[21] Bolun Wang, Xinyi Zhang, Gang Wang, Haitao Zheng, and Ben Y. Zhao. 2016. Anatomy of a Personalized Livestreaming System. In *Proceedings of the 2016 Internet Measurement Conference (IMC '16)*. ACM, New York, NY, USA, 485–498. https://doi.org/10.1145/2987443.2987453