Be a Judge! – Wearable Wireless Motion Sensors for Audience Participation

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Abstract
In recent years the Olympic Games have undergone vast criticism due to perceived subjective scoring in judged events, as for example figure skating and gymnastics. Judges' scores may be influenced by favoritism, human error, or possibly corruption. Audience participation in scoring represents a promising approach to meet these problems. In this paper we present an audience voting system that utilizes the natural behavior of sports spectators: clapping and cheering. The system consists of wireless motion sensors and microphones that enable spectators to cast their vote in real time. The sensors are worn by audience members and determine the clapping frequency of each participant. This facilitates continuous influence on the score throughout an athlete's performance. The audience score is presented on wall-sized stadium displays and might be contrasted with the judges' scores to encourage audience engagement.

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INTRODUCTION
In the history of the modern Olympic Games, a strong connection between some sports and art has appeared. Events that are classified as an art as well as a sport, cannot be judged by quantifiable means, like time, height, or range. For these sports, judging is typically conducted by a panel of five to ten judges. Points are awarded from 0 to 10 based on predefined criteria and performance. The awarded score represents personal opinions of the judges and is susceptible to human error. For example, during the 1992 Summer Games a judge mistyped a score as 8.7 when she intended to give a synchronous swimmer a 9.7 [4]. Due to this mistake, the athlete missed the gold medal. During the 2002 Winter Games in Salt Lake City, there was another controversy that clearly showed that scores in judged events do not always represent justifiable results [4]. One of the figure skating judges was pressured into voting in a certain way, which did not reflect reality. In both of the above cases, the International Olympic Committee (IOC) corrected the judging error and a second gold medal was awarded. However, such incidents have cast a negative shadow on the Olympic Games.

Audience participation
Resolving the previously described problems is essential for the integrity of judged Olympic events. During the Winter Games in Salt Lake City, figure skating viewers were able to cast scores for their favorite athletes on the Internet [13]. Giving spectators the possibility to award scores for each performance will improve the acceptance of these sports. This exact issue is being addressed by the student design competition of the CHI 2004 Conference on Human Factors in Computing Systems. The problem description proposes that the Olympic Committee has decided to pilot audience participation in scoring the gymnastics and diving competitions in the upcoming Summer Olympic Games in Athens, Greece. The quest is to design a system allowing physically present audience members to cast their vote in real time. Such a system would not only help to avoid mistakes by judges, but also make audience members more supportive of the final score due to their participation. Although the objective of this work is to explore a solution for this issue, the audience vote will not have any effect on the athletes' scores at the 2004 Summer Games in Athens.

Judged sports at the Olympic Summer Games

The sports disciplines relevant for the design problem are gymnastics and diving. The first one is subdivided into rhythmic gymnastics, artistic gymnastics, and trampoline, the latter consists of diving and synchronized diving. There are different rules of scoring for each discipline. Judges are divided into different juries, which are responsible for marking different stages of the performance. In artistic gymnastics each athlete starts with a perfect score. Then according to the execution of the performance, judges make deductions from that score. In contrast, in diving each judge awards a score between 0 and 10 for the athlete's performances, based on starting position, jump, execution, and entry into the water. The highest and lowest scores are eliminated and the remaining scores are added and multiplied by the degree of difficulty. The rules of judging are obviously too complex to be applied in a similar way for audience scoring. Any system aimed at audience participation in scoring needs to be less rigid and more straightforward.

We have described the design problem and the context and will now discuss related audience participation approaches. After that, we will present our solution. We will explore our approach, its technical realization, judging issues, and a statement of costs followed by a brief description of our design process. Then we will summarize our ideas and show how we meet the goals of the problem specification. Finally, we will highlight the work left to be done in the future.

RELATED WORK

Traditional methods of audience participation are used in television game shows. Physically present audience members are typically able to cast their votes using pushbuttons. The used device is either held or located in the armrests of chairs, and has pushbuttons corresponding to a scale, for instance 1 to 5. These systems are usually hardwired solutions and therefore can only be used for groups of a few hundred people. For large groups they become too costly. Hence, they do not scale for an audience as expected at the Olympic Games. Additionally, viewers of game shows can sometimes vote via phone calls. Phone calls, however, do not represent a real time solution. In competition shows, loudness measurement is also sometimes applied as method for audience voting. Using this method, the score is usually determined subjectively, by a host who judges which contestant received the loudest audience response.

To enable audience participation for large groups, different techniques have been explored. Recent research work in this area is mostly dominated by interactive musical performances [2,7] and interactive gaming [11]. A camera pointing at the audience can be used for audience tracking. This allows the crowd to influence a system cooperatively, for example in an onscreen game [11]. Such a system supports real time interaction of the audience, but does not provide direct control of an audience member. In contrast, machine vision allows for measuring particular actions of each participant, as used for the red-green voting paddles developed by R. Carpenter at CINEMATRIX [3]. A drawback of this method is that it requires a line-of-sight from camera to participant. Generally, direct methods such as wearable or handheld sensors are more accurate. An example of such a wearable device was used for the "Sophisticated Soiree" installation at Ars Electronica 2001, where the heartbeats of up to 64 participants were measured to trigger various musical and optical processes [1]. However, systems that measure biosignals are not consciously controllable by participants.

M. Feldmeier et al. presented a set of wireless motion sensors for large group musical interaction [7]. They used small, inexpensive transmitters that send a radio frequency (RF) signal, which allow each participant to interact in a musical performance. The device can be either held or worn. The sensor's RF pulses are transmitted to a base station, where the number of pulses is counted and further processed. The system does not differentiate between the input of each participant, but instead reacts to the characteristics of the group's behavior. In preliminary tests, fifteen dancers were equipped with a sensor and the data stream generated by the motion of the dancers was used to generate the music.

As presented in this section, techniques for audience participation in television shows are not suitable for real time voting of thousands of spectators. Approaches taken in interactive musical performances and interactive gaming are more promising for obtaining spectator participation at large scale sports events and formed the basis of our approach as described in the following.

DISPOSABLE WRISTBANDS FOR AUDIENCE PARTICIPATION

People from all over the world, from children to grandparents, who speak different languages and have different cultural backgrounds, will be the audience at the Olympics. This makes it hard to introduce any kind of interface or device that an audience would have to learn how to use. We examined how sports spectators currently "cast their vote" or show how much they like a specific performance. Approval or disapproval is shown through applause and cheering – things audiences have done almost automatically at sports events since ancient times [9]. This observation led to the idea of using exactly these two elements for an automatic system. No interface, nothing new to learn, just doing what you are familiar with and casting your vote seamlessly.

Disposable wristbands that are handed out to each spectator of a sports event are the key elements of this approach. These wristbands transmit RF pulses to stationary mounted receiver stations when people are clapping. Moreover, immediate visual feedback is given through a flashing light emitting diode (LED) on the band itself. The loudness of

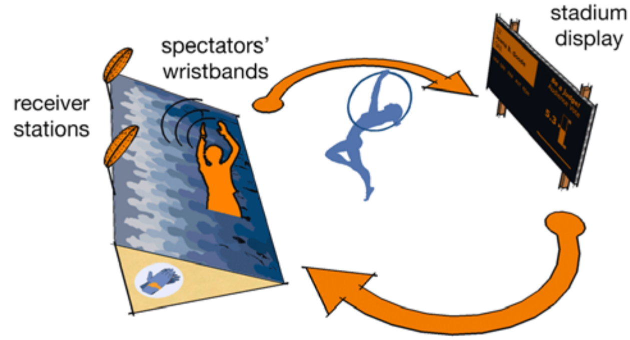

Figure 1. Overview of audience participation system

the crowd (cheering) is measured by microphones at the receiver stations and both clapping and loudness values are processed in a computer system (base station), which calculates the audience's vote and shows it continuously on the stadium displays along with the time left for voting. Thus, multiple seamless and continuous feedback loops are created via CONNECTing the athletes' performances, the individual spectator's impressions, as well as the overall audience's vote (see Figure 1).

Technical realization

The design we chose for our solution is similar to the motion sensors described in [7]. This assures that the basic technology has been tested and is functional. We also use motion sensors, which allow the tracking of audience clapping, and RF bursts to transmit the signals. To meet the requirements for an audience of the size expected at the Olympic Games, we have added several features to the design in order to support users during the scoring process and provide them with continuous feedback.

Essentially, the wireless motion sensor unit consists of a piezo sensor, an LED, and an RF transmitter (see Figure 2). The piezo sensor sets a timer that activates the RF transmitter whenever it is accelerated through motion, such as clapping. To prevent the trigger from being set off by normal arm movements, a sensitivity threshold is set. The LED is connected to the timer and is activated simultaneously with the transmission of an RF burst. This provides audience members with direct feedback about their scoring activity and shows that the device is working properly. The short RF burst duration of 50µs reduces the chance of collisions between signals. This is necessary to be able to receive each participant's action as a distinct event. Feldmeier et al. showed that the probability of two signals lining up is very low, even if several people are trying to synchronize their movements, as can happen with rhythmic applause [12]. We suggest replacing the RF transmitter part from [7] using less expensive parts, such as described in [6,8]. However, the circuit for the RF transmitter has to be adapted to a lower working voltage, since our system is operated with a 3-volt lithium coin cell in contrast to the 4.5 volt used originally. Feldmeier et al. affirmed that the battery would last for a month of continuous usage with two transmissions per second. The integration of an LED increases power consumption only slightly and due to our disposable approach the device will only be operated for single events that typically last for a couple of hours.

The size of the wireless motion sensor unit can be kept very small due to surface mounted device (SMD) technology, and is dominated by the battery cell. It can be reduced even more by using advanced manufacturing techniques, such as wafer level packaging (WLP). The entire technology fits into a case of the size of standard wristwatches. This case is glued onto the disposable wristbands that are made out of synthetic paper as used for music festival passes. We would produce info leaflets containing instructions in several languages in combination with the wristbands ("info card") on a single page.

The technical realization of the receiver stations can be found in [6]. Due to the limited transmission radius of the RF transmitter, the entire area has to be divided into zones, with each zone containing a single receiver. The transmission radius can be adjusted to the size of the stadium and audience by simply changing one resistor in the RF transmitter circuit. However, reflections and variations in signal strength make it difficult to determine the exact radius for transmissions. Therefore, we suggest a combination of various frequency channels and a cellular structure for the zones, similar to the architecture used for mobile phone communications [10]. The seat number that is printed on every ticket [5] and a zone code printed on the wristbands ensure that the spectators receive a wristband that can be operated in their seating area. Receiver stations communicate with the base station via a wireless local area network (WLAN), and we suggest equipping them with low-cost computers. The base station is an ordinary host computer that collects the data streams received from the different zones. The corresponding change of the audience score is calculated and transferred to the stadium displays. As mentioned earlier, our solution uses loudness measurement, too. Standard microphones are installed at every receiver station and the loudness analysis will be done by a software program running on the base station.

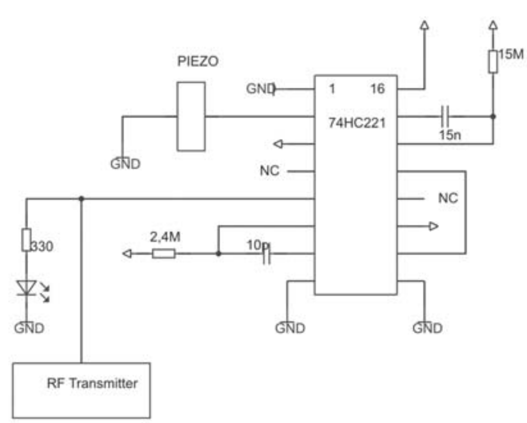

Figure 2. Schematic of wireless motion sensor unit

The final score is presented on the available stadium displays, which are also used to show the official judges' scores. During an athlete's performance they do not reveal their scoring, but the dynamic audience scoring process can be displayed. The vote of the audience can be contrasted to the judges' results after a performance. Many competition venues are still under construction and it was not possible for us to determine the technical state of the stadium displays. We assume that the modern Olympic venues in Athens will be equipped with high-resolution two-colored displays.

Judging of events

A central part of the proposed system is the calculation of the audience's vote from clapping pulses and loudness measurements. Clapping, on the one hand, is measured in terms of its frequency (number of pulses per time): the more claps that are recognized in the measured time, the higher the vote is. Loudness of cheering, on the other hand, is measured in terms of its mean value in the measured time.

The most difficult aspect is the calibration of the system. A base calibration might be carried out using two approaches: video recordings of sports events and test settings at events prior to the Olympics. Moreover, because of the fact that each location is different and different numbers of spectators are involved, we propose fine tuning the system at the beginning of each event. A base level of clapping and cheering can be recognized at the beginning of sports events and this level might be mapped to a specific portion of the scale (i.e. 30% of the highest mark). Furthermore, the mapping curve of clapping and cheering values has to be flattened at the end of the scale in order to prevent votes exceeding the highest possible mark.

A further issue which has to be taken into consideration is "booing" as a sign of dislike and representing a negative vote. This problem is tackled by recognition of loudness together with no or very little applause which we consider as booing.

Moreover, gymnastics events present another problem to audience voting because of the simultaneous appearance of athletes. This issue can be met by guiding the audience voting process via the stadium display on which the name of the athlete to vote on can be presented. Clearly, this represents a more rigid and complex voting scheme than needed for other events, but it is unavoidable in case of simultaneous performances.

Costs

The costs for the wireless motion sensor system are listed in Table 1. Generally, prices of the components for the circuits and production costs are very low due to the large number of items. For the Olympic Games in Athens, approximately 360,000 items will be required, since every spectator receives a wristband for each event s/he is attending. Companies typically provide component prices for a thousand items. Therefore, it is difficult to estimate an exact price breakdown for the elements of the motion sensor unit. Additionally, advanced manufacturing technologies such as WLP are usually used if electronic devices are produced in quantities of several hundred thousand pieces, which reduce the production costs of a single item even more.

Table 1. Costs of the wireless motion sensor system.

Item	Costs per item ($)	Nr. of items	Total costs ($)
Wireless motion sensor unit	1.80	360,000	648,000
Info card	0.30	360,000	108,000
Receiver stations	250.00	110	27,500
Base station	2,000.00	3	6,000
TOTAL			**789,500**

DESIGN PROCESS

The idea of using wristbands for audience participation was inspired by the gesture based computer interface shown in the motion picture "Minority Report". Starting from that, we explored spectators habits in general as well as related to the specific sports involved, in order to proof our assumptions towards broad accessibility and usability for an international audience. In parallel, we investigated how it could be realized technically and came across the work of M. Feldmeier et al. [6,7]. Based on these building blocks and the specifications of the venues in Athens as well as the requirements of the design competition, we developed our system. We discussed our ideas with several collegues throughout development and received consistently positive feedback to our concept. However, a full user study was prepared but could not be conducted yet.

CONCLUSION

Audience participation in the voting process of judged Olympic events is an issue of increasing importance as indicated by controversial discussions during the last years [4], as well as viewer's choice voting systems recently popular on the Internet [13].

Most hardwired systems that are currently available, for example in television shows, cannot be applied to the field of sports because of their limited scalability. Other approaches regarding large group interaction in the fields of interactive music and gaming are more promising for a system that enables audience participation in sports events.

Due to the broad variety of people attending Olympic sports events in terms of age, mother tongue, technological knowledge, and knowledge about judging procedures, each participation system that introduces interface barriers or require essential learning effort is likely to be rejected. Clapping and cheering are the most basic forms of interaction and support and are used by sports spectators internationally since ancient times [9]. Building upon these habits for an automatic audience participation system, would require no learning of new technology and no technological barriers would be erected which ensures greater system usability and accessibility for an international audience.

Technologically, we based our approach on a set of wireless motion sensors for large group musical interaction introduced by M. Feldmeier et al. [7]. These sensors are used in the form of wearable wristbands handed out to the audience. Reliable and robust analogous technology is utilized for transmitting RF burst signals to receiver stations when a spectator is clapping. The second component, the loudness of cheering, is measured via microphones at the receiver stations. Due to the high quantity of units and cheap electronic technology used, the low costs for a single wristband allow it to be a give-away item. Spectators can keep their wristbands as a souvenir which would increase acceptance and spread.

Because of the assignment of tickets to exact seats and sectors within a venue, a zone division scheme comparable to mobile phone communication [10] can be applied ensuring some basic level of tamper resistance.

By using wireless technology, receiver and base stations can easily be transferred, reused, scaled, and adapted to different local conditions. This fact, in combination with the small give-away RF transmitters, resembles a cost-effective system of high flexibility.

The design competition's problem specification asked for a system that allows audience members to cast their vote **following** each Olympians performance. We extended this requirement by allowing spectators to cast their vote **during** an athlete's performance. Presenting feedback on the audience's activity continuously, introduces a much higher level of interactivity, increases audience participation, and has an impact on the athletes. This overall feedback contrasts with the individual's feedback produced by the flashing LEDs built into the wristbands.

Issues that could not be tackled so far and possible future improvements are presented in the following section.

FUTURE WORK

First, user acceptance towards the proposed system should be tested via conducting a user study. An interview guideline for that matter has already been worked out containing three parts: System Walkthrough, Questionnaire, and Test Measurement.

Improvements of the system's accuracy could be made by involving other parameters like the hardness of claps or foot stomps into the measurement. Cultural or national differences might also be taken into consideration i.e. via recognizing differences in zones during the presentation of the countries participating in an event in the context of the event's introductions.

Furthermore, new digital wireless transmission technologies like Bluetooth could be applied to improve tamper resistance. Unfortunately, this technology is still much more expensive than the analogous technology used in the proposed system, thus making a give-away approach hard to maintain.

Last, and most important, test measurements have to be conducted in order to find an accurate base mapping curve of the spectators' votes.

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