Sound Effects in Theatre: Towards Actor-Controlled IoS Devices for Interactive Performance

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***Abstract*—This paper investigates the under-explored potential of actor-controlled sound effects in live theatre using Internet of Sound (IoS) technologies. A technical case study was conducted through a sound design workshop with live actors. Participants were introduced to IoS devices as novel means to trigger and manipulate both pre-recorded samples and procedural audio models in real time. The devices were built using Arduino MKR 1010 Wi-Fi microcontrollers, incorporating a range of sensors, including accelerometers, circular potentiometers, force sensitive resistors, photoresistors. Participant feedback emphasised the importance of early integration into rehearsals, cross-departmental collaboration, and reliability. These findings inform the design of future IoS-enabled performances, with a live deployment planned for December 2025.**

***Index Terms*—Internet of Sound, Procedural Audio, Sound Design, Live Audio.**

I. Introduction

Sound effects and sound design in theatre performances have provided a vital component of storytelling [1]. In theatre, sound helps establish the setting, convey mood, highlight events, and drive the narrative [2]. Today, the most common method for adding sound effects during a live theatre performance is through specialist software [3]. One example of this is QLab[1], which provides high-quality support for operating sound effects during a performance [4]. This software allows users to store all required sounds and offers features such as multi-voice playback, basic editing, parameter automation, and cue-based control. While these tools offer reliability and precision, they are generally operated off-stage, limiting the potential for real-time, performer-driven interaction.

Many believe that sound in live theatre has not advanced [5], yet several innovative productions involving sound have been developed and performed, seeking to engage the public. Examples include the use of binaural audio and on-stage Foley in *The Encounter* by Complicité, where the theatre audience wore headphones to experience the surround sound[2]. Vilkaitis and Wiggins developed an ambisonic version of a production of King Lear [5]. A study which included audio augmented reality within a participatory performances is presented in [6], which includes an overview of the use of interactive technologies in theatre and other performances.

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[1]https://figure53.com/
[2]https://www.complicite.org/work/the-encounter

This paper builds upon a previously reported workshop [7] but focuses specifically on the technical implementation, system architecture, and future deployment of Internet of Sounds (IoS) devices in live theatre. Specifically, it investigates the feasibility of actor-controlled sound effects using networked audio devices within the framework of the IoS. A public engagement workshop into the sound design of a live theatre performance was conducted and included a number of prototype devices. The setup included sensor-controlled devices, with one integrated into a prop, allowing participants to trigger and adjust sound effects in real-time.

The case study presents 9 networked sound devices (1 actor-controlled), within a live rehearsal and performance environment, examining the system architecture, sound reproduction method, and user feedback. The goal of this study is to gain understanding and lay the foundations for future IoS-based, actor-controlled sound effects to be deployed in a live theatre production.

II. Background

The Internet of Sounds (IoS) offers a framework for rethinking how sound can be embedded and controlled in performance environments [8]. The IoS deals with the communication of music and sound-related information over wireless networks, allowing for novel sound-based applications. In terms of a theatre performance, this paradigm offers a shift in control from operators to performers.

A. IoS Subdomains

One of the main subdomains of the IoS is the Internet of Musical Things, (IoMusT) [9]. Performer control using IoMusT devices has been explored in the context of SMART instruments. These are often traditional musical instruments complemented with electronic devices integrated into them to allow the user to create novel performances [10], [11], [12].

The other main subdomain is the Internet of Audio Things (IoAuT) [13]. The IoAuT focuses on distributed networks of non-musical audio things. Some of the main concerns for the IoAuT are with production, reception, and analysis, and includes applications like interactive sonification and wireless acoustic sensor networks [8].

B. Related work

Smart shoes were studied in [14], where the shoes controlled the sound as a sonification of the wearer's gait. This was focused towards medical rehabilitation whereas this study is looking at using similar devices for the control of sound effects during a live theatrical performance, ultimately by the actors.

Selfridge and Barthet [15] explored an interactive live performance using networked devices where digital music instruments sent networked messages to a HoloLens causing mixed-reality visuals to react to the sounds. The additional cognitive load on performers did not appear to be a significant issue while controlling mixed-reality graphics along with the music.

A recent study by Wu [16] focused on the centralisation of the control of sound along with video and lighting. Using existing established stage software (Isadora, ArKaos, grandMAonPC, QLab) it examines synchronisation and single operator control over the multiple systems. This contrasts with the current study, which explores democratising sound effect control by shifting it to the actors. The use of IoS devices supports more dynamic and embodied performances though it may introduce additional cognitive load.

Procedural audio sound effect synthesis uses models that allow real-time manipulation of sound through adjustable parameters [17]. Different sound models range from swinging objects [18], to thunder [19], to door creaks [20], and more. Often these sound effect models use subtractive and additive synthesis methods and are inspired by the physics that generate the sounds in nature [21].

III. Method

A. Workshop Design

The workshop was hosted by The Dibble Tree Theatre, Carnoustie, home of the amateur theatre company, called The Carnoustie Theatre Club. The venue's dual-space layout enabled parallel testing of IoS devices and participant interactions. The event provided participants with the unique opportunity to collaboratively ideate and sketch their sound design while working with the actors (in full costume and make-up) as they rehearsed a scene.

The workshop was scheduled to be 3 hours long and was timetabled as shown in Table I. Following the introduction, sound designers and actors were split into 2 groups, one situated in the main theatre, while the other was in one of the rehearsal rooms.

TABLE I
WORKSHOP TIMETABLE.

Time	Task
00:00 - 00:20	Introduction and background details
00:20 - 01:00	Ideation and rehearsal of 1st scene
01:00 - 01:15	Performance of 1st scene
01:15 - 01:30	Coffee break
01:30 - 02:10	Ideation and rehearsal of 2nd scene
02:10 - 02:25	Performance of 2nd scene
02:25 - 03:00	Feedback and data gathering

B. Participants

11 individuals participated, including 7 sound designers and 4 actors, whose varied backgrounds provided a broad spectrum of user feedback on the usability and integration of IoS devices.

1) Sound Designers: Among the sound designers 6 identified as female and 1 as male. Ages ranged from 16-18 years to 57-69 years, more than half in the 57-69 age range. 5 had acted in amateur theatre, 1 has directed and produced films, including Foley. 4 have also performed backstage roles, producing theatre performances, musical director, sound recorder and lighting director. None of the participants had experience creating a new sound design for a theatrical performance from a blank slate.

2) Actors: All of the actors identified as male with 3 out of 4 in the age range of 57-69 and 1 between 31-43. Previous experience of the actors include 1 who has produced a number of plays, 2 who have been musical directors and 1 who has operated sound effect software in the past. Again, none of the actors have had any direct experience in sound design for live theatre performances.

C. System Architecture

The IoS workshop required several hardware components, with slightly different setups in the theatre and rehearsal spaces due to the PA system being available only in the main theatre. The setup for both spaces is shown in Figs. 1 and 2.

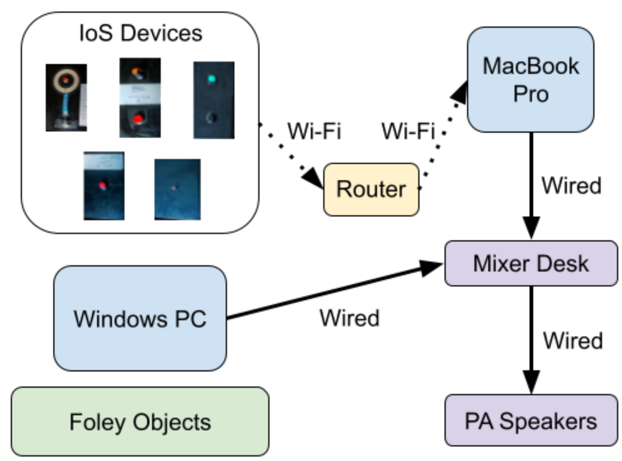

Fig. 1. Hardware setup showing IoS devices communicating via router to the MacBook (running Pure Data) and Windows PC (running SoundPlant), with audio outputs wired through the Front of House PA system.

A number of different sound sources were available in both the performance spaces based on the scene. Foley items provided included empty bottles, slide whistles, rain sticks, a thunder tube, whoopee cushions and wooden pegs. Both spaces also featured a Windows PC running the live performance audio software, *Soundplant*[3]. This software is similar to QLab, allowing samples to be assigned to keyboard keys, which trigger playback when pressed. All samples were uploaded to

[3]https://soundplant.org/

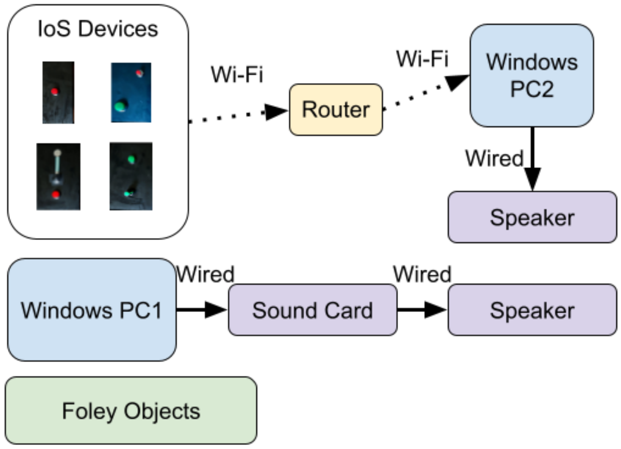

Fig. 2. Hardware setup showing IoS devices communicating via router to a Windows PC (running Pure Data) with audio output routed through an external speaker, and a separate Windows PC (running SoundPlant), with audio output routed through an external soundcard and monitor speaker.

the Windows laptops to act as a backup should the networked devices fail, or as an alternative option for the sound designers.

It can be seen in Figs. 1 and 2, each performance space was equipped with a dedicated router, enabling real-time Open Sound Control (OSC) communication between Arduino MKR 1010- based IoS devices and laptops running the interactive audio software, *Pure Data*[4]. This modular setup allowed for scalable deployment and fault-tolerant design. The IoS devices OSC data [22] via User Datagram Protocol (UDP), commonly used in multimedia communication [23]. Sensors within the IoS devices have their values read by the Arduino MKR 1010 boards, connected to the local network. Data is then sent to a predefined IP address on a stated port. Each data stream is mapped to a unique OSC address, for example, */fsr*, or */buttonState1*, allowing the receiving Pure Data software to distinguish between sensor outputs. Multiple devices can be connected on the same local network in this manner, making the architecture scalable depending on user needs.

The Arduino MKR 1010 boards were chosen because they have built-in Wi-Fi capabilities, are relatively inexpensive, and based on the author's familiarity with the programming environment.

D. Interaction Design

A total of 9 IoS devices were provided to the sound designers, 4 in one space and 5 in the other. The combined output from these devices had a total of 16 different sound effects. For participants to interact with the IoS devices a number of sensors were made available to them. These included accelerometers, a force sensitive resistor (FSR), a circular potentiometer, rotary potentiometers, buttons and a photoresistor. Since the workshop was also a public engagement event, the IoS devices were enclosed in sturdy project boxes in order to prevent unintended damage. All of the sound samples and synthesis models were run in Pure Data, which received the OSC data from the IoS devices.

1) Pre-recorded Sample Interactions: 9 out of the 16 sounds available were pre-recorded samples the control of which was mapped to buttons, causing the sound to play when pressed. These sounds compensated for characters not present, reaction from the chorus or reaction from the audience (common in pantomime performances).

Another pre-recorded sample was triggered using a photoresistor. Here the IoS device was put in a case along with a motion sensing light. The voltage across the photoresistor was mapped to an analogue value (0 - 1024) and when the case was opened by an actor the light came on changing the resistance. When this analogue input value passed a threshold the sample was triggered. Similar to the photoresistor, the voltage across rotary potentiometers were mapped to an analogue value. In these cases the threshold was made just above a value of 0 so that the sample triggered as soon as the knob of the rotary potentiometer was turned. The remaining range of the potentiometer was mapped to the volume of the sample.

2) Procedural Audio Sound Effect Interactions: Procedural audio sound effects were introduced for 4 different sounds available to participants. A button was used to trigger a synthesised spark sounds, adapted from Farnell's *humandspark* model [21]. The output from the button was a direct 1-to-1 mapping to the button in the Pure Data patch to trigger the sound effect, making it the obvious component to present users to interact with.

An FSR was used to control the sound of a squeak. This model was adapted from the patch by Christian Heinrichs, available through the Bela website[5]. Pressure on a FSR was mapped to the amount of squeeze on a rubber duck, giving a different pitch squeak when released, equivalent to releasing a rubber duck. Since pressure has to be applied to a squeaky duck the choice of an FSR made for a more intuitive means of control than, for example, an ordinary potentiometer.

A circular potentiometer was used to control an interactive theremin type sound effect, created by the author. The position the user touches the position sensor was mapped to the pitch of the output, with clockwise increasing the pitch and anti-clockwise decreasing it. The choice of the circular potentiometer was twofold: it provided participants with a different and unique sensor to interact with, and it allows the user to discretely control the pitch purely by the position they place their finger on the sensor. An FSR and potentiometer would require the user to glissando up or down to the desired pitch which was not the intention of this sound effect (although can be achieved by sliding the finger around the sensor).

The final procedural model was a storm sound effect which was created from adapting and combining Farnell's *rain* and *thunder* patches [21]. Both these sound effects were controlled by an accelerometer. The output of the accelerometer was mapped to the two sound effects in order to increase the intensity of the storm when the IoS device was turned. The first

[4]https://puredata.info/

[5]https://learn.bela.io/tutorials/pure-data/synthesis/rubber-duckie/

mapping increased the volume of the rain as the output from the accelerometer increased. The second mapping increased the number of thunder rumbles as output from the accelerometer increased. The use of the accelerometer created an IoS device that resembled a rainstick, a Foley object commonly used to replicate rain. This digital version with added thunder could be called a *'Stormstick'*. An illustration of this and the Pure Data GUI is shown in Fig. 3.

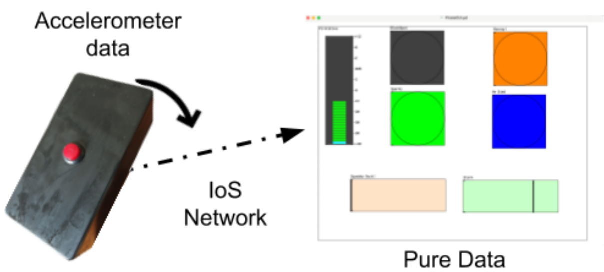

Fig. 3. Operation of the 'Stormstick' IoS device and Pure Data GUI. The angle of the IoS device controlled the level of rain and thunder sound effects produced from the Pure Data synthesis modules. The GUI allows someone in the sound booth to view the operation of the devices on the stage.

The purpose of the interaction design and mappings were to offer participants a variety of common sensors to interact with, affording a variety of control methods. The interactions range from functional to performative and provide a comprehensive overview to inform future developments. A summary of the procedural audio models, mapping and control is given in Table II.

TABLE II
SUMMARY OF PROCEDURAL AUDIO SYNTHESIS MODELS.

Model	**Sensor / Trigger**	**Control**
Sparks	Button	Triggers gain envelope
Squeaky Duck	FSR	Pressure differential input
Theremin	Circular Potentiometer	Frequency of oscillators
Rain / Thunder	Accelerometer	Gain envelope of rain / Trigger rate of thunder

E. Data Collection

Data collection was conducted in 2 parts, using a sequential mixed-methods design [24]. The first data collected was via a questionnaire, gathering quantitative and qualitative data immediately following the workshop (see Table I). Within 14 days following the workshop, semi-structured interviews were carried out to obtain richer qualitative data. All participants (or their parents) signed consent forms prior to data collection. Data was gathered from both sound designers and actors to ensure all opinions available were recorded. Sound design participants are referred to as P01, P02, etc., while actor participants are referred to as A01, A02, etc.

IV. FINDINGS

The feedback from participants provided valuable insights into the performance of the IoS devices, including benefits, challenges as well as design preferences.

A. Post-workshop questionnaire

The questionnaire completed immediately following the workshop mostly focused on their holistic experience of using all the different sound creating methods, (Foley, Laptop and IoS Devices). Along with enjoying the workshop and obtaining a greater understanding of the sound design process as a whole for theatre productions, a number of comments were given in relation to the deployment of IoS devices along with the other sound creating methods.

There was little mention of the IoS devices from the sound designers in the questionnaire. One participant (P03) highlighted the IoS devices as a standout feature of the workshop, noting their novelty and creative potential, while P02 commented that there are more methods for creating sound than they realised. Actor A04's character was the one who interacted with the IoS device integrated within a prop the most. They stated *"the triggers for cast are great"* as well as *"Actor triggered sensors are something to watch out for"*. The reliability of the connectivity of the IoS devices was also noted by A04 as a potential issue for live performance.

B. Interviews

Due to conflicting commitments P06, P07 and A04 were not able to take part in the interview process. The semi-structured interviews were based on 16 questions, adjusted depending on the participants role during the workshop, and occasionally adapted based on the responses during the interview. All interviews were recorded and transcribed before transferred to Nvivo software[6] for thematic analysis [25]. A total of 7 overarching themes were identified through indicative thematic analysis, each with a number of sub-themes. Full details of the thematic analysis can be seen in [7]. This paper focuses on comments and areas specifically related to the development and consequences of the use of IoS devices in live theatre performance.

1) Perceived Benefits of Actor Control: The benefits of having actor-controlled IoS devices is a paramount theme, justifying the research and development.

a) Enhanced Timing and Precision: This concept was strongly supported by actor A01 when they stated, *"something that can be initiated by the actor themselves, I think that's, that's, that's the future I think of actually a brilliant idea"*. From a timing perspective, actor A01 noted that self-triggered cues could eliminate common synchronisation issues with off-stage operators. Actor A03 identified the key benefit of timing from using IoS devices when they states, *"the cues won't be late, the cues won't be forgotten about. So, in the, all other things being equal, it could almost give a better, a better result, performance for the audience benefit I think"*. Sound designer P05 also identified timing as a benefit of using IoS devices, *"It can only help, I would imagine because it should, it would actually be timed exactly with the hand movements or whatever actions are taken last, place. So, I think authenticity would be better, you wouldn't have that mismatch of timing"*.

[6] https://lumivero.com/products/nvivo/

b) Increased Freedom and Real-time Adaptation: The potential for additional creativity from using actor-controlled IoS devices for manipulating sounds was identified by sound designer P03 who commented, *"I think it would, it would just open up a totally different layer for creativity, for improvisation. Yeah, that that's really interesting"*. This additional freedom was also identified by P01 who said, *"add in the sound at a time when you hadn't thought of adding in a sound, but if they feel it goes with whatever they're doing at the time, then they can just add that sound in"*. A specific case was mentioned by P05 in relation to pantomimes, where the audience often communicate with performers. They stated, *"a call out or something that actually stops the flow of what's, what the speech normally hits and then that then affects when the action happens, that then needs a sound effect"*.

c) Enhanced Authenticity and Audience Immersion: Increasing the believability of the sounds being created is another key potential advantage of using IoS devices to control and manipulate the sound effects. Sound designer P01 expressed this point when they said, *"I think it would make them believe in it more because it happens, the actor is able to control exactly when it happens"*, linking believability with the benefit of the actor controlling the timing of the sound effect.

When asked to what extend producing sound effects as a performer might affect an audience's perception of authenticity, A02 stated, *" it's completely important. I think it's, it's crucial for giving the impression that it's all real"*. A02 gave the example of when authenticity was broken when, during a performance they had to answer a telephone, yet the sound of the phone ringing continued after they had picked up the receiver.

d) Actor Agency and Integration into the Production Process: Early integrating of actors into the sound design process was identified as imperative when using actor-controlled IoS devices. The paradigm changes the traditional separation of roles of sound operator and actor, giving the actor increased agency over sound, facilitated by the IoS devices. This was seen as an important progression in theatre production by A01 who said, *"the whole idea of incorporating sound effects that are actually initiated by the actor themselves... ...that's the future"*. Speaking of the workshop experience, A03 stated *"the actor, actors were able to contribute some ideas to them using the tools that were there, so it was very interactive"*.

2) Identified Challenges of Actor Control: Although there are significant perceived benefits of having actor-controlled sound effects, participants identified a number of concerns with the introduction of this technology.

a) Device Reliability and Network Performance: Device reliability is a paramount concern and was an issue through the workshop, where the author often had to reboot the devices when they stopped working. The importance of reliability was highlighted by A02 who emphasised, *"That they work. I think that's the number one thing"*. This was again stressed by P01 who asked, *"Is it going to work every single time?"* Sound designer, P04 highlighted that *"If it's not working then I could see that, that could be a frustration for an actor"*. Actor A02 indicated that having a conventional system as a backup would be sensible.

b) Increased Cognitive Load and Stress for Actors: Introducing actor-controlled sound effect introduces an additional element for actors to consider when performing. This represents an increase in their cognitive load and the potential for additional stress. Actor A03 stated they felt some *"trepidation"* about the concept of actor-controlled sound effects, stating *"it might be a bit, find initially a bit stressful for actors to be actually in charge of their own sound effect"*. This was also highlighted by sound designer P05 who said, *"then the layers of processing and thinking about the environment as well as their own personal actions would be overwhelming"*. Actor A02 indicated that they give sound very little thought when performing, implying that this would be something new and additional they would have to think about - *"the sound aspect, but quite frankly, it hardly even enters my head... ...it's somebody else's problem"*.

c) Integration with Costume, Props, and Stage Elements: Unlike IoMuT devices, which tend to remain integrated in a single instrument, the IoS devices within a live theatre production may well have to be integrated into multiple costumes. This aspect was highlighted by P01 who stated, *"Is it something that's attached to a costume? ...you've got to think about costume changes"*. This was also mentioned by A01 who said, *"You know whether or not they need to build extra pockets in or sew, sew inside pockets in, sew the thing into the costume"*. P01 also indicated that the sensors might be subject to unusual external stresses, for example, *"Is it something that can accidentally be covered over or covered in foam?"*

d) Actor Consistency and Training Requirements: The requirement for actor-controlled sound effects to be integrated as early as possible into rehearsals was highlighted on a number of occasions by different participants. This was clearly encouraged by P03 when they said, *" I think that this creation of sound design by performers should be incorporated into rehearsals as early as possible"*. A03 supported this when they stated, *" I think things like this would have to be rehearsed and rehearsed and rehearsed"*. P03 stated, *"I think if you're going to use sound like live ones, the actor-led ones, they have to be incorporated pretty much from the start so that the actor gets used to using them and it becomes almost, almost second hand"*.

e) Potential for Audience Distraction: If the incorporation of the IoS devices for actor-controlled sound effects is not carefully considered and seamlessly integrated then it was believed that this could prove a potential distraction for audiences. This was most clearly expressed by P03 who stated, *"There's a possibility that the audience might be taken away from, from the performance if sound was being created explicitly, or if there was something being done by that performer, that could distract the audience from the actual performance"*.

V. Discussion

Due to the performative nature of the IoS devices implemented in this study, particularly through the control and manipulation of procedural audio models, it is believed the IoS devices presented in this paper sit more towards the IoMusT domain rather than IoAuT. The findings obtained from participants in relation to actor-controlled sound effects via IoS devices indicates great potential for future live theatre performances.

A. Benefits

The benefits identified were often focused on the timing of sound effects, allowing increased precision, artistic freedom and enhanced authenticity. The vast majority of scenarios participants envisaged actor-controlled sound effects being deployed were for slapstick style sound effects. It should be acknowledged that this may well be influenced by the pantomime scenes that the workshop was built around. Only P03 gave thought to an actor being able to control an atmosphere using an IoS device, *"I think something that would be really interesting is, sort of some, some ambient sounds. Only because ambient sounds can resp, normally ambient sounds respond to what is happening in the scene. So you've got the beginning of it, and then maybe when things are getting more tense, you're, you're noticing the ambience sounds getting stronger and stronger"*. This illustrates that IoS devices have the potential to not only have highly synchronised sound effects reacting to specific interactions on stage, but opens the possibility that atmospheric sound intensity can exactly match the emotional intensity of an actor on stage.

Although procedural audio models were demonstrated to participants of the workshop, there was not the time available to provide an in-depth description of the concepts and models. This goes some way to explain why "procedural audio" was not specifically referenced in the feedback. Sound design participant P02 did reference the control of the squeaky duck procedural model when they stated, *"We didn't feel it was enough of an effect as against the Swanee whistle, but it didn't have big enough range. But you could see how there could be times when that would be used or used in a different way"*. This emphasises the requirement to develop the interface of the procedural audio IoS devices to be able to reproduce the specific sounds, across the required range.

This enhanced timing and artistic freedom are direct affordances based on the IoS concept. By integrating the IoS devices with control of procedural audio synthesis models, novel sound design for performances can be facilitated. Due to the adaptive nature of the synthesis models, every unique performance could have a slightly varied sound design, based on the actors control. When an actor's control of their own sound becomes second nature, then this gives them an additional tool to express their emotion, with the potential for creating a more authentic and captivating performance for audiences.

B. Technical Considerations

As seen in the findings, the participants highlighted a number of potential issues with using IoS devices for actor-controlled sound effects which should be considered in future developments.

The biggest concern from participants by far is reliability, some devices having to be re-booted during the rehearsals. This issue has been noted on Arduino git page under issues for the MRK 1010 with no solution offered[7]. The ability for actors to trigger their own sound cues is a novel concept for them and, as witnessed in the workshop, the IoS devices at times did not produce the sound effect. To reduce this risk early development of the IoS device should be undertaken to ensure a stable Wi-Fi connection. This would include testing within the theatre to ensure there is no site specific interference that could cause issues. Participants did also recommend that a back-up always be available, i.e. through QLab or similar that will be available should there be any live technical issues.

Another issue, which was not identified by participants due to the nature of the prototype IoS devices in the workshop environment, is that an IoS embedded within a costume may get hot. This should be considered when consulting with costume design as well as consideration as to how the IoS device could be cooled during moments that the actor is off-stage. Accessibility to the wearable IoS device is therefore an important consideration. The workshop had the IoS devices contained within project boxes that were secured by screws. This mistake was identified early on when the first device needed rebooted. A quick release box or similar should be used.

A final technical consideration should be given to the sustainability of the IoS devices. It should not be an issue to re-use the IoS device in a different costume, or in a new prop. This may mean changing out sensor components and new models in Pure Data but should have very little waste involved.

C. Production Considerations

As discussed in section V-B, the costume design department will need to be consulted at the very beginning to ensure the smooth integration of the IoS device. This will allow for secret pockets, holes for sensor access and other requirements can be integrated when costumes are being made. It may be more logical that a separate garment is required for the IoS device due to multiple costume changes. Only by early and collaborative discussion with the costume department will solutions be identified.

Discussion with the prop department will also be similarly important for those IoS devices that will be hidden in a prop. It is envisaged that integration into a prop may not be as problematic as into a costume, but there will still be important discussion about how a prop will be placed on stage. Orientation might well be vital, scene changes often take place in very low light and to a precise timescale to

[7] https://github.com/arduino/nina-fw/issues/85

fit in with the next curtain change. Early collaboration and practice should be able to mitigate potential misplacements or accidental triggering when a prop is being placed on stage.

When developing the actor-controlled wearable or prop the ultimate arbiters of the interface (and even inclusion) is going to be the production management team, (Director, Producer, etc.). A collaborative initial discussion with them has to occur before any development takes place. Not only do sounds suitable for actor control need to be identified, but consideration has to be given to the character, as well as the actor playing the character. As identified in the findings, it is believed that inclusion of an IoS device in a live theatre performance will increase the actor's cognitive load. This is due to the shift from the traditional separate dedicated sound team to an additional responsibility for the actor. Therefore, bestowing the responsibility to an unconfident actor who is heavily focused on their lines, movement, timing, interacting with other performers, etc., may be detrimental compared with an actor who is confident with these aspects.

As highlighted by participants, early integration of the IoS sound effect devices is vital. This will help prepare the actor to integrate the use of the device into their performance, reducing their cognitive load.

D. Sound Design Considerations

As with all theatre productions, the sound design will be developed first and foremost around the script and the desires of the production team. Once the sound(s) and actor(s) that will use the IoS devices have been identified, (as per section V-C), the design of the sounds has to be considered. This includes understanding if the sound is a spot sound effect or an atmosphere. It may be that the sound is a non-verbal vocalisation or occurs off-stage. It is also important to consider if the sound will only occur once or will be repeated throughout the performance.

Taking these different sound effect aspects into consideration may well guide as to whether a sample or a procedurally synthesised sound effect might be more suitable. For example, if a single slapstick punch which only occurs once, a sample might be considered most appropriate. If the sample was to be repeated throughout, then ear fatigue should be considered and possibly a more dynamic sound effect would be more suitable. At the other end of the spectrum might be an atmosphere which adapts based on the changing emotion of a character or scene. In these circumstances, a procedural audio synthesis model, which have the ability to adapt and modulate in real-time through sensor-control of an IoS device, might be best suited. As highlighted by P02, the range of control / fidelity of the procedural models afforded by the sensors has to be tailored to ensure the actor's expression is accurately represented.

If using a prop, like a telephone, as described by A02, it might be the case that the actor-controlled device is used to stop the sound effect. For example, a ringing phone stops when the receiver is picked up. The sound design considerations will inform the hardware design. If using a sample sound effect one might choose a button or a FSR as a trigger. If used for non-verbal vocalisations some form of a potentiometer might be more suitable, giving a range of responses. Again, early rehearsals would be required so that controlling the sound effect becomes second nature to the actor.

VI. Future Work

The next stage for this research is to develop and integrate the network sound devices into a live performance. Development for this is already underway with a view to integrating IoS devices in a pantomime performance planned for December 2025. This live performance will serve as a pilot to establish quantitative reliability baselines, including testing network stability and measuring packet loss rates, alongside objective usability metrics for actor-controlled sound effects.

Beyond this, IoS controlled sound effects has the potential to be employed in a more distributive performance, where actors are not co-located, similar to musical performances which became the focus of increased academic research during the Covid 19 pandemic [26]. An example of this could be a novel performance co-located in London's West End and Broadway in New York.

Although UDP is the network protocol of choice to the majority of networked musical implementations [27], it should be noted that systems that use specialist operating systems in relation to remote musical performances [28], and these may help achieve a more robust network connection and hence reliability. Similarly, a bespoke wireless communication implementation in the design of scalable sensor/actuator systems for artistic productions is given in [29]. The choice of microcontroller for this investigation into IoS controlled sound effects was the Arduino MRK 1010. Investigation into more practical solutions should be undertaken. Rushton, et. al. examine a number of different microcontrollers in relation to distributed spatial audio, stating that the Teensy was an attractive candidate based on processor, price and support [27]. The drawback they identified was the low quality audio fidelity offered, but with this (and networking considerations), it should be remembered that the current IoS devices for sound effects are looking at communicating OSC data and not an audio signal.

VII. Conclusion

The use of IoS devices to control sound effects in live theatre performances is an exciting and novel prospect, enabling real-time, actor-driven interaction with sound. Through the facilitation of a workshop, data has been gathered highlighting the benefits of the use of IoS devices to create new interactive, engaging and dynamic theatre performances. The workshop pilot revealed valuable insights to inform future research. Feedback from the workshop participants also offered key lessons on integrating IoS devices with all the different aspects of theatre production. The aim to maximise actor and audience experience throughout a performance, while minimising potential obstacles remains central to future development.

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References

[1] H. Harma and K. Ali, “Unforgettable sound: The magic of audio effects in theater,” *Revue des Arts, Linguistique, Littérature Civilisations*, vol. 4, pp. 279–279, September 2024.

[2] X. Xie, “Sonic interaction design in immersive theatre,” Ph.D. dissertation, University of York, 2022.

[3] J. Simpson, “Live and life in virtual theatre: Adapting traditional theatre processes to engage creatives in digital immersive technologies,” *EVA London 2021: Electronic Visualisation & the Arts*, pp. 109–116, 2021.

[4] D. Kaye and J. LeBrecht, *Sound and music for the theatre: the art and technique of design*, 3rd ed. Focal Press, 2013.

[5] A. Vilkaitis and B. Wiggins, “Ambisonic sound design for theatre with virtual reality demonstration-a case study,” *EPiC Series in Technology*, vol. 1, pp. 60–67, 2019.

[6] A. N. Nagele, V. Bauer, P. G. Healey, J. D. Reiss, H. Cooke, T. Cowlishaw, C. Baume, and C. Pike, “Interactive audio augmented reality in participatory performance,” *Frontiers in Virtual Reality*, vol. 1, p. 610320, 2021.

[7] R. Selfridge, “Interactive theatre sound design: A collaborative workshop.” 17th International Symposium on Computer Music Multidisciplinary Research, London, UK, November 2025.

[8] L. Turchet, M. Lagrange, C. Rottondi, G. Fazekas, N. Peters, J. Østergaard, F. Font, T. Bäckström, and C. Fischione, “The internet of sounds: Convergent trends, insights, and future directions,” *IEEE Internet of Things Journal*, vol. 10, no. 13, pp. 11 264–11 292, 2023.

[9] L. Turchet, C. Fischione, G. Essl, D. Keller, and M. Barthet, “Internet of musical things: Vision and challenges,” *Ieee access*, vol. 6, pp. 61 994–62 017, 2018.

[10] L. Turchet, P. Bouquet, A. Molinari, and G. Fazekas, “The smart musical instruments ontology,” *Journal of Web Semantics*, vol. 72, p. 100687, 2022.

[11] L. Turchet, A. McPherson, M. Barthet *et al.*, “Co-design of a smart cajón,” in *AES*, vol. 66, no. 4, 2018, pp. 220–230.

[12] L. Turchet, “Smart mandolin: autobiographical design, implementation, use cases, and lessons learned,” in *Proceedings of the Audio Mostly 2018 on Sound in Immersion and Emotion*, 2018, pp. 1–7.

[13] L. Turchet, G. Fazekas, M. Lagrange, H. S. Ghadikolaei, and C. Fischione, “The internet of audio things: State of the art, vision, and challenges,” *IEEE internet of things journal*, vol. 7, no. 10, pp. 10 233–10 249, 2020.

[14] L. Turchet, “Interactive sonification and the iot: The case of smart sonic shoes for clinical applications,” in *Proceedings of the 14th International Audio Mostly Conference: A Journey in Sound*, 2019, pp. 252–255.

[15] R. Selfridge and M. Barthet, “Augmented live music performance using mixed reality and emotion feedback,” in *14th Int. Symposium on Computer Music Multidisciplinary Research*, vol. 210, 2019.

[16] X. Wu, “Integration and application of multimedia communication systems in stage “sound, light, and video” linkage control,” in *2024 5th International Conference on Electronic Communication and Artificial Intelligence (ICECAI)*. IEEE, 2024, pp. 130–134.

[17] D. Moffat, R. Selfridge, and J. D. Reiss, “Sound effect synthesis,” in *Foundations in Sound Design for Interactive Media*. Routledge, 2019, pp. 274–299.

[18] R. Selfridge, D. Moffat, and J. D. Reiss, “Sound synthesis of objects swinging through air using physical models,” *Applied Sciences*, vol. 7, no. 11, p. 1177, 2017.

[19] J. D. Reiss, H. T. Tez, and R. Selfridge, “A comparative perceptual evaluation of thunder synthesis techniques,” in *Audio Engineering Society Convention 150*. Audio Engineering Society, 2021.

[20] C. Heinrichs, A. McPherson, and A. Farnell, “Human performance of computational sound models for immersive environments,” *The New Soundtrack*, vol. 4, no. 2, pp. 139–155, 2014.

[21] A. Farnell, *Designing sound*. Mit Press, 2010.

[22] M. Wright, A. Freed, and A. Momeni, “2003: Opensound control: State of the art 2003,” *A NIME Reader: Fifteen Years of New Interfaces for Musical Expression*, pp. 125–145, 2017.

[23] Z.-N. Li, M. S. Drew, J. Liu, Z.-N. Li, M. S. Drew, and J. Liu, “Network services and protocols for multimedia communications,” *Fundamentals of Multimedia*, pp. 535–582, 2021.

[24] J. W. Creswell and V. L. P. Clark, *Designing and conducting mixed methods research*. Sage publications, 2017.

[25] V. Braun and V. Clarke, “Using thematic analysis in psychology. qualitative research in psychology,” *Qualitative research in Psychology*, vol. 3, no. 2, pp. 77–101, 2006.

[26] M. Bosi, A. Servetti, C. Chafe, and C. Rottondi, “Experiencing remote classical music performance over long distance: a jacktrip concert between two continents during the pandemic,” *Journal of the Audio Engineering Society*, vol. 69, no. 12, pp. 934–945, 2021.

[27] T. A. Rushton, R. Michon, S. Serafin, T. Risset, and S. Letz, “Networked microcontrollers for accessible, distributed spatial audio,” *Frontiers in Virtual Reality*, vol. 5, p. 1391987, 2024.

[28] L. Turchet and C. Fischione, “Elk audio os: an open source operating system for the internet of musical things,” *ACM Transactions on Internet of Things*, vol. 2, no. 2, pp. 1–18, 2021.

[29] I. Hattwick, I. Franco, and M. M. Wanderley, “The vibropixels: A scalable wireless tactile display system,” in *International Conference on Human Interface and the Management of Information*. Springer, 2017, pp. 517–528.