EmotiMask: Mapping Mouth Movements to an LED Matrix for Improving Recognition When Teaching With a Face Mask

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Abstract
The Covid-19 pandemic has led to the adoption of face masks in physical teaching spaces across the world. This has in-turn presented a number of challenges for practitioners in the face-to-face delivery of content and in effectively engaging learners in practical settings, where face coverings are an ongoing requirement. Being unable to identify the mouth movements of a speaker due to the lower portion of the face being obscured can lead to issues in clarity, attention, emotional recognition, and trust attribution, negatively affecting the learning experience. This is further exacerbated for those who require specialist support and those with impairments, particularly those centred around hearing. EmotiMask embeds an LED matrix within a face mask to replicate mouth movements and emotional state through speech detection and intelligent processing. By cycling through different LED configurations, the matrix can approximate speech in-progress, as well as various mouth patterns linked to distinct emotional states. An initial study placed EmotiMask within a HE practical session containing 10 students, with results suggesting a positive effect on clarity and emotional recognition over typical face masks. Further feedback noted that it was easier to identify the current speaker with EmotiMask, however speech amplification, additional led configurations, and improved portability are desired points of refinement. This study represents a step towards a ubiquitous solution for tackling some of the challenges presented when teaching in a pandemic or similar situations where face coverings are a requirement and has potential value in other sectors where such scenarios present themselves.

Keywords: Audio Processing, Covid-19, EmotiMask, Emotional Recognition, Face Masks, LED Matrix, Mouth Expressions, Speech Detection, Teaching & Learning

Introduction

The repercussions of the Covid-19 pandemic can be felt across the education sector, impacting the teaching practice of practitioners who had to quickly adapt to a new landscape (Pokhrel & Chhetri, 2021). This was particularly challenging for the face-to-face delivery of content with the various restrictions in place. Face masks or coverings were widely adopted to help mitigate the potential contagion of the virus, becoming mandatory in United Kingom from 24th July 2020. Where face masks are typically mandatory, often learned communication techniques are important to build rapport and garner positive interaction, typically improving outcomes (Crowe, 2020). These types of communication techniques are not necessarily familiar to those who have not had training or dealt with face masks previously, such as many education professionals. By obscuring the lower portion of the face, some of the usual pathways for communication are restricted and mouth movements cannot be seen leading to issues in clarity, attention, and emotional recognition, negatively affecting the learning experience. This is further exacerbated for those who are younger learners or those who may require specialist support, such as learners with impairments, particularly those centred around hearing. In this paper, we present the development of the EmotiMask prototype, where an LED matrix is embedded within a typical face mask to replicate real mouth movements and emotional states through cycling various LED configurations. Direct feedback is gained from learners in an initial study embedded with a HE practical session. The rest of the paper is structured as follows: Related Work discusses present challenges of learning, communication, and expression recognition; the method and systematic development of the prototype are outlined in EmotiMask; Results presents the outcomes from the initial study; Conclusions provide discussion and a look towards future work.

Related Work

The Covid-19 pandemic has had a profound effect on teaching (Jandrić, 2020), whether it be through the incorporation of blended learning models into existing curricula to support remote access or the restrictions put into place for delivery of face-to-face sessions, such as minimum interaction distance. Here we investigate this impact in three key areas, learning, communication, and expression recognition, with a focus towards the disruption caused by the face mask requirement and how this can be mitigated to support student learning.

Learning:

Covid-19 has resulted in a rapid transformation of pedagogy in a relatively short space of time (Oyedotun, 2020). Many typical face-to-face learning activities moved online as a means to continue, with the development of solutions to support the transition such as serious games (O'Connor et al., 2021), virtual reality and immersive worlds (Colreavy-Donelly et al., 2022), and virtual learning environments (Torres et al., 2021). Despite utilising learning theories such as scaffolding, flipped classroom, and active learning, results have been mixed. Some studies show students having a dissatisfied attitude towards remote learning (Torres et al., 2021) and practitioners are noted as having faced difficulties in adapting to the new technologies, with a skills gap identified in some institutions (Hassan, Mirza & Hussain, 2020). In many cases, institutions therefore reinstated face-to-face learning where possible, typically in a blended approach, where measured allowed, albeit with different challenges due to the various restrictions, such as the need for face masks.

Face masks in practice obscure the lower portion of the face, causing issues in some instances with communication due to a combination of speech distortion and the inability lip read the speaker (Nobrega et al., 2020). Further studies have shown that smiling broadens cognition and thereby increases creative thinking (Johnson, Waugh & Fredrickson, 2010), however such emotional recognition is not possible when wearing a typical face mask. Indeed, studies suggest face masks amplify the perceived negative emotions of the wearer resulting in increased anxiety, as well as reduced creativity and problem solving (Lyons & Beilock, 2011).

Communication:

The most basic form of human communication is by facial expressions. Humans are biologically programmed to recognise faces (Rivett et al., 2020). The most recent evolution of the human brain has been influenced by this capability to support the transmission of knowledge:

- Teaching – distribution of knowledge (Henrich, 2016)
- Learning – absorption of knowledge (Spitzer, 2020)

The use of face masks then impedes this process, causing noted issues of

- Clarity
- Attention
- Recognition (Emotional)

by reducing the ability to communicate, interpret, and mimic expressions. Positive emotions become less recognizable and negative emotions are amplified. Those suffering from hearing difficulties may find it challenging to recognise who is speaking, for example in a group setting.

Expression Recognition:

Facial expressions form the basis of communication between humans, a simple universal language that is instinctively understood:

- Smile
- Laugh
- Cry
- Joyous
- Unhappy

Studies suggests that the eyes are the facial feature which are engaged with first and for the longest. Second to the eyes are mouth and nose (Spitzer, 2020).

Suggested Solution:

Conceptually, EmotiMask then serves as a potential solution to these challenges through replicating mouth movements and emotional state by applying intelligent audio processing, often utilised for classification tasks (Bielby et al., 2020) and even recently deployed towards pedagogy (Schlotterbeck et al., 2021) and to support various Covid-19 challenges

(Deshpande & Schuller, 2020). EmotiMask utilises an LED matrix to display an animated mouth that is updated in real-time, essentially unobscuring the lower portion of the face to improve overall clarity, attention, and recognition.

EmotiMask

The first step is to understand what the typical expressions of the mouth are when speaking, focusing on key sounds. A diagram showing the expression for some key sounds is shown in Figure 1. Based on this, patterns which can be represented in an LED matrix were designed, as shown in Figure 2.

A subtle distinction of a nose was also added in a later version of the EmotiMask, shown in Figure 3. This was due to further research expressing the importance of the mouth and nose combined.

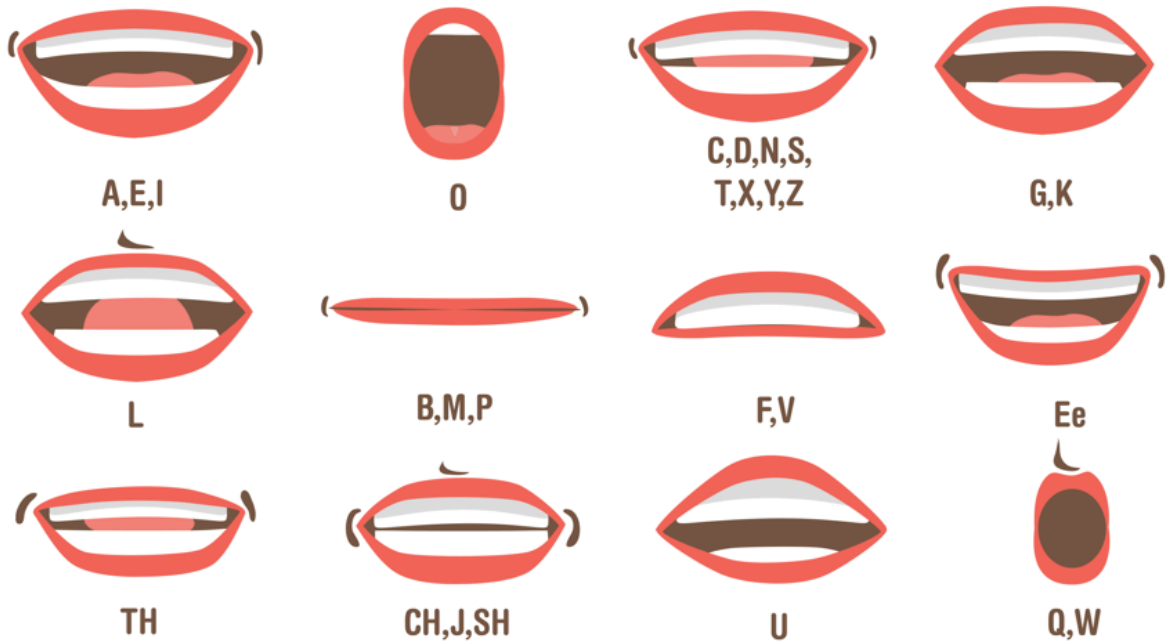

Figure 1: An example of the key expressions and sounds for replicating mouth patterns (image from freepik.com).

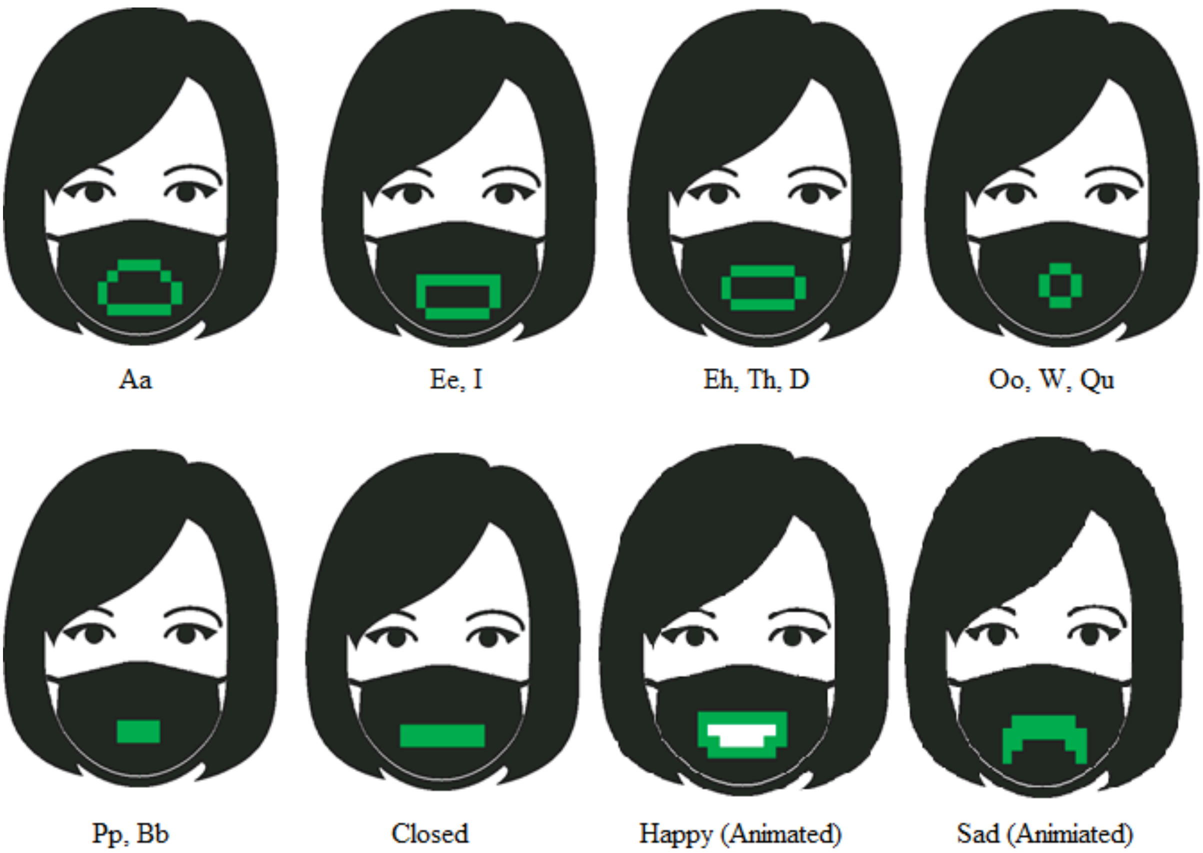

Figure 2: A selection of mouth expression, utilised together with basic emotions for the initial EmotiMask configurations.

Figure 3: Updated versions of the initial configurations included a representation for the nose.

Based on those design decisions, EmotiMask was implemented by embedding an LED matrix within a face mask. An embedded microphone and microcontroller are used for speech detection and intelligent processing. This data is then displayed by cycling through different LED configurations. The matrix can approximate speech in progress and show distinct emotional states.

The following hardware components were utilised to build the prototype for EmotiMask (see Figure 4):

1. Generic cloth face mask
2. Arduino Nano (open-source hardware and software for single-board microcontrollers for building digital devices)
3. 8x8 Addressable RGB LED Matrix (WS2812b)
4. Basic microphone module with built in amplifier and gain pot for adjustments
5. 5.5v USB power pack
6. 10k Ohm Resister & button

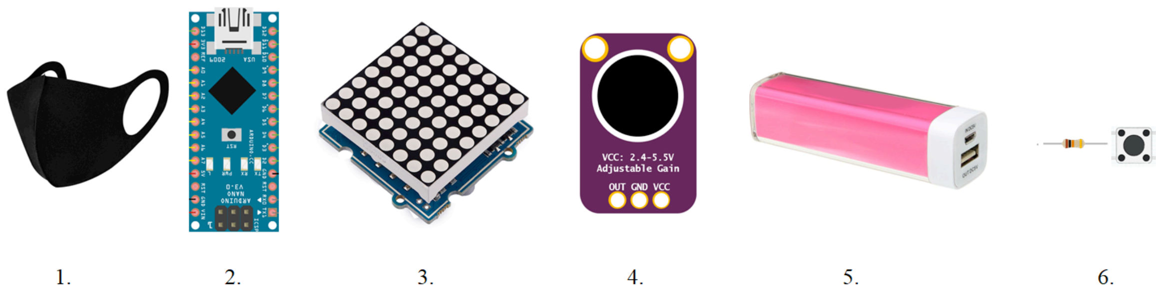

Figure 4: Hardware components.

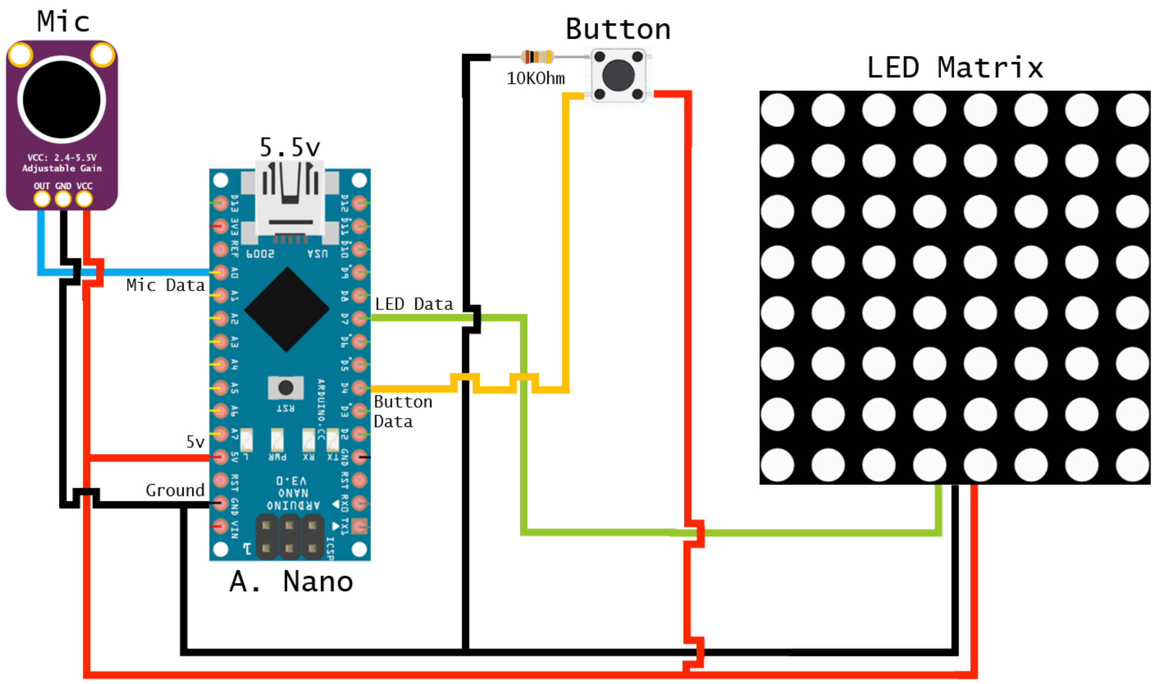

Figure 5: Wiring diagram showing the hardware setup.

The LED Matrix and microphone are placed into the face mask and a wire leads to in-line Arduino Nano. The sealed Arduino Nano on breadboard has an exposed USB port (for power) and button (for settings). Figure 5 shows the overall wiring of the prototype. The final prototype is shown in Figure 6.

Figure 6: EmotiMask hardware Prototype.

Once the hardware was operational the next step is to be able to analyse the voice. The "Speech Banana" (Figure 7) was used to understand the frequencies of sounds when speaking. The diagram plots the phonemes, the basic units of sound in speech, in a grid of frequency (horizontal axis) and loudness (vertical axis). The phonemes used in language fall into a particular area, marked in yellow. Sounds outside this area can be heard, but they were not considered relevant for EmotiMask which relies on speech as input. The hardware was adjusted to cover the "speech banana", taking into account hardware limitations and wearer voice.

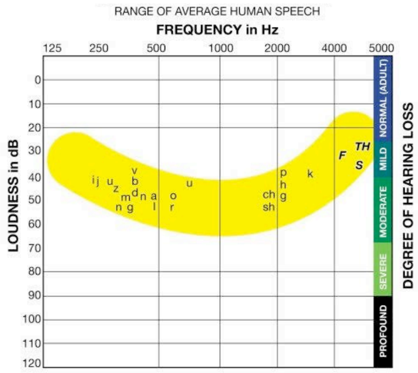

Figure 7: The Speech Banana (Lekashman, 2017).

An Arduino Nano was used as a driver, the microcontroller was programmed with Arduino software (v1.8.13). Two key libraries were used within the EmotiMask Arduino project:

- *arduinoFFT*: A library for implementing floating point Fast Fourier Transform (FFT) calculations on Arduino (Condes, 2020).
- *FastLED*: A library for easily & efficiently controlling a wide variety of LED chipsets (Garcia, 2022).

The FFT is used to transform the speech into a frequency spectrum. The most significant peak of this spectrum is then used, together with the loudness, to identify the spoken phonemes according to the diagram in Figure 7.

The overall process implemented in the microcontroller is given in Pseudo code below. There are a number of helper functions, including a *setup* function to do initialization, and functions (*LEDMouthOO*, etc.) to set the LED matrix to particular patterns. The function *loop* represents the continuously running program. In particular, it performs the FFT and selects LED pattern.

```
void setup
{
        Arduino Setup
        LED Setup
        Microphone Setup
        LEDMouthReset()
        LEDMouthClosed()
}
void loop
{
        …
        Microphone Analog Signal for 3 loops
        FFT analysis of signal
        Find frequency band peak
        Select Appropriate 'LEDMouth'
        Delay
}
void LEDMouthReset{LED Matrix Reset}
void LEDMouthOO{LED Matrix set to OO}
void LEDMouthPP{LED Matrix set to PP}
void LEDMouthAA{LED Matrix set to AA}
```

```
void LEDMouthEH{LED Matrix set to EH}
void LEDMouthEE{LED Matrix set to EE}
void LEDMouthClosed{LED Matrix set mouth closed}
void LEDMouthSmile{LED Matrix set to Smile}
void LEDMouthSad{LED Matrix set to Sad}
```

Additionally, the *Loop* function checks if the button was pressed. Depending on the duration, an expression is shown, overriding the speech pattern:

```
void loop
{
        Short button press
                Adjust microphone sensitivity
        Medium button press
                Cycle LED RGB level
        Long button press
                LEDMouthSmile
                Delay
        Extra-long button press
                LEDMouthSad
                Delay
        ...
}
```

Results

An initial study placed EmotiMask within a HE computing practical session. During this session normal instruction was conducted while wearing EmotiMask, utilising the full range of configurations (see Figure 8). A period post-session was allocated for students to try EmotiMask themselves and complete a questionnaire relating to the session and mask. The questionnaire contained five Likert scale indictors based on the design, ease of use, clarity, attention, and recognition in comparison to a standard face mask. Three further free-form questions allowed for gathering feedback with respect to positive, negative, and missing elements, as well as a final overall rating for the mask itself. For the five indictors, a score out of 5 was recorded, with a higher score indicating a greater level of agreement on the Likert scale towards that indicator. The overall rating was recorded out of 5 stars, with higher star rating indicting a more positive response. A total of 10 responses were collected from students in the post-session.

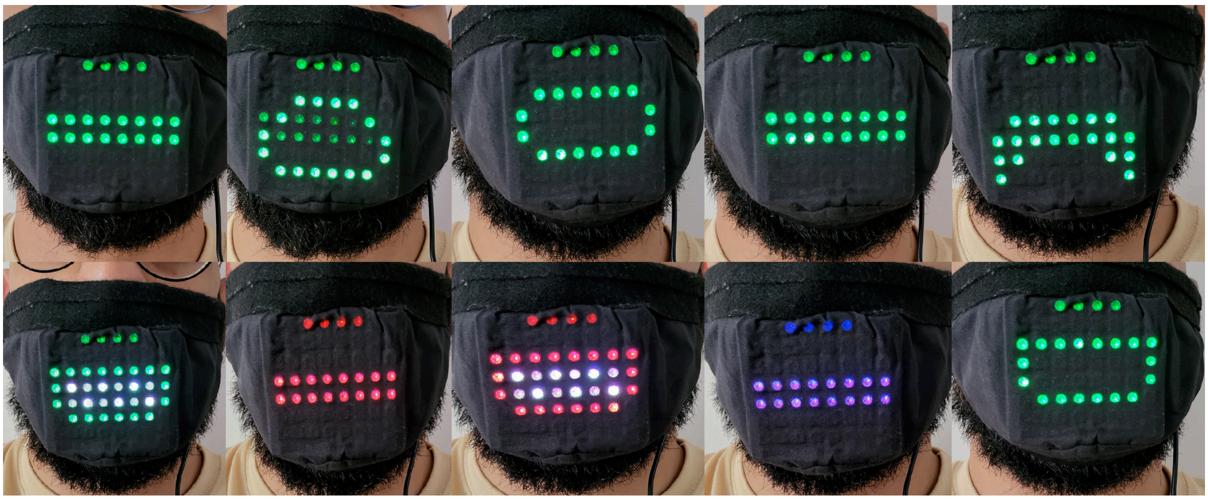

Figure 8: EmotiMask LED configurations and variable settings.

The indictors for design and ease of use both recorded an average response of 4.5 out of 5, suggesting the process of embedding the technology directly within a standard mask resulted in a clear and easy usage experience. It should be noted however that as the sample was from computing students, they would have experience in computing technology and thus would potentially find operating the device easier than students from other disciplines. The indicators for clarity, attention, and recognition, recorded average responses of 3.8, 3.3, and 3.5 respectively, showing a positive response towards the typical areas of concern for teaching with face masks, but also highlighting the potential for improvement. Feedback from the free-form questions supports this outlook, with the responses presented below compiled into two groups, positives and potential improvements:

Positives:

- EmotiMask made it easier to identify the current speaker.
- The mask helped students keep focus on the practitioner.
- Those hard of hearing were able to recognise when someone was speaking with the mask.
- EmotiMask enabled a fun, interesting way of communicating despite the face mask requirement.
- The mask was able to take away any confusion on who might be the one talking in a group environment where there was a need to wear face masks.

Possible Improvements:

- A larger and higher resolution LED screen to improve visibility.
- EmotiMask could also amplify the speakers voice volume.
- Compact and convenient, wires made it uncomfortable to wear for longer periods of time.
- Greater accuracy of imitating moving lips would make the user easier to understand.

The overall rating for EmotiMask was very positive with an average of 4.2 out of 5 stars across the sample. This response in many ways highlights the challenges of face masks in the learning environment and the potential willingness of students to adapt towards such an intelligent technological solution. EmotiMask shows potential as a supplementary tool to support practitioners in their teaching practice and enhance learning in scenarios where face masks are needed.

Conclusions

Here we have presented EmotiMask, a solution to the communication challenges present when teaching with a face mask. It has been identified that through obscuring the lower portion of the face, this can lead to issues with clarity, attention, emotional recognition and trust attribution, when delivering face-to-face content. Through its development, EmotiMask serves a ubiquitous role, being embedded directly within the face covering to maximise ease of adoption and use for practitioners. Extraction of key mouth expressions and emotional states, coupled with intelligent processing for the LED matrix cycles, allows for the replication of the core mouth movements in real-time and the expression of certain emotions. This helps to mitigate the noted issues, with initial results highlighting a positive response in relation to clarity, attention and recognition when compared to a typical face mask. Despite the positive outcomes, several areas were noted through feedback for improvement, including accuracy, resolution, and comfort. This work serves as the initial steps in EmotiMask's development, with further refinement planned towards the goal of a achieving a widespread tool for supporting teaching and learning in conditions where such measures as face masks are required.

Future work on EmotiMask will take several avenues, including the addition and refinement of both mouth expressions and emotional states for improving the overall accuracy of the intelligent processing. At this time, emotional states are selected directly by the user, however incorporating the automatic detection of emotion through artificial intelligence learning solutions would serve to add another layer to EmotiMask and expand on the emotional recognition aspect of the device. EmotiMask currently uses wires to link from the mask itself to the nano controller, which can limit mobility and affect comfort. This and resolution prove challenges in many such wearable devices, including VR headsets, and is an aspect to improve through hardware progression as the device is refined. Finally, integrating EmotiMask into long term teaching curricula will serve to further trial the device.

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