The Light Matrix: An Interface for musical expression and performance

Jonathan Pak
Electronic musician/Engineer
jon@pak.id.au

ABSTRACT
A prototype of the Light Matrix interface is presented here. At the core of this device is a rectangular array of Light Emitting Diodes (LED). Although designed to emit light, it is also possible for LEDs to function as crude photosensors. The Light Matrix exploits the bidirectional properties of the LED to create a light reflection based proximity sensor. The performer interacts with the device through hand movements in front of the LED sensor matrix. The potential of this device as an interface for real-time musical expression for computer based audio systems will be discussed along with its suitability as an instrument for live performance. Here the aspects of performativity covered include performer-instrument interaction and audience perception of the relationship between physical interaction and resulting sound.

Keywords
Music controller, LED photosensors, performativity, real-time expression, mapping visualisation, programmable response.

1. INTRODUCTION
The prototype of the Light Matrix is a computer interface intended for electronic music performance. The face of the device consists of a grid of LEDs functioning as both a proximity sensing array and monochrome display. Figure 1 illustrates the process involved in translating hand movements into musical expression. The intermediate forms of data are shown at each stage of the process.

To begin with, each LED sensor measures the intensity of reflected light, light that is emitted by other LEDs in the matrix. The reflected light intensity is proportional to the proximity of the performer's hand to the plane of the matrix. The raw data from this device may be represented as a moving height field. This data is relayed to a software application running on a computer which translates features of the height field into control messages. In turn these messages may be used to control audio applications, virtual instruments and effects.

The intensities of each LED pixel are independently adjustable which gives rise to some unique features of this device. The Light Matrix responds to the performer not through tactile feedback seen in traditional instruments [10], but through modulating the light intensity pattern of the LED matrix. This optical feedback is derived from three different sources (see Figure 1). These sources are: the height field data, mappings defined by the software application and the resultant audio signal. This optic response modifies the characteristics of physical interaction and provides visual cues to both performer and audience as to how the instrument is operating.

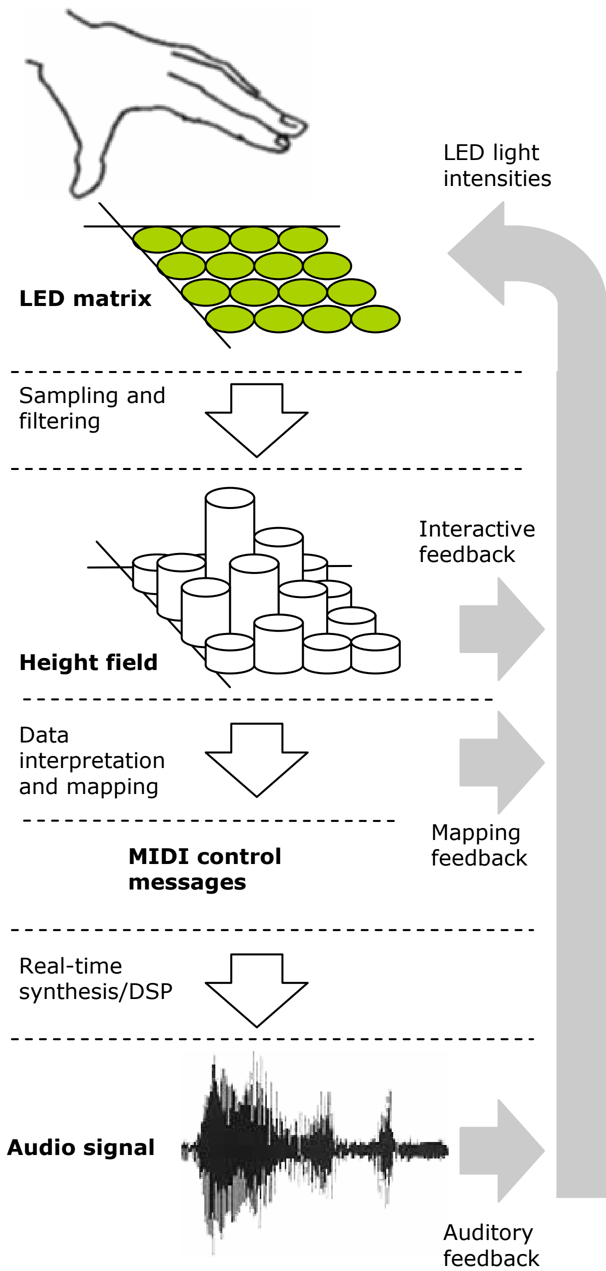

Figure 1. Device concept illustrating multiple stage feedback

2. RELATED WORK

The work of J. Han and associates has also utilised the bidirectional properties of LEDs in their project: Multi-Touch Sensing through LED Matrix Displays [3]. The title of the project alludes to a slightly different focus on multiple contact point detection rather than a quantitative proximity measurement. The display provides no visual feedback and is not specific to musical applications.

The Light Matrix also has parallels with the Tenori-On [4] musical instrument, currently under development by Toshio Iwai. The elements common to both devices are the similar form factor and interactive LED display. One interacts with the Tenori-On by pushing on individual LEDs in the display.

Another comparable device is JazzMutant's musical controller: the Lemur [5]. This features a high resolution pressure sensitive multi-touch display though it lacks the depth sensing capability of the Light Matrix.

The Light Matrix has a tactile counterpart in D. Overholt's MATRIX interface [1]. The limitations of the MATRIX's spring loaded rod assembly are: the substantial force required to push down the rods and the fact that adjacent rods prevent lateral movement of the performer's hand.

3. MUSICAL PERFORMANCE ASPECTS

The advent of the DAW (Digital Audio Workstation) has afforded musicians great scope to explore new sound textures and improvisatory techniques never before possible. Virtual instruments can be much more complicated than their physical counterparts with no upper limit on the number of parameters controlling expression.

Using standard interfaces such as faders, switches, knobs and keyboards, it is difficult to control even a few parameters simultaneously. The consequences of this limited form of control in a live performance are a lack of spontaneity and a possibly unengaging performance.

The Light Matrix is designed to overcome these limitations by providing a greater level of control. The prototype has an 8 × 8 grid of LED sensors each capable of measuring depth with 8 bits of precision. As a controller, the size of the input space makes it possible to realise many complex mapping schemes to translate performative hand gestures into sound.

The low latency of the device coupled with simultaneous control over many parameters makes that the Light Matrix ideal for real-time musical applications in synthesis and DSP (Digital Signal Processing).

The constant low latency of the device means that the interface is both predictable and responsive to the performer's gestures. The degree of simultaneous control gives the artist a broader palette for self expression through music. Both of these factors underscore the immediacy of performance for the audience.

3.1 Physical interaction

The absence of tactile feedback arguably allows a more direct form of expression. Freedom from the physicality of playing a traditional instrument eliminates physical constraints and reduces the effort required to play the instrument. Any effort required to operate the interface translates directly into expressive movement.

The device is capable of detecting the presence of any object that is reflective but in this case the use of hands as the means to convey expression is only logical. The capacity of the human hand to communicate semantic and emotional content is second only to facial expressions. The inherent expressiveness of human hand gestures presents enormous potential for conveying musical expression.

3.2 Optical feedback

The Light Matrix uses a unique form of feedback through light intensity. A more intense light source will enable the LED sensors to detect hand positions further away by causing a stronger reflection. Conversely a weaker light source will limit the usable range of control.

3.2.1 Performer interaction

By continuously updating the intensities of each LED in response to the motions of the performer's hand, the interactive characteristics of the device can be changed. Figure 2 illustrates some of the basic responses used to alter the parameters of physical interaction.

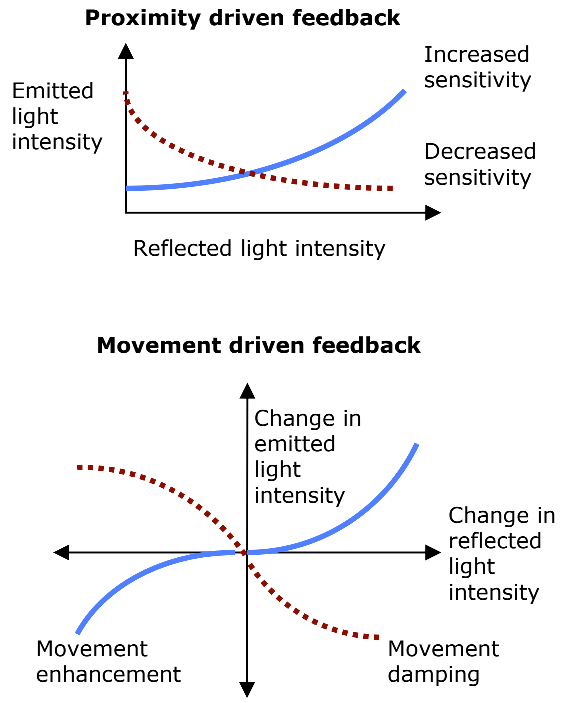

Figure 2. Optical feedback schemes driven by physical interaction.

3.2.2 Functional visualisation of mapping

This technique is used to adjust the interface's responsiveness which is best illustrated with an example:

A practical application of the interface could be to manipulate the timbre of a synthesiser. An illustration of the LED matrix for this example is shown in Figure 3. The volume of low frequency components of the synthesiser's sound is increased by moving closer to the surface on the left side of the matrix. Progressively higher frequencies are controlled by moving towards the right side of the matrix.

Often the volume of high frequencies needs to be tempered in relation to the low tones so as not to sound shrill. The realisation of this mapping should be immediately apparent from the gradient in light intensity. The reduced intensity on the right corresponding to a reduced emphasis on the higher frequencies, making the synthesiser sound less bright. The visual representation of this mapping is not only functional but also informative for the performer and the audience.

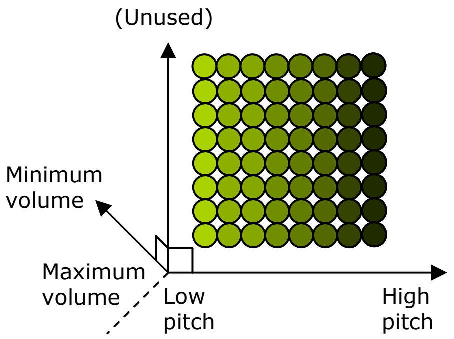

Figure 3. Example of weighted frequency response through visible mapping

3.2.3 Auditory feedback

Auditory feedback is also possible with this system by using sound to control the intensities of the LEDs in the matrix. This can be illustrated by extending the example in section 3.2.2. Figure 4 shows how the sound spectrum of the hypothetical synthesiser may be divided into frequency bands and mapped onto the matrix as variations in light intensity. The result is that the interface reacts more strongly to the most dominant frequencies in the sound spectrum. This type of feedback is a very direct and intuitive form of control as the performer is interacting with some aspect of the sound they are producing.

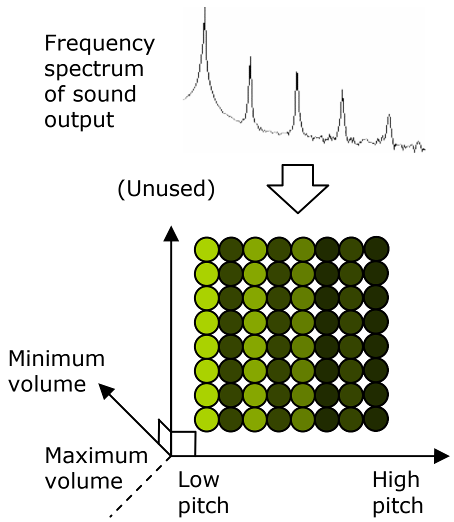

Figure 4. Example of audio-optic feedback

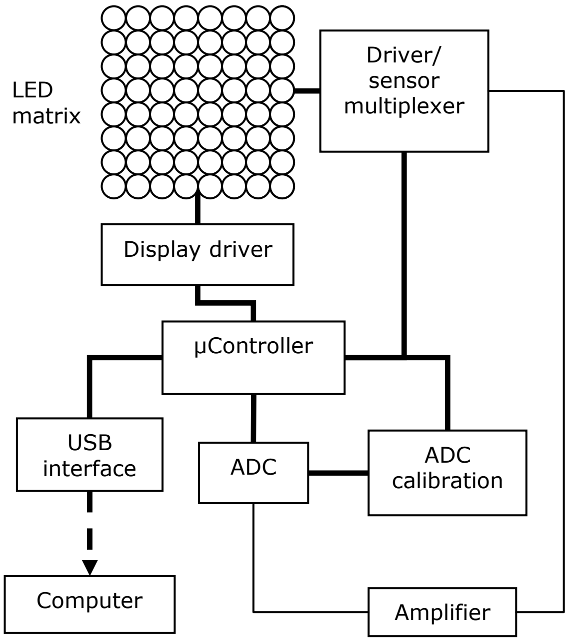

Figure 5. Functional block diagram of hardware

3.3 Audience interaction

The musical purist will always put the sonic outcome foremost in any performance. However a performance not only entails listening but also observing. A recital will always be more engaging if it is interesting to watch. This interest is partly maintained through the audience's understanding of the instrumentalist's craft: how physical interaction with an instrument relates to the sound it produces. It is this cross perceptual reinforcement that enhances the experience of a live musical performance.

When it comes to electronic music performances one of the primary tools is the laptop computer. As a musical instrument the operation of a computer is generally unengaging [11] because there are no motions discernable by the listeners that translate to sound output. The Light Matrix remedies this problem by providing an interface to the computer that removes the physical barrier of the computer screen. Much like a traditional instrument, the gestures and motions of a musician operating the Light Matrix are clearly visible. In addition the interface has a certain aesthetic appeal because the glowing surface of the device highlights the performer's hands.

4. HARDWARE IMPLEMENTATION

The major components of the device prototype are shown in Figure 5. The device communicates with the computer via USB (Universal Serial Bus) protocol. The microcontroller contains inbuilt USB interface circuitry and is also serially programmable over USB.

The height field data is constructed by scanning each LED sequentially in a raster pattern. There are two phases to each LED pixel read operation:

1. A reference measurement: This is performed under "dark" conditions where all the LEDs in the matrix are switched off during the sampling period.
2. The actual measurement: While sampling, all other LEDs in the matrix remain in a light emitting state.

The reference measurement forms the baseline for comparison with the actual measurement. Using the difference between the reference measurement and actual measurement reduces the interference caused by ambient lighting.

The scanning operation is performed at the maximum rate allowable by the ADC (Analogue Digital Converter) chip. Consequently the strobing caused by alternating between these two measurement phases is not perceptible due to the response time of the human visual system. The net effect being that the device is on continuously even though it is actually switched off for some of the time.

4.1 LED matrix

LEDs as sensors in this application offer several advantages. Firstly they are cheaper than photodiodes or phototransistors and the bidirectional property of each element simplifies wiring, mechanical construction and circuit complexity. This in turn reduces cost and allows for increased matrix density and size.

When the LED is forward biased, the current flow causes the device to emit light as per normal. Under certain conditions LEDs can be operated as photosensors [6][7]. As photosensors, LEDs act as a narrow band light sensors, generally picking up wavelengths shorter than those emitted [2]. The prototype utilises high intensity red LEDs which exhibit relatively good sensitivity because the emission spectrum is close to the wavelengths in the absorption spectrum.

4.2 Photosensor amplifier/ADC

The role of the amplifier is to convert the photocurrent from each LED into a voltage, the current being proportional to the light intensity impinging on the diode junction.

The output voltage from the amplifier is then digitised by the ADC which is a 13 bit switched capacitor variety. Calibration of the ADC is done electronically by a pair of DACs linked to the microcontroller. These provide the upper and lower reference voltages needed by the ADC.

4.3 Display driver/multiplexer

The display driver consists of a bank of LED driver chips interfaced with the microcontroller that provide constant current PWM dimming. The multiplexer circuitry is responsible for interleaving the display and sensing phases.

5. SOFTWARE/FIRMWARE

The software is an application written in C# that performs the following tasks:

- Communicating with the Light Matrix device over USB. This includes reading raw height field data from the microcontroller and setting the LED intensity values.
- Mapping height field data to MIDI control messages and sending these messages to a specified MIDI output port.
- Mapping height field data to LED intensity values.
- Frequency and loudness analysis of an audio signal.
- Mapping frequency and loudness data to LED intensity values.

An audio signal is fed into the Light Matrix control software through a purpose built VST [12] effect plug-in. This plug-in acts as a bridge between the host audio application and the Light Matrix control application.

6. FUTURE ENHANCEMENTS

Exploration of the optical feedback and mapping possibilities of the Light Matrix has only just begun. More flexible software is needed to define these mappings.

Use of the antiquated MIDI protocol limits the amount of control available. Open Sound Control (OSC) [8] or a more direct form of communication should be employed.

More investigation is needed to determine an arrangement of LEDs that is more conducive to performance gestures made with hands. The arrangement of the LEDs in a square matrix is probably not the most suitable.

7. REFERENCES

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