Z-Tiles: Building Blocks for Modular, Pressure-Sensing Floorspaces

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ABSTRACT
A new interactive floorspace has been developed which uses modular nodes connected together to create a pressure-sensitive area of varying size and shape, giving it the potential to be integrated into an interactive environment. The floorspace uses an array of force-sensitive resistors on each node to detect pressure, and that pressure information is output by way of a self-organised network formed by the floor nodes. This paper describes the pressure sensing and network systems, suggests potential applications of the floorspace, and introduces the further research on in-network data aggregation being carried out using the system's framework.

Author Keywords
pressure-sensitive, networked floorspace, self-organising, foot sensing, blob detection, responsive environments.

ACM Classification Keywords
C.3 Special-Purpose And Application-Based Systems: Microprocessor/microcomputer applications; Real-time and embedded systems; Signal processing systems. E.4 Coding And Information Theory: Data compaction and compression. H.5.2 User Interfaces: Input devices and strategies

INTRODUCTION
Tracking people's position and motion within an interactive environment is a technical challenge for which many systems have been developed. One of the most popular approaches is using load cells at the corners of a floor, or other surface, which detect changes in weight and position of objects, or people, on that surface[1,8,11]. Other projects, including the Magic Carpet[9] and Litefoot[4] floors, precursor projects to the work described here, take a different approach, creating pixellated surfaces using larger numbers of sensors. These pixellated systems worked well with the applications for which they were designed, but lacked the flexibility to be used in a variety of situations, as each largely consisted of a single piece of floor equipment, rectangular in shape, that was difficult to move and impossible to reconfigure. The primary design consideration when planning a new interactive floorspace was that it should be modular, consisting of individual nodes which would interlock with each other when in use, but which could be separated for easy transportation and then allow for reassembly into a new floorspace of a different shape, if so desired.

As with the previously mentioned systems, the primary application for which our new system was designed was an interactive dance floor, with performance requirements, such as sensing resolution and response time, based upon what is necessary for such an application. The constructed system therefore has a forty millimetre resolution with response time of a few milliseconds, i.e. the data is output in real-time.

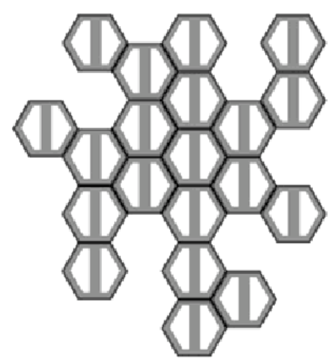

Figure 1. A single Z-Tile made up of twenty hexagonal pressure sensors

THE FLOOR NODES
To achieve the required resolution without having the floorspace nodes too small, each node, known as a Z-Tile[1], has twenty force sensitive resistors (FSR's) on its surface. The nodes themselves have a unique shape, shown in figure 1, which allows them to interlock with each other in a

[1] The name is based upon the fact that while they sense position in the x ,y plane they also measure the magnitude of the pressure on them, i.e. forces acting parallel to the z axis.

regular pattern, shown in figure 2, and to be self-holding. Each hexagon on the tile surface, even those that interlock, has one FSR for reading pressure values, so there are no unsensed areas at tile joints.

When the tiles are being used in a floorspace, the pressure sensors are protected by a 2mm layer of plastic material that covers the surface of each tile.

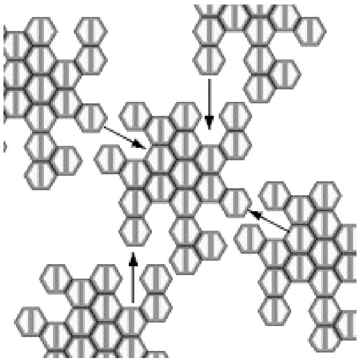

Figure 2. The shape of a Z-Tile node allows tiles to interlock

The control circuitry for each node is contained within the tile casing and consists of five Cygnal C8051F2xx microcontrollers per node, which handle the reading of data from that particular node and communicate with other tiles in the floorspace. This communication is by means of a physical UART connection between the nodes; a connection which is automatically formed by special, spring-loaded connectors when the nodes interlock. As well as having transmit and receive pins, the connectors also have pins for power and ground, so the floorspace can be powered by a single connection to one tile in the floorspace. Power can then be passed through the connectors to every other tile in the floorspace. This eliminates the need for an independent power source in each node.

THE SENSOR NETWORK

One of the most difficult challenges in building the sensor system is providing for the extraction of data from the floor when in use. It is not feasible to have a data wire from each node, so it is necessary to have the interlocking tiles form a self-organising network and pass the data through that network to one tile which would have an external data connection. (In practice, one node serves both as the data "sink node", and as the power source node for the network).

The network protocol developed for use in the floorspace is very lightweight, with the messages that are used to set up and maintain the network no greater than six bytes in size. This tiny protocol overhead is necessary because of the high speeds at which the data must be transferred through the network to the end points, and is made possible by the physical connections between the tiles. Most other sensor networks, such as the Berkeley Motes[6] or SensorWebs[2], for example, are wireless and so have a higher protocol overhead, slower data rates and more restrictive power constraints. The wired connections between tiles allow high speed, directed communication from one node to another in the floorspace network, facilitating real-time data extraction from the network. The data in the network is always routed so that it reaches the sink node with the fewest number of "hops" from one tile to another. A sample routing pattern for a floorspace is shown in figure 3. The protocols for the formation and maintenance of the self-organising network, and how the routing takes place within the floorspace, are described in more detail in [10].

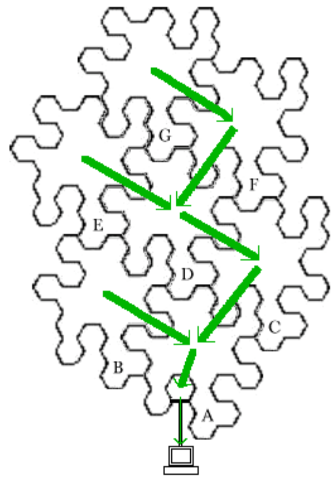

Figure 3. How data is routed through a Z-Tiles floorspace

POSSIBLE APPLICATIONS

There are a large number of possible applications that could use a sensor surface such as the one described here. The first area of use is the original target area of the project, that of music and dance control. Existing sensate floorspaces have been used successfully for generating music from the movements of dancers, and a floor of even a relatively few Z-tiles might be used for this purpose. Pressure sensing can also be used to add another dimension of control for musicians using existing musical instruments, for example, by using pressure sensors positioned under a musician's seat, or integrated into the seat itself[7].

Figure 4. Using weight shifts to control movement in a VR world

A second application area with which the tiles have been tested is as an input device for the control of computer games. In an early demonstration of the Z-Tiles technology, we connected a tile prototype to a computer that was running a virtual reality (VR) application. Within that VR application, we were able to use the connected tile to control the movements of a hovercraft in a racing game. As the player shifted his body weight slightly forwards, backwards or to one side, the hovercraft in the game accelerated, braked or turned in the direction of the weight shift. Figure 4 shows a user balancing as he controls his position in the VR world using his weight.

A pressure sensing surface might also be used in the areas of medicine and sports science, where a therapist or trainer could obtain a dynamic view or recording, in real-time, of the footfalls of people walking, running and jumping on a Z-tiled surface. This information could be used to diagnose illnesses and correct problems with a patient's gait, or to improve an athlete's performance. Other possible application areas include safety and security applications.

ONGOING WORK

We have constructed a number of prototype tiles, which work together in a small floorspace network (see figure 5). In operating tiles, one microcontroller reads pressure values from the pressure sensors on that tile. The pressure readings from the FSR's are twelve-bit values, and a complete scan can be done more than 100 times every second, should this temporal resolution be required. The other four microcontrollers in each tile handle the communication between tiles; outputting the pressure data while keeping track of the state of the network around them.

Because of the volume of data being produced by the Z-tiles, we are now investigating how the network can be made more efficient by having data reduction take place within the network itself.

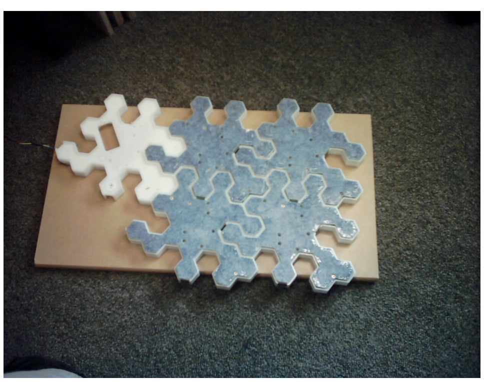

Figure 5. Prototype tiles in a small Z-Tiles floorspace

Accordingly, one specific area of investigation that we are pursuing is matching areas of pressure on the floorspace to geometric figures, such as ellipses or circles, and then outputting the data, not as a series of individual pressure values, but as a series of "blobs" of pressure centred at particular points. Existing algorithms for fitting ellipses to sets of points, such as least squares fitting [3,5], are very computationally intensive and so are problematic for implementation on embedded hardware. We intend to investigate simpler, but less robust methods to match blobs, and then evaluate their suitability for particular end applications. For example, blob detection would most likely not be appropriate for medical applications, where a therapist would want a detailed, dynamic pressure map of a patient's footfalls, but could be very useful in dance applications where exact values are less important and having a rapid response time, and scalable floor area, are critical.

We have successfully implemented a very lightweight form of blob-detection on a standard PC using data captured from the prototype tiles. Once contiguous areas of pressure are detected, the circles or ellipses, shown in figure 6, are matched using very simple calculations. The centre of a pressure area is calculated by averaging out the positions of each pressure sensor in that area. The radii of the circles or ellipses are then calculated by averaging out the distances from that central point to each pressure sensor.

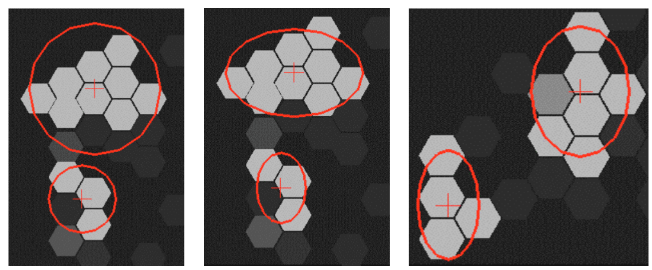

Figure 6. Circles (left) and ellipses matched to pressure data record from Z-Tiles

This work is currently being carried out on a desktop PC running a program designed to simulate a Z-tiles network. Using this program, we are experimenting with several algorithms for blob detection and evaluating their potential as embedded solutions. The best will be implemented as firmware on the Z-tiles themselves.

SUMMARY

We have developed a series of prototype Z-tiles nodes, which join together to form a flexible, pixellated, pressure-sensing surface. This surface provides full time-varying, force-distribution information on any activity taking place on it. This is achieved by having the Z-tile nodes form a self-organising network to allow for easy data extraction from the floor, without restricting the size or shape of the floorspace. We are currently evaluating in simulation a number of algorithms for data compression that match areas of pressure to geometric figures, with the aim of incorporating into the tiles themselves, those algorithms that prove suitable.

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