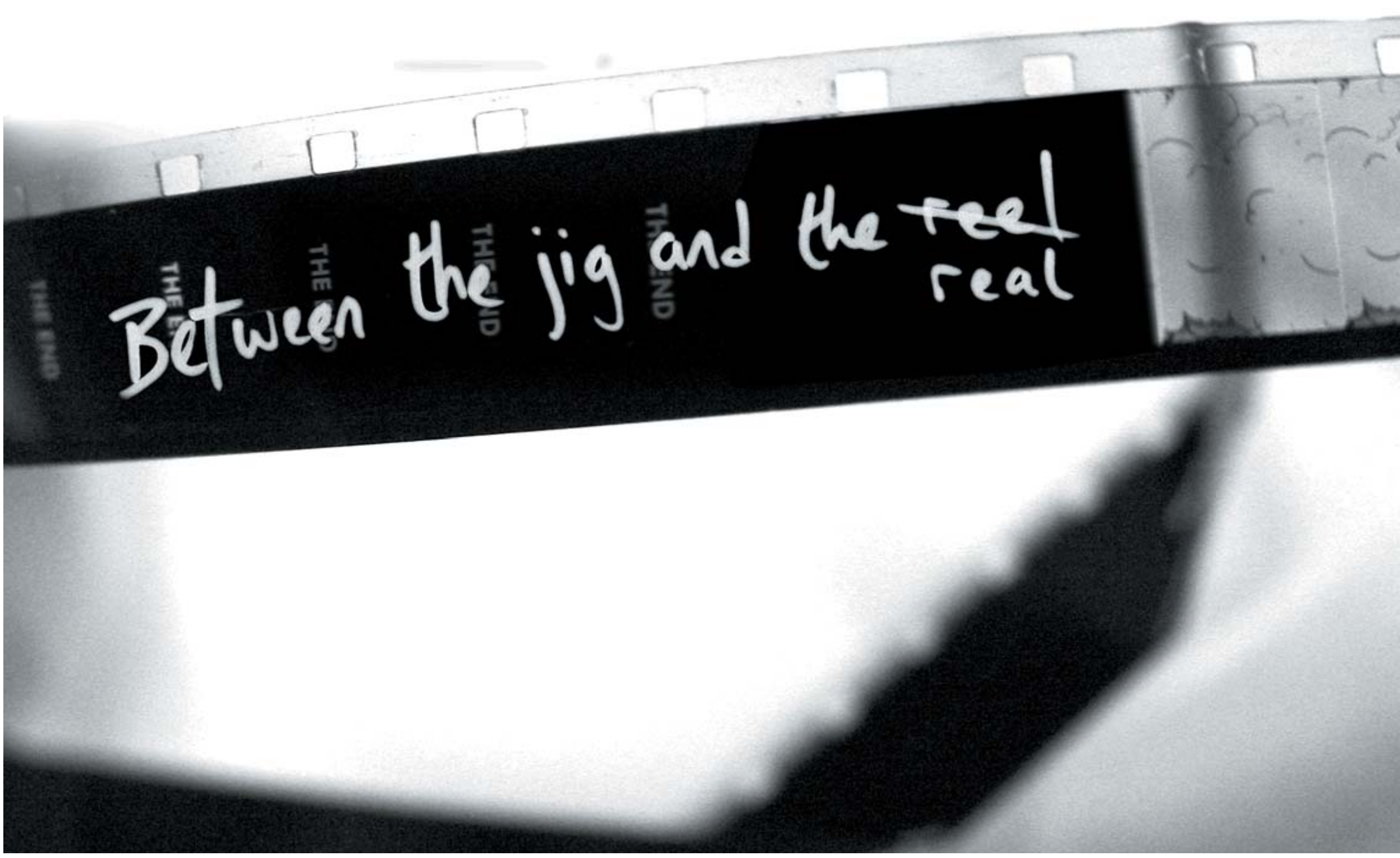
Lisa Mc Elligott
Media Lab Europe
Interaction Design Centre
University of Limerick

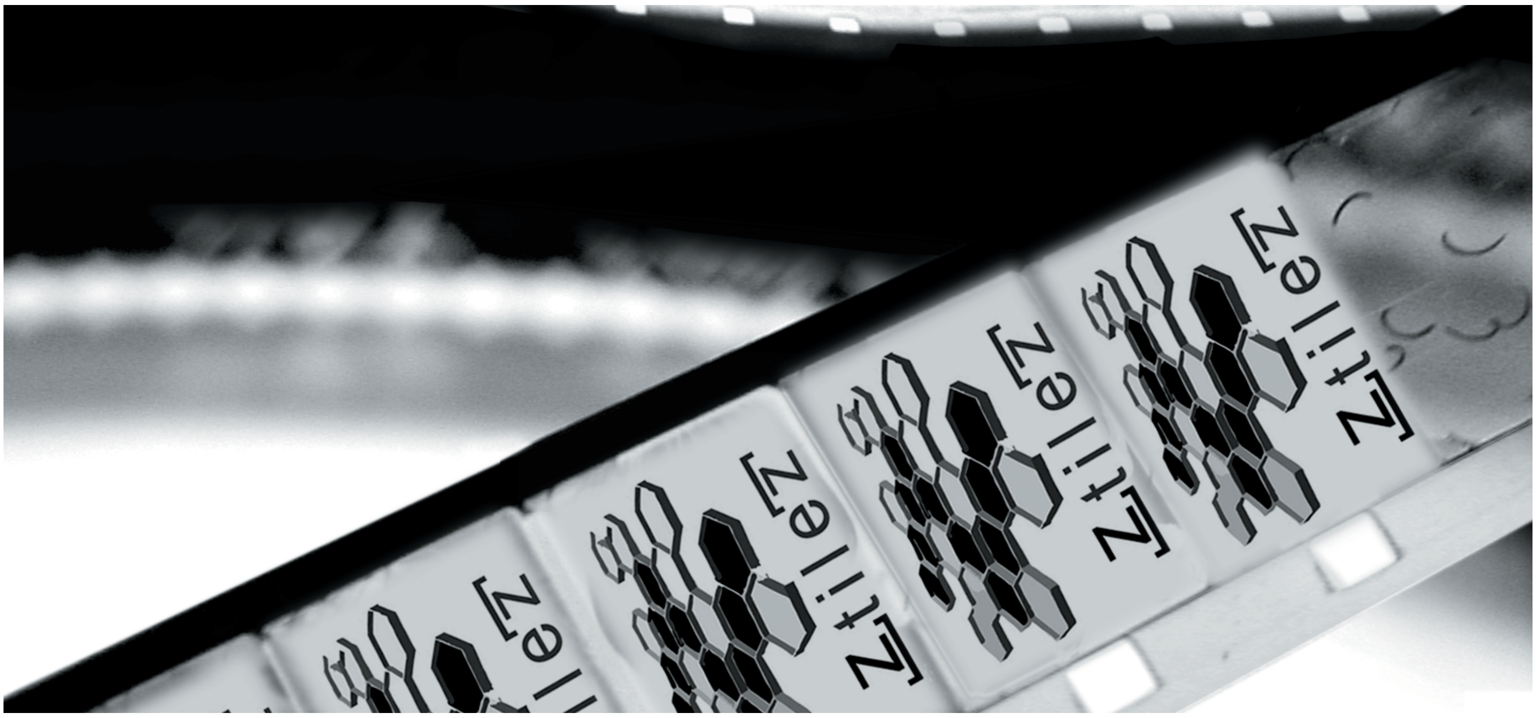
David Carugo
Media Lab Europe
Interaction Design Centre
University of Limerick

Bruce Richardson
Dept. of Computer Science
University of Limerick

Mikael Fernström
Interaction Design Centre
University of Limerick

Joseph Paradiso
Responsive Environments Group
MIT Media Lab





"Between the jig and real"

The Development of Z-tiles: A modular and self-configuring force sensitive input device

ABSTRACT

In this paper we describe the development of a novel sensor design and computational architecture for an interactive floor-space. The Z-Tiles project was initiated almost twelve months ago with an agenda dedicated to the design, development and implementation of a device that would facilitate the exploration of gesture, particularly the "effort" expended in certain gestures. A force sensitive surface allows us to detect, interpret and interface the subtle but integral element of physical "effort". Essentially, the Z-Tiles sensor could be used in any control surface where force or pressure might be exploited as a control parameter.

Keywords
Gesture, effort, movement, pressure, force, sensor, resolution

INTRODUCTION

In 1997, two almost parallel developments were taking place on both sides of the Atlantic, with quite similar objectives. Paradiso et al [3] developed the MagicCarpet, a floor space that detected people's footsteps in terms of location within the carpet and impact force. Almost at the same time, Fernström and Griffith [1] developed Litefoot, a floor slab with embedded sensors that detected people's foot movements on the floor. The objectives of both groups were similar, to create a floor space that could be used as input device in ubiquitous computing or smart environments. Each group was aiming at a gesture sensitive device that could be used for artistic expression and control by dancers as well as a device suitable for installations in public environments such as art galleries and museums. In experimental use, the two different devices showed some interesting properties.

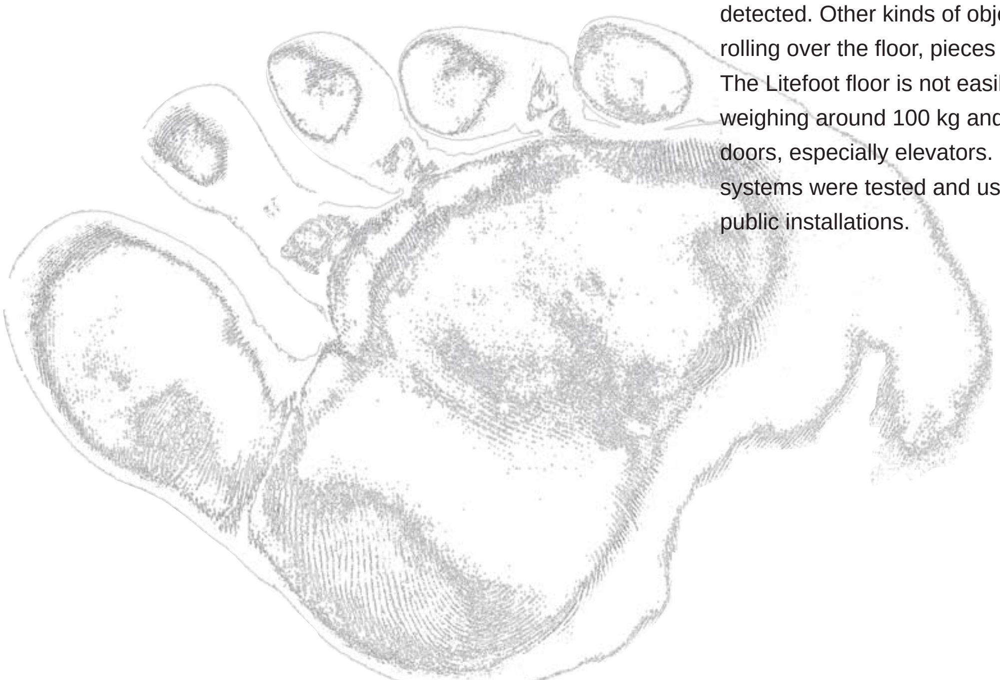
MagicCarpet & LiteFoot

The MagicCarpet is based on a matrix of PVDF cables whose capacitance changes when a force is applied to them. The XY-grid of cables is approximately 10 cm and the signals from the cables multiplexed, scanned along the periphery of the space at 80 times per second. The MagicCarpet is quite responsive but due to the multiplexing, one foot can "hide" another, if they impacted at the same time on the carpet. The MagicCarpet is rectangular 1.8 by 3 metres and easy to transport as it can be rolled up just as a normal carpet.

The Litefoot floor is based on infrared optical proximity sensors that detect if any object reflects the infrared light near the surface of the floor. Almost 2000 optical proximity sensors are placed approximately 40 millimetres apart over a floor space of circa 2 by 2 metres. The architecture of Litefoot is fully pixellated, i.e. all sensors operating in parallel, hence objects cannot "hide" each other. Attempts were made to make the Litefoot force sensitive by applying an accelerometer in one corner under the device, but this meant that simultaneous events could not be separated in time, only in space.

The scan time of the Litefoot is 100 times per second, as part of the design goals were to be able to deal with Irish tap dancing (the world record at the time was 28 taps per second.) As Litefoot detects optical proximity to the surface, also sweeping movements with a foot just above the surface, without any contact force, are detected. Other kinds of objects could also be detected, e.g. a ball rolling over the floor, pieces of paper.

The Litefoot floor is not easily transportable - it's a rigid floor slab weighing around 100 kg and quite cumbersome to get through doors, especially elevators. Over the next couple of years, both systems were tested and used in both artistic performances and in public installations.



Z-TILES CONCEPT

In a new collaborative project that started in 2001 under the auspices of MediaLab Europe in Dublin, Fernström and Paradiso initiated the development of a new modular device, based on our previous experiences. Over a number of design discussions, the concept evolved into Z-Tiles.

Z-Tiles is a new design for a fully scaleable, self-organising, force sensitive surface. This unique interface - with its extensible resolution - allows us to detect a range of objects by employing blob detection algorithms based on perception principles. The Z-tiles detect x/y location as well as the force applied, our z-axis. Based on our experiences with the MagicCarpet and Litefoot, we aimed for a fully pixellated surface area that could detect location and force in real-time. Some simple calculations revealed that to create a massively parallel sensor device connected to a single computer would probably be quite impractical, hence we decided to try a modular design where each module would have its own inbuilt computational power and a communication protocol that allowed modules to use high-level descriptions of their sensor data.

Other than the MagicCarpet and Litefoot, much of the work that has been done in gesture interpretation to date, tends to concentrate on monitoring the position and motion of persons using computer vision techniques, where data from a camera is processed to obtain tracking information [2]. While being effective and useful, these systems do suffer from slow response times for real-time performance, as well as having limitations with multiple users. The current limitations of existing technologies can tend to dictate properties of performances, such as use of space, lighting and even costume. Another considerable flaw in existing systems is their inability to detect the imperative ingredient of weight distribution and transference in movement: the complex dynamic of "physical effort".

Figure 1. Demonstration of *transference*

Effort

The iterative design process of the Z-Tiles sensor has involved working alongside a variety of departments in both the University of Limerick and MediaLab Europe. Matt Goulding, a graduate of the Masters in Contemporary dance at the University of Limerick, tirelessly worked with Z-Tiles team in an attempt to describe and catalogue the richness of motion patterns.

Areas of interest included the exploration of contact space, transference, torsion, anterior and interior applications of pressure as well as the subtleties of shunts, give, turns and pivots, as illustrated in Figure 1. Understanding the nuances of effort would directly affect the design of the sensor system in terms of sensitivity, durability, applicability and usability.

The Z-Tiles surface is designed to measure an extensive dynamic pressure range that will indicate not only where the user is standing, but also how heavily he or she is standing and where the majority of the weight is placed. Higher pixellation allows for increased accuracy and prevents detected objects from "hiding" each other, thereby allowing the surface to accommodate multiple users.

Sensor Design

Fernstrˆm serendipitously stumbled on a possible mixture of silicon rubber and carbon granules that showed interesting properties for inexpensive force sensors. This kind of force sensitive and conductive polymer can be screen-printed on a surface to be made force sensitive. See Figure 2. The sensor works on a simple premise: the electrical resistance of the mixture changes with applied pressure, and this change can be monitored by a microcontroller.

Figure 2. Freshly made polymer sensor applied to circuit board

Modular Tile Design

A number of possible geometries were investigated and as we wanted to find a modular solution that easily could interconnect with other modules, we eventually based our individual sensor geometry on a hexagon and our overall module shape, that would automatically directionally interlock and self-hold, as shown in Figure 3.

The initial housing for the prototype sensor was modelled in AutoCAD and manufactured in plastic. This surface was covered with a protective non-stick, non-slip linoleum surface. The final tile enclosure is currently being manufactured using high-grade aluminium, which will ensure durability.

Each module - a Z-tile - has four connection points along its perimeter where data can be sent and received. These four connection points also provide distribution of power to interconnected tiles. A larger area covered by interconnected tiles can be connected to an external computer (or network) at one or more connection points along its overall periphery.

In our prototype tile, the spatial resolution is 40 millimetres. Each Z-tile has 20 sensors, Prexels (pressure elements) individually covered by our force sensitive polymer. A prexel can detect a wide

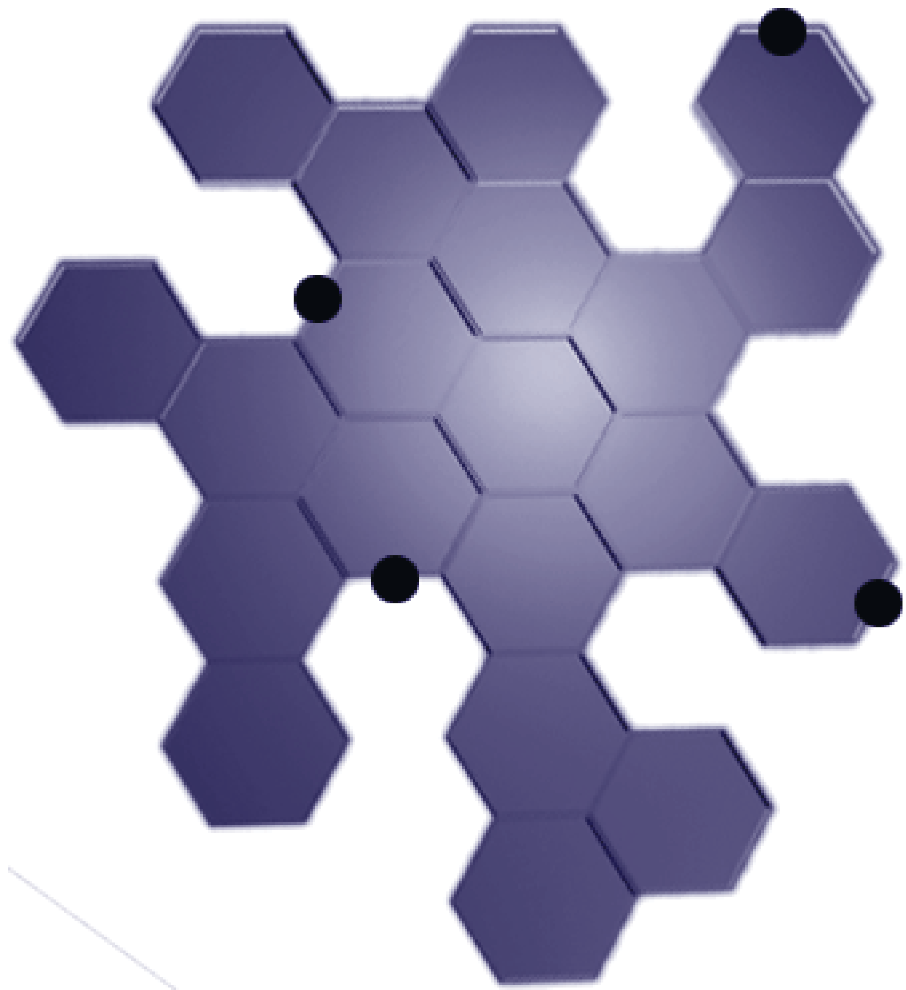


Figure 3. Geometric design of a Z-Tile

range for force. With our current design, using a 12-bit analogue-to-digital converter and a maximum reading for 120 kg, the minimum detected weight is c. 30 grams, i.e. just over the weight of a normal letter.

Software Design

To capture pressure data from an entire floor covered by many tiles, it would be extremely unwieldy to have a separate data connection for each individual tile. We found a possible shape that allowed tiles to interlock like a jigsaw puzzle that could make each tile “aware” of its location within the floor by means of a self-organising network algorithm. Data is then sent and routed through the floor using a high-speed serial communications protocol. Each tile has its own computational power and extracts and features of pressure and location that are then compressed and transmitted. Because these issues require careful consideration when designing and implementing both hardware and software to be run on embedded microcontrollers, we developed a simulator application on an ordinary PC to help us understand the possibilities and constraints. This will eventually make a Z-tiled floor configurable by end-users.

EVALUATION & EXISTING APPLICATIONS

Project developments to date have covered the creation of the sensor material, physical and mechanical design, exploration of its chemical, physical and electrical properties, and integration of the sensor material into a control surface for use in different scenarios.

These include direct mapping to audio-visual representations and an input device for OpenVR [4].
In our first scenario we used a tile as input device for controlling a MIDI module, i.e. as a musical controller. We used direct mappings between location-pitch and force-loudness. A PC was employed to illustrate the voltages as colour changes on a computer screen. The pressure values were displayed as degrees between black and red, as shown in Figure 4. This was felt as a natural mapping that demonstrated the sensors basic capability in a simple but effective manner.

A more interesting scenario was to use the Z-tile as an input device for navigating a virtual reality world by "surfing". A PC read in values from a tile of 20 prexels, demonstrating that a pressure profile could be extracted from the tile. This was used to create vector information about the object on the tile. For example a higher pressure at the front of the tile would indicate a vector pointing forward and could be used as an input device for the computer.
A virtual reality engine program, OpenVR, was recently developed at the University of Limerick and this application was used as a prototype test for the tile. Both a model of the Computer Science Building at the University of Limerick and a game of tag were used as virtual landscapes. The user, equipped with a head-mounted display for visual experience, stood on the tile. If standing upright, the user would remain stationary in the virtual world, while leaning forwards, backwards or sideways would move the user in that direction with a speed proportional to the difference in weight distribution over the tile as illustrated Figure 5.
This was reported by users to feel natural and highly engaging. This application was demonstrated and tested by approximately 50 users, at the University of Limerick and at MediaLab Europe in June 2001. With only a single Z-tile, the users could not walk around, but by standing on the tile and leaning in the direction of desired motion they achieved a "surfing" sensation. It is envisaged that with more tiles, that are interconnected, users will be able to walk around the environment.
The Z-Tile sensor has also been used as volume control for "The Cardboard Box Interface", an installation generated by a student of interactive media in the University of Limerick.

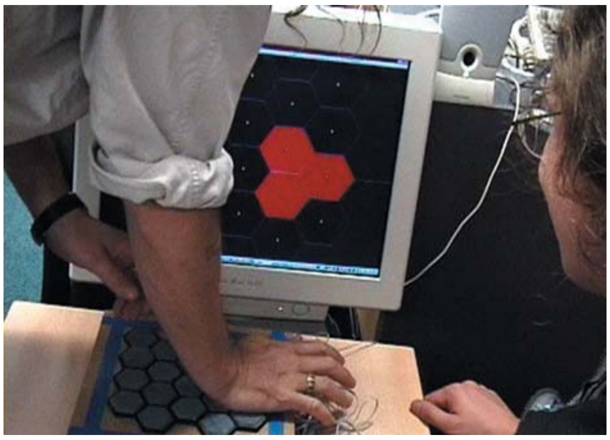


Figure 4. Z-Tile as a control device for MIDI

Figure 5. Using a Z-Tile to "surf" OpenVR

THE FUTURE TILES

The Z-Tiles project is continuously developing. Further testing of the sensor material is ongoing, which will reveal further characteristics of hysteresis and life expectancy of the tiles. The mechanical design of the tiles is an ongoing process being worked in conjunction with re-evaluation of connectors, circuit design and layout and experiments in microcontroller architecture.
At the time of writing, we have started making more tiles and anticipate creating a number of scenarios and demonstrations with multiple interconnected sets of tiles. We have already simulated the application of multiple tiles with a number of self-configuration algorithms, i.e. due to the shape of a Z-tile the software can "know" where in a set of tiles it is located. Our simulations indicate that it will be possible to add or remove tiles while in operation, i.e. a fully self-configuring sensor network.

Potential Applications and Future Developments

Immediate application design is focused on developing the surface for use in interactive networked performance. However, it is foreseen that future developments of the Z-Tile sensor will be concerned with the areas of Ubiquitous Computing and Smart Environments, particularly Smart Floors. It is anticipated that the sensate floor be used to explore gait recognition as a means of identification. Also, due to the malleable nature of the sensor in its pre-vulcanised state, the sensor material can in theory be applied to any given shape thereby making it a potential sensor candidate for the design of multi-dimensional graspable, squeezeable interfaces.

CONCLUSION

The Z-Tiles exists as a force-sensing device that detects movement, pressure and ultimately gesture. The force sensitive polymer has undergone numerous generations, refining it through iterative characterisation procedures. Its ability as a pressure control input device has been illustrated in application demonstrations. The Z-Tiles floor space has been developed into a modular and portable sensor floor. The significance of this floor space lies in the fact that the tiles can detect a significant dynamic force range with multiple users. This increases the potential for free and expressive interaction paradigms. It is anticipated that Z-tiles will be used as input device, interfaced with multimedia and music applications such as EyesWeb, MAX and pd, to extend the present capabilities of computer vision techniques by incorporating unobtrusive yet highly revealing dimensions.

ACKNOWLEDGEMENTS

This research was made possible through a grant from the Irish Higher Education Authority.

We would like to thank Dr. Seamus McMonagle and Dr. Duncan Martin of the Chemical and Environmental Sciences Department and Dr. Vincent Casey of the Physics Department in UL for many creative discussions and access to lab resources and materials.

A special thanks to Josh Lifton of MIT Media Lab for creative advice and discussions about self-organising networks.

Also, special thanks to the media artist Enda O'Donoghue for creating the VR-models used in our experiments.

REFERENCES

1. Fernström, M., Griffith, N. LiteFoot - Auditory Display of Footwork. Proceedings of ICAD98, Glasgow, Scotland, 1998.

2. Maes, P., Darrell, T., Blumberg, B., Pentland, S. The ALIVE System: Full-Body Interaction with Autonomous Agents. Proceedings of the Computer Animation '95 Conference, Geneva, Switzerland, IEEE Press

3. Paradiso, J., Abler, C., Hsiao, K., Reynolds, M. The Magic Carpet: Physical Sensing for Immersive Environ-ments. Proceedings of CHI'97, Atlanta, GA, USA, 1997.

4. Savage, J., OpenVR, Final year project (unpublished), Department of CSIS, University of Limerick 2001.

Authors: lisa.mcelligott@ul.ie; mikael.fernstrom@ul.ie; david.carugo@ul.ie; bruce.richardson@ul.ie; joep@media.mit.edu

Http://richie.idc.ul.ie/ztiles/index.htm

Http://www.medialabeurope.org/ztiles.html