THE·GRID

Large Interactive Display Field

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Summary

Discover an immersive art/engineering installation comprising a forest of radiant "trees". As you move through THE·GRID it senses your presence and initiates a ripple of light and a susurration of subtle clicks, propagating through the system. Traverse your own maze of light or stand back and enjoy the spectacle.

THE·GRID is a 7×7 matrix of aluminium poles, illuminated by white LED strips individually switched by a central controller. User presence is detected by an infrared computer vision system. Applications include a multiplayer virtual "maze", and interactive and passive display patterns.

Requirements: 14m $\times$ 24m unlit ground, mains power (1kW peak).

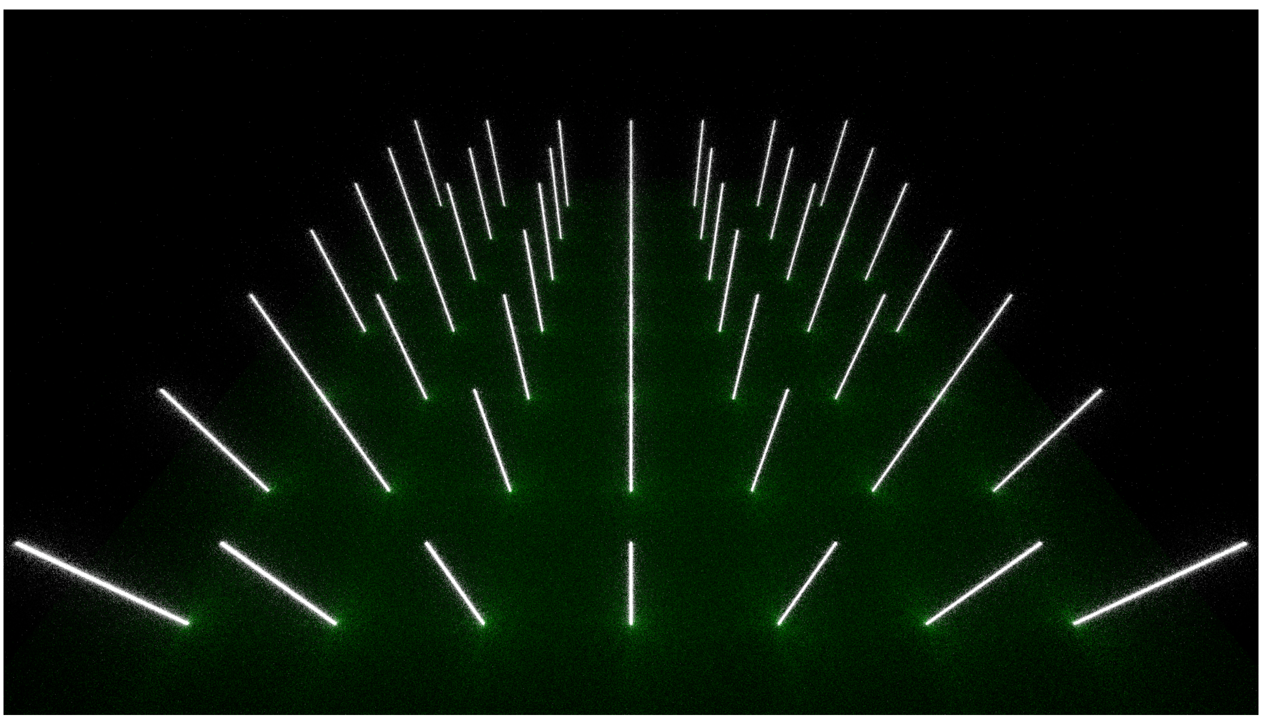

Figure 1: A computer graphics simulation of THE·GRID.

1 Design

1.1 Layout

THE·GRID occupies a space of approximately 24m × 14m. Of this, 12m × 12m is the grid itself, consisting of a 7 × 7 grid of poles with 2m spacing. A backstage area holds the power and control tent as well as the camera mast.

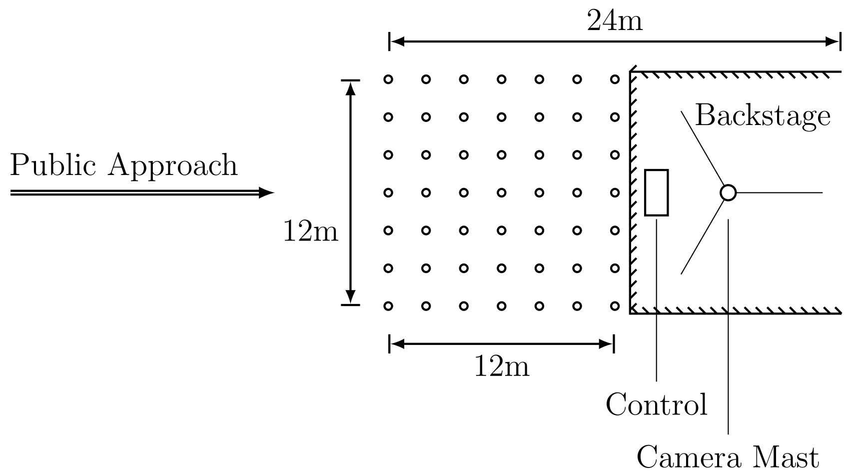

Figure 2: Plan schematic

1.2 Structural

Each pole is 3m long, with 50cm being inserted into the ground. The poles are constructed from $\frac{3}{4}'' \times \frac{3}{4}'' \times \frac{1}{16}''$ aluminium angle section. See Appendix A for detailed drawings.

As the aluminium stock is purchased in 5m lengths, each pole is constructed of either a single 3m section or two overlapping 2m sections, leading to a requirement of 34 5m lengths in total.

We have determined that with this choice of structure, the poles are sufficiently sturdy for the load, remain sound during high wind load, and are stiff enough for display purposes. For detailed calculations see Appendix B.

The interactivity camera will be mounted 8m above the ground on a glass fibre pole, guyed for rigidity. The pole is away from the user area of THE·GRID, and we have determined empirically that it is rigid and sturdy enough for the camera and IR floodlight load.

1.3 Electrical and Electronics

1.3.1 Cabling

Each LED strip consumes 18W when active. The wiring for one strip will consist of twin core cable carrying power and return between the strip and the control tent. Additionally, a coaxial connection will run from the interactivity camera to the control tent.

Ideally, all cabling inside THE·GRID will be buried slightly below ground to avoid a trip hazard. If this is not possible, cabling could be run between the tops of poles at a height of 2.5m.

For the selected layout, a total of 462m of twin-core wire is required, plus approximately 50m slack. See Appendix C for detailed cable layouts.

For the 0.75mm^2 cable we have selected, the voltage drop on the longest segment is 1.34V, which is well within acceptable limits for the LED strip. See Appendix D.2 for details.

1.3.2 Switching

Each LED strip will be controlled using a MOSFET driver. The drivers will be switched by seven 8-output shift registers, themselves controlled by a microcontroller receiving data from the controlling computer.

We anticipate constructing the main electronics assembly on stripboard due to the relatively low complexity and single unit required.

1.3.3 Power

The maximum power consumption of THE·GRID will be 74A. This will be provided by four 550W ATX power supplies, each rated for 32A on its +12V rail. See Appendix D.1 for details.

1.3.4 Lighting

Each pole is illuminated by half of a 5m strip of 30 LED/m 5050-sized white LEDs. These strips take 12VDC input and are readily obtained inside waterproof silicone jackets.

1.3.5 Sound

Each pole will also be equipped with a small relay to provide an audible cue when the LEDs are activated.

1.4 Software and Control

A laptop in the control tent will generate display patterns and handle interactivity. It will transmit lighting data via a serial link to a microcontroller. Upon receiving each frame, the microcontroller will clock the data into the shift registers, then activate the output latch.

An infrared-capable camera mounted on a mast in the backstage area senses movement and tracks the location of people inside THE·GRID to coordinate interactive applications and patterns. Illumination will be provided by IR floodlights.

We anticipate using OpenCV to detect areas of motion in successive frames and mapping these areas onto an approximately chest-height plane which is gridded up into the corresponding THE·GRID cells. This should enable robust and low-CPU detection of which cell a person has entered. The use of IR illumination provides high contrast and operation in low visible illumination.

2 Applications

2.1 aMAZE

aMAZE is an interactive, virtual maze. In this mode, when a user enters THE·GRID, a maze is randomly generated. Squares the user can travel to are lit, while squares representing walls are dark. aMAZE monitors the user's progress and knows if the user completes the maze, or cheats! The twist is that aMAZE only lights the user's square and adjacent squares—the user cannot see ahead and can only explore passages by travelling them.

In multiplayer mode, two users can enter THE·GRID simultaneously, each navigating a different but overlapping maze, racing the other to victory.

2.2 Pong

Users run on either edge of THE·GRID to control a baton bouncing a ball between them in a rendition of the classic arcade favourite.

2.3 Interactive Patterns

A number of interactive patterns will produce interesting visual effects based on the movement of people in THE·GRID, inspired by fluid disturbance and flow.

2.4 Non-interactive Patterns

For times when no users are directly interacting with THE·GRID, non-interactive patterns will display pre-programmed effects resembling waves, stars and sparks.

3 Risk Assessment

3.1 Mechanical

THE·GRID is an interactive exhibit and will involve people walking around a structure in low lighting, however, there is a minimal risk of injury. As poles are embedded in soft ground and are constructed from thin aluminium section, there is no serious risk of injury should somebody walk into a pole.

Poles will be 2.5m (8 foot 2 inches) tall, so there should be no risk of impalement or eye injury.

In the very unlikely case of a pole falling on a person, the pole's light weight (around 500g) means there is minimal chance of injury.

With people walking around the installation in low light, there would be a significant trip hazard were any cabling or guy-wires exposed. For this reason, all cabling inside THE·GRID itself will be buried below the surface of the ground. If the cable cannot be buried, it will be run overhead between the top of the poles. Again, this is high enough that it will be impossible to walk into.

The backstage area will contain cabling running at ground level alongside other hazards and so will be off limits.

3.2 Electrical

All mains electronics will be contained within the control tent and power is distributed through THE·GRID at 12V DC. The control tent will be waterproof, and all exposed cabling, connections and electronics will be waterproof. The low voltage combined with RCD protection means there is a minimal risk of electrocution.

There is minimal risk of the low voltage LED strips in THE·GRID itself posing a fire hazard. In the unlikely event of a fire in the control tent the hazard would be contained in the off-limits backstage area, minimising the risk to users.

3.3 Other

In the event of a nearby thunder storm, the exposed metal poles could attract lightning strikes (although the risk is likely negligible compared to the main NOC mast). If there is a significant chance of a thunder storm, THE·GRID will be disconnected from the mains supply and placed off limits for the duration of the storm.

In the event of high wind loading, at 40mph winds the pole structures may flex up to 56cm, which remains safely within operating conditions of the structure. To minimise the risk of injury, THE·GRID will be off limits in the event of very high wind. See Appendix B.4 for detailed calculations.

There is a risk that individuals with photo-sensitive epilepsy could be affected by THE·GRID. We will have to investigate further how to minimise this risk, whether this be through appropriate warning signage or avoiding problematic patterns such as flashing.

4 Budget

Item	Unit Cost (GBP)	Quantity	Subtotal (GBP)
$\frac{3}{4}''$ aluminium angle, 5m	2.91	34	98.94
White 30LED/m strips, 5m	6.90	27	186.30
0.75mm^2 cable, 100m reel, twin core	17.88	6	107.28
Camera	15.66	1	15.66
Camera Coax†	10.00	1	10.00
ATX PSU†	23.46	4	93.84
IR Floodlights	27.99	2	55.98
Electronics†			50.00
Tent*			–
Camera mast & guying*			–
Total			**618.00**

† Estimated price
* Already owned

While we are able to finance THE·GRID personally, grants would be greatly appreciated.

Some extension ideas that ended up being out of budget include addressable LED strip and 5m tall poles. We believe the current design obtains a good compromise between cost and utility.

A Engineering Drawings

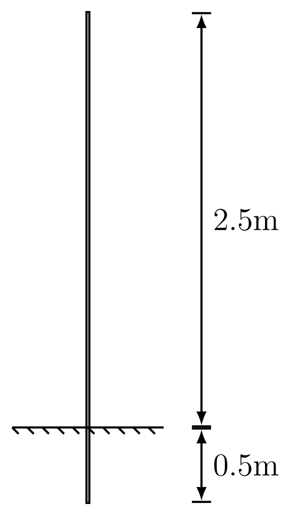

Figure 3: Side view of a single pole

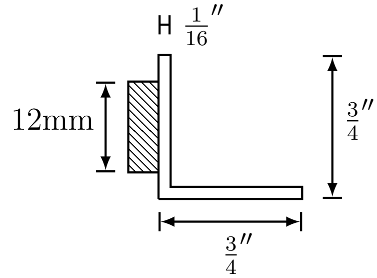

Figure 4: Top view of a single pole with LED strip

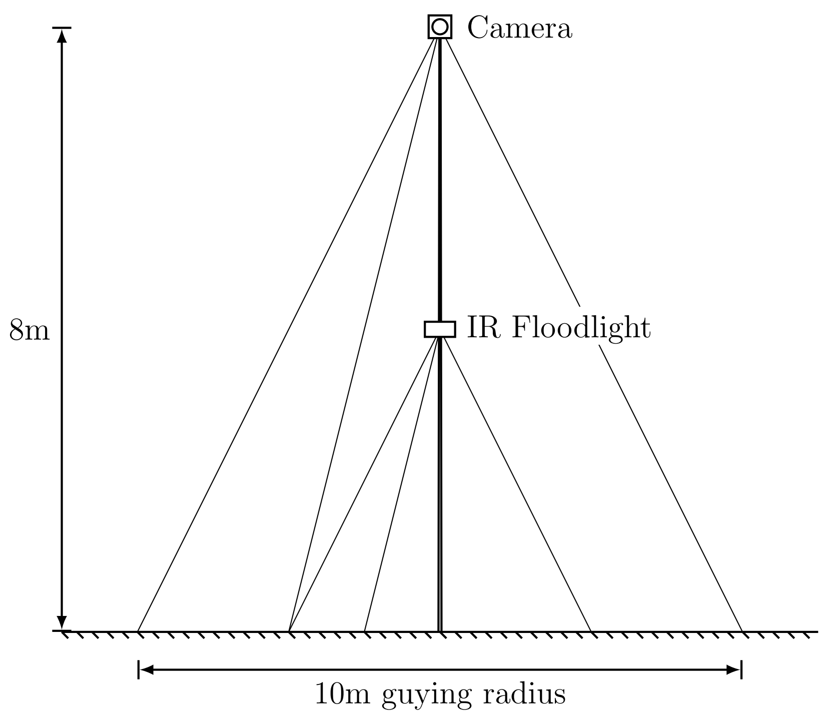

Figure 5: Side view of camera mast

B Structural Design Verification

The structural design can be verified quantitatively using Euler-Bernoulli beam theory. This assumes any deflection is small and that shear forces cause negligible deflection. These assumptions are justified when the beam concerned is slender, i.e. its length is greater than 20 times its thickness, a condition more than satisfied for THE·GRID's poles.

From a basic structural point of view, THE·GRID's poles are slender vertical cantilevers subject to self weight and lateral wind loading.

B.1 Basic Properties

The following calculations are based on the beam's *Second Moment of Area in the U axis* (I_{uu}), *Density* (ρ), and *Young's Modulus* (E). The U axis (45° from the X and Y axes) has the weakest second moment of area (see Figure 6). The second moment of area in the U axis is defined:

$$I_{uu} = \int v^2 \, \mathrm{d}A$$

where the V axis is perpendicular to the U axis. For thin walled equal angle section:

$$\mathrm{d}A = 2t\sqrt{2}\, \mathrm{d}v$$

$$\begin{aligned}
I_{uu} &= 2t\sqrt{2} \int_{\frac{-a}{2\sqrt{2}}}^{\frac{a}{2\sqrt{2}}} v^2 \, \mathrm{d}v \\
&= \frac{2t\sqrt{2}}{3} \left[y^3 \right]_{\frac{-a}{2\sqrt{2}}}^{\frac{a}{2\sqrt{2}}} \\
&= \frac{2t\sqrt{2}}{3} \left(\frac{a^3}{16\sqrt{2}} - \frac{-a^3}{16\sqrt{2}} \right) \\
&= \frac{2t\sqrt{2}}{3} \left(\frac{a^3}{8\sqrt{2}} \right) \\
&= \frac{ta^3}{12}
\end{aligned}$$

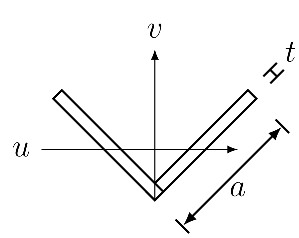

Figure 6: Second Moment of Area for Angle Section

For $a = \frac{3}{4}''$ and $t = \frac{1}{16}''$, $I = 9.15 \times 10^{-10}$ m^4.

Standard values for the density and Young's Modulus of aluminium are used, $\rho = 2,700$kg/m, $E = 69 \times 10^9$GPa.

B.2 Flexural Rigidity

A simple test of a beam's rigidity is its deflection under self weight when mounted as a horizontal cantilever. For a horizontal cantilever of length L with distributed loading w, the deflection is:

$$\delta = \frac{wL^4}{8EI} \tag{1}$$

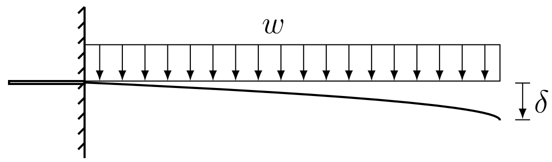

Figure 7: Horizontal cantilever deflection due to self weight

Applying a loading of 1.60 N/m for the weight of aluminium and 0.374 N/m for the LEDs, we get a total loading of $w = 1.97$ N/m and a deflection of $\delta = 0.153$ m.

B.3 Buckling

Slender columns under a compressive load will tend to fail by buckling rather than crushing. The standard formula for the maximum load (applied at the tip of the column) due to Euler buckling is:

$$F_{\text{crit}} = \frac{\pi^2 EI}{(KL)^2}$$

(KL) is the effective length, determined by boundary conditions. THE·GRID's poles are vertical cantilevers, for which the correction factor is $K = 2$. For these poles, the critical force due to buckling is $F_{\text{crit}} = 24.9$ N, or 2.54 kg.

The total weight of the aluminium and LEDs is far less than 2.54 kg and the self-weight loading is distributed rather than applied at the tip, so there is no risk of buckling under self weight.

B.4 Wind Loading

Wind loading upon the poles can be modelled as a vertical cantilever subject to lateral uniform distributed loading. The loading depends on the wind speed and lateral cross sectional area of the pole. At 13.4 m/s (30 mph), loading is 119 N/m^2, and at 17.9 m/s (40 mph), loading is 268 N/m^2. The maximum lateral cross sectional area of the pole is 0.0674 m^2.

Using Equation 1, we find that 30 mph and 40 mph winds give deflection of 0.248 m and 0.559 m respectively.

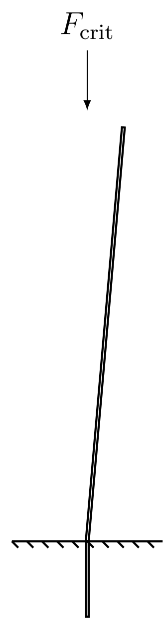

Figure 8: Euler buckling of pole

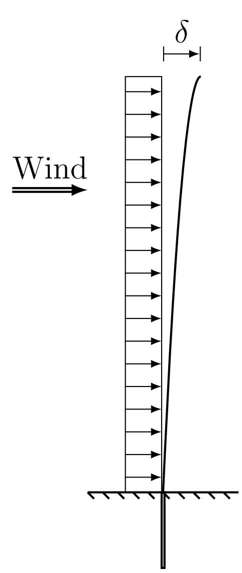

Figure 9: Wind loading on pole

C Cable layout

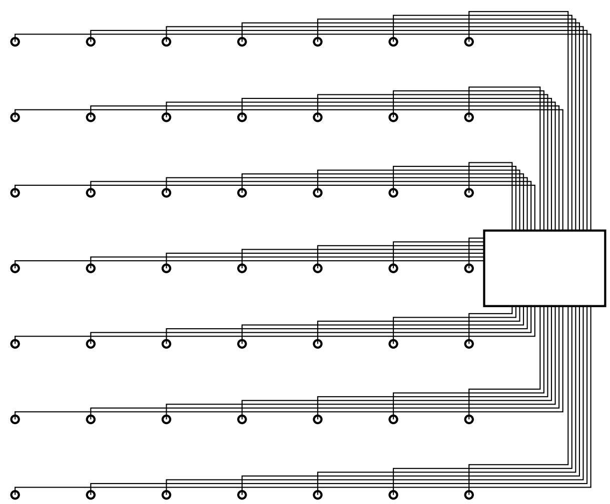

Figure 10: Power/control cable routing

D Electrical Design Verification

D.1 Power and Current Consumption

The power consumption of the LED strip is 7.2 W/m. For 49 poles, this gives a total peak power consumption of 882 W. Using Ohm's Law and the definition of electrical power:

$$V = IR$$

$$P = VI$$

the maximum current flow in THE·GRID is 73.5 A at 12 V DC, although no single conductor carries the entire current.

D.2 Cabling Resistance and Voltage Drop

Cabling between the control tent and poles will be 2-core cable with an area of 0.75mm^2, or 7.5×10^{-7} m^2 per conductor. The resistivity of copper is 1.68×10^{-8} Ωm at room temperature. With a maximum cable length of around 20 m the total conductor length is 40 m, giving a resistance of 0.896 Ω. With a current of 1.5 A per pole, this gives a voltage drop of 1.34 V.

E Preliminary Testing

A prototype pole was constructed from 20mm $\times$ 20mm $\times$ 1.5mm aluminium section (c.f. 19mm $\times$ 19mm $\times$ 1.59mm for the final design). We attached RGB LED strip powered by a bench power supply. This test confirmed the structural rigidity of the pole design as well as the effectiveness of lighting with 30LED/m strip. We also confirmed the acceptable voltage range of the LED strip.

Figure 11: Prototype pole

To verify the basis of the computer vision system, a night vision camera at a height of 4m was used to observe a person at a distance of 10m, with and without an additional IR flood-light.

Figure 12: Night vision camera without IR flood-light

Figure 13: Night vision camera with IR flood-light

12V relays with 10A rated contact current were found to give a satisfying click.