

# ICL Multispectral Light Stage: building a versatile LED sphere with off-the-shelf components

Christos Kampouris and Abhijeet Ghosh

Department of Computing, Imperial College London, UK

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## Abstract

We describe the design and implementation of a versatile multispectral light stage (LED sphere) consisting of 168 RGB and color temperature controllable white (W+) lamps, respectively. The light stage is powered with two sets of off-the-shelf programmable MR16 LED lamps producing RGB and color temperature controllable white (2700K – 5700K) illumination. The design is heavily inspired by various USC-ICT light stages, particularly Light Stages 3, 5 and X. However, unlike a typical geodesic (subdivided icosahedron) dome structure, the structure of the LED sphere has been fabricated along spherical coordinates with latitude-longitude profiles for a simplified wiring and control layout of the LED lamps, and for simplifying polarization of incident illumination. These design decisions facilitate construction while providing a versatile solution for a variety of applications including reflectance capture, image-based lighting reproduction, and multiview facial geometry and appearance acquisition.

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## 1. Introduction

Light stages have a rich history in computer graphics for achieving realistic reproduction of subjects and objects for various applications including film visual effects (VFX), games and virtual reality [Deb12]. They usually involve a geodesic dome structure mounting hundreds of inward pointing lights focused on a subject at the center of the dome allowing controlled measurements of shape and reflectance under a full incident sphere of lighting directions. However, building such an apparatus is usually a very involved process requiring custom design of the dome structure (usually a subdivided icosahedron) for mounting the various lights, their wiring, and custom design and implementation of control circuitry for hundreds of light sources. The design of light stages is usually also dependent on specific target applications restricting their use case for more general applications. This is why light stages have thus far been restricted to a few laboratories with expertise and infrastructure for building such complex devices.

In this paper, we describe the design and implementation of a multispectral light stage (LED sphere) at Imperial College London (ICL) that has been built using off-the-shelf components for LED lighting control and a simplified latitude-longitude profile for the spherical structure (see Fig. 1). The LED sphere is powered using two sets of programmable LED lamps from Philips Color Kinetics pro-



**Figure 1:** ICL multispectral light stage consisting of off-the-shelf RGB and extended white (W+) LED lamps.

ducing RGB and extended (color-temperature controllable) white (W+) illumination, respectively. Furthermore, unlike a typical geodesic subdivision of a sphere, the latitude-longitude profile of the LED sphere's structure simplifies the wiring and control layout for the mounted LED lamps, as well as simplifies their polarization. We demonstrate the versatility of the design and construction with various applications ranging from image-based lighting reproduction, reflectance acquisition and multiview facial capture.

## 2. Related Work

Debevec and colleagues have proposed a sequence of designs for various light stages. Light stage 1 employed a single light source on a two-axis manual rotation mechanism for rotating the light around a subject in a spiral for acquisition of a dense reflectance field [DHT\*00]. The complete acquisition required one minute during which a subject had to stay still. Light stage 2 [HCD01] consisted of 30 bright lights placed on a rotating semicircular arm with one full rotation lasting eight seconds. The design sped up the acquisition of dense reflectance fields and was employed in several film VFX projects in the early 2000s. Light stage 3 (LS 3) [DWT\*02] instead employed 156 controllable RGB LED lamps mounted on a geodesic dome of 2m diameter. The system was designed for image-based lighting reproduction on actors for composition in virtual backgrounds with matching illumination. Light stage 5 (LS 5) [WGT\*05] added 156 bright white LED lamps to the LS 3 structure and employed time-multiplexed illumination and high speed video for acquiring dynamic reflectance fields. A similar setup was employed by Weyrich et al. [WMP\*06] for acquiring dense facial reflectance, while hemispherical dome setups have been employed for acquisition of bidirectional texture functions (BTFs) [SSWK13]. LS 5 was subsequently employed for facial geometry and reflectance capture in conjunction with polarized spherical gradient illumination [GFT\*11]. The most recent design, Light Stage X (LS X), consists of 330 LED light sources, each with many multi-spectral illuminants with fine grained control over spectra, intensity and polarization of incident light [Deb12].

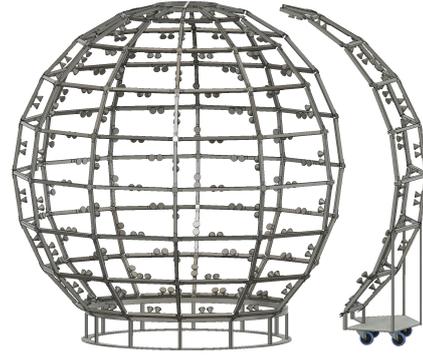
Our LED sphere design is heavily inspired by these systems. We employ off-the-shelf programmable LED lamps similar to LS 3. And similar to LS X, we combine RGB and white LEDs for controlling spectra and polarization of incident illumination. However, we strive for a balance between complexity and versatility of the light stage system. In the following, we elaborate on the design choices and describe the hardware and implementation details of the setup.

## 3. Hardware Setup

### 3.1. Metal Structure

The LED sphere has been built using a custom fabricated steel spherical structure which has diameter of 2.5 m (see Fig. 1). The bottom of the sphere is cropped to create space for a chair to seat a subject and the sphere is mounted on a circular base to ensure the sphere equator is at a height of 1.25m which is the approximate head height for a seated subject. All surfaces, including the walls of the room, are painted in matte black to minimize reflections.

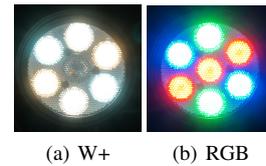
We chose a longitude-latitude design instead of the typical subdivided icosahedron for the structure to simplify the wiring and control layout of the LED lamps and their polarization (detailed in Section 3.2). The structure consists of



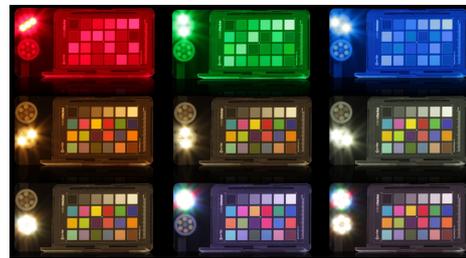
**Figure 2:** CAD model of structure showing separable door.

12 vertical arcs (meridians) and 8 horizontal latitudinal connections between the arcs. In order to enable getting in and out of the LED sphere, we designed a movable door using a section of the sphere consisting of two vertical arcs which have been mounted on wheels and can be separated from the structure (see Fig. 2 for CAD model).

### 3.2. LED lamps



(a) W+ (b) RGB



(c) Illumination spectra

**Figure 3:** Philips Color Kinetics iW MR gen3 and iColor MR gen3 lamps (a, b), and their illumination spectra as observed on an Xrite colorchart (c).

For the LED sphere's light sources, we selected off-the-shelf programmable MR16 LED lamps (5W) from Philips Color Kinetics: 168 iColor MR gen3 lamps for RGB illumination and 168 iW MR gen3 lamps for white illumination, respectively. These off-the-shelf lamps are used for a wide-range of architectural, theatrical and other lighting applications. The iW MR gen3 lamp can produce color temperature controllable white (W+) light ranging from 2700 K

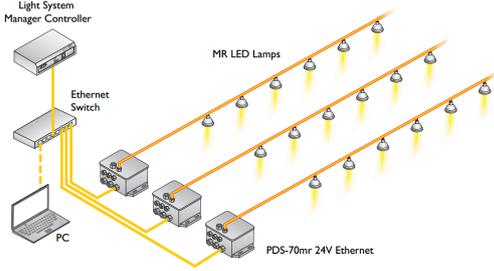


Figure 4: Wiring diagram from [PDS]

– 5700K. More specifically, it consists of three individually controllable channels that provide warm, neutral and cool white light (see Fig. 3). Similarly, the iColor MR gen3 lamp has three individual controllable channels for R, G and B and together both the lamps enable significant spectral control of the illumination. Both types of lamps receive power and control signals from a custom controller unit (PDS-70mr (PDS) 24v power/data supply) using standard 2-pin wiring which simplifies the installation. Each PDS unit can control up to 14 lamps in a series. We employ a total of 24 such PDS units to power the light stage, with each unit powering lights in sequence along a vertical arc. Control signals are sent via Ethernet using KiNET, a proprietary lighting protocol from Philips Color Kinetics similar to DMX512, with each light accepting either 8-bit or 16-bit control for a channel. A wiring diagram for lights in a series is shown in Fig. 4. Each lighting node on the LED sphere consists of one RGB and one W+ lamp. We further mount linear polarizing sheets in front of the lamps in horizontal and vertical orientations to create the latitude-longitude polarization pattern of Ghosh et al. [GFT\*11]. We ensure that both the RGB and W+ banks have an equal number of horizontal and vertical polarizers by oscillating the polarizer orientations between RGB and W+ lamps at successive nodes along an arc.

### 3.3. Cameras

We have currently equipped the light stage with nine Canon 800D DSLR cameras for multiview face capture, and a Point Grey Grasshopper 3 (GS3-U3-41C6C-C) machine vision camera for video rate capture (Fig. 5). The 800D has a 24.2 megapixels APS-C sensor and a burst mode of 6 frames per second. We employ Canon 18-135 mm zoom lenses equipped with glass linear polarizers (Hoya) on these cameras. For applications requiring higher speed capture such as reflectance field acquisition, we employ the machine vision camera equipped with a Navitar 50 mm lens. The camera has a 4.1 megapixels 1-inch sensor, global shutter and is able to capture color images at 2K resolution at 90 fps.



(a) Canon 800D

(b) PointGrey Grasshopper 3

Figure 5: DSLR and machine vision cameras

### 3.4. Synchronization and Data Capture

In our multiview capture setup, it is very important that all DSLR cameras start capturing images at the same time. To avoid synchronization issues, we built a simple optoisolated circuit to send triggering signals to all the DSLRs simultaneously using their remote shutter input. The DSLR cameras are operated at 5 frames per second, storing RAW images in on-camera SD cards. For the machine vision camera, we employ the dedicated I/O pins for triggering and direct download of data via USB. Another issue is how to synchronize the lights with the cameras. The light stage is controlled via Ethernet by sending UDP packets with the desired intensity value for each light to the corresponding PDS unit. To eliminate any delays, we employ a Raspberry Pi 3B to control both lights and cameras in synchronization.

## 4. Applications

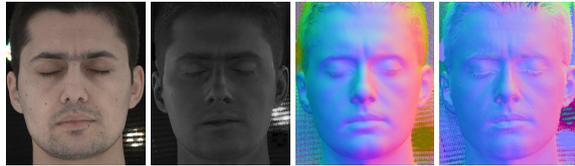
The light stage has been designed to be a versatile system that can be used in a number of different applications. For instance, it can be employed to acquire a reflectance field by capturing images lit by a single lighting node for all 168 light node positions. At each position there is a pair of RGB and W+ lights with opposite polarization and we use both lights to create unpolarized light with a uniform spectrum. We acquire such data at 30 frames per second using the machine vision camera, making the total acquisition less than 6 seconds. The acquired dataset can then be used for image-based relighting or reflectance modeling [DHT\*00, WMP\*06]. Another application is image-based lighting reproduction for digital compositing applications. We can drive the RGB lamps on the light stage according to a given HDR environment similar to [DWT\*02] to reproduce the lighting of a virtual environment (see Fig. 6). Furthermore, it is possible to combine the RGB and W+ LEDs to achieve multispectral lighting reproduction similar to [LYL\*16].

The light stage can also be employed for multiview facial geometry and appearance acquisition. Fig. 7 shows diffuse and specular albedo and photometric normals of a face acquired using the method of [GFT\*11]. We additionally employ our multiview camera setup in conjunction with a photogrammetry software (Agisoft Photoscan) to obtain a



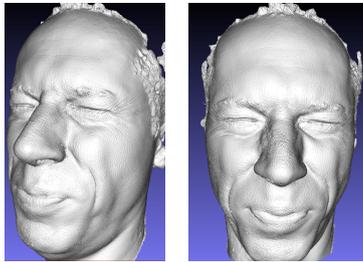
**Figure 6:** Lighting reproduction of Grace Cathedral environment.

base 3D facial geometry. Finally, we emboss the photometric specular normals on the base geometry to obtain high resolution 3D facial models with mesostructure details including skin pores and fine wrinkles (see Fig. 8).



(a) diff. albedo (b) spec albedo (c) diff. normal (d) spec normal

**Figure 7:** Diffuse-specular separation of albedo and photometric normals.



**Figure 8:** High resolution facial geometry with mesostructure details.

## 5. Discussion and Future Work

We presented the implementation of a multispectral light stage using a simple longitude-latitude structural design and off-the-shelf LED lamps. Initial experiments show that the light stage is capable of producing high quality results for a wide variety of applications that were previously only demonstrated on specialized light stages with custom hardware. While our design choices significantly simplified the implementation, they did enforce some limitations. Synchronization between the lights and the cameras is currently not

completely fine tuned for high speed capture. Replacing the Raspberry Pi with an Arduino board might enable more precise timing control. The Kinet protocol for the LED lamps also enforces an upper limit of 44 fps currently for data capture. For future work, we would like to explore more accurate spectral calibration of the LEDs for multispectral lighting and reflectometry applications.

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