Lighting Automation – Flying an Earthlike Habitat

JSC 2017 Innovation Charge Account Project

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Abstract:

Currently, spacecraft lighting systems are not demonstrating innovations in automation due to perceived costs in designing circuitry for the communication and automation of lights. The majority of spacecraft lighting systems employ lamps or zone specific manual switches and dimmers. This type of "hardwired" solution does not easily convert to automation. With advances in solid state lighting, the potential to enhance a spacecraft habitat is lost if the communication and automation problem is not tackled. If we are to build long duration environments, which provide earth-like habitats, minimize crew time, and optimize spacecraft power reserves, innovation in lighting automation is a must.

This project researched the use of the DMX512 communication protocol[1,2] originally developed for high channel count lighting systems. DMX512 is an internationally governed, industry-accepted, lighting communication protocol with wide industry support. The lighting industry markets a wealth of hardware and software that utilizes DMX512, and there may be incentive to space certify the system.

Our goal in this research is to enable the development of automated spacecraft habitats for long duration missions. To transform how spacecraft lighting environments are automated, our project conducted a variety of tests to determine a potential scope of capability. We investigated utilization and application of an industry accepted lighting control protocol, DMX512 by showcasing how the lighting system could help conserve power, assist with lighting countermeasures, and utilize spatial body tracking.

We hope evaluation and the demonstrations we built will inspire other NASA engineers, architects and researchers to consider employing DMX512 "smart lighting" capabilities into their system architecture. By using DMX512 we will prove the "wheel" does not need to be reinvented in terms of smart lighting and future spacecraft can use a standard lighting protocol to produce an effective, optimized and potentially earthlike habitat.

Lighting Automation – Flying an Earthlike Habitat – Detailed Report

Project Description

To assess DMX512 features and capabilities for real time lighting control automation, we built a lighting control rig. The lamps on the test rig include eight large luminous, "cool white", LED light panels and a LED pixel control strip with red, green, blue, and white LEDs. DMX512 decoders, which are addressable high channel count pulse-width-modulated (PWM) DC dimmers, provide the method for intensity control. The decoders are controlled using a Madrix® Plexus controller. This controller, in-turn is programmed using a Madrix® DMX 512 compliant programming application. This application, which allows usage of scripting is further controlled via the usage of a C/C++ API.

As part of our demonstration we integrated a timer, an illumination sensor, and a Kinect® 3D sensor with the DMX512 controller to enable smart lighting and showcase three operational demos.

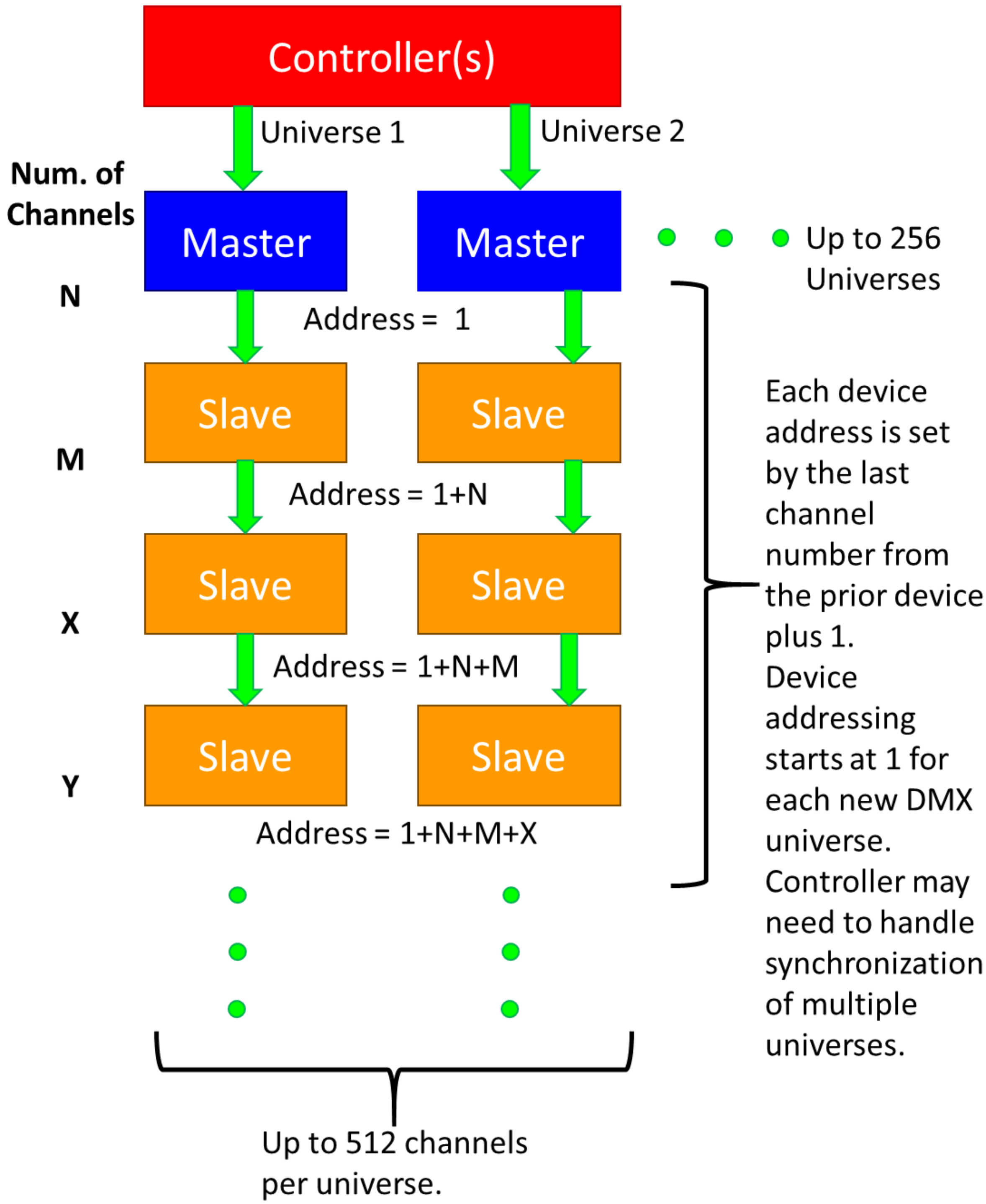
- The system simulates an enforced lighting schedule, a 24-hour sunlight cycle that enforces the Circadian rhythm.
- The lighting system monitors the illumination on a surface and provides real time control input to LED light panels to maintain a constant illumination level, thus balancing outside light with LED light panel illumination and enabling smart power conservation.
- The system commands individual LEDs of a light strip to track a user moving along a line of path, to demonstrate lighting spatial body tracking.

In the process of building this system, we documented hardware, software, and system engineering design constraints for both the implementation of this system and the expected hurdles for expanding the design for a larger habitat or lighting architecture.

Basics of DMX512

There are multiple lighting communication protocols. However, for this evaluation, we focused on the usage of DMX512 protocol because of its longevity in the theatrical and lighting control industry which has an expectation of performance for high end customers. DMX512 utilizes a master-slave device addressing topology, see Figure 1. The command signal utilizes an asynchronous serial format with integrated addressing to control up to 512 devices[1,2]. The most current standard[1], DMX512-A, provides detailed guidance on cable, connector, shielding, grounding, and impedance requirements to ensure quality signals are received at each device. This same standard provides a wealth of guidance for the development of custom control devices that could utilize this communication standard.

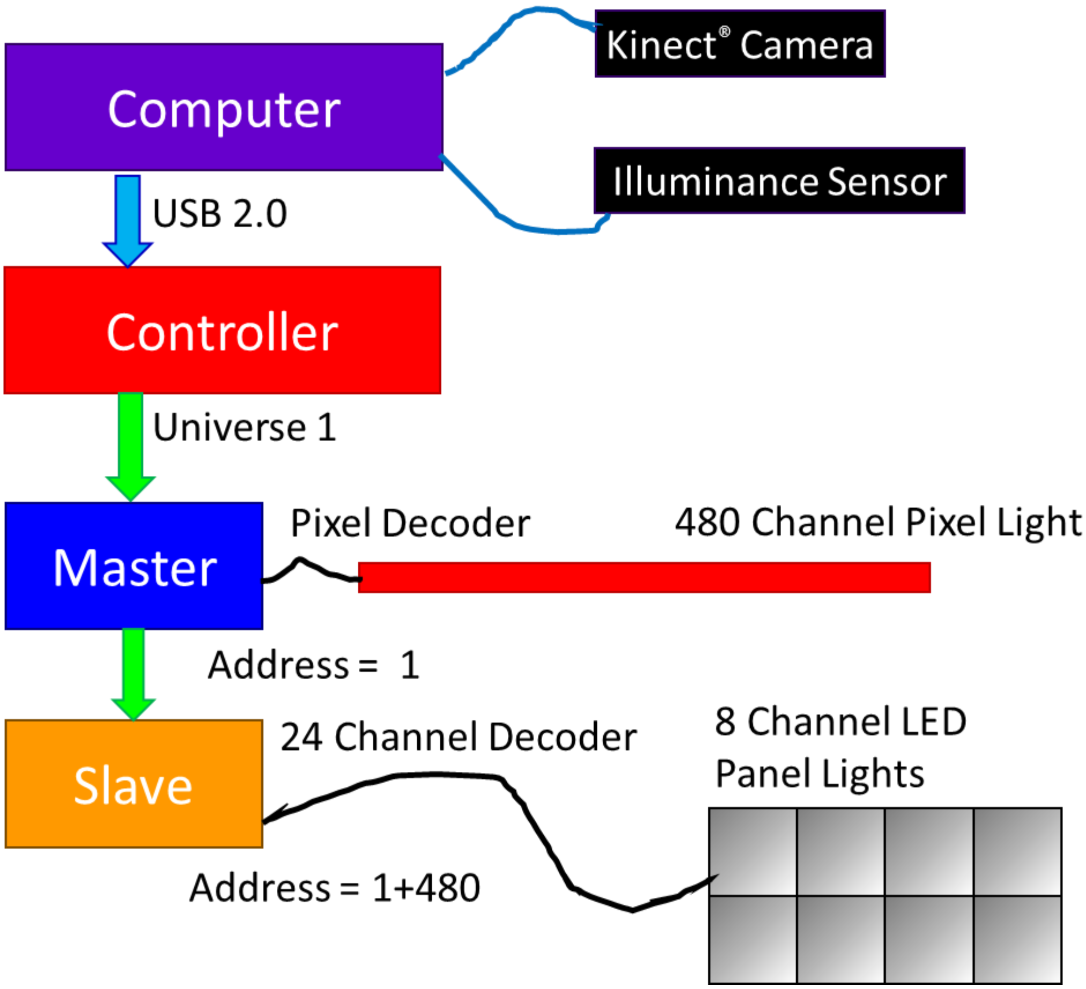
Figure 1: DMX512 Master-Slave Topology



System Diagram

For this project, we used Commercial Off the Shelf (COTS) DMX512 compliant controllers, and decoders (high channel count dimmers) for the intensity control of LED lighting components. The controller was programmed with a COTS lighting control software application that was compatible with the lighting controller. The controller and application software were both made by Madrix®,[7], a well-known high end DMX lighting control hardware/software manufacturer. Decoders were generic COTS high channel count dimmers, compatible with DMX512, which also accommodated certain performance needs such as switching voltage and dimmer Pulse Width Modulation frequency. Figure 2 shows the system configuration of the lighting system for this research project.

Figure 2: High Level System Diagram



DMX Demonstrations & Outcomes

Utilizing a Madrix® lighting control and programming application, combined with scripts and C++ coding, we developed three demonstrations, each requiring a different level of programming. Each demonstration showcases a feature of lighting automation that could be expanded upon at an architectural system level and provides insight on the innovation potential in transforming how spacecraft habitats manage lighting systems. Figure 3 shows an image of the lighting demonstration in use.

Figure 3: Lighting Control Simulation

Circadian Lighting Countermeasure

For the Circadian Lighting Countermeasure demonstration, a Red-Green-Blue-White (RGBW) Pixel LED strip was used to generate a multi-spectrum light output. The LED strip was powered by a special decoder called a pixel decoder. This type of decoder has the ability to provide data and dimming intensity information to each color channel on the LED strip. For this pixel LED strip, each LED was four channels (red, green, blue, white) and each LED was addressable. The pixel strip, for this demonstration, was programmed such that all LEDs were synchronized so that their color matched. Utilizing the lighting control programming application, a set of colors that represented warm, neutral, and cool white light was put into a table function with timing settings. The software interpolated the dimming intensity ranges for each color channel such that the apparent "color" of the white light has the proper gradient from one color of white to the next over a range of times. For demonstrations purposes, the simulation provides an accelerated representation of a 24 hour circadian lighting countermeasure.

This schedule based lighting automation showcases a variety of potential applications for crew health and productivity.

- Enforcement of a lighting schedule to improve crew circadian heath.
- Integration of various light spectrums and intensities over course of day to help crew with sense of time by emulating earth day/night cycle.
- Timed automation can assist with timing related alarms such as wake up calls and critical time related tasks.
- Timed automation of lights can assist with spacecraft power conservation by turning off unneeded lighting.
- Crew time in maintenance of on/off switches is reduced through computer control of lamps.

Illumination Maintenance (Steady State Light Levels)

For the illumination maintenance simulation, the goal was to show how real time monitoring of sensor data could be used dynamically to adjust intensity level. The application for doing so is to limit light output to meet illumination requirements and thus save on power usage. For example, if significant sunlight was entering the vehicle such that human task illumination requirements are met, energy that otherwise would have been spent on manually switched lamps, could be reduced or turned off. Alternatively, when shadowing becomes a problem in meeting task illumination levels, the system could dynamically respond and increase light levels.

The simulation utilized a set of signal channel LED light panels with PWM dimming provided by a DMX512 decoder. The lighting control system utilized the Madrix® lighting control and programming application, scripts, and real time USB illuminance light sensor data fed to a buffer via C++ coding. An open loop control algorithm provided direction for increasing or decreasing lighting intensity until the light sensor data fell within a threshold.

Timing to reach steady state was dependent on frame rate of the feedback loop for the dynamic control input, sensor sensitivity, and size of the illuminance threshold.

Follow the Leader

To advance the concept of occupancy sensors and lighting where it is only needed, a simulation was developed that made a group of LEDs on a LED pixel strip to follow the movement of an object near the light strip. The simulation used a Kinect® camera, a RGBW LED pixel strip, a RGBW pixel LED strip, a DMX512 compatible pixel decoder, a DMX controller, C++ coding, scripts and a Madrix® lighting control and programming application. The simulation successfully demonstrated the use of 3D position monitoring devices to control the state of a light with respect to that lamp's location in 3D space. In this instance, the program caused LEDs to follow the position of a hand waving in space. Once the system acknowledged the gesture of the hand wave, it then followed from left to right the location of the individual's hand.

While this demonstration was for a small volume, 3D sensing cameras could be used to monitor crew gestures and positions within the habitat to cause the lighting to dynamically respond to modifying intensity, color, and area of illumination coverage required for a task. A system could "follow" a crew member through a large habitat such that manual activation of lighting would not be needed as the crew member moves from space to space. Hand gestures could be used for commanding sets of lamps to activate. Usage of 3D monitoring and gesture commanding may actually be more reliable than occupancy sensors, which can be fooled by users who become very still in their task. The level of detail to drive lighting control response to sensor feedback could indicate the status, extent, and required duration of lighting needed for a task.

<u>Challenges</u>

There are some challenges in implementing a lighting control system. These challenges are listed here, including those specific to DMX512 communication protocol.

- The size of the system drives the number of control devices. For DMX512, the number of channels that can be controlled is 512 per universe. However up to 255 universes can be in the same system, allowing for control of 130,560 device intensities. Additionally if DMX512 (Master-Slave topology) is used in conjunction with Art-Net™ [8] (Star distribution topology) the number of controllable devices could be significantly increased.
- Not all DMX controllers are designed to integrate up to the maximum size of a DMX512 system. Controllers need to be selected that can handle the required addressing and synchronization.
- Usage of newer addressable LED strips such as LED pixel can consume large amounts of channels per linear length quickly. This can affect the size of the system.
- Master-Slave topology allows for large cable lengths, but this may be a challenge for wire layouts designs that favor "hub" instead of a "snake" distribution.
- DMX512 provides guidelines for managing ground loops and signal degradation, but these requirements need to be accounted for at sub-system and end item cable design plans.
- Lighting controls that may require the development of zone control may need to carefully plan out how lamps map to a DMX addressing scheme.
- System update rates for active feedback control could be limited by system size (too many devices to talk to within a certain frame rate) or signal degradation due to cable design.
- There are many lighting control application options including devices that can run standalone (lighting control firmware that communicates via DMX) making it imperative to understand the user and system engineering constraints.
- There are a lot of COTS DMX512 compatible control devices with prebuilt electronics. Survivability of COTS DMX512 control system components, including high channel count dimmers (decoders) are unknown. While it would be great to be able to use COTS, the need to make custom circuits may be necessary[3,4,5,6].

Envisioning Future Spacecraft Lighting Architectures

Given the opportunity to implement a system level lighting automation platform that could be controlled by the spacecraft's avionics computers, a world of efficiencies could be integrated into realizing a smart habitat. To make this work well, however, good system engineering practices should be employed to ensure system level performance requirements are implemented well at sub system and end item system component levels. Additionally, if the spacecraft system employs the usage of a standard communication protocol for the lighting system, approaching spacecraft and temporary habitat modules to modular long duration habitats or long duration transport vehicles could integrate their lighting controls, allowing for a seamless operational environment. This could be especially beneficial if visiting spacecraft are relying on the main transport vehicle to provide power.

Long duration missions away from the earth-moon system will also have the challenge of stimulating the crew and providing an environment conducive to good physical and emotional health. A dynamic lighting environment that provides proper task level lighting, and maintains a healthy circadian lighting environment, while reducing crew time to maintain and operate the lighting system should be considered both a realizable and worthwhile goal using today's technology.

By allowing the avionics computers to control the automation of the lighting system, other opportunities for innovation become available. Ambient lighting and colored light sources could be controlled using the same lighting control protocol for any reason. Lighting could be tied into spacecraft features such as Caution & Warning, vehicle status, timed tasks, and emergency egress guidance. Automation of exterior lighting could facilitate better monitoring and guidance systems for approaching spacecraft. External mounted sensors on the hull of a spacecraft could be tied into the lighting automation system to assist the crew as they move about the surface during an EVA. Any automation that could enhance crew time, and provide additional safety to hardware and personnel could be integrated into an automated lighting system.

Conclusion

It is a paradigm shift to migrate manual spacecraft lighting controls to an automated system by the avionics computers. The implementation of automated lighting systems would require changing how we author requirements for human rated spacecraft architectures. Requirements would need to focus on system, subsystem, and end-item requirements to ensure proper operation of the system. Astronauts would need to learn to trust the automation in the lighting system to maximize its efficiencies. Finally, developers need to consider that an automated lighting system could be a user interface with just as many complexities as a display device. A successful implementation will also require that the lighting control system components can be made flight worthy, and automation software designed with rigor and reliability. Assuming this paradigm shift could be realized, smart spacecraft lighting systems will have arrived.

References

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