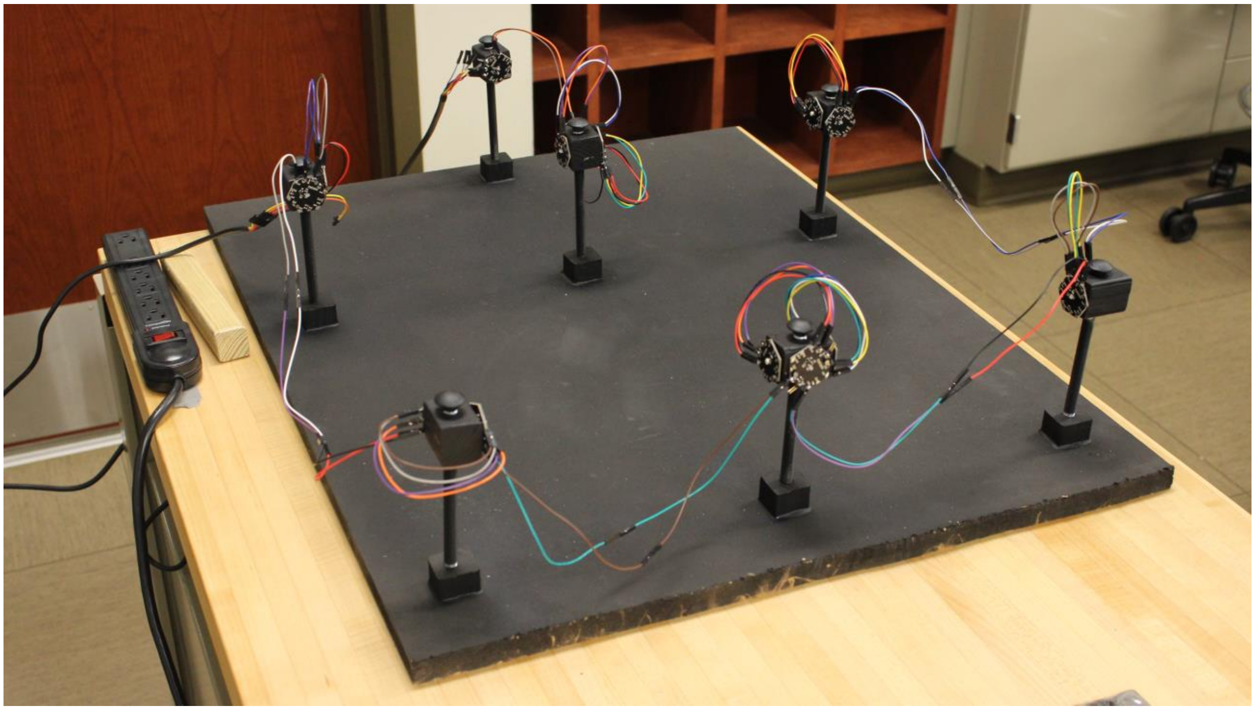
Senior Design II Due on: 5/02/2016

MOWE Relay Final Design Report

Version 1.1



Team Members: Will Nichols, Brian Gilder

Submitted to: Dr. Hazem Refai, Mr. Asaad Kaadan, Dr. Peter LoPresti, Mr Doug Jussaume

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Acknowledgments

Thanks to Mr. Asaad Kaadan and Dr. Hazem Refai for funding this project and providing such an interesting hardware concept. Thanks to Mr. Douglass Jussaume and Dr. Peter LoPresti and the rest of the University of Tulsa Electrical and Computer Engineering department for their help, resources, and support.

Executive Summary

Problem Statement

The goal of this project was to use the Modular Optical Wireless Elements (MOWE) components to develop a relay system that included a redundant path to the destination. This would allow for improved reliability in the system while increasing the range of transmissions. The particular elements that needed to be designed for this project were a 1-1 (1 input, 1 output) relay, a 1-2 splitter, and a 2-1 switch. These elements needed to be designed as both hardware and software.

Description of Solution

The final solution to this problem was a set of 7 nodes which comprised a complete network which would demonstrate the necessary functionality. The hardware used a minimalistic design, having 2 MOWE chips in each relay (1 receiver and 1 transmitter), and 3 chips in both the splitter and switch (1 receiver and 2 transmitters, and 2 transmitters, 1 receiver respectively). The software design setup memory transfers from each receiver to a transmitter's infrared LED, turning them on when the receiver read a value greater than its programmed threshold. The switch has more complicated programming, as it is designed to change its output from one of its receiver modules to another if the signal has been "lost" (as defined by being low for at least one second). This was implemented by using timer interrupts on the transmitter module.

Goals

This design was not only able to meet all design goals, but it was also able to exceed the expectations by transmitting data across the relay system. The requirements only consisted of being able to detect the state of the initial transmitter (being able to read a DC value). However, our design demonstrated the capability to transmit the ASCII encoded values for "Red Sox" across the system. Our project was also delivered on-time and well under budget, spending only half of our $200 budget (not counted the MOWE chips donated to the project by our customer). All other requirements (see the requirements document for a full list) were also achieved.

Customer Satisfaction

Our customers have expressed their approval for this project's outcome, and have shown interest in continuing to collaborate with the Electrical and Computer Engineering

department in the future. Their goals for this research extends to in-field deployment, and further research is necessary to develop the platform even further. Our customers were pleased with our product and have expressed a desire to continue developing the MOWE project with TU.

Recommendations for Next Generation

In continuing to move this project forward, there are several areas for further improvement. First, the current protocol for sending data across the devices is extremely primitive and inherently unreliable. Improving this protocol to include sampling, error detection, and acknowledgments would greatly improve the reliability of the transmission. An encoding scheme like 4B/5B would also help in preventing long streams of 0s, which may otherwise be misinterpreted as a lost signal.

In order to implement an acknowledgement, either half or full duplex communication would need to be introduced, which would also be a useful improvement by itself. Once error detection bits are implemented, improving the switch software to compare the data it receives on both receivers and to choose the correct data would also greatly increase reliability.

As previously mentioned, modifying the hardware and software to allow for half or full duplex communication would further extend the utility of this platform. While the implemented simplex design works well for demonstrations and proof of concept, duplex operation is better suited for many practical applications of free space optics. Furthermore, it can be used to implement a better communication protocol.

Another possible extension would be to attempt to increase the datarate of the transmission by having the splitter node divide the signal into two streams each carrying half of the original message. This would require the switch node to be able to recombine the signal at the destination.

The final recommendation is not explicitly for this project,but rather for the MOWE elements as a whole. When attempting to develop the hardware for the nodes, it was extremely difficult to solder at the angles required for a relay, since relays are attempting to transmit in the direction opposite of what they receive. Two modules are not currently able to be directly connected with the transmitter and receiver 180^{o} apart, as this would require soldering the V^{+} ports of one module to the ground ports of the other. If the design of the MOWE chips was reworked (or simply another design introduced), then all of the wires used in this project could be replaced by just soldering the components directly to each other.

Signatures

Created by:

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Brian Gilder

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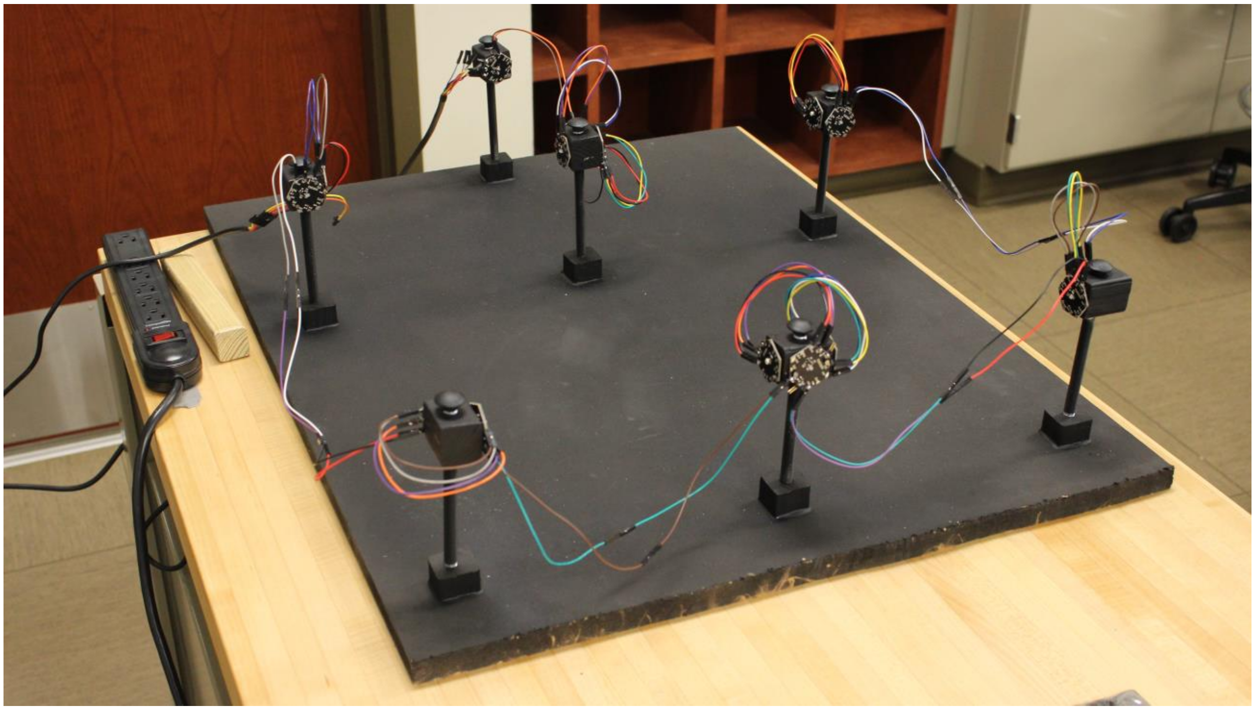
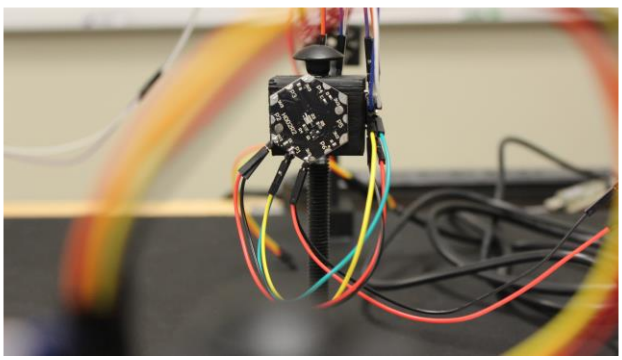
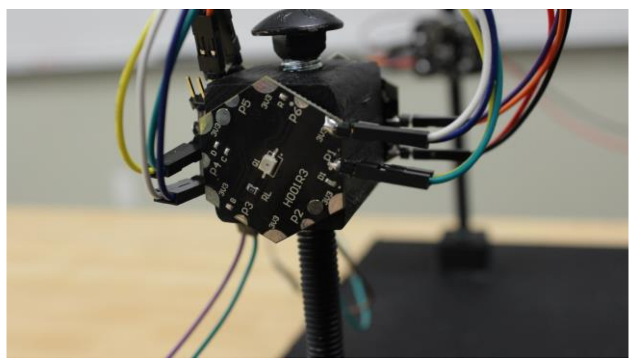
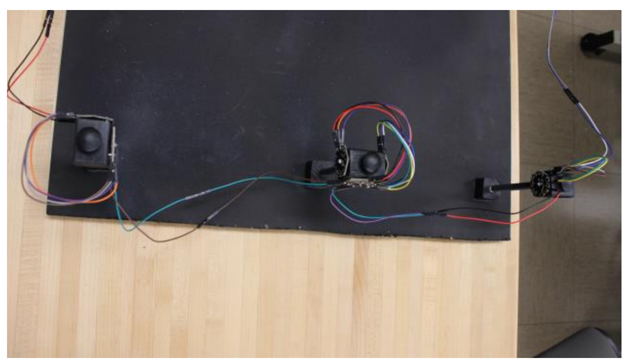
Will Nichols

Photographs





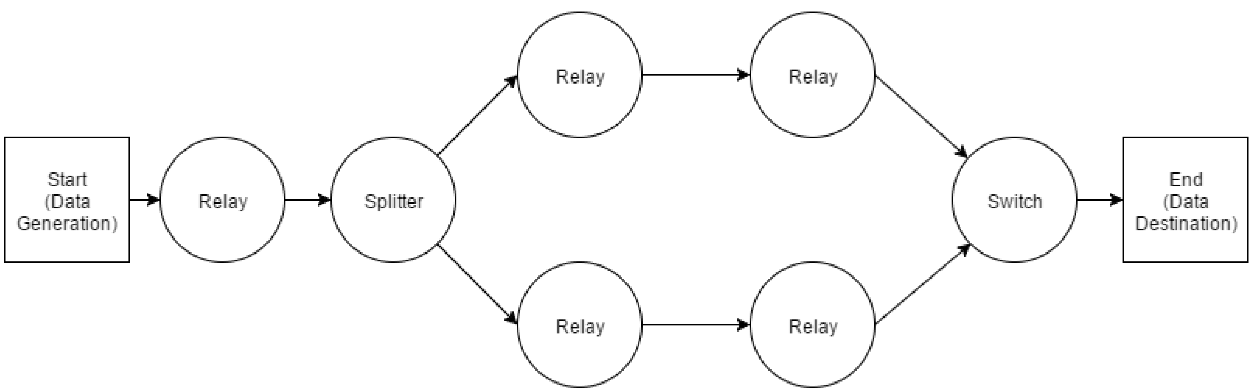




Statement of Work

"The Modular Optical Wireless Elements (MOWE) system consists of smart, electrically interconnected optical modules that can be combined together to build flat and curved optical wireless arrays. This novel design offers lightweight, inexpensive, and wide field-of-view terminals for various applications ranging from user tracking and noise measurements to broadband connectivity and MIMO FSO [free space optics]."[1]

This project will use MOWE chips to design a multi-node optical relay system. The relay will accept computer-generated signal inputs and transmit the data optically across diverse paths to deliver the signal to the opposite end of the system. The basic nodes will be simple relays, which will receive data from 1 source and retransmit it to 1 destination. An intermediate splitter node will receive data from 1 source and split it into 2 identical data streams. The two data streams will be relayed between basic relay nodes before being received by a switching node. The switch node will receive data from one of the streams, and in the absence of data, will switch reception to the alternate stream after at most 1 second of inactivity, and pass that signal to the data's final destination. The required network topology is shown below.



The MOWE chips are 3 cm across (flat edge to flat edge). They communicate via 850 nm carrier frequency. They operate using a 3.3V digital logic voltage. The transmitter has a ±10^{o} field of view and the receiver has a ± 60^{o} field of view. Since the transmission field-of-view is the limiting factor, the transmitter has been used to calculate the allowable lateral tolerances. The lateral chip alignment must stay within 1.41 inches for non-interruptible links and 2.47 inches for interruptible links.

The nodes comprising the split data streams will be spaced such that the distance between nodes will allow for interruption of the flow of data. This will allow for the switch to detect an absence of data and change to the alternate stream. The rest of the nodes will be spaced without the intention of blocking the optical communication between nodes. The physical spacing will be 14 - 20 inches between nodes for both interruptible paths and 8 - 14 inches

[1] http://ouwecad.github.io/MOWE/

between nodes in the non-interruptible paths. The relays will operate with simplex communication, meaning the flow of data only needs to go in one direction.

The data being transferred does not need to be encoded. Simple steady state value detection and retransmission is sufficient to prove the proper operation of the project. Monetary budget is limited to $200. The final prototype, with documentation, will be due for delivery on May 2, 2016.

Conceptual Design and Analysis

Concepts Generated

Minimalist (2-3 Chips): This design uses the most minimal hardware possible for each node. Relay nodes require 2 chips (one transmitter and one receiver), while the switch and splitter require an additional receiver and transmitter respectively. The downsides of this design involve the limited adaptability and modularity of each of the nodes. Additionally, the chips could not be soldered directly to each other unless the relay was designed to transmit in the direction of the received signal.

Hemispherical: This design uses a large number of chips to create a half-sphere design. While this is very modular, it would be extremely complex to build and program, and the large number of solder joints reduces its overall reliability. The benefits gained from modularity do not outweigh the disadvantages due to this design's complexity.

Spherical: Similar to the hemispherical design, but with an even larger number of chips. This design would be far more complex to build and program, with very little benefit over the hemispherical design. Additionally, the internal pads would be difficult to solder when closed off to the outside, especially if a support structure is needed for this arrangement.

Hexagonal Ring: This design uses 6 chips per node in a hexagonal ring (see Appendix A-1). One side of the ring would be transmitters, and the other side would be receivers. This design is very modular, as the same design can be applied for all nodes in the relay system; however, this design still uses a large number of chips and requires significant work to solder together. Due to the large number of potential failure points, this design's reliability is suspect.

Triangular: This design would use 3 chips directly connected to each other in a triangular fashion. While this is slightly more modular than the minimalist design, this design is exceedingly difficult to physically realize, as it requires soldering at interior angles in the triangle. Overall, is design has few advantages over the minimalist design, with added disadvantages.

Design Choice

The final design to be used will be the minimalist design. This design has the fewest overall pieces and the fewest number of solder joints. The two/three-chip design allows for the removal of extraneous chips in each module and grants the ability to send data directly from the receiver to the transmitter without having to route data through intermediate chips.

The hexagonal ring was most modular of the feasible design concepts, but would have required a complicated support structure and precise soldering angles. The hexagonal ring also required more chips than were given to us, so extra hardware would need to be ordered to build the modules. The software would also need to account for added chips between the signal source and destination within modules, and data would need to be routed among chips in the ring before reaching the transmitter. This adds unnecessary complexity in both software and hardware. If all joints were soldered, there would be 252 points of potential solder failure. Each of those points would need to be verified. The ring design is the most general-purpose of the planar options, but the generality isn't a design requirement, and the software would eliminate most of the general-purpose features at runtime, so that potential feature is essentially eliminated.

The triangular design seemed to offer the best compromise between modularity and simplicity, but when soldering the chips, the internal angles prevented solder from adhering to the pads. The soldering irons were also too large to fit in the spaces between chips to solder the ports on the internal angles without coming too close to components on the chips. Also, the separation distances between adjacent pads over the external angles was exaggerated by the widths of the boards, and would have needed to be jumped with small wires in order to avoid shorting the ground and power pads.

Arriving at the final minimalist design led to using wires to connect the ports and power/ground pads of the transmitter and receiver chips. This does not restrict the chips to being soldered to other chips directly adjacent, but instead being electrically connected while also inheriting a small amount of physical flexibility garnered by the wires connecting them. If there is any physical misalignment between nodes, the wire-connected design allows for readjustment of one side's alignment without compromising the alignment of the other side. Only having two chips per basic node (and three for the specialty nodes) significantly simplifies both the building and coding aspects of each module.

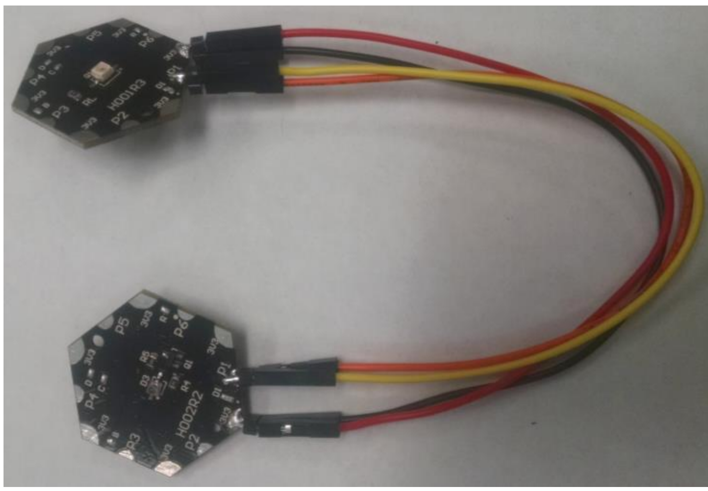
Since only four pads need to be connected per chip in a basic relay, the soldering load is significantly reduced. Overall, the total number of solder joints is reduced from 252 total joints to 80 when compared to the original hexagonal ring design. To verify solder joints, a simple electrical continuity check can be performed. Since there are far fewer solder joints than in the hexagonal design, performing these checks will be significantly less labor-intensive.

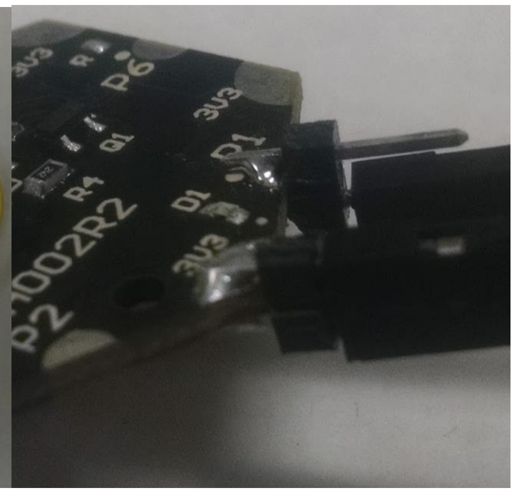
Additional links between chips might confuse the software, so only the minimum number of necessary links between chips will be used. The simplest designs have been chosen to minimize the possible points of failure and to allow more time for programming the communication and data relay software.

Detail Design

Hardware

The hardware design for the relay elements involves a 2-chip design using one receiver and one transmitter. Since the chips cannot be directly soldered to each other in this design, the relay nodes have 4 wires electrically connecting the V+, GND, Rx, and Tx ports on each chip, as pictured below.





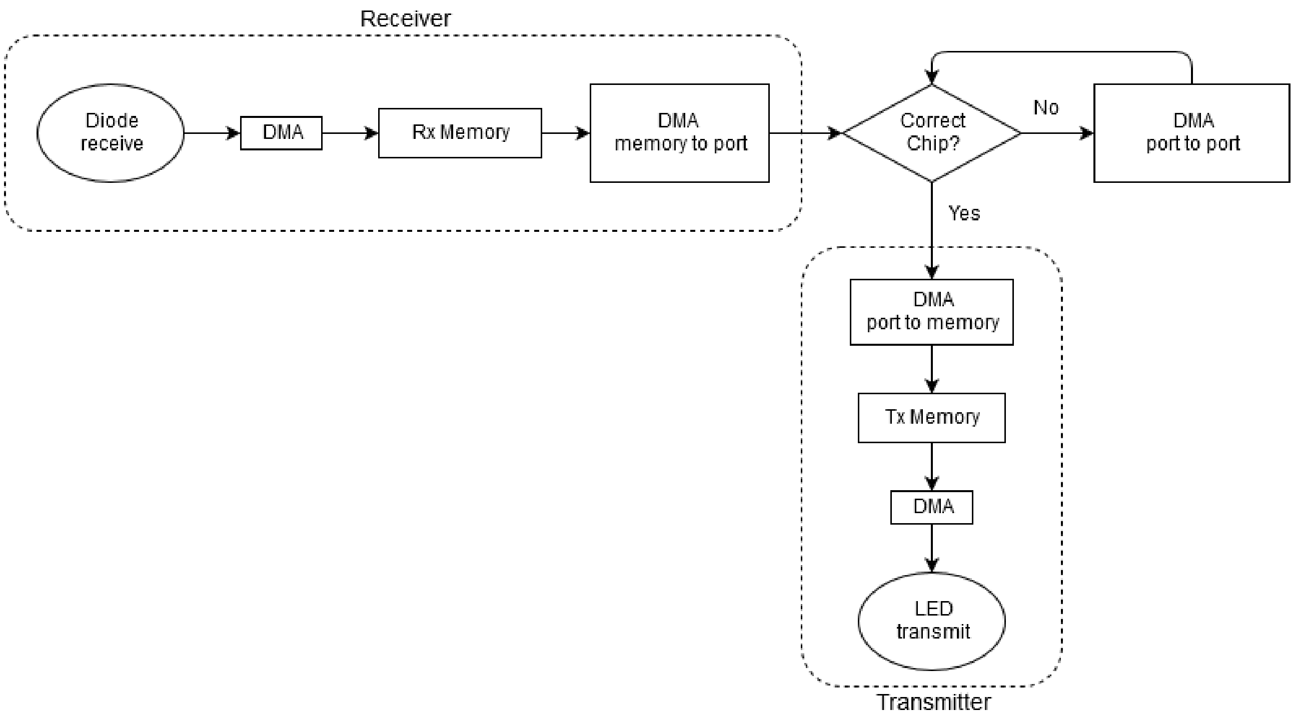
The pads are soldered to pairs of header pins, which can then be connected to jumper wires. Currently, the data port needed for programming the chip (Port 1) is being used for communication between chips as well, and since the chips are soldered to headers and connected via removable wires, there is not a need for additional port access while programming the chips. The same port can be used for programming and for interchip communication. Wire connections can be made on the fly.

The splitter and switch nodes each require 3 MOWE chips, adding a transmitter and receiver respectively to the above design. Adding the extra chip requires another 4 wire connections to the original relay design.

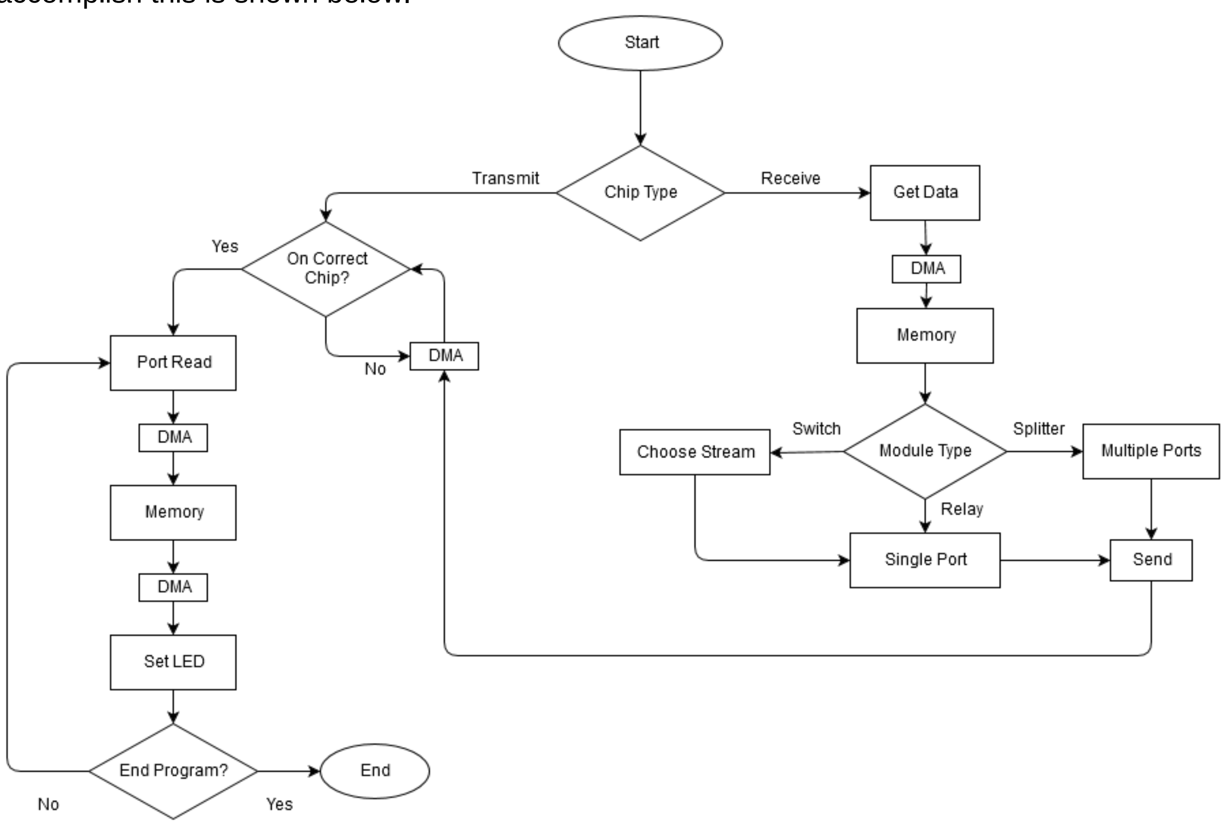
For the entire network, this design requires 16 MOWE chips: 8 transmitters and 8 receivers. There are 8 solder joints are required per relay node, and 16 solder joints required for the splitter and switch nodes, for a total of 80 solder joints.

Software

The dataflow for each module is diagrammed below. DMA refers to Direct Memory Access, which is able to move data without using the processor. This feature is highly efficient, and has consistent timing, which is required for data communications. The alternative approach involves using the pre-built message-passing system, which lacks consistent timing. As such the final design relies on DMA to achieve consistent timing.



This design involves moving incoming data from the receiver into memory, then from memory to an adjacent chip. The receiving transmitter chip stores the data stream into its internal memory, and then sets the transmitting LED accordingly. The software flowchart to accomplish this is shown below.



As detailed above, the software required varies based on the type of chip and which type of node the chip is a part of. The receiving chip stores the incoming data stream, then sends the data to the appropriate receiver(s) using DMA based on the type of node. The transmitter chips store the data relayed to it via DMA, then set the transmitter LED based on the data stored in its memory.

In addition to the above diagrams, the transmitter module on the switch has additional programming to change the active stream. When the active stream reads low, a timer interrupt is scheduled to occur in one second. This interrupt has the sole purpose of changing the active stream. Reading a value of high on the current stream cancels the interrupt. To receive data at the switch node, a second timer is used to trigger interrupts at a set interval to read and store the current bit into memory. In order to not receive spurious data from unexpected interruptions in the data stream, the switch looks for exactly one low signal followed by a high signal to indicate the beginning of an asynchronous data stream.

Procurement and Manufacturing

The total cost of this project is detailed in the Appendix B budget, which also shows the vendor and manufacturer for each product. However, this excludes cost reductions for components already available to the project, including the 16 MOWE chips. The total cost of the project including the MOWE components is $151.26. For full instructions on how to replicate this project, consult https://github.com/OUWECAD/MOWE/wiki/Project:-MOWE-Optical-Relay.

As shown in Appendix C, this project required roughly 152 hours of work, while 260 hours were estimated. This means we completed the project using about 60% of time anticipated. This is most likely a result of overestimating the time required for most tasks. The manufacturing component which would need to be repeated to build another prototype (soldering relays and building the support structure) took roughly 20 hours of work. As for this project's schedule, as shown in Appendix D, several tasks were finished behind schedule, particularly the poster, but this did not stop the overall forward progress of the project. Many of these work items only had slight modifications after their intended stop date, and did not preclude starting other tasks on time. Starting the coding and preliminary testing early allowed for some leeway in other areas, and helped the entire project end on schedule.

Testing and Modifications

The first test run on the prototype discovered an issue with the threshold for the receiver modules being set poorly. By running a quick program intended to debug this issue, it was discovered that the threshold for the longer links was too high, which resulted in the reception flickering. This threshold was lowered accordingly. The shorter links underwent a similar process, and their threshold was raised to correspond with the much higher signal they naturally received.

Additional testing was done to determine functionality in different ambient light conditions. Since the versions of the components used did not have visible-light filters built in, there was interfering noise received from the ambient light around the structure when in use. This extra noise caused the relays to function differently in different lighting conditions. For this reason, ambient light tests were employed to determine new threshold values as well as to determine the maximum operational ranges for the modules under different light.

Maximum operational distances were reported by the customer to be 24”, but tests showed that in near total darkness, maximum DC operational distance was 19.5”, in semidarkness 22.25”, and in normal bright light conditions (with inherent noise) the maximum operational distance increased to 42”.

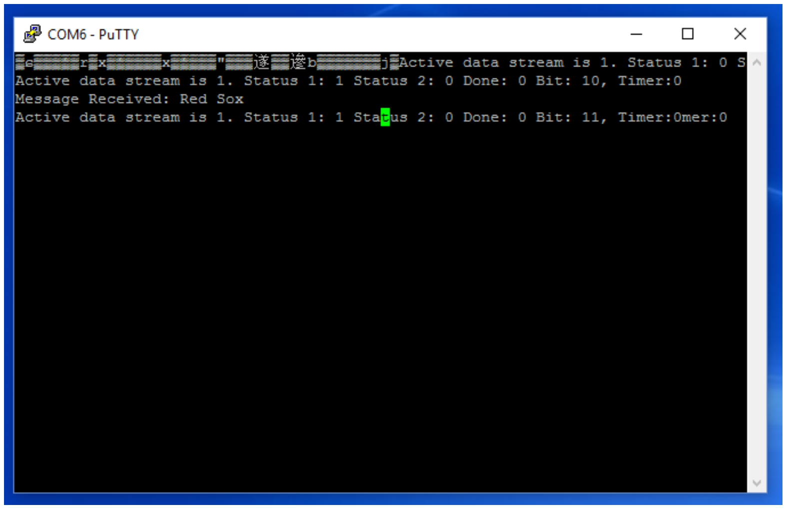
Acceptable lateral tolerance was also tested. With modules placed facing each other with transmission angle centerlines parallel, the short links still functioned up to 2.5” out of alignment which gives an acceptable out-of-alignment transmission angle of 15.25° and the long links functioned up to 4” laterally, giving an acceptable out-of-alignment transmission angle of 14.93°. These alignment numbers represent the distance side-to-side that the modules will still receive a signal if they are not rotated to face each other, but are instead facing parallel.

The support structure was constructed in such a way that individual nodes can be rotated to accommodate lateral misalignment in both the left and right directions, but also move vertically to accommodate vertical misalignment. Since the transmission zone is a 3-dimensional cone, vertical alignment is also a necessary consideration. All nodes were within ±½” of 5 ⅛” vertically, well within the 2.5” safe zone for all node links.

A reflection test was conducted to determine whether the signal would be obscured or interfere with itself vis a vis reflection off of nearby structural elements. Reflection tests were conducted to see distances and angles at which steady state values would be received via reflection from the structural base, which was painted with a matte black paint. In darkness, transmission occurred 1.75” facing the base and 79° from parallel between two nodes, and in the light transmission occurred at 1.25” at an angle of 83°. Since all nodes are above 1.75”, and well within 83°, surface reflection need not be a consideration for data corruption or interference.

Final Prototype

The final prototype meets the requirements and specifications. It is capable of relaying both a DC signal and a data signal, which is split using a dedicated splitter node, across two distinct paths, both of which are received by a dedicated switch node at the end of the network. The nodes are housed on adjustable mounts and are self-contained on a moveable platform. The physical topology is shown in Appendix A-2. If one of the signal paths is obscured or for any other reason the signal is lost for at least one second, the switch treats the other signal path as the active path, rerouting the network and displaying the data from the new path instead. Data communication, while primitive in its current implementation, is an additional delivered feature not in the original project requirements. A example output from the switch node (connected to an external computer via the P1 Tx port) is shown below. (There are some garbage characters visible as the communication was first established.)



Recommendations for Next Generation

In continuing to move this project forward, there are several areas for further improvement. First, the current protocol for sending data across the devices is extremely primitive and inherently unreliable. Improving this protocol to include sampling, error detection, and acknowledgments would greatly improve the reliability of the transmission. An encoding scheme like 4B/5B would also help in preventing long streams of 0s, which may otherwise be misinterpreted as a lost signal.

In order to implement an acknowledgement, either half or full duplex communication would need to be introduced, which would also be a useful improvement by itself. Once error detection bits are implemented, improving the switch software to compare the data it receives on both receivers and to choose the correct data would also greatly increase reliability.

As previously mentioned, modifying the hardware and software to allow for half or full duplex communication would further extend the utility of this platform. While the implemented simplex design works well for demonstrations and proof of concept, duplex operation is better suited for many practical applications of free space optics. Furthermore, it can be used to implement a better communication protocol.

Another possible extension would be to attempt to increase the data rate of the transmission by having the splitter node divide the signal into two streams each carrying half of the original message. This would require the switch node to be able to recombine the signal at the destination.

The final recommendation is not explicitly for this project, but rather for the MOWE elements as a whole. When attempting to develop the hardware for the nodes, it was extremely difficult to solder at the angles required for a relay, since relays are attempting to transmit in the direction opposite of what they receive. Two modules are not currently able to be directly connected with the transmitter and receiver 180^o apart, as this would require soldering the V^+ ports of one module to the ground ports of the other. If the design of the MOWE chips was reworked (or simply another design introduced), then all of the wires used in this project could be replaced by just soldering the components directly to each other.

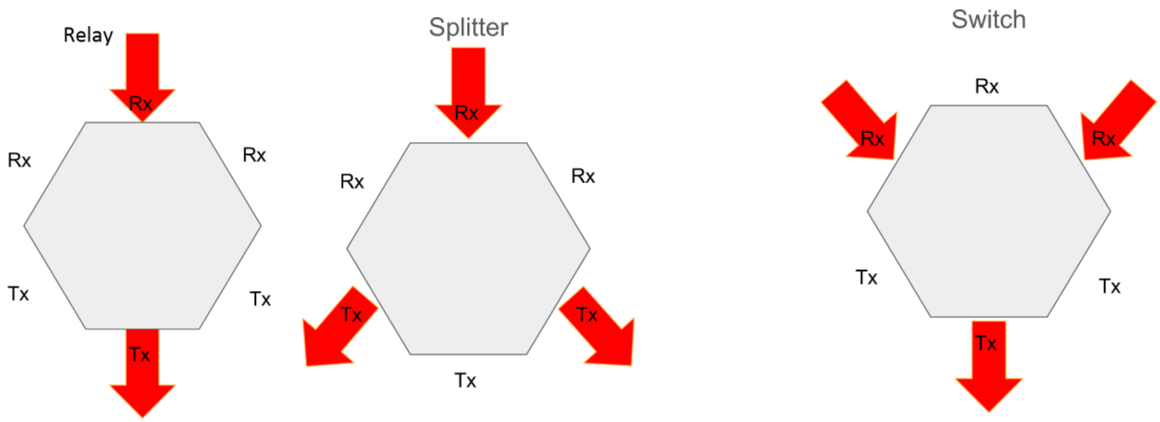
Project Summary and Conclusion

For this project, three specialized sets of modules (nodes) were employed. The first, and simplest, was the relay node, comprised of one receiver and one transmitter. This node retransmits the information it receives further along the network. This functions to both boost the signal strength of the transmission and possibly redirect it. The second node employed is the splitter node, which is comprised of one receiver and two transmitters. This node duplicates the data it receives and transmits it to two nodes further in the network, both downstream nodes receiving identical copies of the data. The final node employed was the switch node, comprised of two receivers and one transmitter. This node detects if a stream is active or blocked (if it has not seen a high value for at least one second), and switches to an active stream accordingly. This project has been completed on time and under budget, meeting all customer requirements.

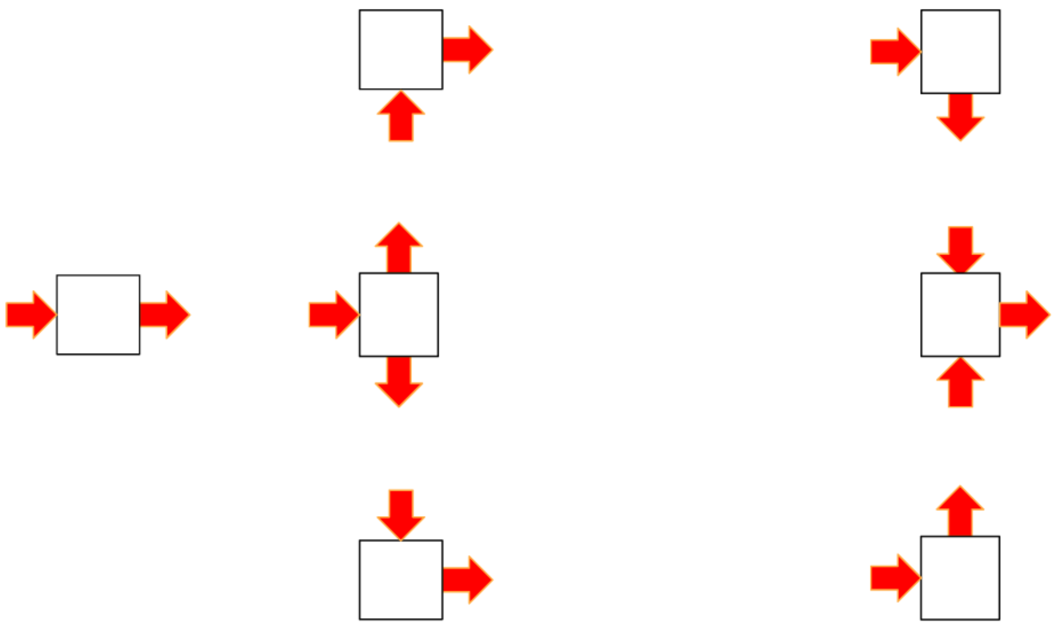
Our customers have expressed their approval for this project's outcome, and have shown interest in continuing to collaborate with the Electrical and Computer Engineering department in the future. Their goals for this research extends to in-field deployment, and further research is necessary to develop the platform even further. Our customers were pleased with our product and have expressed a desire to continue developing the MOWE project with TU. Additional information, including fabrication instructions and code for the project can be found at https://github.com/OUWECAD/MOWE/wiki/Project:-MOWE-Optical-Relay.

Appendices

Appendix A-1: Hexagonal Design Drawings



Appendix A-2: Physical Hardware Topology Drawing

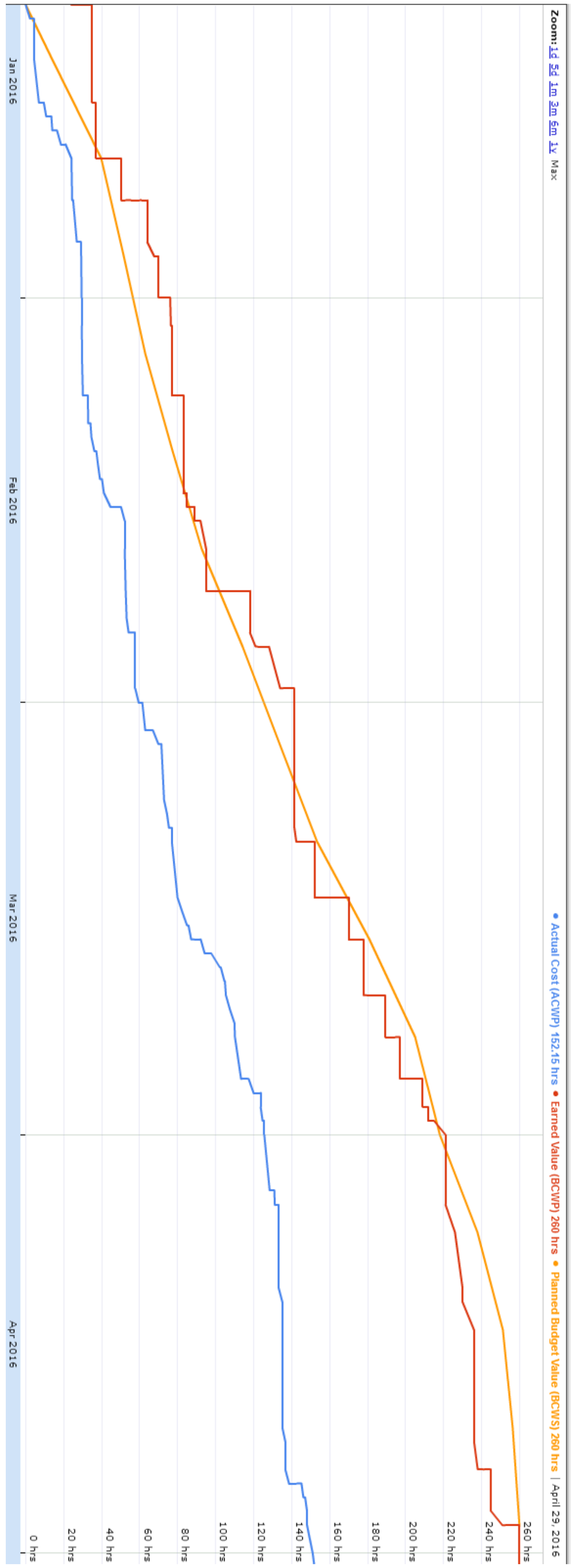


Appendix B: Budget

Part Name	Amount Required	Manufacturer Part Number	Manufacturer Name	Vendor Part Number	Vendor Name	Cost/ Unit	Number in Stock	Number to be Ordered	Total Cost/Part
USB to UART Cable	4	C232HD-DDHSP-0	FIDI	768-1011-ND	DigiKey	$26.00	2	2	$52.00
Cables (Male-Female)	2	MIKROE-512	MikroElektronika	1471-1231-ND	DigiKey	$3.06	0	2	$6.12
Cables (Male-Male)	1	MIKROE-513	MikroElektronika	1471-1232-ND	DigiKey	$3.06	0	1	$3.06
Cables (Female-Female)	4	MIKROE-511	MikroElektronika	1471-1230-ND	DigiKey	$3.06	0	4	$12.24
Headers	5	61302021121	Wurth Electronics	732-5301-ND	DigiKey	$1.25	0	5	$6.25
Solder	1					$1.25	1	0	$0.00
Spray Paint (Flat Black)	1	002006624746	Rustoleum	2006624746	Walmart	$3.86	0	1	$3.86
2x2x8 Treated Lumber	1		Lowe's	489328	Lowe's	$3.57	0	1	$3.57
3/8in x 6in Rounded Bolt	7		MG Chemicals	63345	Lowe's	$1.10	0	7	$7.70
3/8in Washers (10pk)	1		Hillman	58126	Lowe's	$1.24	0	1	$1.24
17GA x 7/8in Nail (1oz)	1	532674-B	Hillman	128237	Lowe's	$1.97	0	1	$1.97

Total Cost: $98.01
Total Allowable Budget: $200.00

Appendix C: Budget Lines



Appendix D: Schedule