Wavelength-Division Multiplexed Free-Space Optical Communications

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Background

- Free-space optical (FSO) communications is a branch of communications in which data is transmitted by light propagating in space.
  - Contrasts with fiber optic communications, which requires physical connections between transmitter and receiver
  - Contrasts with radio frequency (RF) communications, in which the signal is a carrier for the information rather than the information itself.
- FSO systems promise high data rates and secure communications, but suffer from a range of problems including beam dispersion, severe attenuation from weather, and high directionality. Thus, they see limited use in present-day communication systems.

Objectives

- Deployable high-rate communication systems are far beyond the scope of the project; thus, we are interested in low-cost and creative modulation schemes.
- We wish to design a transmitter-receiver pair with high-order modulation, channel coding, and a sufficiently-developed front end presentation.
- One area of particular interest is in multi-light arrays to transmit multiple data streams at once.
- Focus is away from data rates

Challenges and Limitations

- Synchronization between transmitter and receiver remains a significant challenge
- LED-based systems magnify the dispersion problem, but also make it possible to demonstrate a creative solution
- Signal recovery at the receiver side is highly attenuated, making noise an issue
- Range is severely limited due to cost considerations

Acknowledgement

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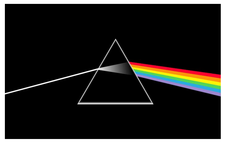
System Design

Modulation techniques

- On-off keying (OOK): Presence of a light indicates a “1”, absence indicates a “0”
  - Additional forms: NRZ and RZ
  - Most intuitive, least susceptible to noise, but bit-to-symbol ratio is low
- Pulse-amplitude modulation (PAM): Data encoded in the intensity (amplitude) of light
  - Higher bit-to-symbol ratio than OOK
  - Noise becomes a serious problem
  - Adding one bit requires doubling of amplitude levels – bit rate scales linearly, difficulty scales exponentially
- Wavelength-division multiplexing: Transmission of separate streams of data across different frequencies
  - In FSO, this means multiple colors of light
  - Can be combined with other modulation types

Wavelength-Division Multiplexing



- “Dark Side of the Moon” modulation
- Multiple lights interfere with each other to produce white light – we use a glass prism to decompose back into components

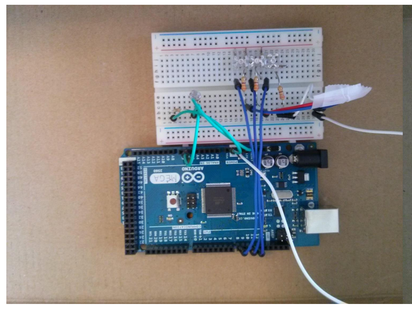
Results

System implements the following:

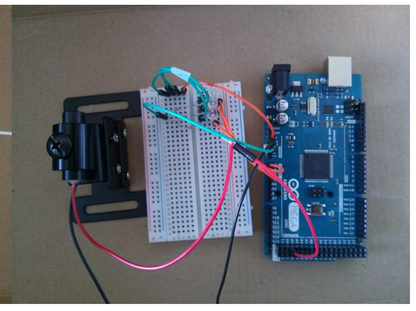
- Frequency division multiplexing
- Pulse-amplitude modulation
- Simple software-implemented forward error correction (FEC)
- Duplex link for automatic repeat request (ARQ) or hybrid ARQ

Future work includes:

- Improvements to symbol synchronization
- Upgrading light power to increase range
- Better-integrated forward error correction and HARQ
- General improvements to bit rate
- Migration away from prototype Arduino boards



Transmitter



Receiver

Scaling

- Wavelength-division multiplexing is a promising strategy for transmitting separate data streams
- Decomposing light via prism offers a unique transmission method
- On very small scales, can be used for intra-chip communication where lights easily interfere
- On very large scales, can be used to combat beam dispersion