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Vehicle to Vehicle Optical Communication Using Laser

KEYWORDS
vehicle to vehicle communication; optical communication; audio over laser

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ABSTRACT *We present a proof-of-concept device that transmits an audio signal using a laser beam whenever brake is applied. If another vehicle is close to it, it will receive the signal transmitted by the laser and a sound or alarm will be produced indicating that the vehicle in front has applied brakes. We can also remove the need for the user to align the beam themselves by using servo motor.*

Introduction

RECENTLY vehicle safety has aroused a lot of interest. As the number of vehicles on the road is increasing rapidly, accidents have become common.The main motivation for vehicular communication systems is safety and eliminating the excessive cost of traffic collisions. According to World Health Organizations (WHO), road accidents annually cause approximately 1.2 million deaths worldwide; one fourth of all deaths caused by injury. Of late, light emitting diode (LED) based optical wireless communication (OWC) systems have been developed. Especially, an OWC technology using visible light LEDs and lasers, referred to as visible light communication (VLC), has been receiving much attention. The laser is suitable as an optical-signal-sending device because light intensity of the laser can be modulated at high speed in comparison with traditional lighting devices, such as incandescent bulbs and fluorescent lamps and also the laser signal travels a longer distance without any disturbance as compared to LEDs. We use audio transmission over laser to establish vehicle to vehicle communication. The transmitter circuit consists of a laser present at the back of the vehicle which transmits the optical signal to a solar array in the receiver circuit present at the front of another vehicle . Thus, a communication is established when the vehicle which is ahead of another vehicle applies the brake, by transmission of a short duration audio signal.

Overview of Optical V2V Communication System

Fig.1 illustrates the optical V2V communication system. In this figure, a leading vehicle (LV) has laser transmitters that use vehicle brakes as input. A following vehicle (FV) has a horizontal solar panel. The LV collects its internal data and sends these data to the FV by optical signals. At the same time, the optical receiver, i.e, the solar panel on the FV captures the optical signal and the speaker gives the output messages like “applying brakes”. In addition to it, messages like “turning left” or “turning right” can also be sent by connecting the input with the indicators of the car. The receiver system monitors the light intensity in the detected region and receives the optical signals.

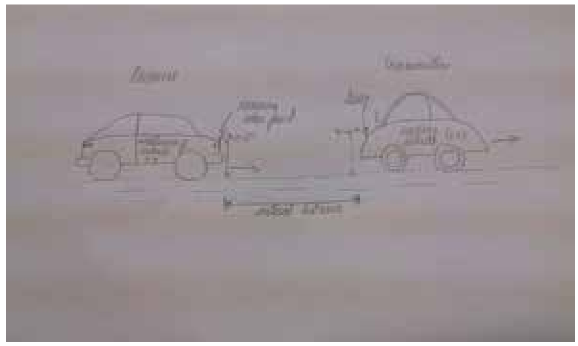


Fig. 1. Illustration of the optical V2V communication system.

transmitter circuitry

The transmitter is broken down into three circuits. The first circuit, which is similar to the receiver end, is the laser audio transmission circuit. This transmitter works by modulating the amplitude of the laser based on the amplitude of the audio signal that we are trying to transmit.

The audio, which is fed to the circuit through a standard 3.5mm audio jack, is sent to an adder circuit. The adder, shown below, consists of two inputs and a negative feedback resistor that will be summed together. The two connections to the non-inverting input of the op-amp are the audio signal and a DC bias signal that is generally kept at around 3V. This voltage can be modified by adjusting a potentiometer.

The signal to the inverting input of the op-amp is half that of the output, which is obtained by using a voltage divider of two equal resistors. This feedback allows the op-amp to follow the amplitude of the non-inverting input as it attempts to equate the voltages at the two inputs.

The output of the op-amp is sent directly to the laser. The amplitude of the laser is proportional to the voltage that is applied to it. The amplitude linearly follows the voltage up to roughly 4V, at which point the response is more exponential. We are taking advantage of the linear region of the response to send a mostly unmodified audio signal to the receiver for playback.

The laser needs to be turned off while the transmitter is scanning for the receiver, mainly for safety and power reasons. To achieve this, the 9V supply to the op-amp is controlled by an NPN transistor, which can act as a switch controlled by the microcontroller.

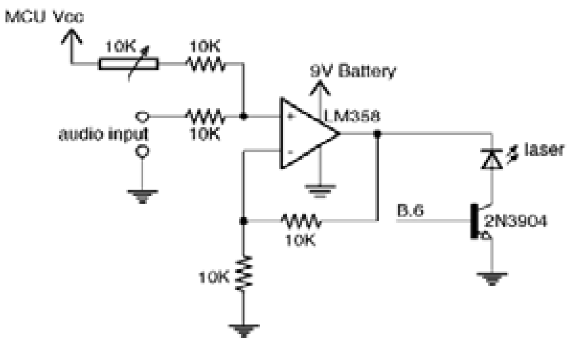


Figure 2: Main transmitter circuit. Modulates laser amplitude based on audio input.

The second circuit in the transmitter is based on a phototransistor that responds to red light. When V_{CE} of the transistor is set to 5 volts, the current flowing through the transistor is proportional to the amount of red light that is incident upon the detector. The current flows through the 10K resistor, resulting in a measurable voltage that is proportional to the incident light. This voltage is fed to the analog-to-digital converter of the microcontroller, and determines whether the receiver and transmitter are properly aligned and ready for transmission.

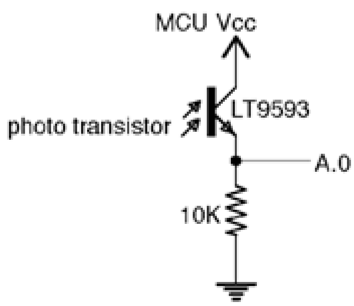


Figure 3: Transmitter photo detector used for alignment purposes.

The last piece of the transmitter is the motor controlling circuit. We are using a servo motor to control the direction of the transmission. The motor is opto-isolated from the rest of circuit, and particularly, the microcontroller. This means that the motor is powered by a different power supply, and has no direct connections with any terminal of the microcontroller.

The servo motor is controlled by a pulse, whose length corresponds with the desired position of the motor. Servos can achieve absolute positioning, while other types of motors can only be positioned relative to the current state. The precisely timed pulse is sent through a 330W resistor to the input of the isolator. The output of the isolator is simply the same pulse with a 5 volt amplitude, which is then sent to the motor for positioning.

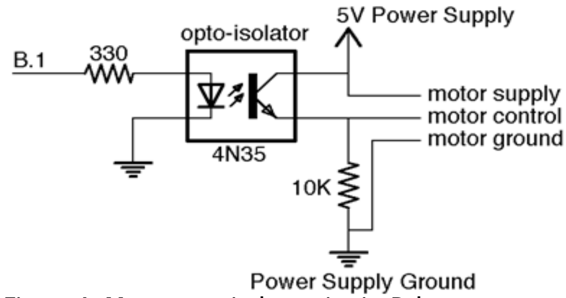


Figure 4: Motor opto-isolator circuit. Pulse output goes to motor for angle control.

RECEIVER CIRCUITRY

The receiver circuit somewhat resembles the transmitter circuit. Rather than a single phototransistor, however, it instead uses three photodiodes, which have much larger sensitive areas compared to the transistor. Since the response of the diodes directly affects the audio quality, a more complex circuit is called for. The diodes themselves are placed between the two terminals of an op-amp, whose output voltage is determined by the current that flows through the diodes. Using an op-amp instead of biasing the diodes allows us to utilize a near-ideal short-circuit current. With three diodes in parallel, we effectively triple the area upon which we can receive a signal. After amplifying the signal with a second op-amp, the result is then fed directly to an audio jack, where the signal can be heard using any compatible device.

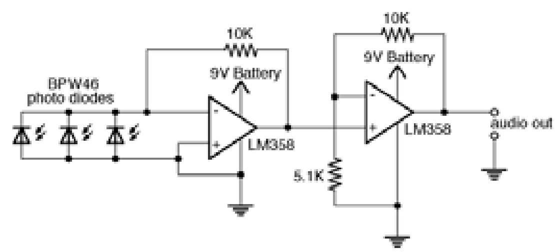
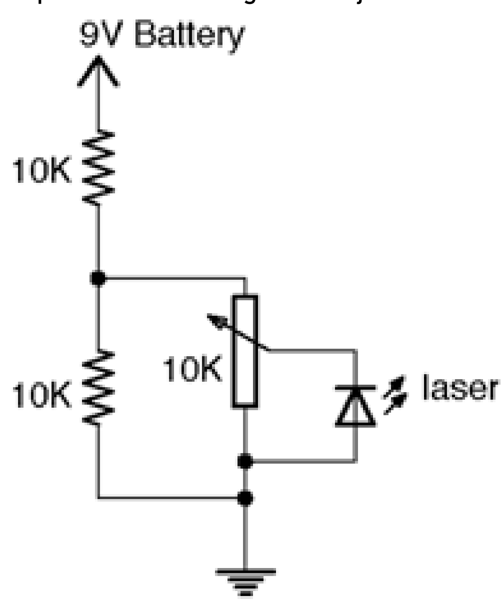


Figure 5: Receiver main circuit. Reads detector voltage and amplifies before sending to audio jack.



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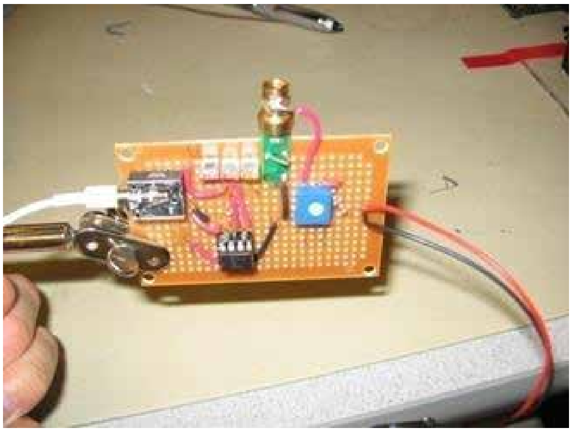


Figure 6 (left): Receiver laser circuit. Used for alignment purposes.

SOFTWARE

The software is designed to be completely interrupt-driven. Timing is based around the ability to control an output pin with a precise PWM output, allowing us to accurately control the motor for scanning purposes. The interrupt service routine is called once every five microseconds. Upon each interrupt, the program updates its timing counters, reads the output of the analog-to-digital converter when necessary, and performs state updates for receiver tracking purposes.

```
#include <inttypes.h>
#include <avr/io.h>
#include <avr/interrupt.h>
void initialize(void);
void stateupdate(void);
void track(void);
#define MIN 1200            // minimum pulse length (angle)
#define MAX 1400   // maximum pulse length (angle)
#define INTPTIME 200 // inter-pulse time in ms
#define INCREMENT 5  // distance between two adjacent angles (min. 5)

#define THRESHOLD 50 // Minimum intensity to measure for a lock
#define GUESSMAX 20  // Number of steps to take in a direction before giving up
#define TRACKMAX 2          // Number of times to switch directions while tracking before
                            // giving up completely
                            // State Machine States
#define SCAN 1
#define MAYBEDETECT 2
#define LOCK 3
#define MAYBELOST 4
#define TRACKLEFT 5
#define TRACKRIGHT 6
volatile unsigned int uscount = 0, mscount = 0;
    // us and ms counter
volatile unsigned int pulsetimer = 0, pulselength = 1300;
    // pulse timer and pulse length in us
volatile unsigned char pulseflag = 0, updown = 1, adcout;
    // flags for pulse trigger, scan direction, and A/D conversion value
unsigned char state = SCAN, lastdir = 5, guesscounter=0, trackattempt=0;
    // State vairable, last state, counters for GUESSMAX and TRACKMAX
unsigned char lastworked = 5;
    // Last good tracking direction
volatile unsigned char pinout = 0;
    // Value to send to PORTB
ISR (TIMER0_COMPA_vect)
{
// Used to keep track of time, and generates the motor control signal.
uscount+=5;          // Conversion factor of 5 us per 80 ticks
if (uscount == 1000)
{
mscount++; // Count milliseconds
uscount = 0;
if (mscount == INTPTIME)
{
        // Pulse interval begins; start the control pulse and another A/D conversion
if (state != LOCK)
{
pulseflag = 1;
pinout |= 0x2;
}
mscount = 0;
adcout = ADCH;
ADCSRA |= (1<<ADSC);
stateupdate();       // Update state
track();             // Perform state-specific actions
}
}
if (pulseflag)
{
// While we're sending the pulse, keep track of when to stop it
pulsetimer+=5;
if (pulsetimer == pulselength)
{
pulsetimer = 0;
pulseflag = 0;
pinout &= 0xFD;
}
}
PORTB = pinout;
}
int main (void)
{
initialize();
while(1)
{
// Everything is interrupt-driven!
// =]
}
}
void stateupdate (void)
{
switch (state)
{
case SCAN:
        //        While we're scanning, we're looking for something to show up on the phototransistor
if (adcout > THRESHOLD)
{
lastdir = state;
state = MAYBEDETECT;
}
break;
case MAYBEDETECT:
        // Authenticate that we've found the receiver, otherwise go back to whatever it was we're doing
```

```
if (adcout > THRESHOLD) state = LOCK;
else state = lastdir;
break;
case LOCK:
    // Just wait until we lose the receiver
if (adcout < THRESHOLD) state = MAYBELOST;
break;
case MAYBELOST:
// Authenticate the loss and start tracking
if (adcout < THRESHOLD)
{
state = lastworked;
}
else state = LOCK;
break;
case TRACKLEFT:
case TRACKRIGHT:
    // Once we find it again, remember which direction
worked
if (adcout > THRESHOLD)
{
lastworked = state;
lastdir = state;
state = MAYBEDETECT;
}
break;
default: state = SCAN;
}
}
void track (void)
{
switch (state)
{
case SCAN:
        //      Scan for the receiver by going back
and forth between MIN/MAX
        //      LED displays the current direction
pinout &= 0xFE;
PORTD = (updown << PORTD2);
//PORTB = pinout;
if (pulselength >= MAX) updown = 0;
else if (pulselength <= MIN) updown = 1;
if (updown)  pulselength += INCREMENT;
else                    pulselength -= INCREMENT;
break;
case MAYBEDETECT:
        //      Stop scanning, but don't turn on the
laser
pinout &= 0xFE;
//PORTB = pinout;
break;
case LOCK:
        //      Enable the laser, blink the LED
pinout |= 0x1;
PORTD ^= (1<<PORTD2);
//PORTB = pinout;
break;
case MAYBELOST:
        //      Keep the laser up-- for now
pinout |= 0x40;
break;
case TRACKLEFT:
    // See if the receiver went left.
pinout &= 0xFE;
PORTD = (0 << PORTD2);
    //PORTB = pinout;
pulselength -= INCREMENT;
guesscounter ++;
if (guesscounter == GUESSMAX || pulselength <= MIN) //
When we reach the end or give up
{
guesscounter = 0;
trackattempt ++;
pulselength += GUESSMAX * INCREMENT;
if (trackattempt < TRACKMAX) state = TRACKRIGHT;// Go
back to scanning if we just can't get it
else
{
state = SCAN;
updown = 1;
}
}
break;
case TRACKRIGHT:
        //      Same as TRACKLEFT, but mirrored
pinout &= 0xFE;
//PORTB = pinout;
pulselength += INCREMENT;
guesscounter ++;
if (guesscounter == GUESSMAX || pulselength >= MAX)
{
guesscounter = 0;
trackattempt ++;
pulselength -= GUESSMAX * INCREMENT;
if (trackattempt < TRACKMAX) state = TRACKLEFT;
else
{
state = SCAN;
updown = 0;
}
}
break;
default:;
//PORTB = 0;
}
}
void initialize (void)
{
DDRB = 0xFF;            // Port B0 and B1 as output
DDRD = (1<<PORTD2); // Enable the output for the LED
PORTB = 0;
// set up timer 0
OCR0A = 80; // clear after 80 counts (5us)
TIMSK0 = (1<<OCIE0A);  //turn on timer 0 cmp-match ISR
TCCR0A = (1<<WGM01); // turn on timer 0 clear on match
TCCR0B = 1; // run at full speed
//init A/D converter
ADMUX = (1<< REFS0) | (1<< ADLAR);
ADCSRA = (1<<ADEN) | ((1<<ADSC) + 7);
// Start up the interrupts
sei();
}
```

The State Machine

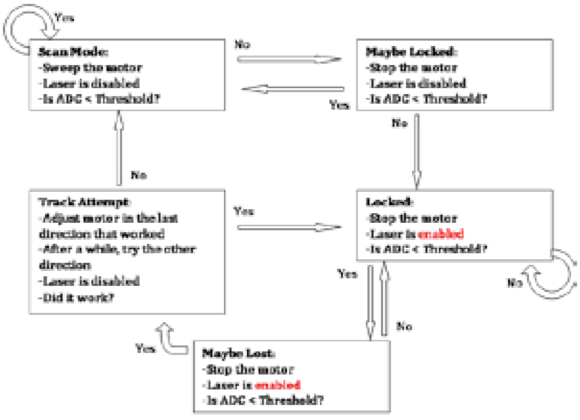


Figure 7: Software state machine, used for transmitter scanning.

We use a simple Moore machine to control the actions of the transmitter. The diagram above outlines its behavior.

Motor and Alignment

The small servo motor performs admirably under the load of the transmitter circuit, operating smoothly and consistently. However, the physical connections to the power supply for the motor and the stk 500 causes the base to slide on all but the roughest of surfaces without adhesives. Once anchored, this is a non-issue.

The transmitter and receiver align moderately well. Care must be taken in placing the receiver, as its laser must point towards the center of rotation of the transmitter. Even with this satisfied, there remains a degree of flexibility in the angle of the transmitter while in the LOCK state, which means that the transmitter beam can miss the photodiodes of the receiver as the distance between the two increases. WE can switch to the array of three photodiodes, then the frequency of this misalignment occurring decreased noticeably. Partial misses can also occur when the beam is between two diodes or slightly off one of them. The result is that different volumes are required in the source to prevent distortion.

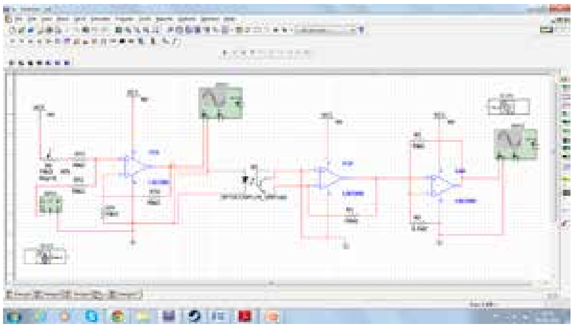
WORKING

The transmitter circuitry is placed in the leading vehicle. Whenever brakes are applied, and audio message is given to the transmitter circuit. This message is sent over the laser. A solar panel in the following vehicle captures the message when laser falls on it, which is then played through a speaker. It is the receiver's responsibility to decide the relevance of emergency messages and decide on appropriate actions. In case, the person in following vehicle decided to apply brakes, the message is in turn sent to the transmitter circuitry, which has a laser transmitter placed at the back of the vehicle. Thus, a chain of warning can be produced to avoid accidents due to collision.

APPLICATIONS

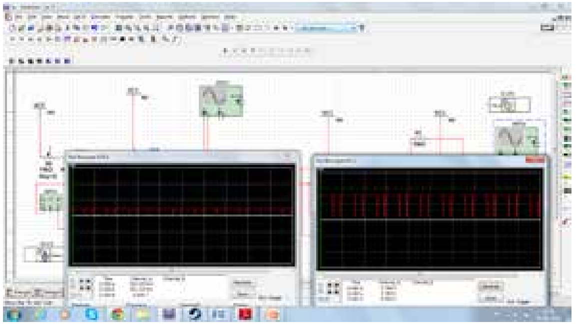
Vehicular communication networks will provide a wide range of applications with different characteristics. As these networks have not yet been implemented, a list of such applications is speculative and apt to change in the future (However safety, which is the main purpose of these networks, will most probably remain the most important applications).The primary application of optical vehicle to vehicle communication is :Safety- Sudden halts warnings, Lane change warnings, Warnings on entering intersections, Warnings on departing the highways

simulation circuit



Results

When dealing with audio transmission, an important consideration is how well a range of frequencies is preserved in the output. Generally, the audible frequencies range from 20 to 20,000 Hz.



CONCLUSION

In this paper, we presented a V2V communication system based on OWC technology linked by laser transmitter and a photosensitive solar receiver. The laser transmitter is capable of sending various audio messages which would tell the following vehicle that the leading vehicle is applying brakes, and even other messages like turning left or right. This model can prove to be a breakthrough in optical communication.

LITERATURE REVIEW

Genetic Algorithm-based Dynamic Vehicle Route Search using Car-to-Car Communication (Oh, Na, Yang, Park, Nang, Kim) -Tackles genetic algorithms for route searching

Vehicle ad hoc networks: applications and related technical issues IEEE communications journal (Toor, Inira, Muhlethaler and Laouiti) -Tackles Security

Unicast routing protocols for vehicular ad hoc networks: A critical comparison and classification University of Kentucky -Talks about communication paradigms Different V2V protocols and their algorithms

FUTURE DEVELOPMENTS

Use of laser has certain limitations and will not offer communication between large number of vehicles, such as vehicles at a junction, etc. So, GPS and wifi are the two methods by which any type of communication can be achieved in all types of conditions. Automatically analyzing the traffic signs and signals is also possible by incorporation of cameras onto the vehicles or emission of warning signals directly from the traffic boards which can be read by the receivers in the vehicles.

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