DEVELOPING A PROTOTYPE OF A SMART-LIGHTING SYSTEM FOR ISOLATED RURAL INTERSECTIONS

FINAL PROJECT REPORT

by

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16. Abstract

Rural intersections are high-risk locations for road users. Particularly, during the nighttime, lower traffic volumes make it difficult for drivers to discern an intersection despite traffic signs. The lack of alertness may lead to severe crashes. An effective way to reduce the likelihood of crashes at isolated intersections is to warn road users of the intersection in advance. A smart-lighting system can detect approaching vehicles using sensors and transmit this information to a receiver to illuminate the intersection. By deploying a demand-responsive light, it is expected that the system will provide adequate warning to road users, both motorized and non-motorized. This report documents the development and deployment of a smart-lighting system at the University of Alaska Anchorage (UAA).

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

Rural intersections are high-risk locations for road users. Particularly, during the nighttime, lower traffic volumes make it difficult for drivers to discern an intersection despite traffic signs. The lack of alertness may lead to severe crashes. An effective way to reduce the likelihood of crashes at isolated intersections is to warn road users of the intersection in advance. A smart-lighting system can detect approaching vehicles using sensors and transmit this information to a receiver to illuminate the intersection. By deploying a demand-responsive light, it is expected that the system will provide adequate warning to road users, both motorized and non-motorized. This report documents the development and deployment of a smart-lighting system at the University of Alaska Anchorage (UAA).

CHAPTER 1. INTRODUCTION

In 2019, about 45 percent of the traffic fatalities occurred in rural regions[1]. The data for traffic crash fatality rates per 100 million miles traveled show that the rural areas experience twice the risk compared to urban areas (LRRB, 2015). Studies have found that poor lighting plays a significant role in crashes. Since the rural roads have low traffic volumes at night, drivers do not expect other vehicles (Minnesota DOT, 2015). The reason for intersection crashes during nighttime hours may be poor driver perception of conflicting traffic or the presence of an intersection. In rural regions, the primary source of lighting is vehicle headlights. The illumination of roadways improves motorists' recognition of crossing points, and sign and marking readability. A study in Minnesota showed that an increase of 1-lux in lighting reduced crashes by as much as 94 percent at unlighted intersections (Minnesota DOT, 2015).

Most of Alaska is rural, and its intersections are isolated. Alaskans also experience long dark hours in winters. These unique conditions pose challenges to rural Alaskans in terms of traffic safety. Since the rural regions in Alaska have a lower population and limited resources, they may not have sufficient technical know-how or workforce to develop and implement safety interventions. Additionally, a lack of efficient incident management and emergency response systems can also contribute to the crash fatality risk. This motivated our research to develop an easy-to-deploy and affordable prototype of a smart-lighting system to enhance the safety of isolated intersections in Alaska. This report summarizes the development, design, and deployment of the system and the challenges faced.

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[1] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/813206

CHAPTER 2. THE DESIGN OF THE SMART-LIGHTING SYSTEM

This chapter covers the design of the smart-lighting system. This chapter contains the following subsections: 2.1) The design concept, 2.2) Components, and 2.3) Design and implementation.

2.1. The Design Concept

Due to the long winter nights and the lack of a reliable energy source, constant illumination of rural intersections may not be feasible. An alternative option is illuminating the intersections when vehicles approach. Figure 1 shows a schematic diagram of our proposed smart-lighting system for a 4-way intersection. It contains three major parts: (1) sensor & transmitter units, (2) a receiver unit, and (3) a light unit. Depending on the number of approaching roads, the number of sensor & transmitter units will vary. Each of these components is discussed next.

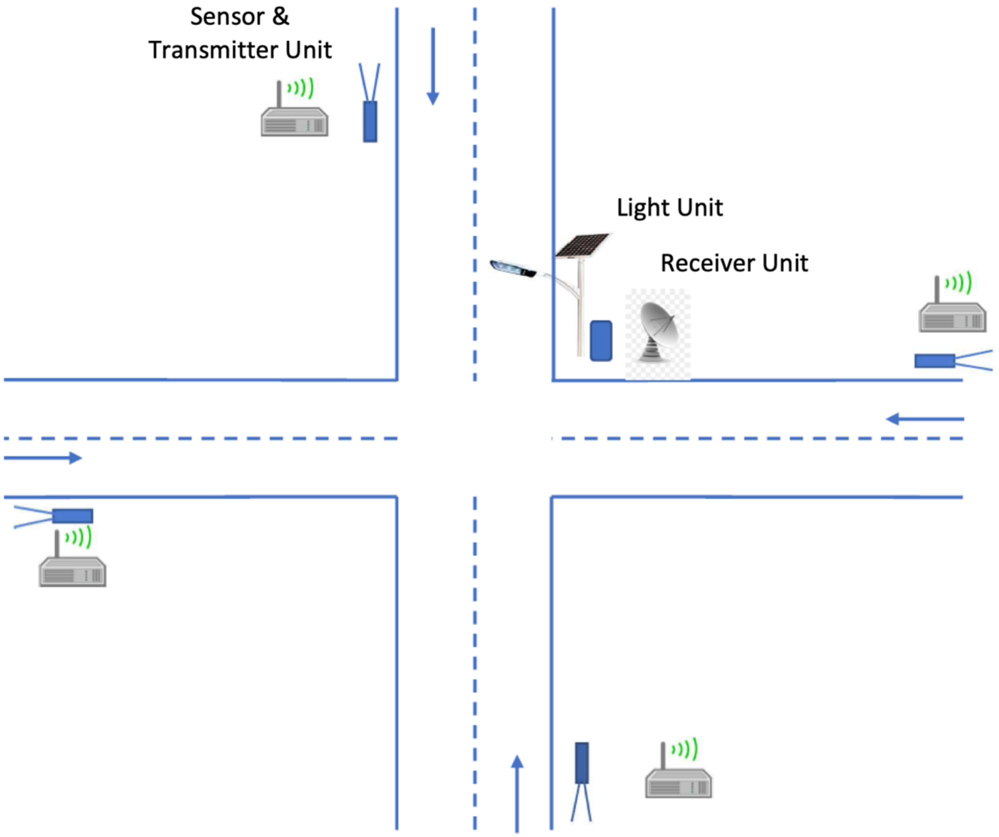

Figure 2.1 Schematic diagram of the proposed smart-lighting system

2.2. Components

Sensor & Transmitter Units: Since accurate vehicle detection is an essential requirement of the system, the research team explored various sensor options. The team found both laser detector and Doppler radar as promising choices for the proposed system. The advantages and disadvantages of the two sensing technologies were meticulously studied. Doppler radars are inexpensive and can detect objects within a more significant portion of the road. Laser detectors are typically more expensive and precise calibration must be maintained in order for them to work properly. In order to meet the objectives of the project in developing a low maintenance and easy-to-deploy smart-lighting system, we chose Doppler radar. Among multiple Doppler sensors available, we chose OmniPresense OPS243A. With a range of up to 100 m (~328 ft), this sensor has the most extended range among all the low-cost options available. The radar is capable of taking between 1,000 and 100,000 samples per second. Lower sampling frequency means higher accuracy in locating the object; however, it limits the detection sensitivity only to slow-moving objects. Increasing the sampling frequency could enable detecting objects with higher speed, but will compromise the accuracy of reporting the exact location of the object (for example, if frequency is set to 1,000 the max reported speed is 7.0 mph ±0.014. While with a frequency of 100,000 the max reported speed is 696.4 mph ±1.358).

The second major component of the sensor & transmitter unit is the transmitter. We purchased RF Link 434 MHz transmitter (from www.sparkfun.com). The sensor continuously monitors the detection zone for moving objects. Once an object is detected, the information is processed to capture the required parameters such as speed and location of the detected objects. In our project the processing was performed in an Arduino interface. The Arduino and its underlying software will trigger the transmitter when the sensed values exceed the defined thresholds. The thresholds include approaching speed and size of the moving objects and they can be adjusted based on the ground conditions. This will provide the end users the ability to customize the prototype based on the specifics of their deployment site. We performed some basic experiments by changing the approach speeds and size to reduce false detection without omissions. Hence, the initial thresholds that could best fit the vehicles on the streets were determined.

Receiver Unit: The purpose of this unit is to receive the signal from the transmitter, process it, and turn the light unit on. After checking the configurations, we selected RF Link 434Mhz receiver in this project. This unit uses an Arduino to process the received data. Once this unit receives the detection information from the sensor & transmitting unit, it will send a signal to the light unit.

Light Unit: The light unit is another integral part of the smart-lighting system. In our design, we used an LED light as the light unit. Due to lower power consumption, an LED light was used to test the functionality of the prototype; however, this will be replaced with a high-intensity light in the next phase of the project.

2.3. Design and Implementation

We started with initial testing of each sensor to make sure they function as expected. Initial assessment of the Doppler radar showed that they were capable of detecting speed; however, they failed to detect vehicles approaching with speed less than 15 mph. We fine-tuned the sensor to ensure they are capable of detecting objects within the speed range of 0 mph and 120 mph, which represents a typical speed range of traffic. In order to guarantee the interoperability of the sensor and transmitter, we developed a C++ script (see Appendix B) to ensure real-time communication of information. Another C++ script (see Appendix B) was written to enable communication between the receiver unit and the light unit. A 20000 mAh portable charger was used to power the receiver and the sensor & transmitter units. The next task was to have multiple sensor & transmitter units communicating with one receiver unit. This was a challenging task as the receiver unit could receive conflicting signals from different sensors. This caused inconsistency in the way the light unit is turned on. For example, if there are two sensor & transmitter units installed, one facing an approaching vehicle will detect the object and send an “Incoming” signal; however, the one facing the opposite direction will not detect this vehicle, thus sending an “All Clear” signal to the receiving unit. To fix this we wrote a function to prioritize the incoming signals making sure the light unit will remain on while a vehicle is detected by any of the installed sensors. To summarize, the design process can be illustrated in the following steps:

Step 1) The sensor & transmitting unit detects a vehicle

Step 2) The unit sends an “Incoming” signal to the receiver unit and starts a countdown.

Step 3) The receiver unit receives the signal and communicates to turn the light unit on for a predefined duration.

Step 4) At the receiving unit there are two possibilities:

- If a vehicle is detected by one or more of the sensors & transmitter units, restart the countdown.
- If no vehicles are detected by any of the sensor & transmitter units while the countdown is in progress, turn off the light unit.

CHAPTER 3. THE END PRODUCTS

There are three end products for this project: 1) A functional smart-lighting system prototype, 2) Design and installation guideline, and 3) The final technical report.

We tested the designed prototype at the UAA campus with the following specifications.

- ***Maximum speed threshold:*** For this prototype we used a frequency of 10,000 with a maximum reporting speed of 120 mph ± 0.278.
- ***Minimum speed threshold:*** For this prototype we used 3 mph as the threshold.
- ***Maximum distance between the sensor and approaching vehicle:*** The distance depends on the detection range of sensors. In this case the range is about 200 ft.
- ***Maximum communication distance between the sensor & transmitting unit and the receiving unit:*** The distance depends on the communication range of the transmitter and the receiver. In our case this range is about 300 ft.

Figure 2 shows the experimental set up of our prototype. As it can be seen, the LED bulb lights up after the sensor detects an approaching vehicle.

Figure 3.1 The experimental set up at UAA

Appendices A-C of this report provides detailed information on the circuits, codes used in the Arduino, and the setup of the sensor used in the system.

List of References

Local Road Research Board, 2015. *Rural Intersection Lighting Reduces Nighttime Crash Rates*. <https://www.lrrb.org/media/reports/201505TS.pdf>. Accessed May 15, 2020.

Minnesota Department of Transportation, 2015. *Lighting Levels for Isolated Intersections: Leading to Safety Improvements.* <https://www.dot.state.mn.us/trafficeng/safety/docs/lightinglevels.pdf>. Accessed June 20, 2020.

APPENDIX A: BASIC CIRCUIT DIAGRAMS

The Sensor & Transmitter Unit

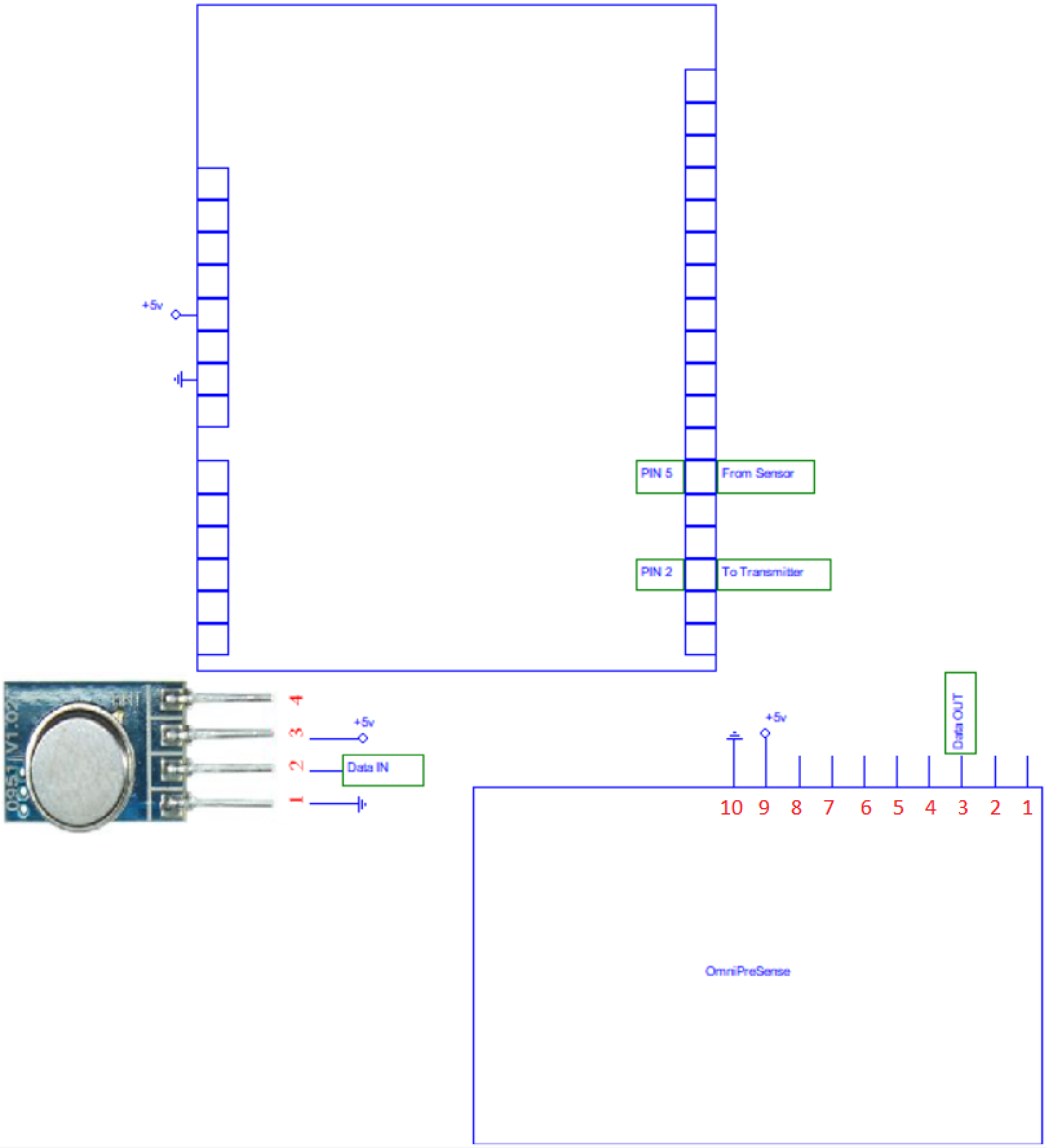

Figure A.1 Basic circuit diagram of the sensor & transmitter unit

The Receiver Unit

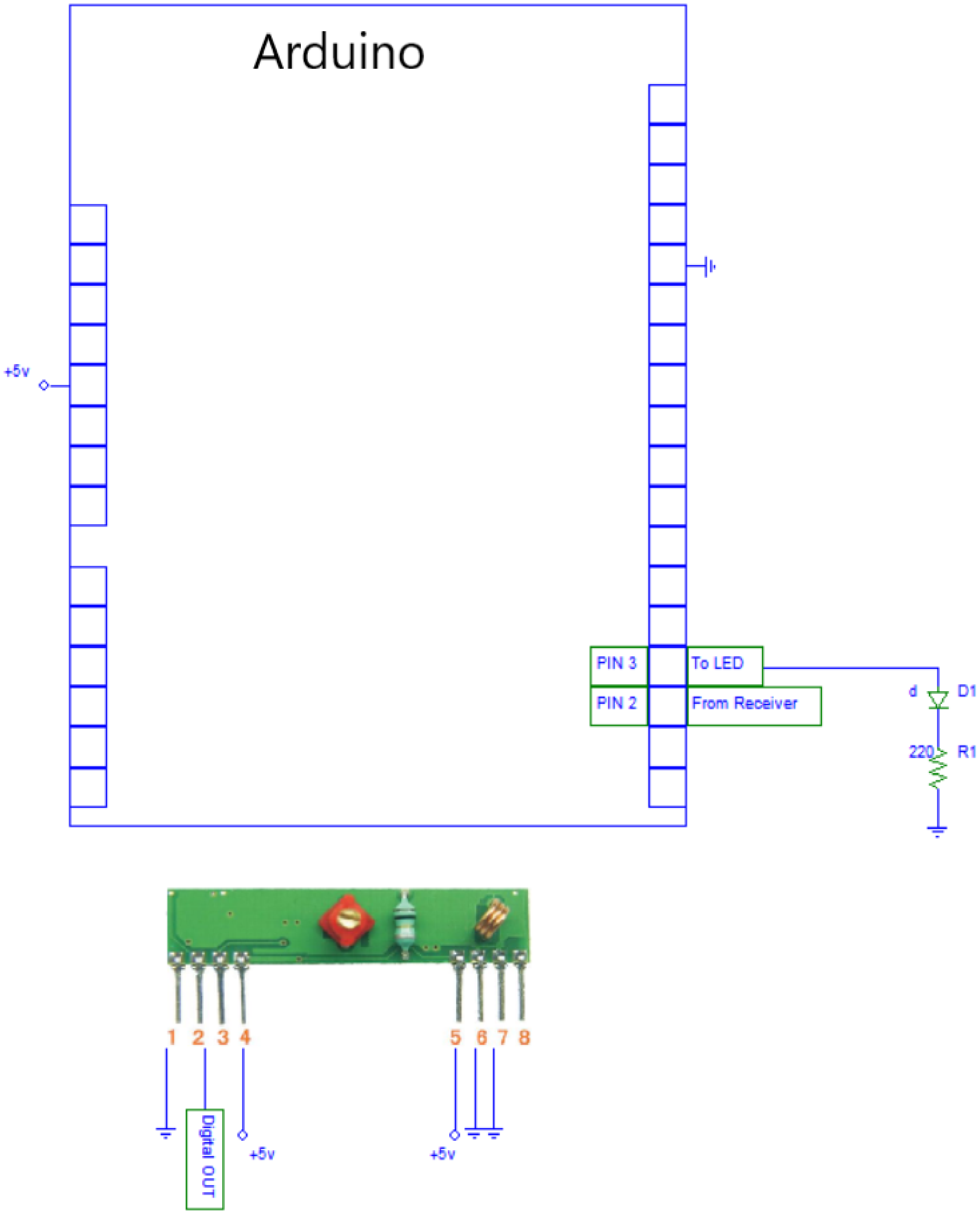

Figure A.2 Basic circuit diagram of the receiving unit

APPENDIX B: ARDUINO CODE

The Sensor & Transmitter Unit

```
// ask_transmitter.pde
// -*- mode: C++ -*-
// Simple example of how to use RadioHead to transmit messages
// with a simple ASK transmitter in a very simple way.
// Implements a simplex (one-way) transmitter with an TX-C1 module
// Tested on Arduino Mega, Duemilanova, Uno, Due, Teensy, ESP-12

#include <RH_ASK.h>
#ifdef RH_HAVE_HARDWARE_SPI
#include <SPI.h> // Not actually used but needed to compile
#endif
//RH_ASK driver;
RH_ASK driver(2000, 4, 2, 0); // ESP8266 or ESP32: do not use pin 11 or 2
// RH_ASK driver(2000, 3, 4, 0); // ATTiny, RX on D3 (pin 2 on attiny85) TX on D4 (pin 3 on attiny85),
const int omniOutPin = 5;
int omniState = LOW;
void setup()
{
#ifdef RH_HAVE_SERIAL
  Serial.begin(9600);      // Debugging only
#endif
  if (!driver.init())
#ifdef RH_HAVE_SERIAL
       Serial.println("init failed");
#else
        ;
#endif
pinMode(omniOutPin, OUTPUT);
}
void loop()
{
  omniState = digitalRead(omniOutPin) + 48;
  char temp = char(omniState);
  char *msg = &temp;
  if (*msg == '0') {
    driver.send((uint8_t *)msg, strlen(msg));
    driver.waitPacketSent();
    Serial.print(*msg);
    delay(1900);
  }
  delay(100);
}
```

The Receiver Unit

```
// ask_receiver.pde
// -*- mode: C++ -*-
// Simple example of how to use RadioHead to receive messages
// with a simple ASK transmitter in a very simple way.
// Implements a simplex (one-way) receiver with an Rx-B1 module
// Tested on Arduino Mega, Duemilanova, Uno, Due, Teensy, ESP-12
#include <RH_ASK.h>
#ifdef RH_HAVE_HARDWARE_SPI
#include <SPI.h> // Not actually used but needed to compile
#endif
RH_ASK driver(2000, 2, 5, 0);
const int ledPin = 3;
int ledState = LOW;
int coolDown = 0;
void setup()
{
#ifdef RH_HAVE_SERIAL
   Serial.begin(9600);      // Debugging only
#endif
   if (!driver.init())
#ifdef RH_HAVE_SERIAL
        Serial.println("init failed");
#else     ;
#endif
pinMode (ledPin, OUTPUT);
}
void loop()
{
  delay(300);
   uint8_t buf[RH_ASK_MAX_MESSAGE_LEN];
   uint8_t buflen = sizeof(buf);
   if (driver.recv(buf, &buflen)) // Non-blocking
   {
     if (*buf == '0') {
       ledState = HIGH;
       coolDown = 10;
     }
   }
   else if (coolDown <= 0){
     ledState = LOW;
     coolDown = 0;
   }
   coolDown--;
   digitalWrite(ledPin, ledState);
}
```

APPENDIX C: SENSOR SET-UP

1. Go to “putty.org” and download PuTTY
2. Open PuTTY
3. Under “Specify the destination you want to connect to” for “Connection type” select “Serial”
4. Open the computer’s “Device Manager”
5. Scroll down to “Ports (COM & LPT)” and expand the menu
6. Connect the OmniPresense OPS243A to the computer using a micro-USB cable, a new COM port should appear labeled “USB serial device (COM#)”
7. In PuTTY enter the number shown next to “COM” in the previous step on the line under “Serial line”
8. Click open
9. Type the following commands (case sensitive)

Command	Message	Effect
I1	{“UartBaudRate”:9600}	Changes the Uart Baud rate to 9600
IG	{“Interface”:”Enable Motion Sensor on GPIO”}	Enables simple motion detection
US	{“Units”:”mph”}	Changes units to MPH
R>5 “enter”	{“RequiredMinSpeed”:5.000, …} (If a different minimum reporting speed is required, substitute the desired speed in for 5)	Changes minimum reporting speed to 5MPH
R+	{"RequiredMinSpeed":5.000, "RequiredMaxSpeed":"No Maximum Speed", "RequiredDirection":"Towards Only"}	Only detect on-coming vehicles
A!	{“INFO”:”Saving current values to Persistent Settings.”}	Saves changes

(Note: If an invalid command is entered, the message {“UnknownCommand”:”___”} will appear. Re-enter the desired command.)

10. Close PuTTY