PPU College Of Engineering and Technology

The Home of Competent Engineers and Researchers

Palestine Polytechnic University

College of Engineering

Electrical Engineering Department

Electronics and Communication Engineering

Bachelor Thesis

Graduation Project

Traffic Congestion Management at Road Intersections Using Wi-Fi Technology

Project Team

Abdulghafar Shabaneh

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Supervisor: Dr. Murad AbuSubaih

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By the guidance of our supervisor, and by the acceptance of all members in the testing committee, this project is delivered to department of electrical engineering in the college of engineering, to be as practical fulfillment of the requirement of the department for the degree of B.Sc.

Supervisor Signature

Testing committee signature

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The head of department signature

جامعة بوليتكنك فلسطين

كلية الهندسة

دائرة الهندسة الكهربائية

Traffic Congestion Management at Road Intersections Using Wi-Fi Technology

فريق المشروع

عبد السلام شبانه　　　عبد الغفار شبانه　　　ابراهيم الصغير

بناء على نظام كلية الهندسة وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة المناقشة، تم تقديم هذا العمل إلى دائرة الهندسة الكهربائية. وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة الاتصالات .

توقيع المشرف

توقيع اللجنة المناقشة

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توقيع رئيس الدائرة

الإهداء

إلى الذين صنعوا من الأيام قضية عُمر..

إلى الشمعة التي أنارت لي دربي....إلى من عجز قلمي عن وصف حبي وتقديري له...

إلى من حصد الأشواك عن دربي ليمهد لي طريق العلم..

إلى والدي العزيز

إلى أرقى وأروع حب عرفته البشرية..

إلى نبع الحنان الدائم الذي سهر كي أنام وأبقى..

إلى القلب الناصع بالبياض..

رضاك يا والدتي

إلى من شاركوني أجمل الذكريات وكانوا معي كل اللحظات..

أصدقائي الأعزاء

إلى الذين بذلوا كل جهدٍوعطاء لكي أصل إلى هذه اللحظة..

أساتذتي الكرام

إلى كل طلاب العلم والمعرفة في كل مكان...

إلى كل أهلي وأقاربي في كل مكان وإلى أبناء شعبي ووطني كافة

أهدي إليهم جميعًا باسمي هذا العمل.

الشّكر والتّقدير

نتقدم بجزيل الشكر وعظيم الامتنان إلى الأستاذ الدكتور الفاضل مراد أبو صبيح صاحب الفضل الكبير في إرشاداته لنا وإتمام وإخراج هذا المشروع بصورته النهائية من خلال إرشاداته ومساعدته القيمة.

كذلك نتقدّم بجزيل الشكر والعرفان إلى كل الذين ساعدونا ومدّو لنا يد العون ولم يبخلوا علينا بالعلم، سواء من أساتذة أو طلاب أو أقارب... نشكرهم جميعاً.

ولا يسعنا في هذا المقام إلاّ أن نتقّدم أيضاً بجزيل الشكر والعرفان إلى جميع أعضاء الهيئة التدريسية في كلية الهندسة على الجهد والعطاء الذي منحونا إيّاه.

أيضاً نشكر أهلنا وجميع زملائنا.

وفي النهاية نتقدم بالشكر الجزيل لجميع من ساهم بإنجاح هذا العمل.

فريق العمل

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Abstract

Traffic problems nowadays are increasing because of the growing number of vehicles and the limited resources provided by current infrastructures. This project develops a solution for traffic congestion at road intersections. The system tries to avoid congestion by alerting neighbor drivers over Wi-Fi connections, so that they choose alternative routes. The system is mainly based on cameras for monitoring and image processing unit for characterizing congestion level. The system will be supplied with solar power with battery backup to assure the working of it at nights.

الملخص

مشاكل المرور تتزايد في الوقت الحاضر بسبب العدد المتزايد من السيارات ومحدودية الموارد المقدمة من البنى التحتية الحالية. يقوم هذا المشروع على تطوير حل للازدحام المروري على تقاطعات الطرق. حيث يقوم النظام بإبلاغ السائقين المجاورين بوجود الازدحام لتجنبه بواسطة الاتصالات اللاسلكية وعليه يقوم السائقون باختيار الطرق البديلة. ويستند هذا النظام بشكل أساسي على كاميرات لرصد حركة السيارات ووحدة معالجة صور لتحديد مستوى الازدحام. وسيتم تشغيل النظام عن طريق الطاقة الشمسية مع بطارية احتياطية لضمان استمرار العمل أثناء فترة الليل.

Chapter 1

Introduction

1.1 Problem statement

1.2 Motivation

1.3 Approach

1.4 Objectives

1.5 Literature review

1.6 Project schedule

1.1 Problem statement

In modern life we have to face with many problems one of them is traffic congestion, which is becoming more serious day after day. It is characterized by slower speeds, longer trip times, and increased vehicular queuing [1].

Traffic congestion occurs when a volume of demand for space greater than the available road capacity. There are a number of specific circumstances which cause or aggravate congestion, most of them reduce the capacity of a road at a given point or over a certain length, or increase the number of vehicles required for a given volume of people or goods [2].

The major cause leading to traffic congestion is the high number of vehicles, which was caused by the population and the development of economy, most of the rest is attributed to traffic incidents, road work and weather events. Moreover, some people park on the roads so decreases the space in cars path, and offending drivers can be considered one of reasons that leads to congestion.

Traffic congestion has a number of negative effects. The most important is during emergency situations, when it interferes with the passage of emergency vehicles traveling to their destinations. In addition, congestion wastes time of motorists and passengers, increases chance of collisions due to tight spacing [1].

One solution to reduce traffic congestion is to adjust the transportation system. This can be done by increasing the number of roads or road capacity, and reduces the number of vehicles passes to the congested roads. Another alternative is congestion management. This can be achieved through directing vehicles to avoid congested junctions. In this work, it is intended to develop and implement such a system.

1.2 Motivations

This project deals with a very important and vital aspect in human life that is the traffic congestion on streets and roads.

The idea is not implemented in our country which really needs a planned and a well-designed system that informs the drivers about congestion state before they arrive tat congested intersections. Here are some points that motivate us to work on this project:

- Saving time and effort for drivers and passengers.
- Saving the fuel.
- Saving the roads from the heavy load that results from Conglomeration of the cars especially in the bridges.
- In general, the congestion causes noise in the city and bothers all people in the area around.
- Congestion increases the emitting of harmful gases in the middle of the city which increases the air pollution.
- Sometimes, congestion has negative effects on people, so that it may cause nervous tension to some of them due to the delay.
- Congestion causes failure in the job of the firemen, ambulance which could leads to disastrous and terrible results.
- We are reducing the consequences of congestion represented mainly by accidents.
- Congestion is a cause to several accidents, especially at road intersections.

1.3 Approach

This project develops an automatic way for road congestion management. It uses a monitoring system, digital image processing and wireless communication network. A camera will be installed alongside the road. It will capture image sequences. Based on image processing results, a transmitter device sends alarm signal via Wi-Fi to the receiver devices installed in the cars around the area of this intersection, if congestion is recognized.

This alarm helps drivers by providing pre-knowledge of traffic congestion at next intersection and changes their routes before reaching this congested intersection. In order to increase the reach ability of alarm to all cars, it is intended to display alarm signals at LCD's installed at road sides before the intersection.

The system will be supplied with solar power with battery backup to assure the working of it at nights.

1.4 Objectives

The project objectives can be summarized as:

- Use image processing techniques on the snapshots of the camera for improving congestion recognition.
- Enable drivers to change their paths before reaching congested road intersections by providing them with the current state of congestion.
- Mounting, installing and testing the system practically on a chosen intersection at different conditions.
- To design a useful practical system using the new technologies in this era to benefit our society.

- Power the circuits and modules from a solar energy system with chargeable batteries.
- To contribute with such system design and implementation to overcome daily problems of traffic congestion.

1.5 Literature review

Now let’s talk briefly about some previous related literature that suggested and used different solutions and systems to deal with this disturbing problem, traffic congestion.

One of these literatures is based on exploiting the variation in wireless link characteristics when line of sight conditions between a wireless sender and receiver vary. This system comprises of a wireless sender-receiver pair across a road. The sender continuously sends packets. The receiver measures metrics like signal strength, link quality and packet reception. These metrics show a marked change in values depending on whether the road in between has free-flowing or congested traffic. The Wi-Fi Shield makes the Arduino Uno Wi-Fi compatible. The project plan is to create a wireless sensor network that is capable of estimating the density of traffic. The PIR Sensor will detect infrared movement. The sensor will send the information to the Arduino Uno and the WiShield. The wireless router is used to make the connection between the Arduino Uno and webpage. The sensor will detect car movement by the change in infrared patterns. The data will then be transmitted to the Arduino Uno, then the personal computer which will display the webpage and binary numbers [3].

Another previous research is suggesting the single magnetic sensor to detect and record the time of vehicles passing it, calculates the length of vehicle based on the time assuming constant speed common to all vehicles. From a large number of samples of time and vehicle length, they calculate median of the two metrics and estimate median speed as (median length/ median time). If this median speed deviates from expected median speed, congestion is reported [4].

Other researches proposed the use of audio-based techniques like Microwave radars and ultrasonic sensors. Microwave radars use specially allocated radio frequency for detecting vehicles. There are two types of microwave radar detectors. The type of microwave radar uses the Doppler principle to detect vehicles. According to the Doppler Principle the difference in frequency between the transmitted and received signals is proportional to the speed of the vehicle. So this type of microwave radar first transmits electromagnetic energy at a constant frequency. If the detector senses any shift in the received frequency it deduces that vehicle has passed. On major problem with this type of microwave radar is that it cannot detect stationary vehicles. The second type of microwave radar detector transmits a frequency-modulated continuous wave that varies the transmitted frequency continuously with time. This enables the system to measure the range of the vehicle from the detector. Hence, this type of microwave radar can detect stationary vehicles as well. Speed of the vehicle can be calculated by measuring the time taken by a vehicle to move between two internal markers separated by a known distance. However, even these microwave radar systems have problems like over estimating speed and occupancy values. But ultrasonic sensors use sound waves (above the audible range) to determine the presence or distance of an object. Ultrasonic detectors transmit sound at 25 KHz to 50 KHz. A part of the transmitted energy is reflected back from the road or the vehicle to the receiver. By measuring the time taken for the sound echo to return the distance of an object can be found. The ultrasonic Doppler detector that also measures vehicle speed is much more expensive than the presence detector. These technologies are sensitive to noise and environmental conditions. They are commonly used for cops while chasing cars. Using these techniques for congestion recognition may face many challenges on a road since radars require the sound beam to be "aimed" at a specific vehicle and not to a whole bunch of congested vehicles of various sizes that will cause multiple reflections and make it too hard to decide whether or not the traffic is congested [5].

Other studies suggested using of probe-vehicles' GPS traces, they first classify the road network into segments delimited by traffic signals. Temporal and spatial speed traces within each segment are then analyzed, and a threshold technique is developed to categorize traffic within the segment as congested versus free-flowing. Such probe-based techniques are more applicable to developing regions due to the lower cost, and lack of traffic orderliness assumptions [4].

Other project was developed in our university used fixed number of sensors of a specific type will be distributed along the road. The distance between each two consecutive sensors are known and specific. Each sensor will sense the part of the road in front of it and check if a vehicle exists in this part or not. So, each sensor in this road will get analog data refer to its part status and send them continuously by a transmitter to a control module that will gather this data, make some analysis depending on the assumptions and theories that we will use, then get the conclusions, finally send the results to an interne website using wireless technologies

The last project is the ramp meter, it is a device, usually a basic traffic light or a two-section signal (red and green only, no yellow) light together with a signal controller that regulates the flow of traffic entering freeways according to current traffic conditions. It is the use of traffic signals at freeway on-ramps to manage the rate of automobiles entering the freeway. Ramp metering systems have proved to be successful in decreasing traffic congestion and improving driver safety [6].

1.6 Project schedule

Now let us review the project schedule involving the main activities with which the project will be developed by. The project schedule is divided in two schedules:

1) **First semester project schedule**: Schedule refers to the activities that should be complete in the first semester. Table 1.1 shows first semester activities.
2) **Second semester project schedule**: Schedule refers to the activities should be done in the second semester. Table 1.2 shows second semester activities.

Table 1.1 First semester project schedule

Activity description	1-Sep	8-Sep	15-Sep	22-Sep	29-Sep	6-Oct	13-Oct	20-Oct	27-Oct	3-Nov	10-Nov	17-Nov	24-Nov	1-Dec	8-Dec	15-Dec
	Week's Number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Submit Proposal																
Specify project activities																
Collect related information																
Prepare project documentation																
Search suitable chips																
Prepare initial design																
Prepare project presentation																
Submit project document																

Table 1.2 Second semester project schedule

Activity description	2-Feb	9-Feb	16-Feb	23-Feb	2-Mar	9-Mar	16-Mar	23-Mar	30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May
	Week's Number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Electronic chips buying and shopping																
Electronic chips testing																
Preparing circuit schematics																
Connecting circuits																
Implementing software programs																
System testing																
Preparing full project documentation																
Submitting project documentation																

Chapter 2

Components Background

2.1 Cameras

2.2 Image processing

2.3 Microcontrollers

2.4 Digital signal processing

2.5 Wi-Fi Technology

2.6 Wireless Transceivers Technologies

2.7 Solar Energy

2.1 Cameras

Closed-circuit television (CCTV) cameras can produce images or recordings for surveillance purposes, and can be either video cameras, or digital stills cameras [7].

It is most often applied for surveillance in areas that may need monitoring such as banks, airports and convenience stores.

2.1.1 Video Cameras

Video cameras are either analog or digital.

- **Analog**: Can record straight to a video tape recorder which is able to record analogue signals as pictures.
- **Digital:** These cameras do not require a video capture card because they work using a digital signal which can be saved directly to a computer [7].

2.1.2 History

The first CCTV system was installed by Siemens AG in Germany at 1942. The earliest systems required constant monitoring because there was no way to record and store the information. Recording systems would be introduced later, when primitive reel-to-reel media was used to preserve the data, where the magnetic tapes had to be changed manually. It was a time consuming, expensive and unreliable process; the operator had to manually thread the tape from the tape reel through the recorder onto an empty take-up reel. Due to these efforts, video surveillance was rare. Only when VCR technology became available in the 1970s, which made it easy to record and erase information, did video surveillance start to become much more common.

During the 1990s digital multiplexing, which allowed for several cameras to record at once, and introduced time lapse and motion only recording has increased the use of CCTV across the country and increased the savings of time and money.

In recent decades, especially with general crime fears growing in the 1990s and 2000s, public space use of surveillance cameras has taken off [8].

2.1.3 Some Types of Cameras

- **Infrared/Night Vision**: These night-vision cameras have the ability to see images in pitch black conditions using IR LEDs. In some cases they are for mobile applications.
- **Network/IP**: These cameras, both hardwired and wireless, transmit images over the Internet, often compressing the bandwidth so as not to overwhelm the web. IP cameras are easier to install than analog cameras because they do not require a separate cable run or power boost to send images over a longer distance.
- **Wireless**: Not all wireless cameras are IP-based. Some wireless cameras can use alternative modes of wireless transmission
- **Day/Night**: Day/night cameras compensate for varying light conditions to allow the camera to capture images. These are primarily used in outdoor applications
- **High-Definition Cameras** :These give the operators the ability to zoom in with extreme clarity
- **Board Cameras**: These tiny cameras are well suited for desktop use [9].

2.1.4 Applications

- Transport safety
- Traffic monitoring, as shown in figure 2.1
- Industrial processes
- Crime prevention

Figure 2.1 Traffic monitoring cameras

2.2 Image processing

Image processing is a method to convert an image into digital form and perform some operations on it, in order to get an enhanced image or to extract some useful information from it. It is a type of signal dispensation in which input is image, like video frame or photograph and output may be image or characteristics associated with that image. Usually Image Processing system includes treating images as two dimensional signals while applying already set signal processing methods to them.

It is among rapidly growing technologies today, with its applications in various aspects of a business. Image Processing forms core research area within engineering and computer science disciplines too [10].

Image processing basically includes the following three steps:

- Importing the image with optical scanner or by digital photography
- Analyzing and manipulating the image which includes data compression and image enhancement and spotting patterns that are not to human eyes like satellite photographs.
- Output is the last stage in which result can be altered image or report that is based on image analysis [10].

2.2.1 Purpose of Image processing

The purpose of image processing is divided into 5 groups [10]. They are:

1) Visualization - Observe the objects that are not visible.

2) Image sharpening and restoration - To create a better image.

3) Image retrieval - Seek for the image of interest.

4) Measurement of pattern – Measures various objects in an image.

5) Image Recognition – Distinguish the objects in an image.

2.2.2 Types of Image processing

The two types of methods used for Image Processing are Analog and Digital Image Processing. Analog or visual techniques of image processing can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. The image processing is not just confined to area that has to be studied but on knowledge of analyst. Association is another important tool in image processing through visual techniques. So analysts apply a combination of personal knowledge and collateral data to image processing.

Digital Processing techniques help in manipulation of the digital images by using computers. As raw data from imaging sensors from satellite platform contains deficiencies. To get over such flaws and to get originality of information, it has to undergo various phases of processing. The three general phases that all types of data have to undergo while using digital technique are Pre- processing, enhancement and display, information extraction [10].

2.2.3 Image processing applications

Digital image processing, as a computer based technology, carries out automatic processing, manipulation and interpretation of such visual information, and it plays an increasingly important role in many aspects of our daily life, as well as in a wide variety of disciplines and fields in science and technology, with applications such as television, photography, robotics, remote sensing, medical diagnosis and industrial inspection, and this list:

1) Intelligent transportation systems.
2) Remote sensing.
3) Moving object tracking.
5) Biomedical imaging techniques.
4) Defense surveillance.
6) Automatic visual inspection system [11].

2.2.4 Image Processing Software

GNU Octave is a free and open source alternative to Matlab. It was initially conceived around 1988 as an accompaniment for a textbook on chemical reactor design, at the University of Wisconsin . It was developed further in 1992, leading to a full 1.0 release in 1994. It was licensed under the GPL, a free and open-source software license, as part of the GNU Project1, hence the name "GNU Octave" [12].

GNU Octave is a high-level language, primarily intended for numerical computations. It provides a convenient command line interface for solving linear and nonlinear problems numerically, and for performing other numerical experiments using a language that is mostly compatible with Matlab. It may also be used as a batch-oriented language.

Octave has extensive tools for solving common numerical linear algebra problems, finding the roots of nonlinear equations, integrating ordinary functions, manipulating polynomials, and integrating ordinary differential and differential-algebraic equations. It is easily extensible and customizable via user-defined functions written in Octave's own language, or using dynamically loaded modules written in C++, C, Fortran, or other languages [13].

2.3 Microcontrollers

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications [14].

2.3.1 Applications

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes [14].

Some featured types of applications:

- Alternative Energy
- Automotive & Transportation
- Consumer & Portable Electronics
- Industrial
- Medical
- Smart Grid

2.3.2 Classification of Microcontrollers

Microcontrollers are classified on different aspects like architecture, programming language used, bus width, memory, instruction set etc. There are a huge variety of microcontrollers. The can be classified on following:

- Internal bus width:
    - 4 bit, 8 bit, 16 bit, 32 bit
- Instruction set:
    - C.I.S.C
    - R.I.S.C
- Architecture:
    - Harvard
    - Von Neumann (or Princeton)

- Memory:
    - FLASH
    - EEPROM
    - SRAM
    - Embedded memory
    - External memory
- Families:
    - ATMEL AVR - atmega, Xmega, Attinyâ
    - PIC - PIC16F, PIC18F
    - ARM - ARM7, ARM9, ARM11
    - 8051 - AT89s52, p89v51rd2
    - Motorola - 68HC11
- Integrated Peripherals:
    - Number of I/O ports.
    - Number and type of timers.
    - A.D.C
    - Other I/O interfaces like U.A.R.T, S.P.I [15].

2.3.3 Raspberry Pi Microcontroller

The **Raspberry Pi** shown in figure 2.2 is a single-board computer developed in the UK by the Raspberry Pi Foundation. The Raspberry Pi is a credit-card sized computer that plugs into the TV and a keyboard. It’s a capable little PC which can be used for many of the things that a desktop PC does, like spreadsheets, word-processing and games. It also plays high-definition video. The design is based around a Broadcom BCM2835 SoC, which includes an ARM1176JZF-S 800 MHz processor, Video Core IV GPU, and 256 or 512 Megabytes of RAM. The design does not include a built-in hard disk or solid-state drive, instead relying on an SD card for booting and long-term storage. This board is intended to run Linux kernel based operating systems [16].

Figure 2.2 Raspberry Pi module

The foundation has released two versions, Model A & Model B.

- **Model B (Revision 2.0)**: It's a latest launched Raspberry Pi Revision 2 with 512MB of RAM memory, two USB ports and a 10/100 Ethernet controller.
- **Model B (Revision 1.0)**: has 256MB RAM memory, two USB ports and a 10/100 Ethernet controller.
- **Model A** - has 256 Megabytes (MB) RAM memory, one USB port and no Ethernet controller. Though the Model A doesn't have an RJ45 Ethernet port, it can connect to a network by using a user supplied USB Ethernet or Wi-Fi adapter. As typical of modern computers, generic USB keyboards and mice are compatible with the Raspberry Pi.

The Raspberry Pi use Linux-kernel based operating systems. Debian GNU/Linux, Ice weasel. The Raspberry Pi does not come with a real-time clock, so an OS must use a network time server, or ask the user for time information at boot time to get access to time and date info for file time and date stamping. However a real time clock (such as the DS1307) with battery backup can be easily added via the I2C interface.

The Raspberry Pi Foundation has released various SD Card images that can be loaded onto an SD Card to produce a preliminary operating system. The image is based upon Linux version of Debian OS (Raspbian) with the LXDE desktop and the Midori browser, plus various programming tools. The image can also run on QEMU allowing the Raspberry Pi to be emulated on various other platforms [16].

2.3.4 Arduino Uno microcontroller

Arduino shown in figure 2.3 is an open-source electronics prototyping platform cased on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists and anyone interested in creating interactive objects or environments.

The Arduino Uno is microcontroller equipped with ATmrga328. It has 14 digital I/O pins of which 6 can be used as PWM outputs, 6 analog inputs, a 16 MHz crystal oscillator, a USB connector, a power jack an ISCP header, and a reset button [17].

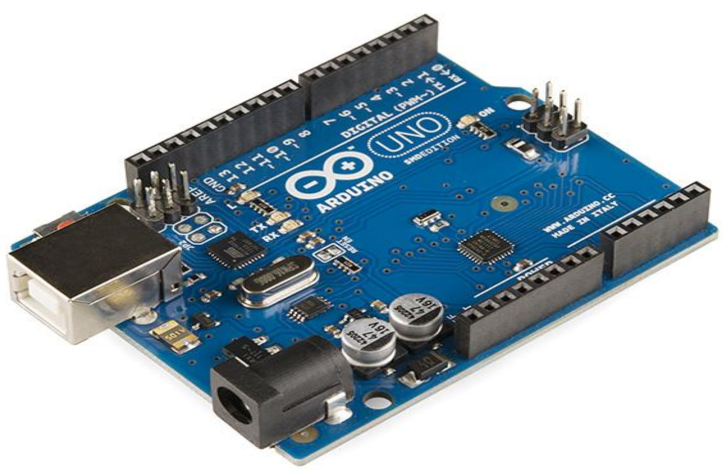


Figure 2.3 Arduino Uno module

2.3.4.1 Power

The board can be powered via USB, DC adapter (wall-wart) or battery. The power source is selected automatically. To use AC to DC adapter we need 2.1mm center-positive plug power jack. Battery can be connected either to USB, power jack or inserted in Gnd and Vin pin heads of the POWER connector. The recommended range of supply is 7 to 12 volts despite limits of 6 to 20 volt due to the fact that voltage lover than 7V makes 5V onboard pin unstable and voltage higher then 12V can lead the voltage regulator to overheat and directly damage the board [17].

2.3.4.2 Memory

The ATmega328 has 32 KB (with 0.5 KB used for the boot loader). It also has 2 KB of SRAM and 1 KB of EEPROM [17].

2.3.4.3 Programming

As it comes to programming Arduino Uno can be programmed with provided software. The board is pre burned with boot loader that allows to upload new code to it directly via USB, no external hardware programmer needed [17].

The Arduino programming language is a simplified version of C/C++ [18].

It is intended to use Raspberry Pi rather than Arduino Uno microcontroller because the project deals with cameras that are easier to be connected to Raspberry Pi. Also microcontroller must perform the image processing that requires high processing speed.

2.4 Digital signal processing

Signal processing is the action of changing one or more features (parameters) of a digital signal according to a predetermined requirement. The parameters that are to be changed may be amplitude, frequency, and phase.

The signals that are to be processed are converted into numerical form before any processing. This conversion is known as sampling, the sampling wave is shown in figure 2.4, according to sampling theorem, an analog signal can be exactly reconstructed from its samples if the sampling rate is at least twice the highest frequency component present in the signal [19].

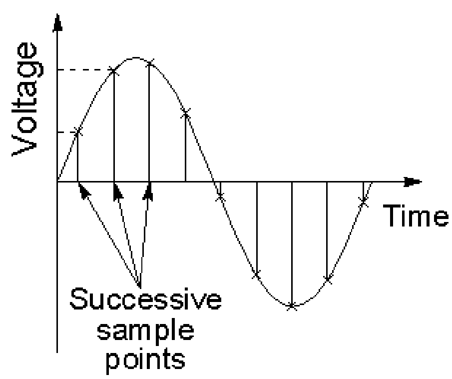


Figure 2.4 Sampling wave

Information contained in an analog signal is first converted to digital samples which are equally spaced in time it is done by analog to digital converter. The digital samples are stored in the computer’s memory to applied operation on it by processing unit. After processing the samples have to be converted back to analog voltage by digital to analog converter. Figure 2.5 shows the DSP system [19].

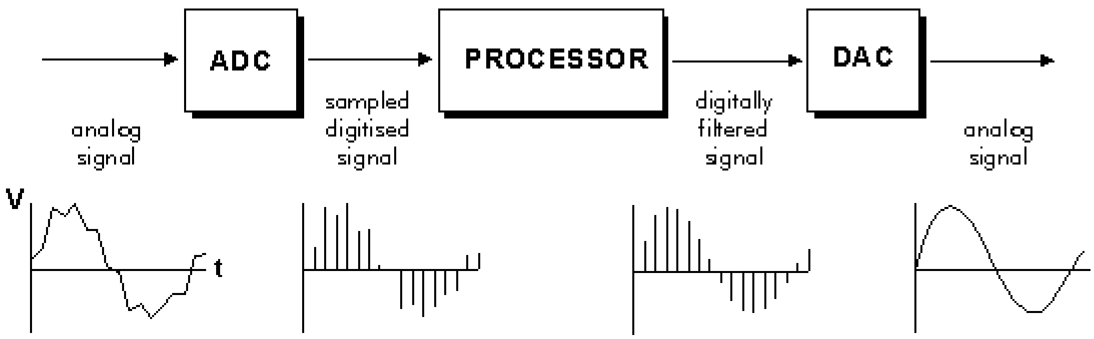


Figure 2.5 DSP system

2.4.1 Digital Signal Processors (DSPs)

A digital signal processor contains these key components:

- **Program Memory**: Stores the programs the DSP will use to process data.
- **Data Memory**: Stores the information to be processed.
- **Processing unit**: Performs the math processing, accessing the program from the Program Memory and the data from the Data Memory.
- **Input/output**: Serves a range of functions to connect to the outside world [20].

2.4.2 Advantages of DSPs

- Allow flexibility in reconfiguring the DSP operations simply by changing the program.
- Processing of 0 and 1 is almost immune to noise and data are easily stored without distortion.

- Security can be introduced by encrypting [21].
- Complex algorithms fit into a single chip.
- Digital processing is insensitive to component tolerances, aging, environmental conditions and electromagnetic interference.
- Noise is easy to control after initial quantization [22].
- Cheaper to implement.
- Can be stored on disk [23].

2.4.3 Disadvantages of DSPs

- Require significantly more power [22].
- When the signal is weak, within a few tenths of millivolts, we cannot amplify the signal after it is digitized.
- Finite word length problems [23].

2.4.4 DSP Applications

- **Communication systems**
  Modulation/demodulation, channel equalization, echo cancellation.
- **Music**
  Synthetic instruments, audio effects, noise reduction.
- **Consumer electronics**
  Perceptual coding of audio and video on DVDs, speech synthesis, speech recognition.
- **Experimental physics**
  Sensor-data evaluation.

- **Medical diagnostics**
  Magnetic-resonance and ultrasonic imaging, computer tomography, audiology.

- **Engineering**
  Control systems, feature extraction for pattern recognition.

- **Security**
  Surveillance system, signal intelligence [22].

- **Image processing**
  Filtering, edge effects, enhancement [23].

2.5 Wi-Fi Technology

Wi-Fi is an abbreviation of the phrase Wireless Fidelity. Wi-Fi is a popular technology that allows an electronic device to exchange data or connect to the internet wirelessly using radio waves. The Wi-Fi Alliance defines Wi-Fi as any "wireless local area network (WLAN) products that are based on the Institute of Electrical and Electronics Engineers' (IEEE) 802.11 standards". Wi-Fi technology in recent years is growing rapidly and is widely used throughout the world.

Many devices can use Wi-Fi, e.g. personal computers, video-game consoles, smart phones, some digital cameras, tablet computers and digital audio players. These can connect to a network resource such as the Internet via a wireless network access point. Such an access point (or hotspot) has a range of about 20 meters (65 feet) indoors and a greater range outdoors. Hotspot coverage can comprise an area as small as a single room with walls that block radio waves, or as large as many square miles achieved by using multiple overlapping access points [24].

2.5.1 Historical Background

Wi-Fi technology has its origins in a 1985 ruling by the US Federal Communications Commission that released the ISM band for unlicensed use. In 1991, NCR Corporation with AT&T Corporation invented the precursor to 802.11 intended for use in cashier systems.

A key patent used in Wi-Fi was developed by the Australian radio astronomer John O'Sullivan as a by-product in a CSIRO research project, "a failed experiment to detect exploding mini black holes the size of an atomic particle". In 1992 and 1996, Australian organization CSIRO obtained patents for a method later used in Wi-Fi to "unsmear" the signal.

In 1999, the Wi-Fi Alliance was formed as a trade association to hold the Wi-Fi trademark under which most products are sold [25].

2.5.2 Advantages and Limitations

Advantages:

The main advantages of using Wi-Fi technology is the lack of wires. This is a wireless connection that can merge together multiple devices. Wi-Fi network is particularly useful in cases where the wiring is not possible or even unacceptable. For example, it is often used in the halls of conferences and international exhibitions. It is ideal for buildings that are considered architectural monuments of history, as it excludes the wiring cables.

Wi-Fi allows cheaper deployment of local area networks (LANs). Also spaces where cables cannot be run, such as outdoor areas and historical buildings, can host wireless LANs.

Wi-Fi networks are widely used to connect a variety of devices, not only between themselves but also to the Internet. And almost all modern laptops, tablets, and some mobile phones have this feature. It is very convenient and allows to connect to the internet almost anywhere, not just where the cables are laid [26].

Limitations:

- Wi-Fi has a limited radius of action and it is suitable for home networking, which is more dependent on the environment.
- At high density Wi-Fi-points operating in the same or adjacent channels, they can interfere with each other. This affects the quality of the connection [27].

2.5.3 Wi-Fi Standards

802.11 Protocols

The 802.11 family consist of a series of half-duplex over-the-air modulation techniques that use the same basic protocol. The most popular are those defined by the 802.11b and 802.11g protocols, which are amendments to the original standard.

802.11-1997 was the first wireless networking standard in the family, but 802.11b was the first widely accepted one, followed by 802.11a and 802.11g. 802.11n is a new multi-streaming modulation technique. Other standards in the family (c–f, h, j) are service amendments and extensions or corrections to the previous specifications. Table 2.1 shows some of 802.11 protocols and their properties such as data rate and the range at different environment [28].

Table 2.1 Characteristics of 802.11 protocols

Protocol	Release	Freq. (GHz)	Data Rate (Mbit/s) (Typical / Max)	Range (m) (Indoor/outdoor)
A	Sep 1999	5 / 3.7	20 / 54	35 / 120
B	Sep 1999	2.4	5.5 / 11	35 / 140
G	Jun 2003	2.4	22 / 54	38 / 140
N	Oct 2009	2.4 / 5	110+ / 300+	70 / 250

2.6 Wireless Transceivers Technologies

A transceiver is a device comprising both a transmitter and a receiver which are combined and share common circuitry or a single housing. When no circuitry is common between transmit and receive functions, the device is a transmitter-receiver. The term originated in the early 1920s. Technically, transceivers must combine a significant amount of the transmitter and receiver handling circuitry. Similar devices include transponders, and repeaters.

In radio terminology, a transceiver means a unit which contains both a receiver and a transmitter. From the beginning days of radio the receiver and transmitter were separate units and remained so until around 1920. Amateur radio or "ham" radio operators can build their own equipment and it is now easier to design and build a simple unit containing both of the functions: transmitting and receiving. Almost every modern amateur radio's equipment is now a transceiver but there is an active market for pure radio receivers, mainly for shortwave listening (SWL) operators. An example of a transceiver would be a walkie-talkie, or a CB radio[29].

The RF Transceiver uses RF modules for high speed data transmission. The microelectronic circuits in the digital-RF architecture work at speeds up to 100 GHz. The objective in the design was to bring digital domain closer to the antenna, both at the receiver and transmitter ends using software defined radio (SDR). The software-programmable digital processors used in the circuits permit conversion between digital baseband signals and analog RF [30].

2.6.1 ZigBee

ZigBee is a specification for a suite of high level communication protocols used to create personal area networks built from small, low-power digital radios. ZigBee is based on an IEEE 802.15 standard. Though low-powered, ZigBee devices often transmit data over longer distances by passing data through intermediate devices to reach more distant ones, creating a mesh network; i.e., a network with no centralized control or high-power transmitter/receiver able to reach all of the networked devices. The decentralized nature of such wireless ad hoc networks makes them suitable for applications where a central node can't be relied upon. Figure 2.6 shows the ZigBee module [31].

Figure 2.6 ZigBee module

ZigBee is used in applications that require a low data rate, long battery life, and secure networking. ZigBee has a defined rate of 250 Kbit/s, best suited for periodic or intermittent data or a single signal transmission from a sensor or input device. Applications include wireless light switches, electrical meters with in-home-displays, traffic management systems, and other consumer and industrial equipment that requires short-range wireless transfer of data at relatively low rates. The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth or Wi-Fi.

ZigBee networks are secured by 128 bit symmetric encryption keys. In home automation applications, transmission distances range from 10 to 100 meters line-of-sight, depending on power output and environmental characteristics [31].

2.6.2 WiFly GSX transceiver

The WiFly GSX module shown in figure 2.7 is a standalone, embedded wireless 802.11 networking module. The module is fully qualified and Wi-Fi certified 2.4 GHz IEEE 802.11b/g transceiver.

Because of its small size and extremely low power consumption, the WiFly module is perfect for mobile wireless applications such as asset monitoring, GPS tracking and battery sensors.

In the simplest configuration the hardware only requires four connections (PWR, TX, RX, GND) to create a wireless data connection. The WiFly GSX module is programmed and controlled with a simple ASCII command language. Once the WiFly GSX is setup it can scan to find an access point, associate, authenticate and connect over any Wi-Fi network .

The WiFly code operates in one of two modes, data mode and control mode. Data mode is a simple data-in data-out mode; data written to the UART is sent out over Wi-Fi and data received over Wi-Fi is written out over the UART. A programmable escape sequence transitions the module into command mode where data written to the UART (or Wi-Fi if enabled) is used to configure variables such as SSID's and pass-phrases [32].

Figure2.7 WiFly GSX module

2.6.2.1 Applications

- Wireless audio.
- Remote equipment monitoring.
- Telemetry.
- Security.
- Industrial sensors and controls.
- Home Automation.
- Medical devices [32].

2.6.2.2 WiFly 4

WiFly 4.00 is the default firmware for all Wi-Fi modules, replacing all previous WiFly versions. WiFly 4.00 provides a number of enhancements such as enterprise security, AP Mode and secondary UDP broadcast [32].

It is intended to use a Wi-Fi transceiver rather than ZigBee transceiver since it is planned to have a centralized network that sends the multicast alarm messages to specific receivers. So the Ad-hoc network of ZigBee is not of high interest. Also messages must be sent to far distances which are only possible by Wi-Fi.

2.7 Solar Energy

Solar energy is energy that comes from the sun. Every day the sun radiates an enormous amount of energy. The sun radiates more energy in one second than people have used since the beginning of time. All this energy comes from within the sun itself. Like other stars, the sun is a big gas ball made up mostly of hydrogen and helium. The sun generates energy in its core in a process called nuclear fusion.

During nuclear fusion, the sun's extremely high pressure and hot temperature cause hydrogen atoms to come apart and their nuclei to fuse or combine. Some matter is lost during nuclear fusion. The lost matter is emitted into space as radiant energy.

It takes millions of years for the energy in the sun's core to make its way to the solar surface, and then approximately eight minutes to travel the 93 million miles to earth. The solar energy travels to the earth at a speed of 186,000 miles per second, the speed of light.

Only a small portion of the energy radiated by the sun into space strikes the earth, one part in two billion. Yet this amount of energy is enormous. Every day enough energy strikes the United States to supply the nation's energy needs for one and a half years! About 15 percent of the sun's energy that hits the earth is reflected back into space. Another 30 percent is used to evaporate water, which, lifted into the atmosphere, produces rainfall. Plants, the land, and the oceans also absorb solar energy. The rest could be used to supply our needs [33].

2.7.1 Principle of Operation

Light (photons) striking certain compounds, in particular metals, causes the surface of the material to emit electrons. Light striking other compounds causes the material to accept electrons. It is the combination of these two compounds that can be made use of to cause electrons to flow through a conductor, and thereby create electricity. This phenomenon is called the photo-electric effect. Photovoltaic means sunlight converted into a flow of electrons (electricity).

Solar power is a rapidly developing energy source in Australia and around the world. The potential for using the sun to directly supply our power needs is huge, Solar panels can generate electricity without any waste or pollution, or dependence on the Earth's natural resources once they are constructed. Solar panels have no moving parts so they are very reliable and have a long life span. Solar panels are relatively easy to install and are very low maintenance .

A useful characteristic of solar photovoltaic power generation is that it can be installed on any scale as opposed to conventional forms of power generation which require large scale plant and maintenance. Solar panels can be installed to generate power where it is needed which removes the need to transport and distribute power over long distances to remote areas [34].

2.7.2 Photovoltaic Panels

Photovoltaic Panels are used to transform sunlight energy into electrical energy as shown in figure 2.8. “PV panel” is the common name for a photovoltaic panel. Literally translated photovoltaic means "light-electricity".

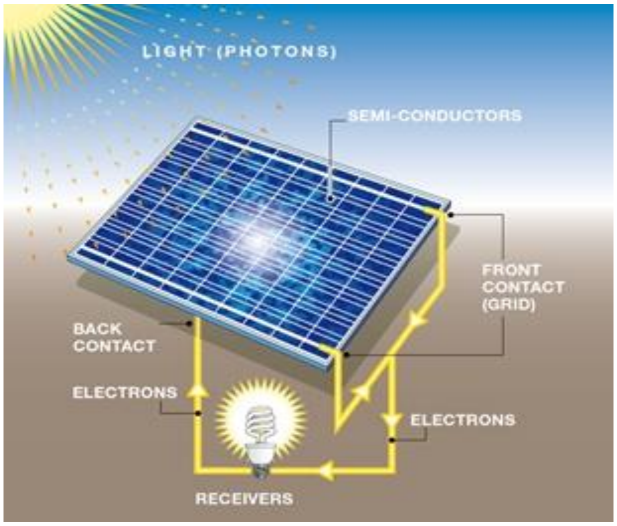


Figure 2.8 Photovoltaic panels

Photovoltaic means "light-electricity". It is formed from photo- which means light and -voltaic which means electrical current or electricity. PV panels are made up of smaller sections called solar cells. Solar cells, like batteries, each have a rated value of voltage (V or volts) and amperage (A or amps). The total power in wattage (W or watts) delivered is the voltage times the amperage.

Volts x Amps = Watts or V x A = W

Batteries can be arranged in parallel or in series depending on the requirements of the device we want to power [35].

2.7.3 Solar Cells

Solar cells shown in figure 2.9 are devices which convert solar light energy directly into electricity and function by the photovoltaic effect. Photo- means light and -voltaic means electrical current or electricity (light-electricity). A solar cell provides direct current (DC) electricity that can be used to power DC motors and light bulbs among other things. Solar cells can even be used to charge rechargeable batteries so that electricity can be stored for later use when the sun is not available.

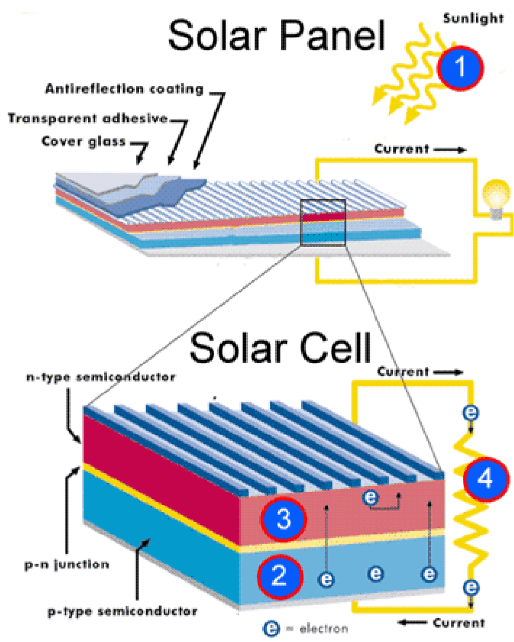


Figure 2.9 Solar cell

The fully charged batteries are portable energy that can be used whenever and wherever they are needed.

Solar cells provide DC electricity similar to batteries; however, batteries differ because they operate through a process known as an electrochemical reaction. This process will provide an electrical current from a chemical reaction that occurs inside the battery. When a load to the battery is hooked up, the reaction begins and electrons flow. Direct current (DC electricity) is different from the alternating current (AC electricity) that is used to power the TV, refrigerator, and other appliances in homes; however DC can be converted to AC when needed.

Solar cells produce DC electricity from light. Sunlight contains packets of energy called photons that can be converted directly into electrical energy. One can't see the photons but they hit the cell and produce free electrons that move through the wires and cause an electrical current as shown in figure 2.9. The electrical current is the electricity that powers the load. Although the photons can't be seen, one can see the light and assume that the amount of photons hitting the solar cell is related to the amount of light hitting the solar cell. A greater amount of light available means a greater amount of photons are hitting the solar cell and generating more power from it [35].

2.7.4 Advantages and Disadvantages of Solar Energy

Advantages:

- Solar energy makes use of a renewable natural resource that is readily available.
- Solar power does not create carbon dioxide or other toxic emissions.
- Use of solar thermal power to heat water or generate electricity will help reduce the Territory's complete dependence on fossil fuels.
- Solar water heaters are an established technology, readily available on the commercial market, and simple enough to build, install and maintain.
- The production of electricity by the photovoltaic process is quiet and produces no toxic fumes.
- PV cells generate direct-current electricity that can be stored in batteries and used in a wide range of voltages depending on the configuration of the battery bank.
- Although most electric appliances operate on alternating current, an increasing number of appliances using direct current are now available. Where these are not practical, PV-generated direct current can be changed into alternating current by using inverters [36].

Disadvantages:

- Solar thermal systems are not cost-effective in areas that have long periods of cloudy weather or short daylight hours.
- The arrays of collecting devices for large systems cover extensive land areas.
- Solar thermal systems only work with sunshine and do not operate at night or in inclement weather. Storage of hot water for domestic or commercial use is simple, using insulated tanks, but storage of fluids at the higher temperatures needed for electrical generation, or storage of electricity itself, needs further technical development.
- Photovoltaic-produced electricity is presently more expensive than power supplied by utilities.
- Batteries need periodic maintenance and replacement.
- High voltage direct-current electricity can pose safety hazards to inadequately trained home operators or utility personnel [36].

2.7.5 Applications

- Indoor and outdoor Lighting
- Water heating
- Cooking using solar cookers
- Water treatment using Solar Stills
- Battery Charging
- Electricity production

Chapter 3

System Conceptual Design

3.1 Overview

In this chapter we will describe the system main parts and the design concepts. We will illustrate the general block diagram, system main components. Then describe some details of the inner blocks or components and how it is related to other components will be described.

3.2 General block diagram

The main parts of the system as shown in general system block diagram figure 3.1 are: solar system as a power supply, congestion detection system to decide the congestion occurrence, Wi-Fi transmitter, Wi-Fi receiver with alarm system to alert the drivers if congestion occurs.

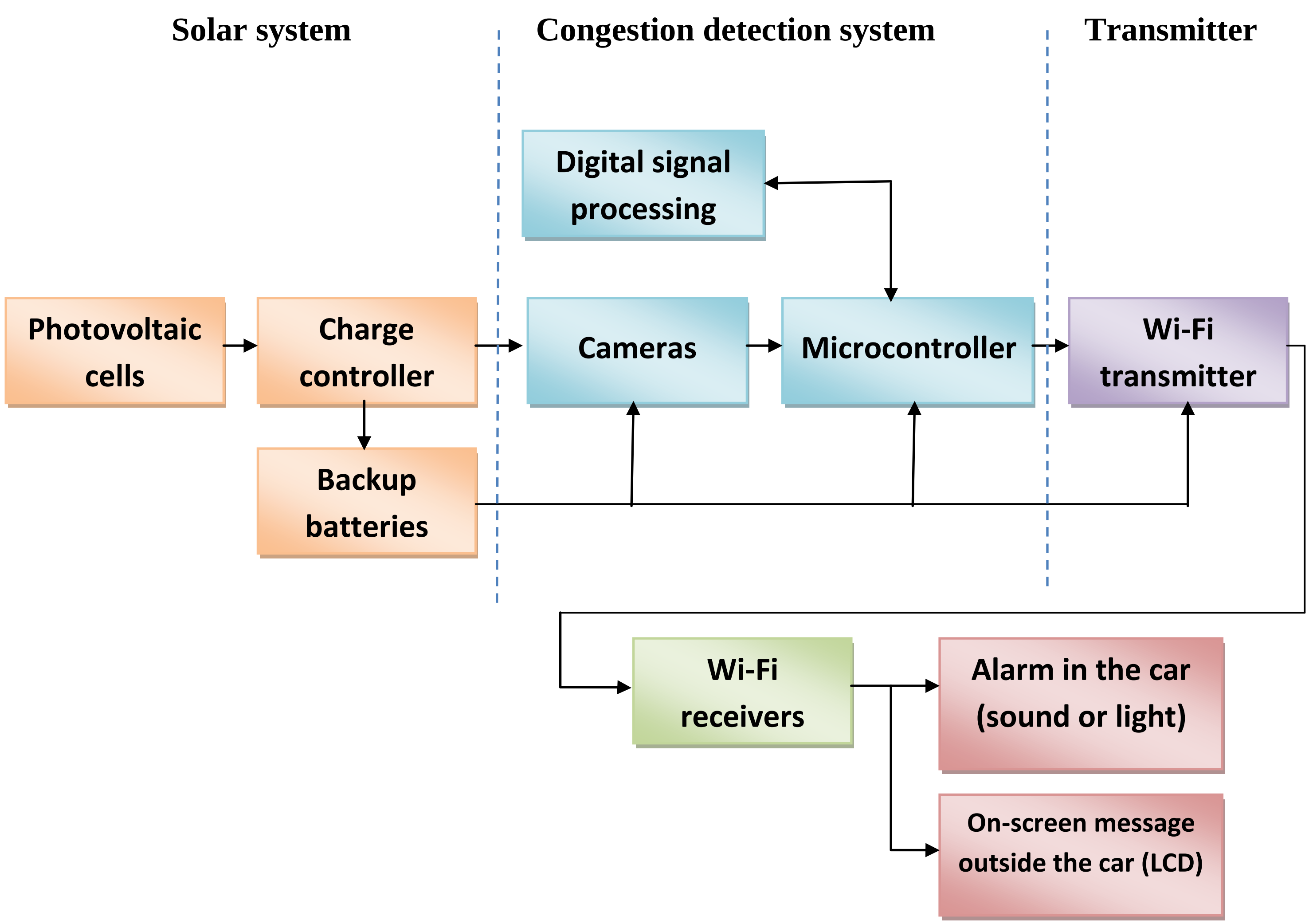


Figure 3.1 General block diagram

3.3 Main components

3.3.1 Solar System

Solar power systems provide a continuous, reliable power solution that's easily deployed, cost-effective and require little maintenance. As shown in figure 3.2, the main components of the solar system are:

a) **Photovoltaic cells**: Photovoltaic is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, resulting electric current can be used as electricity. Silicon is a material known as a semiconductor as it conducts electricity and it is the main material for photovoltaic cells. Impurities such as boron or phosphorus are added to this base material. These impurities create the environment for electrons to be freed when sunlight hits the photovoltaic panel. The freeing of electrons leads to the production of electricity [37].

b) **Charge controller (CC):** is needed to prevent overcharging of the batteries. Proper charging will prevent damage and increase the life and performance of the batteries [38].

c) **Backup batteries:** Batteries are used to store energy for use at a later time, like night time or on cloudy days. The number of batteries used by the system varies with battery type and anticipated storage needs [39].

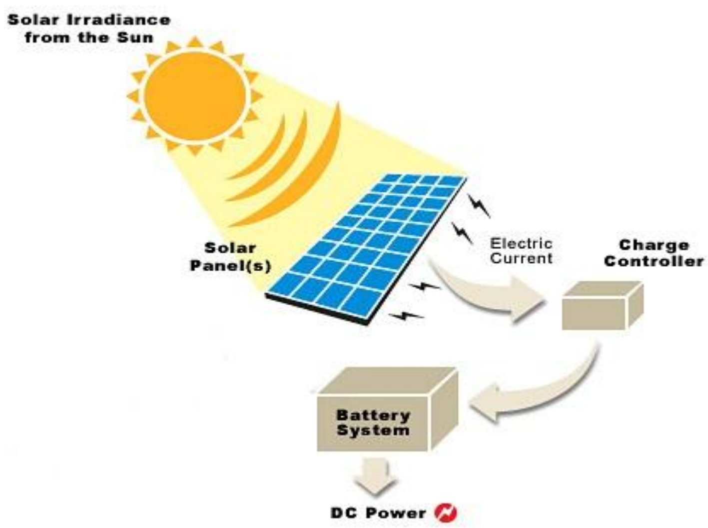


Figure 3.2 Solar system

3.3.2 Congestion Detection System

Cameras are connected to the microcontroller. The MC takes and processes the snapshots of the video camera. We will use two different ways for detecting the cars. One is to compare the snapshots with previously saved images with congestion and announce the intersection state to the transmitter. The other option is to process each snapshot to count the number of vehicles. Figure 3.3 explains the connection of the congestion detection system.

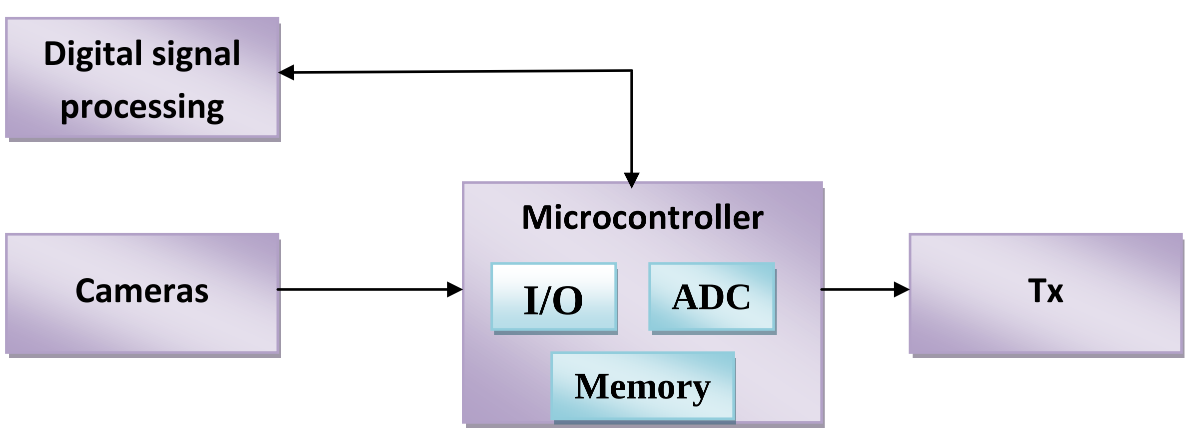


Figure 3.3 Congestion detection system

a) **Cameras:** It is planned to use a camera to communicate with the microcontroller that has a camera interface. One camera may be not enough to observe all ways of the intersection even with a wide angle range of view; so three to four cameras will be used.

b) **Microcontroller Unit:** The image processing algorithm for traffic measurement is realized by an image processing code written as Matlab commands that can be run on the microcontroller.

1. **A/D converter**

   The continuous analog signal of the camera is converted to digital to extract the snapshots at different time intervals. This filter processing allows normalized images to be obtained when there are variations in the lighting due to external environmental conditions .

2. **DSP algorithms**

   The image processing algorithm generated by Matlab software performs the required analysis on the current frame of the video to decide the intersection state.

3. **Memory in the microcontroller**

   The built in memory is used for storing images for later use and process by the system. Snapshots are stored for reference comparing issues, or taken at specified time intervals for direct processing .

4. I/O interfaces

The microcontroller Ethernet interface will be used for the microcontroller to join the network. This will provide a continuous connection to the access point. Also it will be used to communicate with the PC. Other built-in interfaces are found as GPIO pins that will be used if needed .

3.3.3 Wi-Fi Transmitter

The microcontroller has an Ethernet port; it is easy to be connected to a Wi-Fi access point. This access point will have an external directional antenna for the signal to reach the far distances needed. Three or four external directional antennas will be used to send to all the four lanes of the intersection.

3.3.4 Wi-Fi Receivers with built-in Alarm

The message from the antenna will reach the Wi-Fi devices since they are connected to the access point. The devices are previously programmed to respond to the message type as an alarm for the drivers to avoid the intersection, or as permission for the drivers to continue their routes. The alarm is either a Buzzer sound on the same receiver module.

3.4 System Flowcharts

3.4.1 Transmitter side: figure 3.4 shows the transmitter-side flowchart.

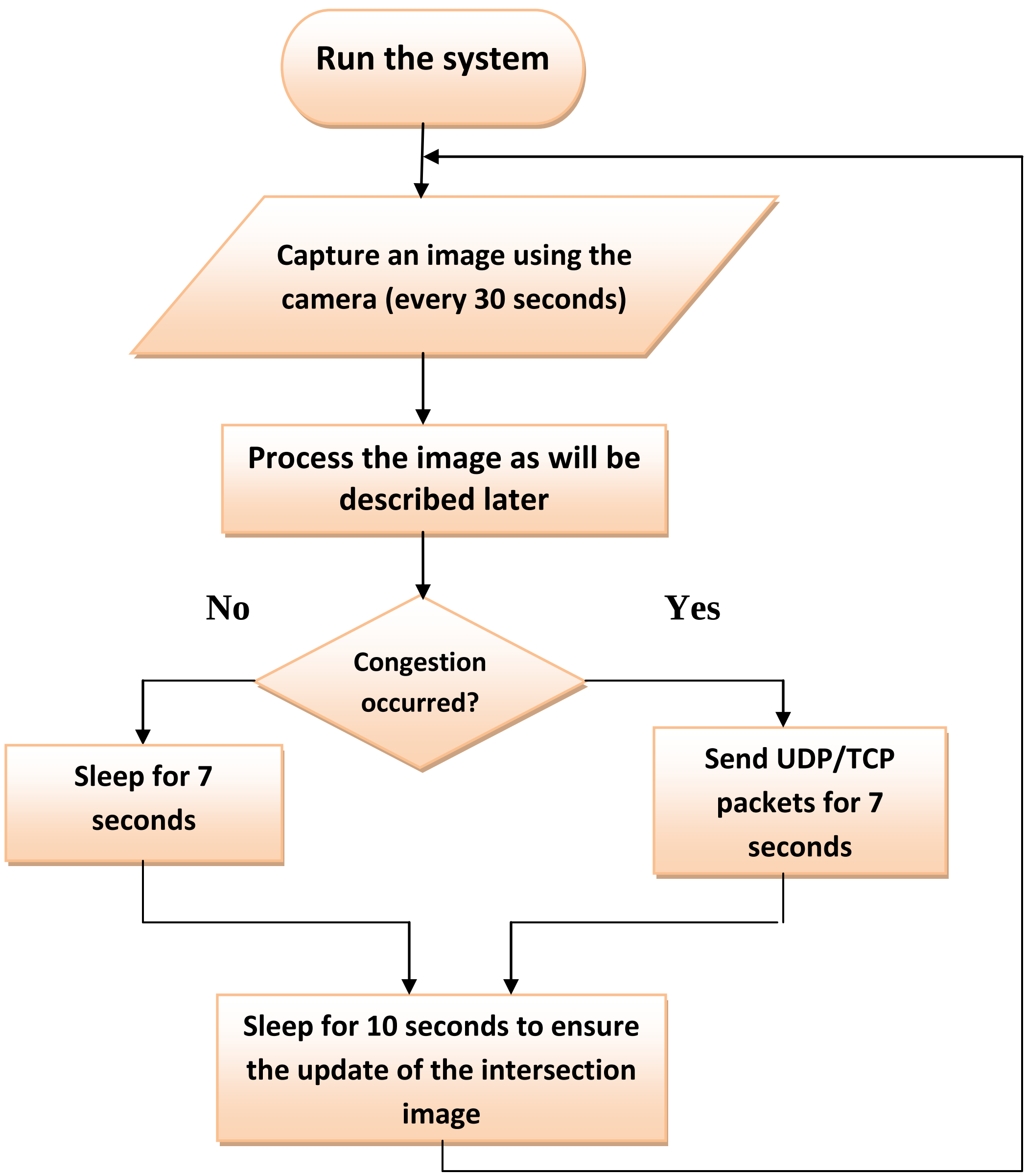


Figure 3.4 Transmitter-side flowchart

3.4.2 Receiver side: figure 3.5 shows the receiver-side flowchart.

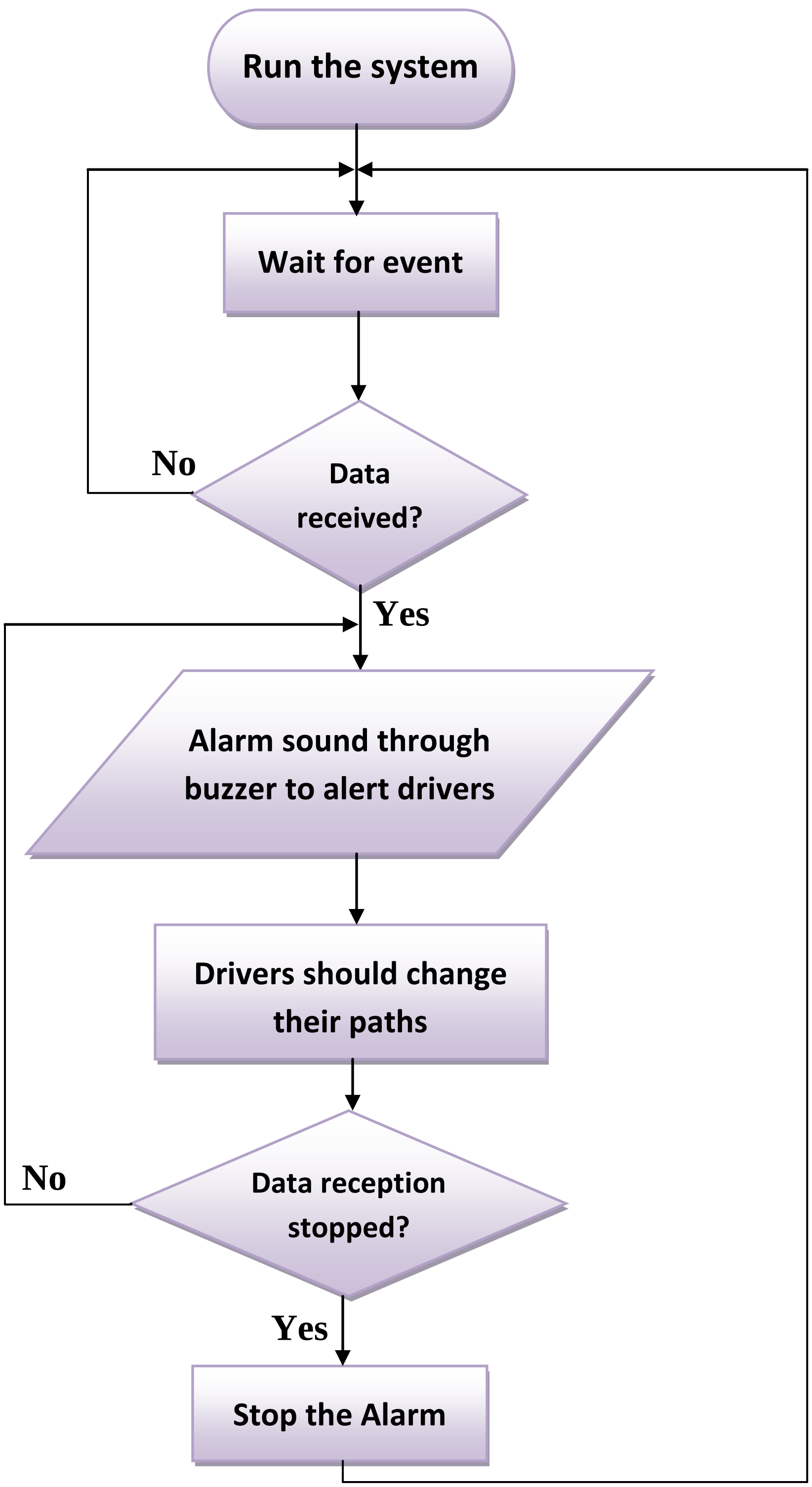


Figure 3.5 Receiver-side flowchart

3.5 System Functions

In this section we show the functions at the intersection and at drivers' side. This is illustrated in figure 3.6.

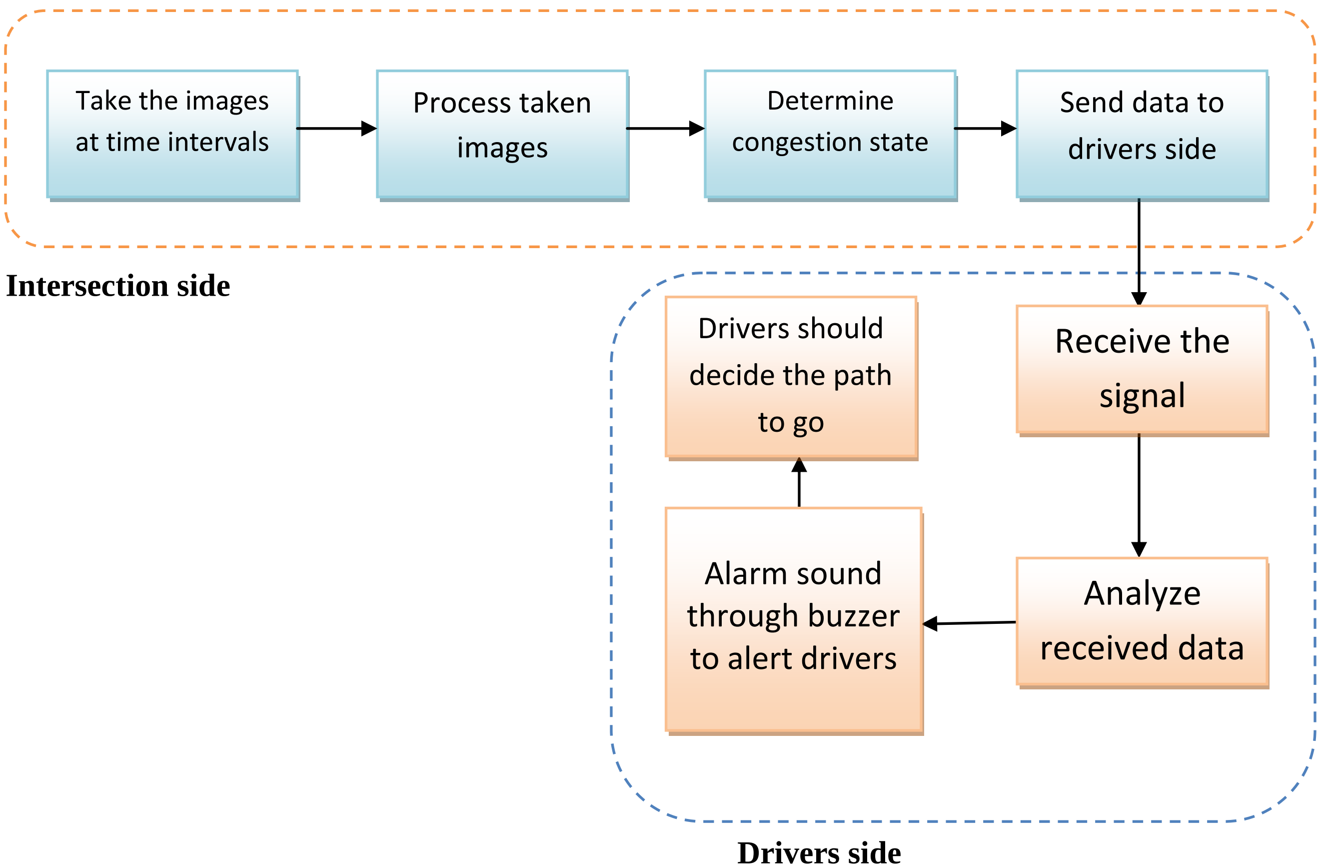


Figure 3.6 System functions

3.6 Software

3.6.1 Raspberry Pi Programming

Raspberry pi is a miniature ARM based microcontroller that depends on Linux, which is an incredibly robust and flexible operating system that can run on everything from large supercomputers all the way down to small embedded devices. To work with the Raspberry pi; It is required to put one of the supported Linux-based OS images such as Raspbian , available on their official web site, to an SD card by special disk imaging software, then install it on the microcontroller.

Raspberry pi supports a lot of programming languages. Some of them are: Octave, Bare metal, C/C++, Java, Python, Scratch or any language that can be compiled for the ARMv6 chip.

Model B of the raspberry pi that will be used supports a Matlab programmed code. This code will be written within terminal in the Raspberry pi operating system via the Ethernet interface [40].

3.6.2 Wi-Fi Module Programming

Programming the Wi-Fi module is just required at the receiver; because we are using an access point at the transmitter. After this programming the Wi-Fi module will be able to connect to the access point, receive the transmitted signal and translate it to an alert for the drivers.

3.6.3 Image Processing Technique

Figure 3.7 shows the image processing technique

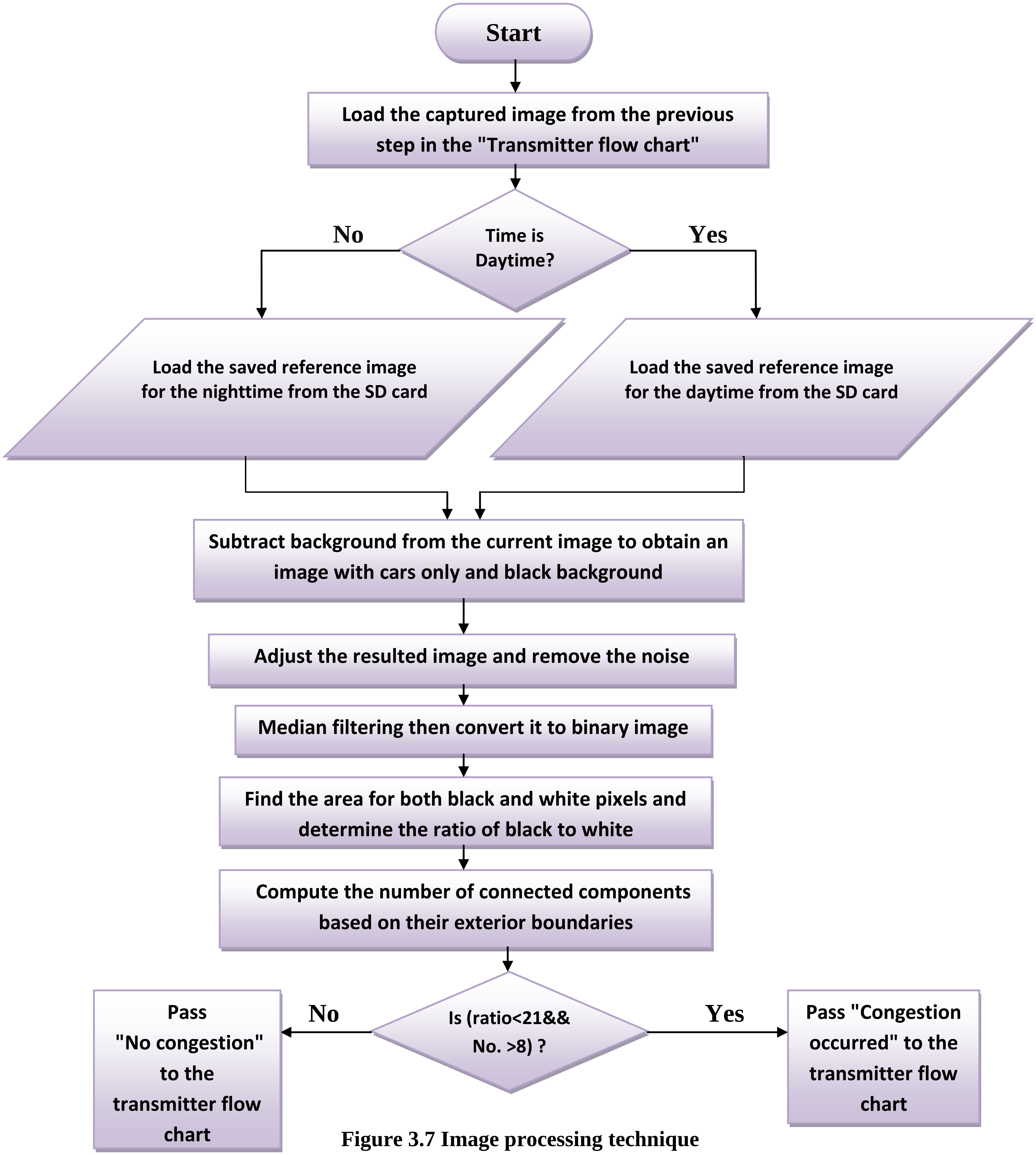


Figure 3.7 Image processing technique

Chapter 4

System Implementation

4.1 Overview

4.2 Solar power Parameters

4.3 Microcontroller Specifications and Setup

4.4 Network Configuration and Access points

4.5 Access the Raspberry pi GUI

4.6 Webcam Connection and Configuration

4.7 Image Processing Software (Octave)

4.8 Receiver Implementation and Configuration

4.9 Implementing the Image Processing Code

4.1 Overview

In this chapter we will explain the system design in details. We will calculate the solar power system parameters, number of devices used and the software code to be used for image processing.

4.2 Solar power parameters

By examining the power dissipation of system appliances it is found that the total wattage needed is 23 Watt. Here are the wattage values for them:

Quantity	Load	Power usage for one	Power
2	Wi-Fi access point	8	16
2	Raspberry pi and webcam	3.5	7
			Total = 23 watt

Considering the low power sleeping modes of devices and the time the system is not working, we assume a working load of 16 hours in a day. Therefore total daily watt-hours required is 23w*16hr = **368**WH/day

V_B = **12**V, Battery charging efficiency = **87**%

Watt-hours required for maximum depth of discharge of 87% is 368/0.87 = **423**WH
Minimum Battery Capacity = 423/12v = **35.25** Ah

Average rate of solar radiation in Palestine is G = 5400 WH/ m^2 /day

PV area= wattage / ($\eta_{battery}$ *$\eta_{pv} *$ G)

PV area= 864 / (0.87 * 0.14 * 5400) = 0.56 m^2

Figure 4.1 shows the solar power system connection to supply the DC loads. A DC-to-DC converter may be used to supply low voltage devices. Figure 4.2 shows the physical devices that have been used.

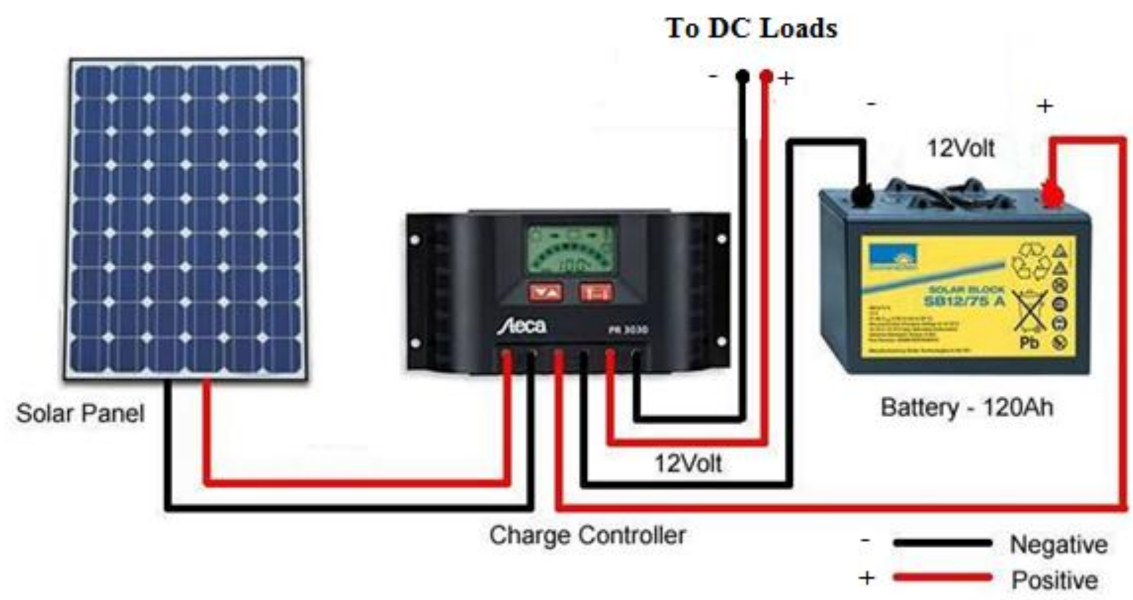


Figure 4.1 Solar system connections to supply DC loads

4.3 Microcontroller Specifications and Setup

Raspberry Pi model B microcontroller will be used. It has the following specifications [41]:

- System on a chip: Broadcom BCM2835
- CPU: 700 MHz ARM1176JZF-S core (ARM11 family, ARMv6 instruction set).
- GPU: Broadcom Video Core IV @ 250 MHz, OpenGL ES 2.0 (24 GFLOPS), MPEG-2 and VC-1.
- Memory (SDRAM): 512 MB (shared with GPU).
- USB 2.0 ports: 2 (via the built in integrated 3-port USB hub).
- Video input: A CSI input connector allows for the connection of a camera module, USB camera.
- Video outputs: Composite video, HDMI (not at the same time).
- Audio outputs: 3.5 mm jack, HDMI.
- Onboard storage: SD / MMC / SDIO card slot.
- Onboard network: 10/100 wired Ethernet RJ45.
- Low-level peripherals: General Purpose Input/Output (GPIO) pins, Serial Peripheral Interface Bus (SPI), Universal asynchronous receiver/transmitter (UART).
- Power source: 5V @ 700 mA via MicroUSB or GPIO Header
- Power ratings: 700mA, (3.5 W).

Figure 4.2 shows all components and interfaces of the raspberry pi model B.

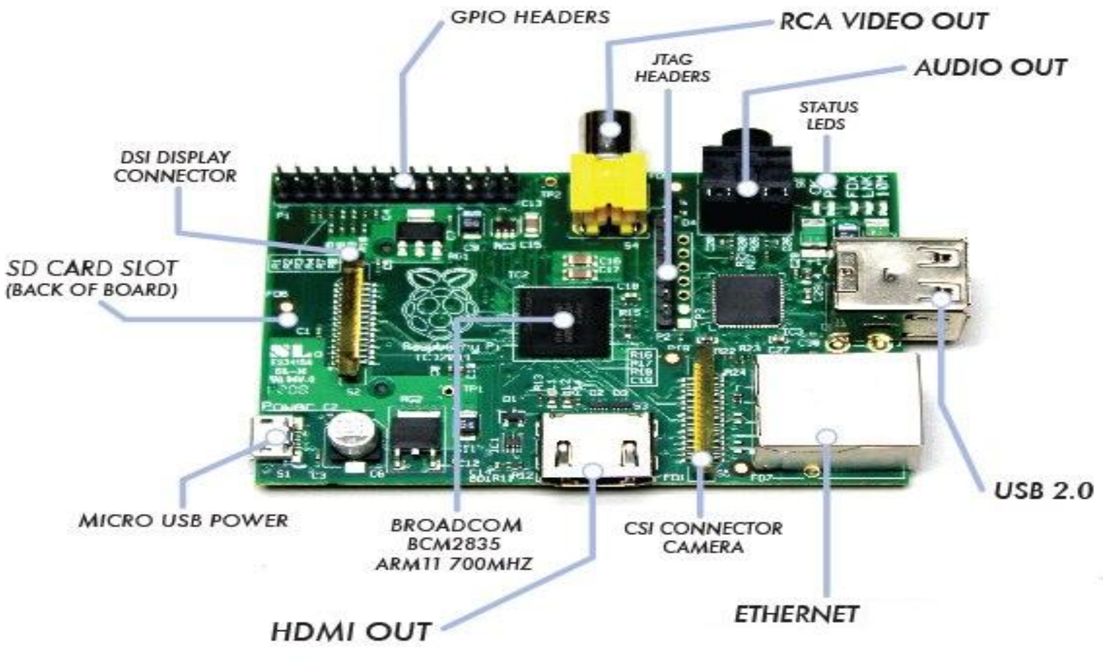


Figure 4.2 Raspberry pi model B components and interfaces

In order to use the Raspberry Pi, it is needed to install one of the images of the Linux operating system onto an SD card. We chose to install Raspbian OS image as follows [40]:

1) Insert an SD card that is 4GB or greater in size into a PC computer.
2) Format the SD card so that the Raspberry can read it.
3) Unzip the downloaded image file of Raspbian.
4) Copy the extracted files onto the SD card that we just formatted.
5) Insert the SD card into its place in Raspberry and connect the power supply.
6) Choose to install, a temporary display will be connected to show the status and help us proceeding with the install.

Having done that, Raspberry will be able to interact and communicate with the peripherals that we want to connect.

4.4 Network Configuration and Access points

TP-LINK 2.4GHz High Power Wireless Outdoor Access point (TL-WA5210G) will be used. Figure 4.3 shows this access point and table 4.1 provides its specifications and features [42].

Figure 4.3 TP-LINK TL-WA5210G outdoor wireless access point

Table 4.1 Specifications of TP-Link TL-WA5210G

HARDWARE FEATURES	
Interface	1 10/100Mbps Auto-Sensing RJ45 Port(Auto MDI/MDIX, PoE) 1 External Reverse SMA Connector One Grounding Terminal
Button	Reset Button
External Power Supply	12VDC / 1.0A Linear PSU
Wireless Standards	IEEE 802.11g, IEEE 802.11b
Antenna	12dBi Dual-Polarized Directional Antenna
Dimensions (W x D x H)	10.4 × 4.7 × 3.2 in. (265x120x83mm)
Antenna Beamwidth	Horizontal: 60° Vertical: 30°
Protection	15kV ESD Protection, 4000V Lightning Protection Grounding Terminal Integrated
WIRELESS FEATURES	
Frequency	2.4-2.4835GHz
Signal Rate	11g: Up to 54Mbps(dynamic) 11b: Up to 11Mbps(dynamic)
EIRP	<20dBm (EIRP, For countries using CE Standards) <27dBm (Peak Output Power, For countries using FCC Standards)
Reception Sensitivity	802.11g 54M: -76dBm 48M: -78dBm 36M: -82dBm 12M: -91dBm 9M:-92dBm 802.11b 11M:-90dBm 5.5M:-92dBm 1M:-98dBm
Wireless Modes	AP Router Mode AP Client Router Mode (WISP Client) AP/Client/WDS Bridge/Repeater mode
Wireless Functions	WDS Bridge, Wireless Statistics
Wireless Security	SSID Enable/Disable MAC Address Filter 64/128/152-bit WEP Encryption WPA/WPA2/WPA-PSK/WPA2-PSK (AES/TKIP) Encryption
Wireless Range	15km with Integrated Antenna 50km Maximum (High gain directional antenna required)
Advanced Functions	Up to 60 meters PoE is supported Provides 4-level signal LED indicator
OTHERS	
Certification	CE, FCC, RoHS
Environment	Operating Temperature: -30°C~70°C (-22°F~158°F) Storage Temperature: -40℃~70℃ (-40°F~158°F) Operating Humidity: 10%~90% non-condensing Storage Humidity: 5%~95% non-condensing

This access point will be mounted at high place at the intersection and directed towards the meant way; because the access point has a directional antenna. The microcontroller will be able to connect to this access point through its Ethernet interface using a typical Ethernet cable. The raspberry pi is going to send a flow of data, whenever it recognizes congestion, using this network which has the receiver modules associated to it. Figure 4.4 shows the access point page that is used to assign static IP-addresses to Wifly modules and to the Raspberry pi.

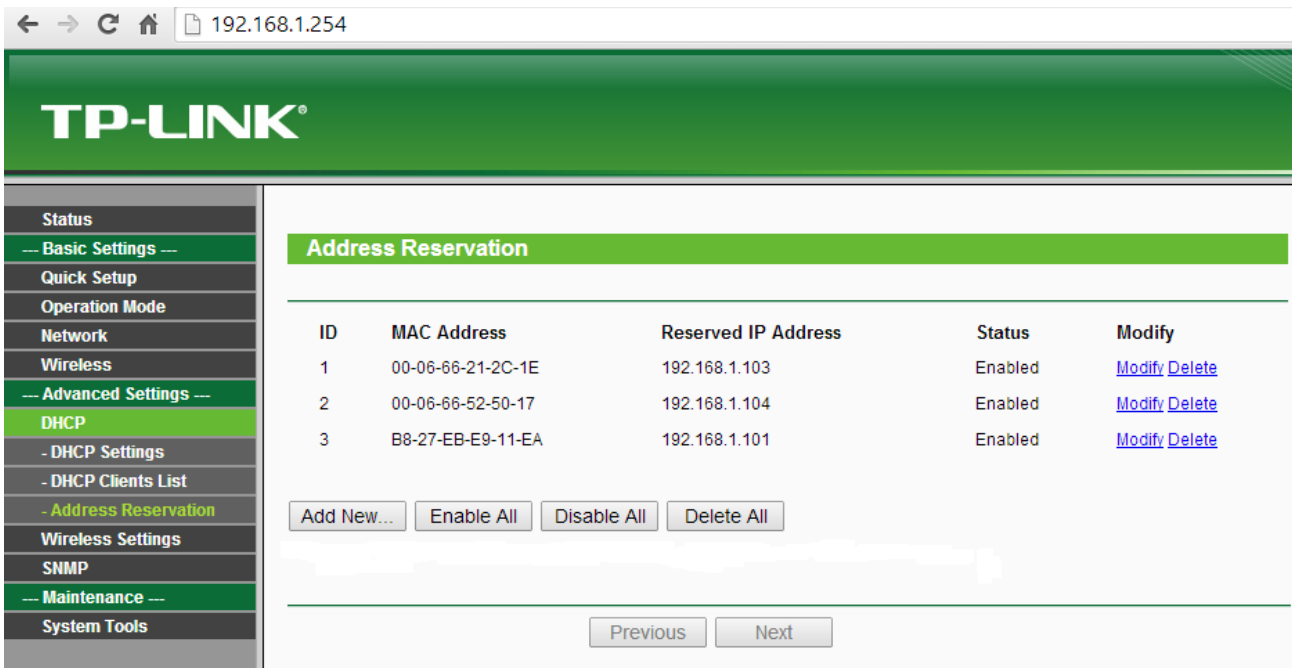


Figure 4.4 Access point reserved IP addresses

4.5 Access the Raspberry pi GUI

Despite that the Raspberry pi can be connected directly to a monitor via HDMI port; it is planned to access the GUI over the local network using the VNC viewer to ease dealing and command testing for the code. This will be done by the VNC viewer on a PC and a VNC server that can be installed on the Raspberry Pi. Having the Raspberry Pi powered up, one end of the Ethernet cable is connected to the board and the other end to the access point. The following are explained steps for installing and using the VNC:

The Raspberry Pi is connected to the access point via the Ethernet cable. The default configuration for the raspberry pi is that it makes an SSH server as it boots up; therefore we can access its LX Terminal from any PC connected to the same access point using Putty as SSH client, the raspberry pi's socket address will be 192.168.1.x:22 as shown in figure 4.5.

The default username for the connection is "pi" and the default password is "raspberry", the terminal window shows up as in figure 4.6 if connection approved.

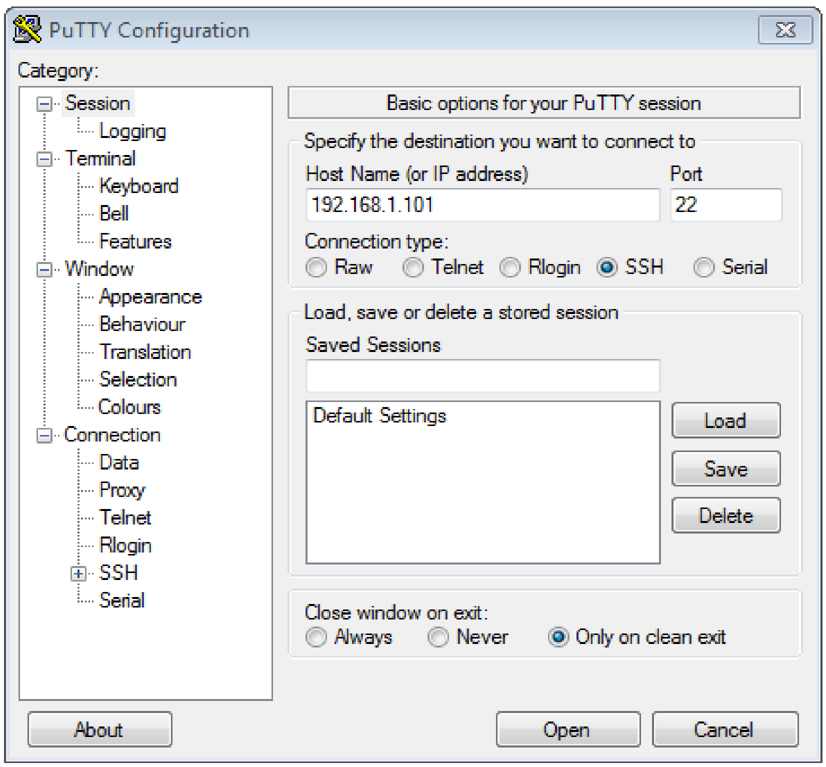


Figure 4.5 Connecting to the Raspberry Pi SSH server using PuTTY

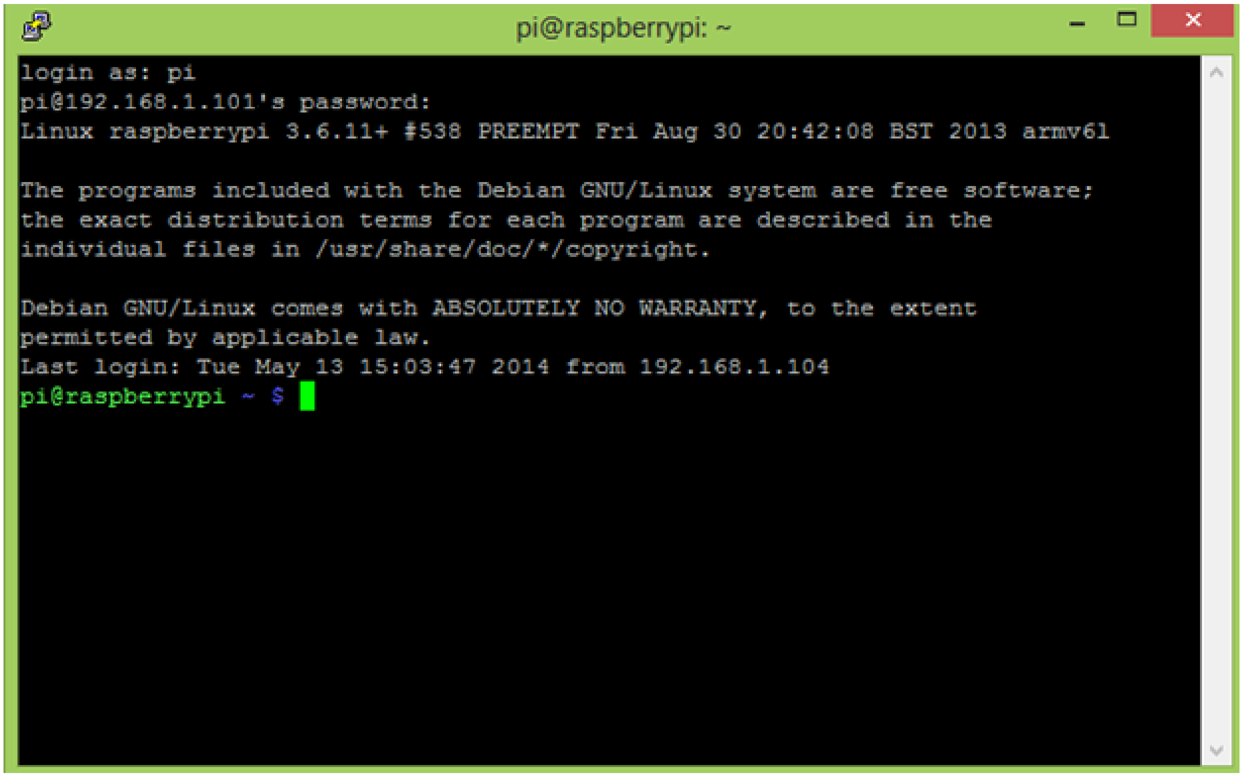


Figure 4.6 Terminal window for raspberry pi commands

To download any needed software packages in the raspberry pi; the operating system should be up to date, this can be done by writing these commands in the terminal [43]:

$ sudo apt-get update

$ sudo apt-get upgrade

$ sudo reboot

To access the raspberry pi Graphical user interface (desktop), the VNC server must be installed and running, this can be done by the following commands [43]:

$ sudo apt-get install tightvncserver // install VNC server

$ tightvncserver // run the program

After executing these commands, the VNC client on the PC can connect to Raspberry Pi desktop as shown in figure 4.7. Figure 4.8 shows the desktop of the Pi.

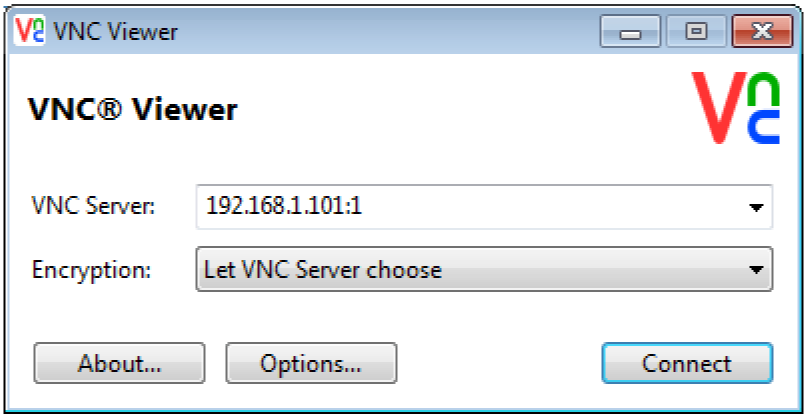


Figure 4.7 Connecting to VNC server

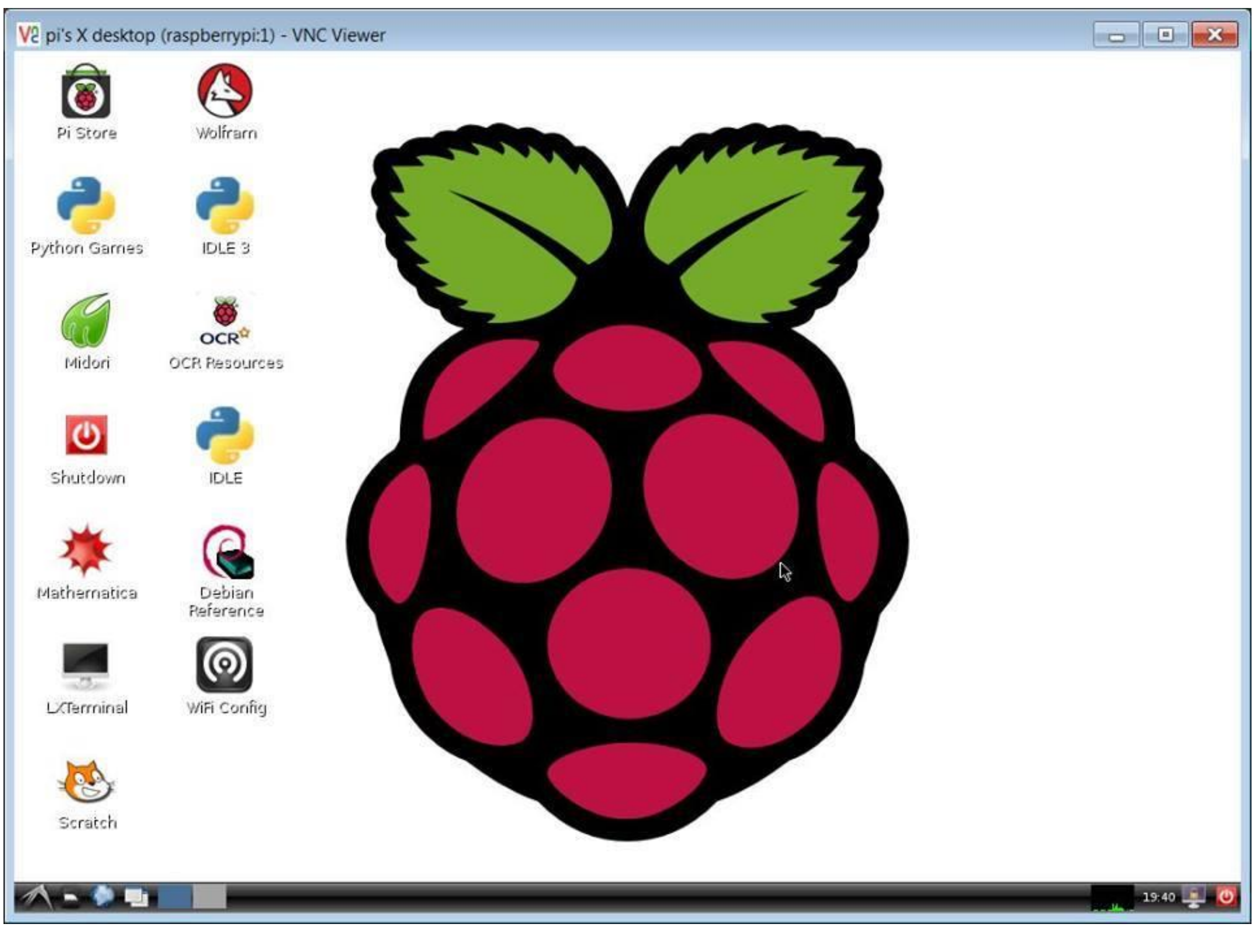


Figure 4.8 Raspberry pi Desktop

4.6 Webcam Connection and configuration

The Logitech C310 Webcam will be connected to the USB port of the Raspberry, the USB webcam is selected because it supports 720P video quality, and also it is tested to work fine without external power from a USB power hub. The code below will be used to capture images from the webcam and process them directly by octave [44].

First it is required to check if webcam is detected correctly by the following command:

```
ls -l /dev/video*
```

If the webcam is detected correctly "/dev/video0" will be printed as shown in figure 4.9, then webcam capture software can be installed using the command:

```
sudo apt-get install fswebcam
```

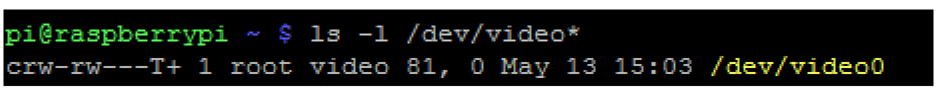


Figure 4.9 Detection of the webcam

"fswebcam" command will be used to capture images from the webcam. The best image dimensions were found to be 640x480 that maintains both the speed of the processing code and the quality of the image to get best results. These images are taken every 30 seconds (using –l parameter) with the same file name; the old image will be replaced by the current image. This can be done by the following command after installing "fswebcam".

```
fswebcam --no-banner -d /dev/video0 –l 30 -r 640x480 current.jpg
```

Figure 4.10 shows the webcam connection to the raspberry pi, which is powered up using a DC-to-DC converter from the battery.

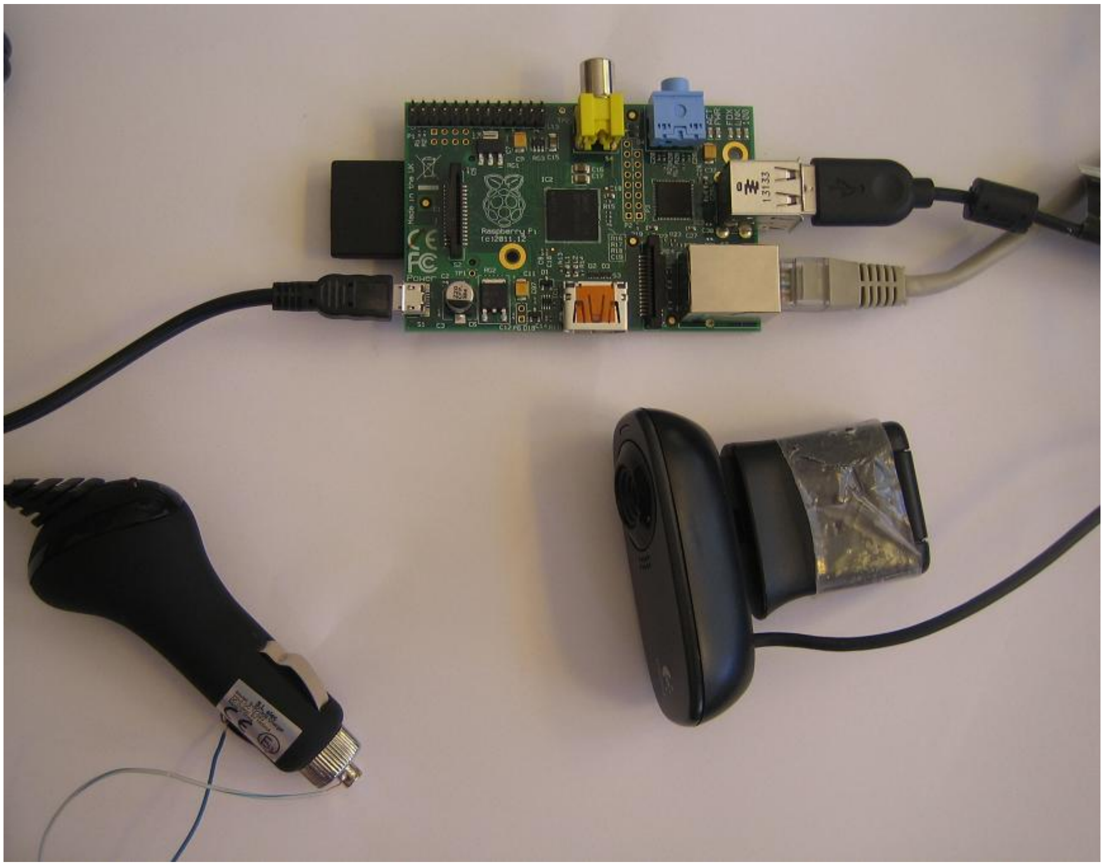


Figure 4.10 Raspberry Pi connections

4.7 Image Processing Software (Octave)

Image processing will be done by the Octave software which is alternative to Matlab, considered as open-source Matlab. Octave will be running in the raspberry pi operating system and continuously execute the image processing code. Here are briefly explained steps for setting up both the octave environment and auto login to Raspberry Pi as it powers up:-

Note: These steps are to be done once just after installing the operating system of the Pi. Then with auto starting of the code within Octave and image capturing script, the Raspberry Pi will be automatically running.

1- Install the octave software on raspberry pi using the command[45]:

```
sudo apt-get install octave
```

2- Install required octave packages using the command [45]:

```
sudo apt-get install octave-“package_name”
```

Required packages within Octave:

“image” and “general” packages: required for image processing and other functions using:

```
sudo apt-get install octave-image
sudo apt-get install octave-general
```

“sockets” : required for sending packets using:

```
sudo apt-get install octave-sockets
```

3- Raspberry Pi auto login

The Raspberry Pi will not start the code and the image taking script until it logins to “pi” account. The following steps show how the Raspberry Pi will auto login to any account such as “pi” account [46], this is shown in figure 4.11.

a- Open a terminal session and edit “inittab” file.

```
sudo nano /etc/inittab
```

b- Find the following line in “inittab”

```
1:2345:respawn:/sbin/getty 115200 tty
```

Add a ‘#’ at the beginning of the line to comment it out

```
#1:2345:respawn:/sbin/getty 115200 tty1
```

c- Add the following line just below the commented line, then save and exit.

```
1:2345:respawn:/bin/login -f pi tty1 </dev/tty1 >/dev/tty1 2>&1
```

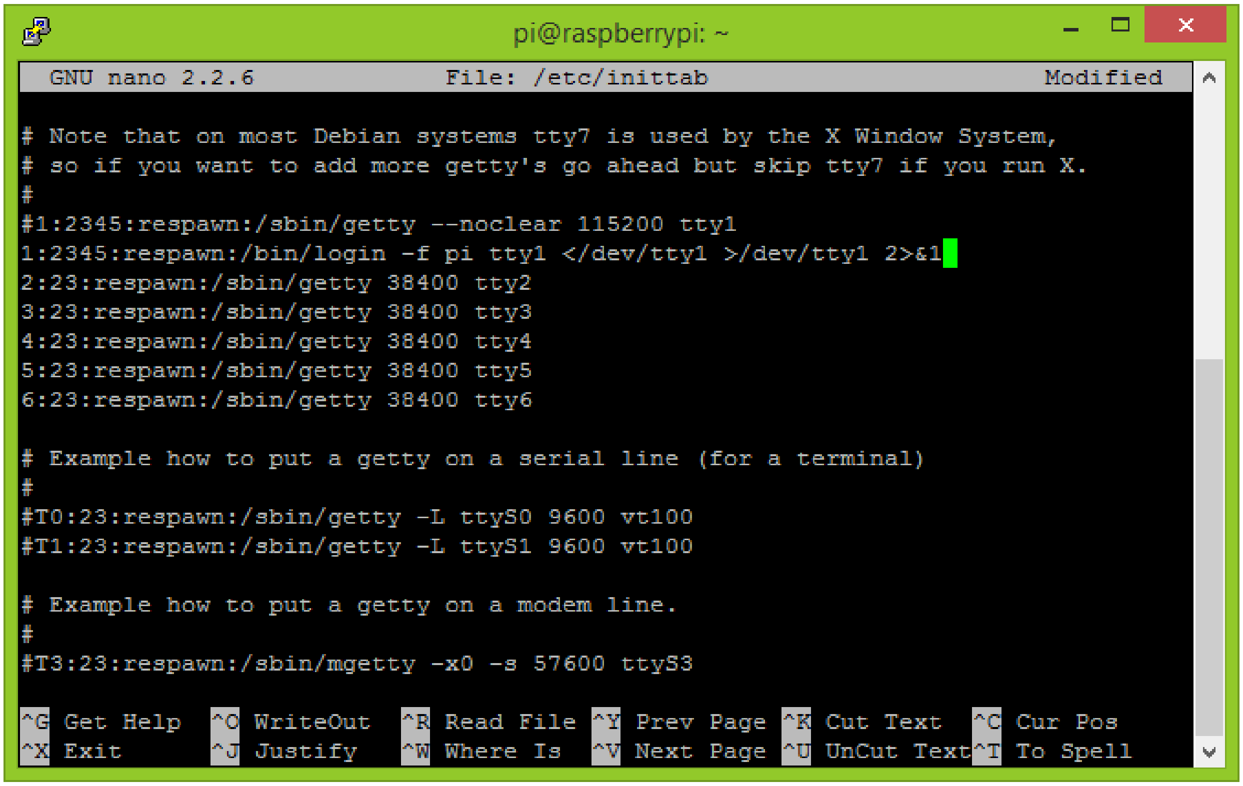


Figure 4.11 Auto login to Raspberry Pi

4- Script auto start

To automatically run both the image processing code and the image-capturing script as the Raspberry Pi boots up, the following two steps are done with the added commands [46], the edited file is shown in figure 4.12.

a- Open a terminal session and edit the file /etc/profile by typing this command

```
sudo nano /etc/profile
```

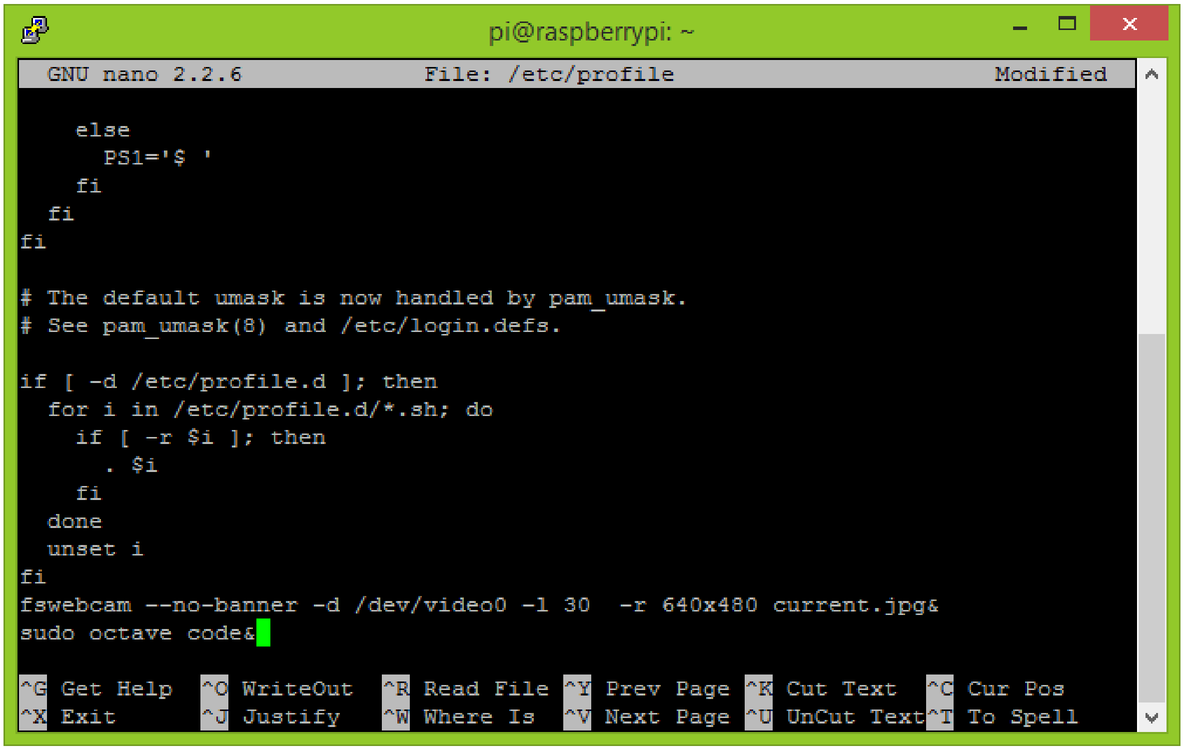
b- Add the following commands to the end of the file, then save and exit.

```
fswebcam --no-banner -d /dev/video0 -l 30  -r 640x480 current.jpg&
```

```
sudo octave code&
```

First command is for taking snapshots every 30 seconds.

Second one is the image processing code which is saved in the directory '/home/pi' with a file name "code"


```
pi@raspberrypi: ~
GNU nano 2.2.6                File: /etc/profile                        Modified

    else
      PS1='$ '
    fi
  fi
fi

# The default umask is now handled by pam_umask.
# See pam_umask(8) and /etc/login.defs.

if [ -d /etc/profile.d ]; then
  for i in /etc/profile.d/*.sh; do
    if [ -r $i ]; then
      . $i
    fi
  done
  unset i
fi
fswebcam --no-banner -d /dev/video0 -l 30  -r 640x480 current.jpg&
sudo octave code&

^G Get Help  ^O WriteOut  ^R Read File ^Y Prev Page ^K Cut Text  ^C Cur Pos
^X Exit      ^J Justify   ^W Where Is  ^V Next Page ^U UnCut Text^T To Spell
```

Figure 4.12 Auto starting of both the code and the image-capturing script

The contents of the file "code" are shown in the end of the chapter.

4.8 Receiver Implementation and Configuration

4.8.1 Module Specifications and Features

RN-131G WiFly GSX transceiver will be used, which is ultra low power embedded TCP/IP solution. The WiFly GSX module is a stand alone, embedded wireless 802.11b/g networking module. The combination of ultra low power and the ability to wake up, connect to a wireless network, send data and return to sleep mode in less than 100 milliseconds, allows the WiFly GSX to run for years on two standard AA batteries. Using only 100mWatts when awake and 10uWatts when asleep, figure 4.13 shows the Wifly, tables 4.2 and 4.3 with figure 4.14 show the datasheet of the pins.

The WiFly GSX module incorporates a 2.4GHz radio, processor, TCP/IP stack, real-time clock, crypto accelerator, power management and analog sensor interfaces. This complete solution is preloaded with software to simplify integration and minimizes development of the application. In the simplest configuration the hardware only requires four connections (PWR, TX, RX, GND) to create a wireless data connection. The transmit range can be up to 330' (100m), but since the modules are used as receivers, the range of the Wi-Fi is determined by the transmitter [32].

Figure 4.13 WiFly RN-131G

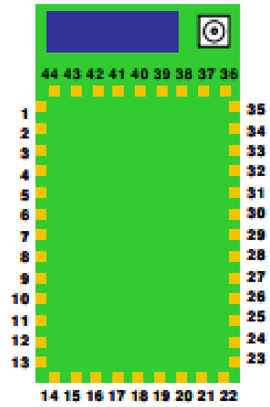


Figure 4.14 Wifly RN-131G pins

Table 4.2 Pins description

Pin	Name	Description
5	RESET	Module reset, Active Low
10	GPIO-13	3.3V tolerant
11	GPIO-12	3.3V tolerant
18	3.3V-REG-IN	boost regulator control input
19	GND	Ground
20	VDD-BATT	Battery input, 2.0-3.3V with boost regulator in use
21	VDD-IN	3.3 to 3.7 voltage, do not connect when boost regulator is in use
24	GPIO-9	Connected to enable Ad-hoc mode
25	GPIO-8	GPIO, 24mA drive, 3.3V tolerant
26	GPIO-7	GPIO, 24mA drive, 3.3V tolerant
27	GPIO-6	Connection STATUS, 24mA drive, 3.3V tolerant
28	GPIO-5	Data transfer STATUS, 24mA drive, 3.3V tolerant
29	GPIO-4	Association STATUS, 24mA drive, 3.3V tolerant

Table 4.3 Sensors description

Pin	Name	Description
1	SENSOR-6	Sensor interface, analog input to module, 1.2V
2	SENSOR-4	Sensor interface, analog input to module, 1.2V
3	SENSOR-5	Sensor interface, analog input to module, 1.2V
4	SENSOR-7	Sensor interface, analog input to module, 1.2V
30	SENSOR-1	Sensor interface, analog input to module, 1.2V
31	SENSOR-2	Sensor interface, analog input to module, 1.2V
32	SENSOR-3	Sensor interface, analog input to module, 1.2V
33	SENSOR-PWR	Voltage output from module to power external sensors, 1.2-3.3V
34	SENSOR-0	Wakeup from external condition

Features:

- Ultra low power 100mWatt active, 10uWatt sleep mode.
- Host Data Rate Up to 100 Mbps for SDIO, 44 Mbps for SPI and 2.7 Mbps for UART.
- Throughput 4 Mbps with TCP/IP and WPA2.
- UART hardware interfaces.
- 10 general purpose digital I/O.
- 8 analog sensor interfaces.
- Real-time clock for wakeup and time stamping.
- Accepts 3.3VDC regulated or 2-3VDC battery.
- Supports Ad-hoc connection.
- Real time clock for time stamping, auto-sleep and auto-wakeup modes.
- Configuration over UART or wireless interfaces using simple ASCII commands.
- Over the air firmware upgrade (FTP), and data file upload.
- Secure Wi-Fi authentication WEP-128, WPA-PSK (TKIP), WPA2-PSK, EAP-TLS for WPA1 & WPA2 Enterprise.
- Built in networking applications DHCP, UDP, DNS, ARP and ICMP [32].

4.8.2 Alarm Configuration and Circuit Design

Data transfer pin in the module will be connected to a Buzzer. Buzzer will continue running as long as the octave is sending data packets. Figure 4.15 shows the circuit diagram. The following commands will be integrated with the image processing code on octave auto-startup file. Sending data to the Wifly module will take place whenever the processing code decides a congestion, data transfer will last for 7 seconds until we check again [32].

4.8.3 Hardware Setup and Configuration

The implemented receiver modules are shown in figure 4.16, for the first run, the Wifly is connected to make its own Ad-hoc network that will be used to send commands for the module to associate with an access point, and save the configuration.

To enter the command mode, ‘*$$$*’ are typed. The module replies with ‘CMD’ to indicate it is in command mode. The module has to be associated with the secured network automatically upon booting (i.e., persistent configuration); so "*set wlan*" command will be used as follows [32]:

These commands are set just for the first time:

set wlan channel 1 // used Wi-Fi channel is '1'
set wlan ssid ABIT // sets the SSID with which the module associates
set wlan auth 4 // sets the authentication mode to WPA2-PSK
set wlan passphrase dwarfdwarf // sets the password of the Wi-Fi connection
set wlan join 1 // associate with the access point that match the // stored SSID, passkey, and channel
save // save settings in configuration file – for "set" commands
reboot

After reboot, the normal connection is taking place for the wifly to be associated with the access point and given a static IP address. This IP address will be used to establish the connection with the module by the octave in Raspberry pi any time it is required to send data.

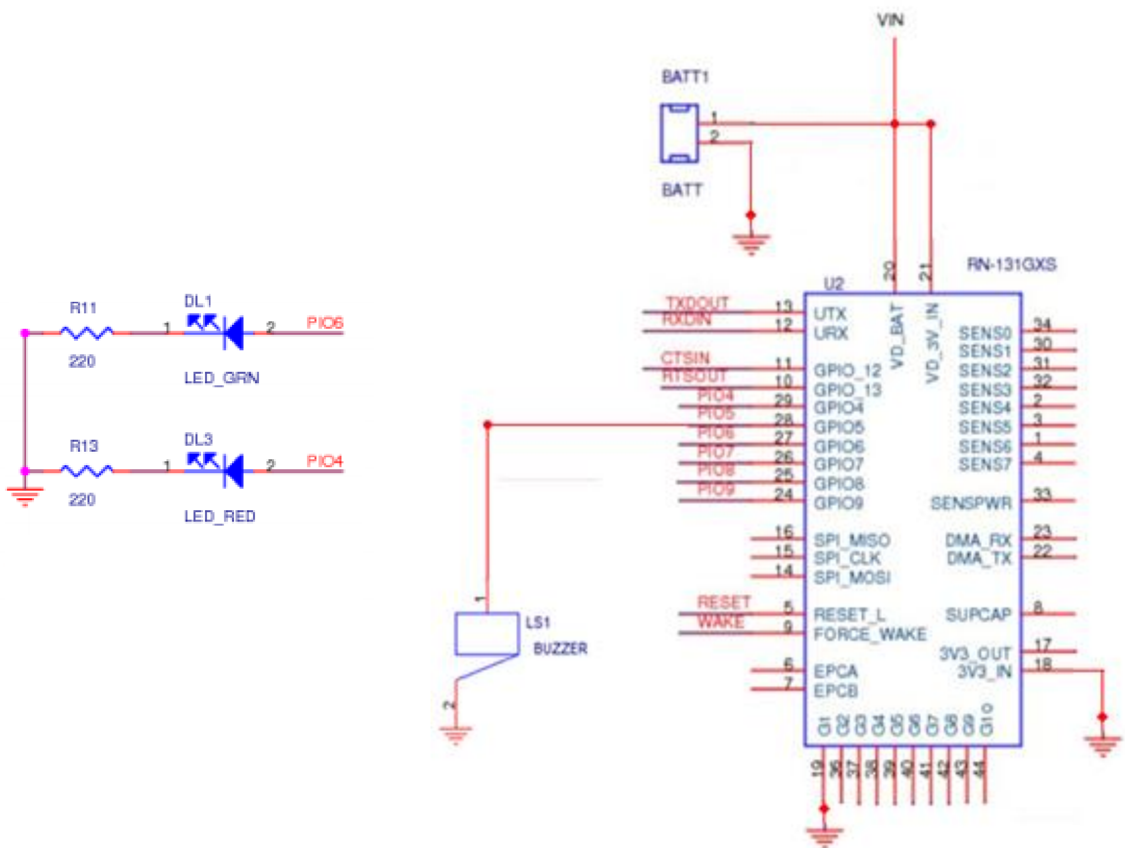


Figure 4.15 WiFly RN-131G connection with Buzzer

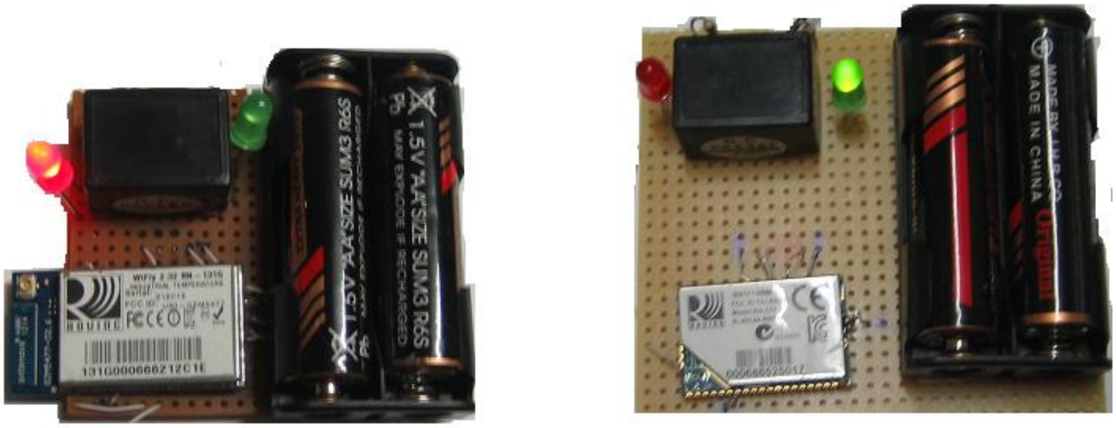


Figure 4.16 WiFly Receiver Modules

4.9 Implementing the Image Processing Code

The following lines of codes are the contents of the file named 'code' mentioned in section 4.7 to detect the traffic congestion and to send the fake data to Wifly whenever it occurs. The background image without cars is subtracted in the beginnig of the code. The code -as designed in chapter 3- converts the cars to blocks with white pixels and finds the ratio of resulted black to white area. The code checks this ratio (s-value in the following code), and finds a rough estimation for the number of white areas, then checks both the ratio and the number to decide the congestion state. The criteria is different for each lane, the best implementation for this lane is found to be (s<21&&L>8) in nighttime and (s<17&&L>8 | | s<25 &&L>30) in daytime to specify a congestion.

```
r=ones(3); r=im2bw(r,0);          // binary-converted matrix to be used to dilate  the white pixels.
while true                        // the code should be always running
b=imread('/home/pi/reference.jpg');       // load the prepared reference image for daytime
c=clock; c=c(4);                  // use clock function to know the time, the forth element is the "Hour"
t=imread('/home/pi/current.jpg');     //this image is taken using the webcam- changes every 30 seconds
d=b-t;                            // subtract original image from reference image
if ((c<6) | | (c>19))             // the night hours
b=imread('/home/pi/reference1.jpg');      // load the prepared reference image for night
d=t-b;                            // subtract reference image from original image
end
```

```
d=imcomplement(d);                        // each pixel value is subtracted from the max-pixel value (255)
d=d-100;                                  // decrease the brightness of the image
d = imadjust(d,stretchlim(d),[0  .9]);    // finding the lower and upper limits for contrast stretching
                                          // of the image, imadjust to increase the contrast of the image
d=rgb2gray(d);                            // convert from RGB image to gray scale
d=imadjust(d);                            // adjusting image intensity
th=graythresh(d);                         // computes threshold  for conversion from gray scale
if ((c<6) | | (c>19))                     // check the night hours to apply the night threshold
th=.25; end                               // night threshold is fixed at 0.25
d=medfilt2(d);                            // to binary image right after the median filtering
d=im2bw(d,th);                            //black and white image, value of any pixel is either zero or one (binary)
d=imcomplement(d);                        // black and white are reversed
d=bwmorph(d,'majority',9);                // morphological operation to remove tiny unwanted objects
d=imdilate(d,r);                          // dilate the white pixels using a 3×3 white matrix
blackcount = sum(sum(d==0));              // calculate the total area of black pixels of value '0'
whitecount = sum(sum(d));                 // calculate the total area of white pixels with value '1'
s=blackcount/whitecount;                  // find the ratio of black to white
cc=bwboundaries(d,8,'noholes');           //compute exterior object boundaries using 8-connected objects
L=numel(cc);                              // compute the number of objects based on their exterior boundaries
if ((c<6) | | (c>19))                     // check the night hours to apply a criteria
if (s<21&&L>8 )  transmitting             // check the criteria in nighttime and transmit if true
else sleep(7) end                         // sleep 7 seconds if no congestion at night
else if (s<17&&L>8 | | s<25 &&L>30)       // check the criteria if it detects a congestion – this criteria
                                          // is different for the daytime
transmitting end                          // call the m-file that we built using socket for transmission
else sleep(7)                             // sleep 7 seconds if no congestion at daytime
end
sleep(10)                                 // sleep10 seconds before checking again
end
```

The m-file of "transmitting.m" is copied to the Octave image-package directory to be called from inside the previous code. The m-file contains the following commands:

```
inf1=struct('addr','192.168.1.103','port',2000);   // structure array with the receiver info.
inf2=struct('addr','192.168.1.104','port',2000);
 s1=socket();    s2=socket();
 status1=connect(s1,inf1); status2=connect(s2,inf1);     // connecting to the socket
tic                                                // for timing
while (toc<7)                                      // sending for 7 seconds
send(s1,'jhjh'); send(s2,'jhjh');                  // any string can be sent
sleep(0.05);                                       // to slow down the transmission rate; for Wifly
end                                                // to keep up with the transmission
```

To remove everything in the image except cars, i.e. having a complete background subtraction with resulted images contain cars only, the following reference images in figures 4.17, 4.18 and 4.19 have been prepared for each lane in daytime and nighttime.

Figure 4.17 Reference image for the first lane in daytime

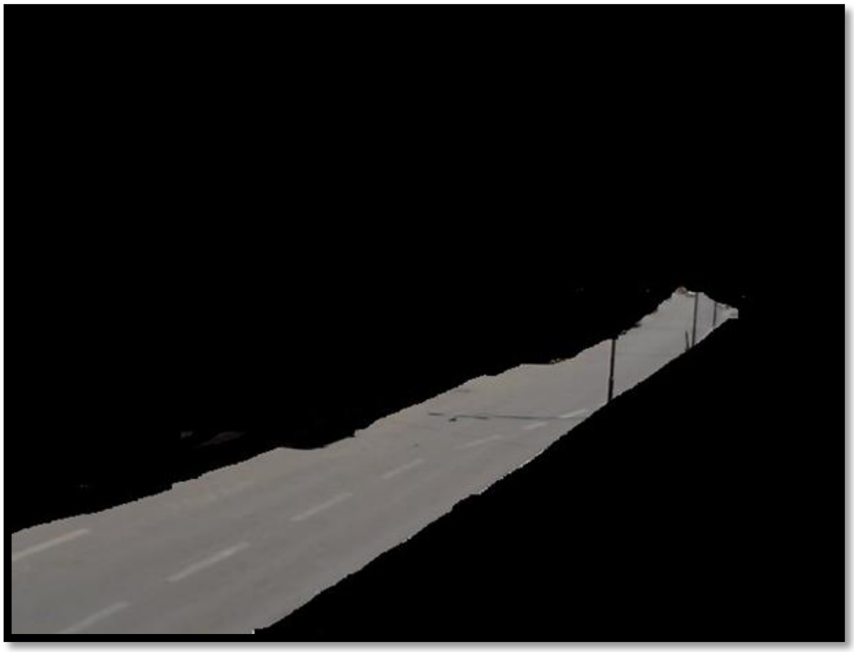


Figure 4.18 Reference image for the second lane in daytime

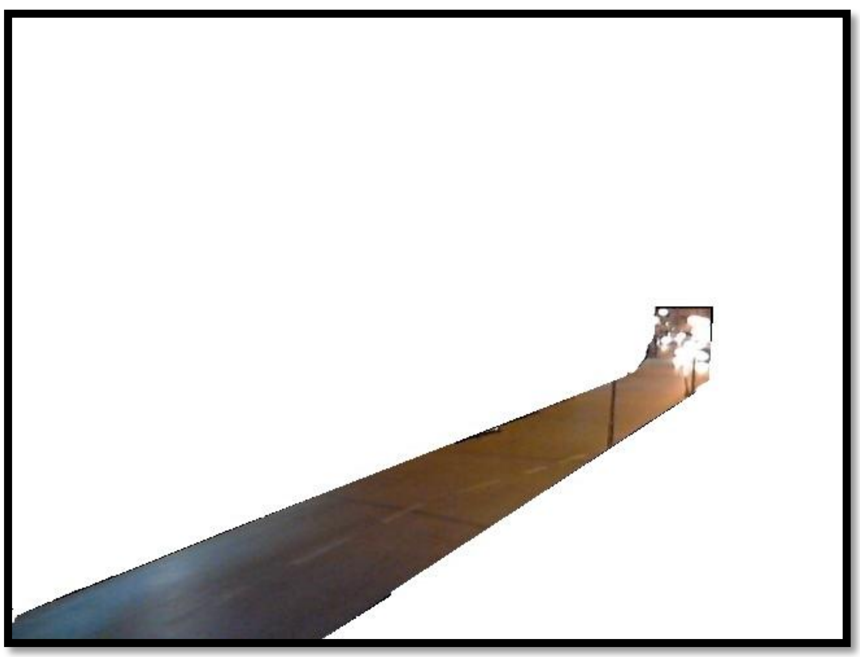


Figure 4.19 Reference image for the second lane in nighttime

Chapter 5

Testing and System's Performance

5.1 Overview

This chapter illustrates measuring performance and how we tested the system physically in an intersection located in Hebron city and captured about 500 images, 80 of them were for congestion cases. The images were taken for two lanes both in daytime and nighttime. The location of the camera and access point was chosen to achieve best capable performance. Testing takes place mainly in the image processing code and its performance from the microcontroller. In addition to transmitters and designed receivers.

5.2 Testing and Results

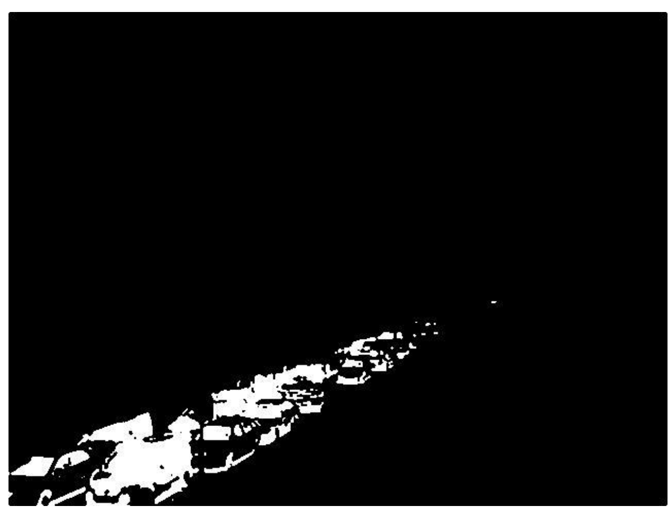
5.2.1 Testing the Image Processing Code

The code is running on the Raspberry pi using Octave software. To test the code on the two different lanes, each lane is assigned a camera for capturing, Raspberry Pi and a TP-link transmitter. If the taken image of the first lane looks like the one in figure 5.1, which is congested, the processing results and the result of the checking statement in the code are illustrated right after the original image.

Figure 5.1 First lane congested image

Figures 5.2 and 5.3 Subtracted from the reference image, complemented and brightness-adjusted

Figures 5.4 and 5.5 Adjusted image using the contrast limits, converted from RGB to gray scale



Figures 5.6&5.7 Median filtered image, converted to binary image (black/white), complemented

Figure 5.8 to the right is the final image in the processing of the original image. The next step in the code is to find the black and white areas using the “sum function”, the ratio of black to white area in this resulted image is s=20 and the number of exterior objects is L=10.

Figure 5.8 Small structures removed – resulted image

In the code checking “if (s<25 &&L>8 | | s<30&&L>25)” returns true, and there is a congestion; transmission takes place for 7 seconds. Now, the code checks again after 10 seconds if the congestion is still exist. For the testing scenario, it is said that the following image in figure 5.9 is taken, the same process as previous is illustrated with figures.

Figure 5.9 First lane uncongested image

Figures 5.10 and 5.11 Subtracted from the reference image, complemented and brightness-adjusted

Figures 5.12 and 5.13 Adjusted image using the contrast limits, converted from RGB to gray scale

Figures 5.14 and 5.15 Median filtered image, converted to binary image, complemented

Figure 5.16 to the right is the final image in the processing of the original image. The next step in the code is to find the black and white areas using the “sum function”, the ratio of black to white area in this resulted image is s=79.8 and the number of exterior objects is L=10.

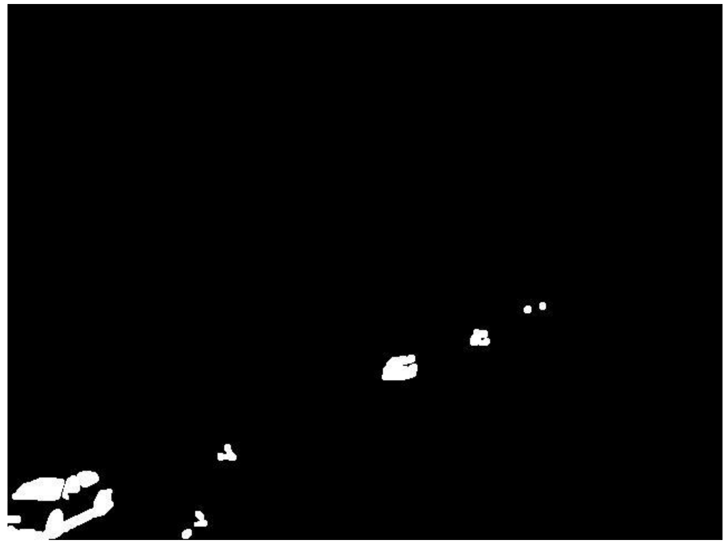
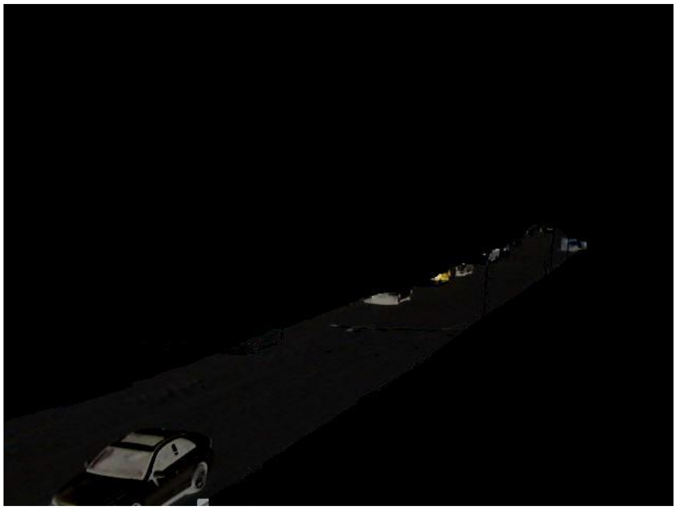
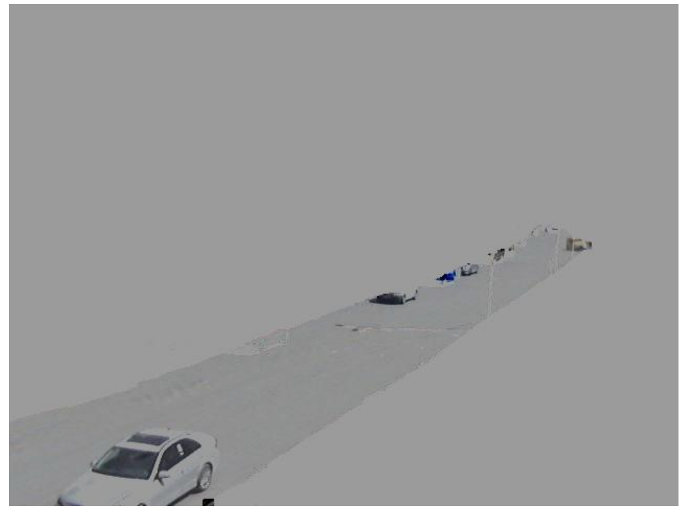


Figure 5.16 Small structures removed – resulted image

In the code checking “if(s<25 &&L>8 | | s<30&&L>25)” returns false, and there is no congestion; sleeping for 17 seconds until checking again.

The following testing is for the other lane, the criteria for this lane is found to be “if(s<17&&L>8 | | s<25 &&L>30)” and is implemented using another Raspberry Pi with TP-link and a camera unit. It is said that the image in figure 5.17 is taken.

Figure 5.17 Second lane uncongested image

Figures 5.18 and 5.19 Subtracted from the reference image, complemented and brightness-adjusted


Figures 5.20 and 5.21 Adjusted image using the contrast limits, converted from RGB to gray scale


Figures 5.22 and 5.23 Median filtered image, converted to binary image then complemented

Figure 5.24 to the right is the final image in the processing of the original image. The next step in the code is to find the black and white areas using the "sum function", the ratio of black to white area in this resulted image is s=62 and the number of exterior objects is L=10.

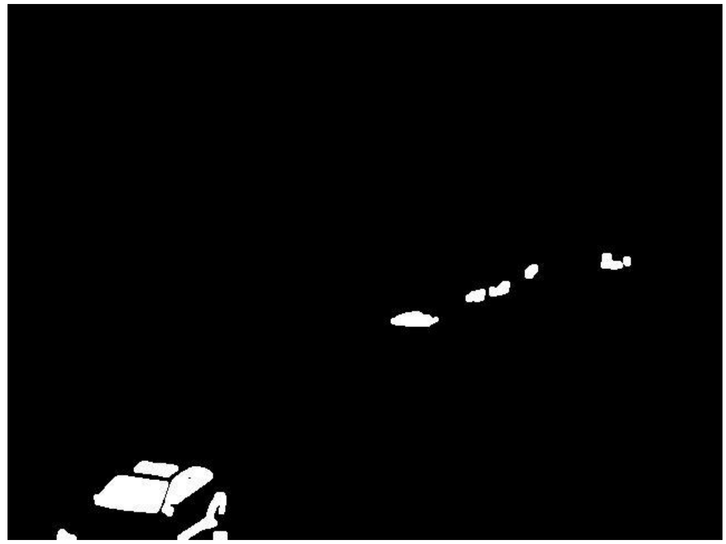


Figure 5.24 Small structures removed – resulted image

In the code checking "if(s<17&&L>8 | | s<25 &&L>30)" returns false, and there is no congestion; sleeping for 17 seconds to make sure another image is captured. Now, the code produces a new result again after 14 seconds (the delay time of the processing). If the image in figure 5.25 is taken after 30 seconds (time between snapshots) the process resulted image is shown in figure 5.26 and processed to tell a congestion after 15 seconds of capturing the image (delay time of processing plus the end of the previous sleep time).

Figure 5.25 Second lane congested image

The ratio of black to white is 15.8 and number of exterior objects is 28. These values are clearly reflecting congestion after executing the "check statement". The Alarm in the receiver has worked for 7 seconds.

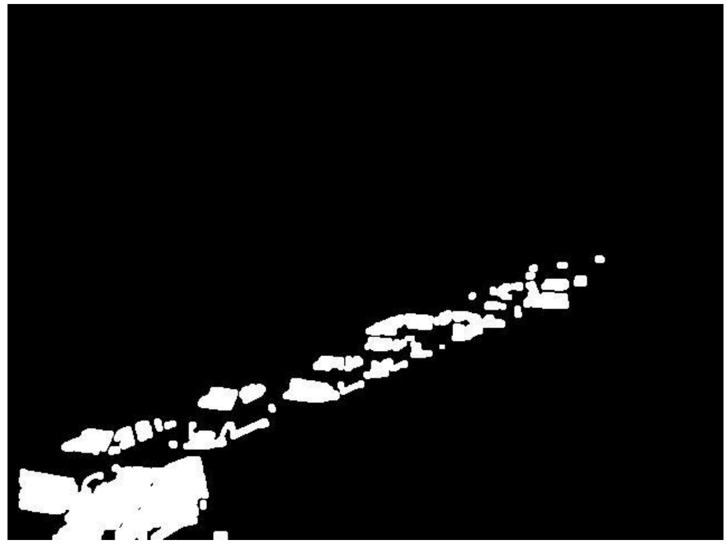
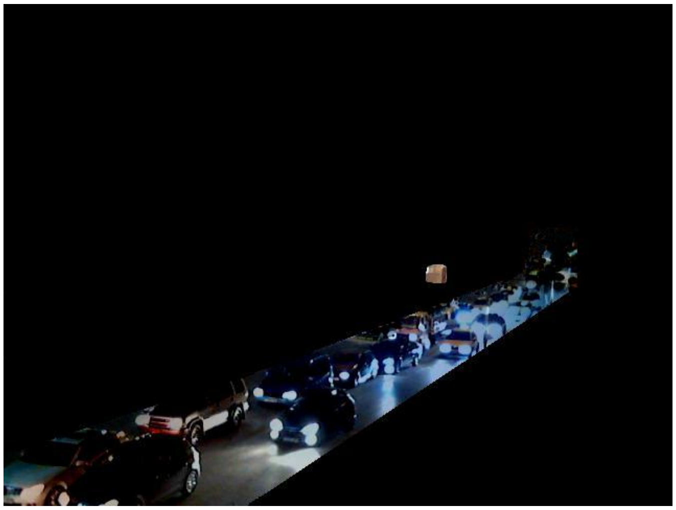
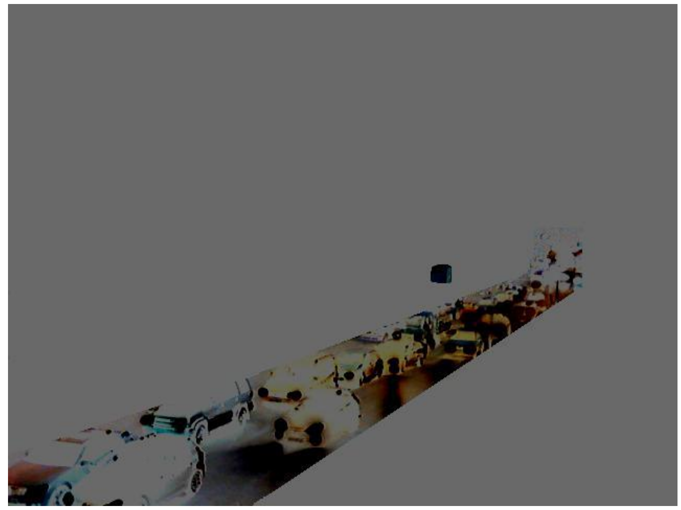


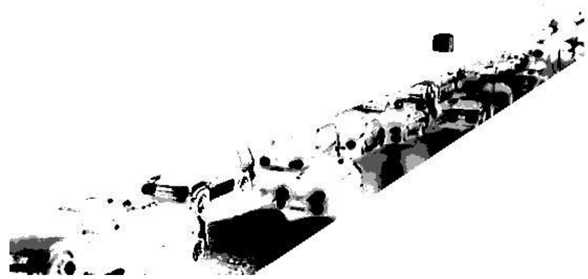
Figure 5.26 Resulted image

The code is also tested in the night and has worked fine but with changing the reference image and the subtraction order, which is checked at the beginning of the code. The criteria for this lane in the night is found to be "if(s<21&&L>8)".Here is a sample of the results in the night. Figure 5.27 shows a congested traffic in the night, followed by the same illustration with figures.

Figure 5.27 Congested traffic at night

Figures 5.28 and 5.29 Subtracted from the reference image, complemented and brightness-adjusted

Figures 5.30 and 5.31 Adjusted image using the contrast limits, converted from RGB to gray scale

Figures 5.32 and 5.33 Median filtered image, converted to binary image, complemented

Figure 5.34 to the right is the final image in the processing of the original image. The ratio of black to white area in this resulted image is s=14.8 and the number of exterior objects is L=22.

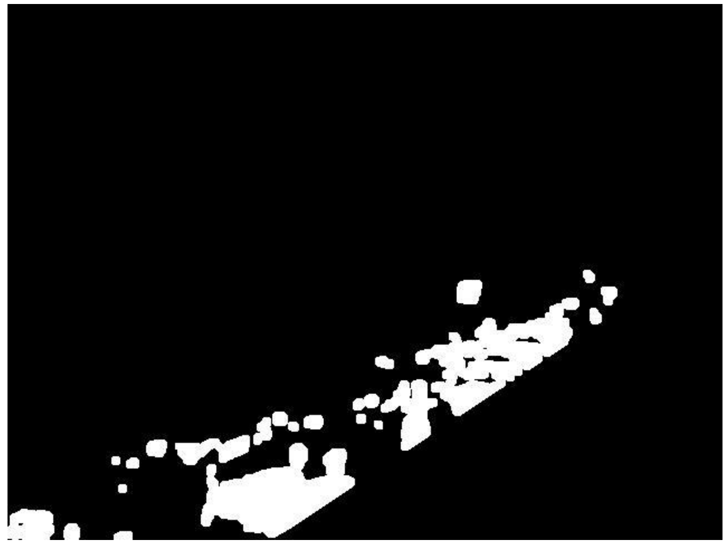


Figure 5.34 Small structures removed – resulted image

In the code checking “if(s<21&&L>8)” returns true, and there is a congestion; transmission takes place for 7 seconds, then checking again after 10 seconds, and so on.

5.2.2 Testing the Wifly Modules

Throughout the previous testing, the Wifly receiver modules were working fine on their battery power by turning on the circuit, searching for the saved access point SSID and channel number, associating with this access point and alerting a sound whenever there is a congestion. The “transmitting.m” file which is programmed as in section 4.9 is executed in Octave to test the Wifly modules. The modules were producing their alarm sound correctly while the code is running.

5.2.3 Testing the Wi-Fi Network

The outdoor TP-link access point has a directional antenna that is directed towards the coming traffic; therefore the coverage has reached a distance of about 280 meters. This distance is enough to send the alarm and let the drivers change their routes if the traffic is congested.

5.2.4 Testing the Solar System

PV-panel and the charge controller with the battery were tested many times in sunny days, the panel is producing about 55W of power at 19 volts, the charge controller was charging the battery at 12V. The battery was supplying the two TP-link access points and the two raspberries with the power, it worked for about 6 hours in the night, which is enough for running the system in the possible congestion traffic times after sunset.

5.3 Performance Evaluation

In this section, evaluation results of system components are presented. This includes selection probability and response time.

5.3.1 Response Time of the Raspberry Pi

The main delay of the Raspberry Pi is in the processing time at the Raspberry Pi, image capturing and storing to '/home/pi/current.jpg' requires 4 seconds with a complexity of order 1 'O(n)', and the image processing code with complexity of order 2 '$O(n^2)$' since it handles two while loops, it needs 10 seconds to be executed. This total delay of 14 seconds can be reduced to 11 seconds by speeding up the Pi to 950MHz from the configuration, but this state decreases the life time of the Pi and hence not implemented. This delay time does not exceed the traffic lights stopping time of about 52 seconds in one lane and more than a minute in the other.

5.3.2 Response Time of Wifly Modules

The wifly modules takes about 1 second to be associated with the access point, but after running for a long time on the same batteries, the supplied power for the wifly decreases and causes a delay of about 3 seconds to be associated, to improve this response time, batteries should be replaced.

5.3.3 Evaluation Results

The following table provides the evaluations results for both lanes with the computed percentage of performance for the system.

Table 5.1 Evaluation results

	Tested images	Correct Decisions	Errors		Performance
			Real congestion but not detected	No congestion but false alarm	
First lane	72	68	3	1	94%
First lane night	58	54	1	3	93%
Second lane	94	84	5	5	89%

Chapter 6

Learning Outcomes and Future Work

6.1 Introduction

6.2 Acquired Learning Outcomes

6.3 Future Work

6.4 Conclusion

6.5 Problems

6.1 Introduction

This chapter describes the learning outcomes that have been acquired during the work on the project, suggestions for future work and development. Problems that raised during the work on the project are also mentioned.

6.2 Acquired Learning Outcomes

Upon accomplishing the project tasks many talents and abilities have been acquired, such as:

1- Dealing with Raspberry Pi microcontroller.
2- Dealing with Wifly module.
3- Image processing using octave.
4- Learning and dealing with solar power systems.
5- Troubleshooting and problem solving.

6.3 Future Work

Different ideas have appeared while implementing the system, such as:

1- Linking this project with smart phone devices to spread the alarm system.
2- Keep sending packets during image processing.
3- Install the cameras on a fixed high place to capture better images and get a better performance.
4- Integrate the project to detect the traffic congestion from any system with traffic-monitoring video.

6.4 Conclusion

1. We designed and implemented an operational system for congestion recognition and alerting.
2. Testing Results have shown acceptable performance over large number of runs.
3. System adoption is very easy and direct.
4. Requirements are simple and in hands.
5. Drivers can be alerted over their smart phones or special units with Wi-Fi Interface.
6. Our Next Step: Consult Hebron Municipality and other responsible parties in the country and present the system for real deployment and use.

6.5 Problems

Many problems have been raised during the work on the project. Some of these problems are:

1. The availability of the project's components.
2. Slow response in the system because the image processing steps.
3. Big time spent to choose the suitable location to take snapshots for the intersection.

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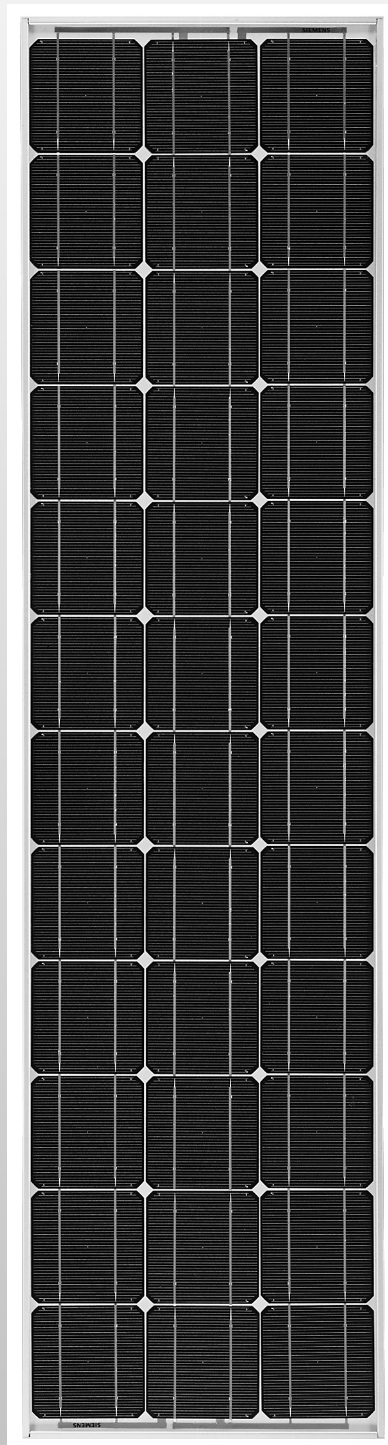
Appendix

Datasheets

SIEMENS

Solar module SM55



When it comes to reliable and environmentally-friendly generation of electricity from sunlight, solar modules from Siemens provide the perfect solution. Manufactured in compliance with the most stringent quality standards, Siemens Solar modules are designed to withstand the toughest environmental conditions and are characterized by their long service life. Siemens Solar modules are covered by a 25-year limited warranty on power output – your guarantee of trouble-free solar power generation.

PowerMax® technology

Siemens' proprietary PowerMax® technology optimizes the energy production of individual cells and solar modules for all types of environmental conditions. PowerMax® process optimization includes a special refining technique for ingots, a clean room semiconductor grade production process, and a multistage proprietary TOPS™ (Texture Optimized Pyramidal Surface) process. The TOPS process incorporates the formation of textured pyramids on the surface of the solar cell. These pyramids are then specially treated to passivate the surface which optimizes the cell's optical properties for maximum absorption of photons from the sun's light. TOPS also maximizes photon absorption from direct and diffused light (typical under cloudy conditions). This means that light absorption is especially high, even at low light levels. Siemens PowerMax® solar cells deliver maximum energy throughout the day.

Solar module

Model:	**SM55**
Rated power:	**55 Watts**
Limited Warranty:	**25 Years**

Certifications and Qualifications

- UL-Listing 1703
- TÜV safety class II
- JPL Specification No. 5101-161
- IEC 61215
- MIL Standard 810
- CE mark
- FM Certification (SM55-J)

Intelligent module design

- All cells are electrically matched to assure the greatest power output possible.
- Ultra-clear tempered glass provides excellent light transmission and protects from wind, hail, and impact.
- Torsion and corrosion resistant anodized aluminum module frame ensures dependable performance, even through harsh weather conditions and in marine environments.
- Built-in bypass diodes (12V configuration) help system performance during partial shading.

High quality

- Every module is subject to final factory review, inspection and testing to assure compliance with electrical, mechanical and visual criteria.
- 36 PowerMax® single-crystalline solar cells deliver excellent performance even in reduced-light or poor weather conditions.
- Cell surfaces are treated with the Texture Optimized Pyramidal Surface (TOPS™) process to generate more energy from available light.
- Fault tolerant multi-redundant contacts on front and back of each cell provide superior reliability.
- Solar cells are laminated between a multi-layered polymer backsheet and layers of ethylene vinyl acetate (EVA) for environmental protection, moisture resistance, and electrical isolation.
- Durable back sheet provides the module underside with protection from scratching, cuts, breakage, and most environmental conditions.
- Laboratory tested and certified for a wide range of operating conditions.
- Ground continuity of less than 1 ohm for all metallic surfaces.
- Manufactured in ISO 9001 certified facilities to exacting Siemens quality standards.

Easy installation

- Standard ProCharger™-S terminal enclosures are designed for trouble-free field wiring and environmental protection. (Modified versions also available, e.g., as SM55-J with the special ProCharger™-CR junction boxes.)
- Lightweight aluminum frame and pre-drilled mounting holes for easy installation.
- Modules may be wired together in series or parallel to attain required power levels.

Performance warranty

• 25 Year limited warranty on power output.

Further information on solar products, systems, principles and applications is available in the Siemens Solar product catalog.

Siemens modules are recyclable.

Solar module SM55

Electrical parameters		
Maximum power rating P_{max}	[Wp] 1)	55
Rated current I_{MPP}	[A]	3.15
Rated voltage V_{MPP}	[V]	17.4
Short circuit current I_{SC}	[A]	3.45
Open circuit voltage V_{OC}	[V]	21.7

Thermal parameters		
NOCT 2)	[°C]	45 ±2
Temp. coefficient: short-circuit current		1.2mA / °C
Temp. coefficient: open-circuit voltage		-.077V / °C

Qualification test parameters 4)			
Temperature cycling range		[°C]	-40 to +85
Humidity freeze, Damp heat		[%RH]	85
Maximum permitted system voltage		[V]	600 (1000 V per ISPRA)
Wind Loading	PSF	[N/m²]	50 [2400]
Maximum distortion 3)		[°]	1.2
Hailstone impact	Inches	[mm]	1.0 [25]
	MPH	[m/s]	52 [v=23]
Weight	Pounds	[kg]	12 [5.5]

1) Wp (Watt peak) = Peak power (Minimum Wp = 50 Watts)

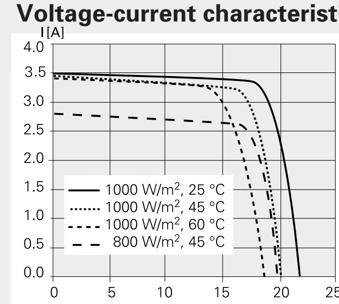
Air Mass AM = 1.5
Irradiance E = 1000 W/m²
Cell temperature T_C = 25 °C

2) Normal Operating Cell Temperature at:
Irradiance E = 800 W/m²
Ambient temperature T_U = 20 °C
Wind Speed v_W = 1 m/s

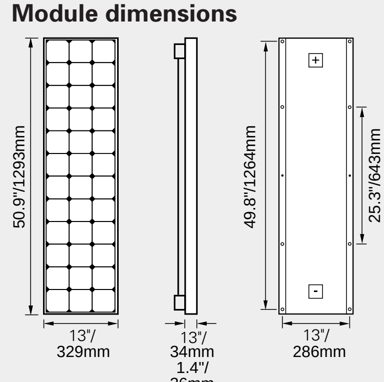
3) Diagonal lifting of module plane

4) Per IEC 61215 test requirements

Voltage-current characteristic



Module dimensions

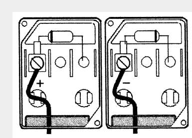


Hole Diameter 0.26 inch (6.6mm)
Mounting hole dimensions are center to center

ProCharger™-S Junction-box

Maximum cable diameter: 4mm²

Type of protection: IP44



Your address for photovoltaics from Siemens Solar

Siemens Solar GmbH
A joint venture of
Siemens AG and Bayernwerk AG
Postfach 46 07 05
D-80915 München
Germany

Siemens Solar Industries
P.O.Box 6032
Camarillo, CA 93011, U.S.A.
Web site: www.siemenssolarpv.com
E-mail: sunpower@solarpv.com
Tel: 805-482-6800
Fax: 805-388-6395

Siemens Showa Solar Pte. Ltd.
166 Kallang Way
Singapore 349248
Tel: 65-842-3886
Fax 65-842-3887

Order No. 019895, Rev. C

Multifunctional double road solar street lamps controller

SLD-D series instructions

Thank you for using our products, the use of the products before, please read the instruction for use

Product introduction

This product is the new generation of intelligent solar recharge controller, the industrial product design reliability, with super stability and high life-span

★The department example product automatic identification system voltage 24V 12V and

★With multi-stage single session and multilevel double time control functions, satisfy personalized requirements

★Three charging and discharging LED indicator, capacity state

★Using LED digital tube display Settings process, simple operation, easy to master

★With strong charger, balanced filling and floating filling 3-sectional series PWM charging ways

★High precision temperature compensation, a variety of work mode, pure light-activated and steerable open + delay shut, but any setting time

★Have overall electronic protection function: it has the overcharge put, overload, short-circuit, answer the reverse, etc

★Has the TVS lightning protection, no jump line design, can enhance the system reliability and durability

★Parameter Settings with power lost save functions, namely system model and control parameters and other important data are stored in chip inside, fell after power not to lose, and makes the system more reliable.

★

All control all adopt industrial-class chips and precision components, can in cold, high temperature, humid environment normal operation

Product installation and illustrations

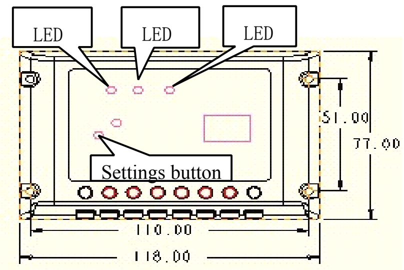
The installation environment

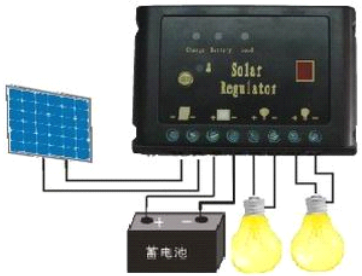
The department example products through strict water-proof treatment, had better install lamp pole or sealing the cabinet, avoid exposure rain, in order to prevent terminals in short circuit, please make sure rainstorm weather no ponding submerged.

This product with battery should be installed in the same place, ensure products and battery attachment does not exceed 1 meters, facilitate accurate testing battery voltage and environmental temperature, adjust charging status

.

Each indicator status explanation:





LED1 (green) long bright says charging normal, Rapid flashes said system voltage overpressure, Not bright says solar panels with no voltage.

LED2 (red, green, double color lamp) green said battery voltage normal, Green slow flash said battery full; Orange (red, green, mixed) says battery voltage, Red to represent battery voltage protection.

LED3 (red) long bright says load working properly, Slow flash said at load overload, Flash said at load or product internal short circuit.

Digital tube: short click, display load 1 and 2 of the load working status, before 3 seconds to display load 1 set condition (X), after 3 seconds (display load 2 installed state x.). (X represent 0 ~ 7 any numerical)

note:

1、This product can intelligent identification battery types, is applicable to any circulation rechargeable batteries

2、Load working current is greater than controller rated current of the 1.25 times normal, 60 seconds later shut load output, Load working current is greater than 1.5 times rated current controller, 5 seconds after closing load output, When load appear short circuit, controller negative immediately shut off the load output.

Load working mode setting method

Work mode descriptions

Pure light-activated mode: light-activated open + light-activated shut. When the night comes, solar panels input voltage drops to 5V (natural light about 10 lumen), 10 minutes later, controller startup start work load, When morning comes, solar panels voltage up to 5V, 10 minutes later, shut load output. (load 1 and 2 start-up and shut load will remain consistent)

Optical drive + possession in close: when night comes, solar panels input voltage drops to 5V (natural light about 10 lumen), 10 minutes later, controller startup start work load, When work to predetermined time, load 1 and 2 will be set according to the load time, successively shut (this setting can play b&t lamp cooperate each other and achieve reasonable distribution of light energy consumption); time Light-activated control priority possession in control.

Common control mode: this mode cancel steerable, possession in, delay output, and other functions, as a continuous uninterrupted output power generation systems charge-discharge controller used. (load 1 and load 2 will remain consistent)

Debug mode: used for debugging use, canceled 10 minutes of delay effect, execute instant pure light-activated control, i.e. only if the voltage is lower than 5V solar panels, immediately start load output, And vice versa.

Setting method

A long press the "set" button for 5 seconds, digital tube flashing loosen key-press, then every short at once that convert a digital, when from 0 ~ 7 one week after conversion (which is the load 1 Settings), then enter 0. ~ 7. Choice (load 2 Settings, please note that the Numbers behind the "point" to avoid mix up). While the digital pipe display Numbers corresponding user from the table chooses mode, stop buttons, waiting for digital tube digital is not beating, and then use the same method set another way load output.

Settings averageserving:

load1	load2
Digital tubes work display mode	**Digital tubes work display mode**
0 Optical drive + light-activated shut	0. Optical drive + light-activated shut
1 Light-activated open+ delay 4 hours off	1. Light-activated open+ delay3 hours off
2 Light-activated open+ delay 6 hours off	2. Light-activated open+ delay 5 hours off
3 Light-activated open+delay8 hours off	3. Light-activated open+ delay 7 hours off
4 Light-activated open+ delay 10 hours off	4. Light-activated open+ delay 9 hours off
5 Light-activated open+ delay 12 hours off	5. Light-activated open+ delay 11 hours off
6 General control mode	6. General control mode
7 Debug mode	7. Debug mode

note:

1、Check the current setting can be short click "set" button, the top three seconds display the current setting, the load 1 after three seconds shown as load current setting of

2、Check the current setting can be short click "set" button, the top three seconds display the current setting, the load 1 after three seconds shown as load current setting of 2.LED

3、Digital tube is 0 7 0. 7. 0 short circular display.

4、In 0 or 0., 6 or 6., 7 or 7. Be after use, two ways of output is also control, need to reset 1-5 and 1-5. Rear accessibility two ways of output independent control。

Common faults and processing method

Fault phenomena	Processing method
Cannot charge, a green light does not shine	LED2 displayed in red, load doesn't work
Rechargeable lights (green) rapid flashes	System voltage overpressure, check the battery is open, or whether reliable connect battery recharging circuit, or damage
Load LED3 (red) bright lights, load doesn't work	Check whether the connect. Load
Load LED3 (red) rapid lights flashing, load doesn't work	Please check whether the load short circuit
Load LED3 (red) slow lights flashing, load doesn't work	Load power is too high
LED2 displayed in red, load doesn't work	batteryundervoltage，Please charge

Technical parameters

Rated voltage	12V24VAutomatic identification
Strong charging pressure	14.6V/29.2V
Balanced filling	14.4V/28.8V
Float charging pressure	13.6V/27.2V（25℃）
Charging resuming voltage	13.2V/26.4V
Low pressure load off voltage	11V/22V±0.2
Load resuming voltage	12.5V/25.5V
Temperature compensation coefficients	-5mV/Ċ/2V
Total fixed charging electric current	5/10/15A/20A
Total fixed load current	5/10/15A/20A
Maximum wiring diameter	4mm²
Weight (gross) / sets	200g
Product size	118*78*32.5mm
Working temperature	-40~60Ċ
Protection grade	IP56

This instruction, if there is any change, without prior notice

"WiFly GSX" 802.11G Module

Features

- Qualified 2.4GHz IEEE 802.11b/g transceiver
- High throughput, 1Mbps sustained data rate with TCP/IP and WPA2
- Ultra-low power - 4uA sleep, 40mA Rx, 210mA Tx (max)
- Small, compact surface mount module
- On board ceramic chip antenna and U.FL connector for external antenna
- 8 Mbit flash memory and 128 KB RAM
- UART hardware interface
- 10 general purpose digital I/O
- 8 analog sensor interfaces
- Real-time clock for wakeup and time stamping
- Accepts 3.3V regulated or 2-3V battery
- Supports Adhoc connections
- On board ECOS -OS, TCP/IP stacks
- Wi-Fi Alliance certified for WPA2-PSK
- FCC / CE/ ICS certified and RoHS compliant.

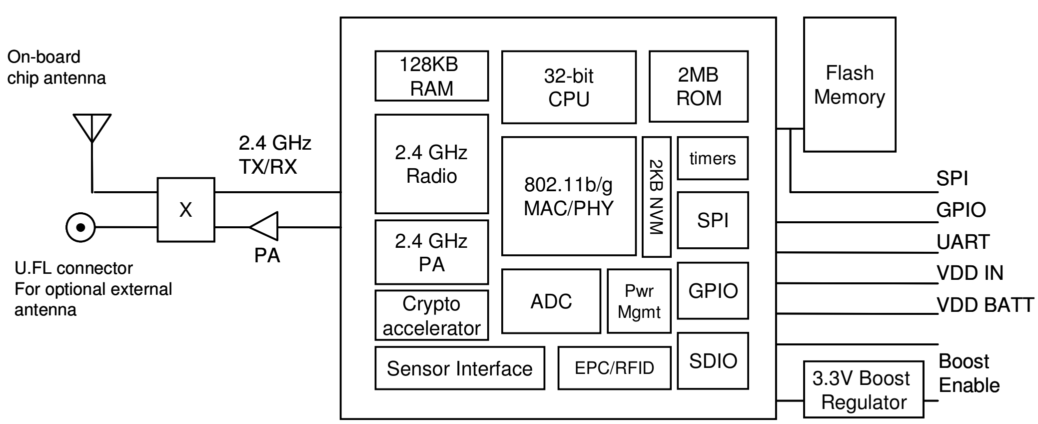
Description

The WiFly GSX module is a stand alone, embedded wireless 802.11 networking module. Because of its small form factor and extremely low power consumption, the RN-131G is perfect for mobile wireless applications such as asset monitoring, GPS tracking and battery sensors. The WiFly GSX module incorporates a 2.4GHz radio, processor, TCP/IP stack, real-time clock, crypto accelerator, power management and analog sensor interfaces. This complete solution is preloaded with software to simplify integration and minimizes development of your application. In the simplest configuration the hardware only requires four connections (PWR, TX, RX, GND) to create a wireless data connection. Additionally, the sensor interface provides temperature, audio, motion, acceleration and other analog data without requiring additional hardware. The WiFly GSX module is programmed and controlled with a simple ASCII command language. Once the WiFly GSX is setup it can scan to find an access point, associate, authenticate and connect over any WifI network.

Applications

- Wireless audio
- Remote equipment monitoring
- Telemetry
- Security
- Industrial sensors and controls
- Home Automation
- Medical devices

Block Diagram



Overview

- Host Data Rate up to 1 Mbps for UART
- Intelligent, built-in power management with programmable wakeup
- Can be powered from regulated 3.3-3.7V source or 2.0-3.0V batteries
- Real time clock for time stamping, auto-sleep and auto-wakeup
- Configuration over UART using simple ASCII commands
- Web Server or Telnet configuration over WiFi
- Over the air firmware upgrade (FTP)
- Memory 128 KB RAM,2MB ROM, 2 KB battery-backed memory, 8 Mbit Flash.
- Secure WiFi authentication WEP-128, WPA-PSK (TKIP), WPA2-PSK, EAP-TLS for WPA1 & WPA2 Enterprise
- Built in networking applications DHCP, UDP, DNS, ARP, ICMP
- 802.11 power save and roaming functions

Environmental Conditions

Parameter	Value
Temperature Range (Operating)	-40 °C ~ 85 °C
Temperature Range (Storage)	-40°C ~ 85 °C
Relative Humidity (Operating)	≤90%
Relative Humidity (Storage)	≤90%

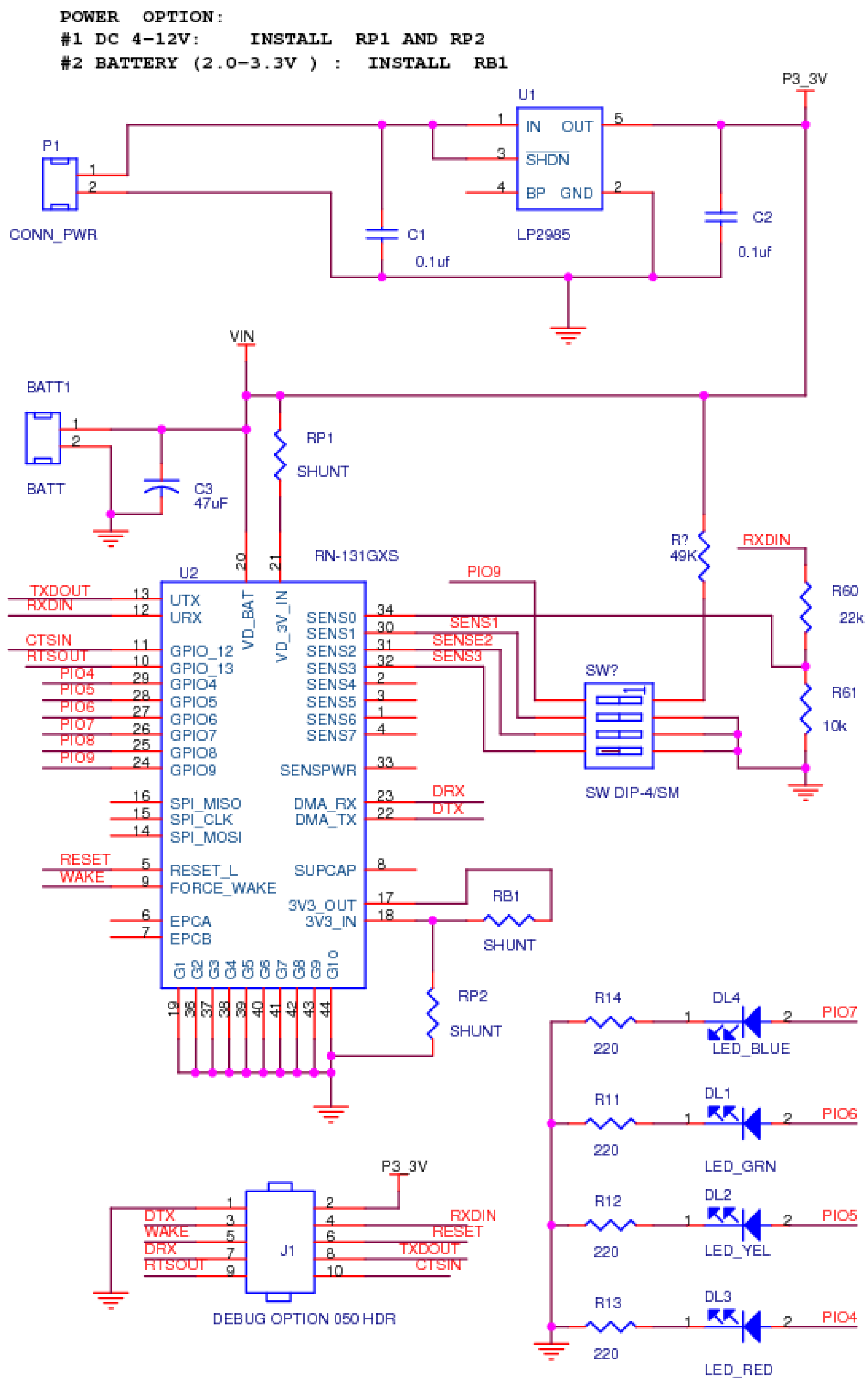
Electrical Characteristics

Supply Voltage	Min	Typ.	Max.	Unit
Supply Voltage VDD	3.0	3.3	3.7	VDC
Supply Voltage (VBATT option)	2.0	3.0	3.3	VDC
Power consumption				
Sleep		4		uA
Standby (doze)	-	15	-	mA
Connected (idle, RX)		40		mA
Connected (TX)		140	212	mA

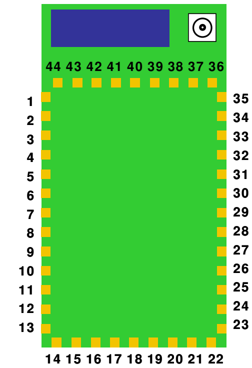
Radio Characteristics

Parameter	Specifications
Frequency	2402 ~ 2480MHz
Modulation	DSSS(CCK-11, CCK-5.5, DQPSK-2, DBPSK-1)
Channel intervals	5MHz
Channels	1 - 14
Transmission rate (over the air)	1 – 11Mbps for 802.11b / 6 – 54Mbps for 802.11g
Receive sensitivity	-85dBm typ.
Output level (Class1)	+18dBm
Maximum RF input to U.FL connector	10 dBm

Typical Application Schematic



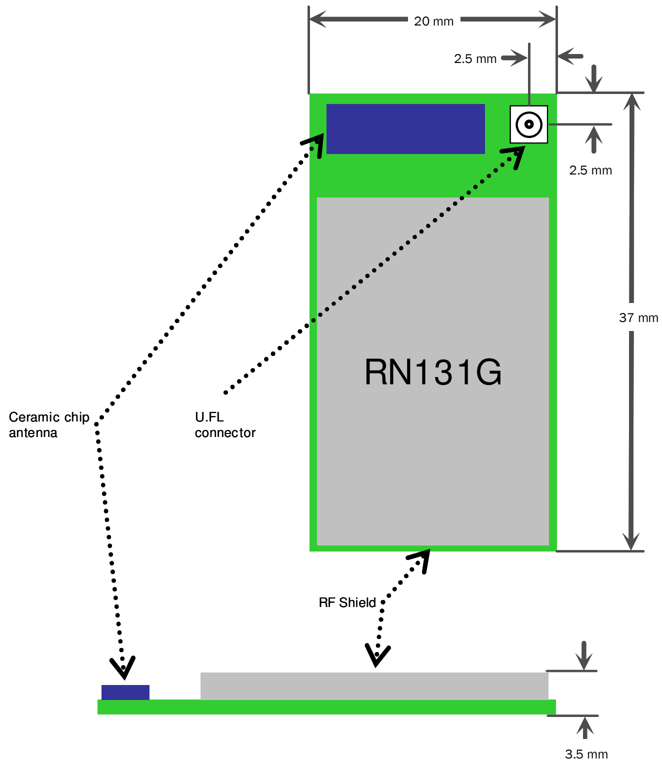
Pin Description

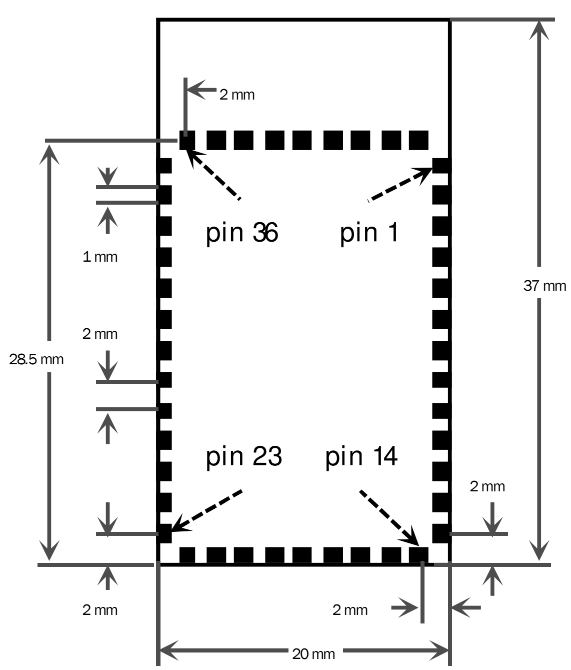


Top view
(pads not visible from top)

Pin	Name	Description	Default
1	SENSOR-6	Sensor interface, analog input to module, 1.2V	No connect
2	SENSOR-4	Sensor interface, Analog input to module, 1.2V	No connect
3	SENSOR-5	Sensor interface, Analog input to module, 1.2V	No connect
4	SENSOR-7	Analog input to module, 1.2V	No connect
5	RESET	Module reset, Active Low, reference to VDD-BATT, 160 min. pulse	Pull up
6	EPC-ANT-A	EPC port, RFID antenna A	No connect
7	EPC-ANT-B	EPC port, RFID antenna B	No connect
8	SUPERCAP	Balance center pin voltage on stacked super capacitors, Analog 3.3V	No connect
9	FORCE_AWAKE	Force the module to wakeup, input to module, 31us min. pulse	
10	GPIO-13	UART RTS flow control, 8mA drive, 3.3V tolerant	
11	GPIO-12	UART CTS flow control, 8mA drive, 3.3V tolerant	
12	UART-RX	RX to the module, 8mA drive, 3.3V tolerant	
13	UART-TX	TX from the module, 8mA drive, 3.3V tolerant	
14	SPI-MOSI	SPI master data out (Contact Roving Networks for details)	No connect
15	SPI-CLK	SPI clock, (Contact Roving Networks for details)	No connect
16	SPI-MISO	SPI master data in (Contact Roving Networks for details)	No connect
17	3.3V-REG-OUT	boost regulator control output, connect to 3.3V-REG-IN to enable	No connect
18	3.3V-REG-IN	boost regulator control input, connect to 3.3V-REG-OUT to enable	GND to disable
19	GND	Ground	
20	VDD-BATT	Battery input, 2.0-3.3V with boost regulator in use, 3.0-3.7V otherwise	
21	VDD-IN	3.3 to 3.7 voltage, do not connect when boost regulator is in use	
22	DMA-TX	Debug port	No connect
23	DMA-RX	Debug port	No connect
24	GPIO-9	Restore factory resets, 8mA drive, 3.3V tolerant	
25	GPIO-8	GPIO, 24mA drive, 3.3V tolerant	Weak pull down
26	GPIO-7	GPIO, 24mA drive, 3.3V tolerant	Weak pull down
27	GPIO-6	Association STATUS, 24mA drive, 3.3V tolerant	LED, Weak pull down
28	GPIO-5	Data transfer STATUS, 24mA drive, 3.3V tolerant	LED, Weak pull down
29	GPIO-4	Connection STATUS, 24mA drive, 3.3V tolerant	LED, Weak pull down
30	SENSOR-1	Sensor interface, analog input to module, 1.2V	
31	SENSOR-2	Sensor interface, analog input to module, 1.2V	
32	SENSOR-3	Sensor interface, analog input to module, 1.2V	
33	SENSE-PWR	Voltage output from module to power external sensors, 1.2-3.3V	
34	SENSOR-0	Wakeup from external condition	
35	NO CONNECT		No connect
36-44	GND	Must be connected for proper antenna performance	

Physical Dimensions



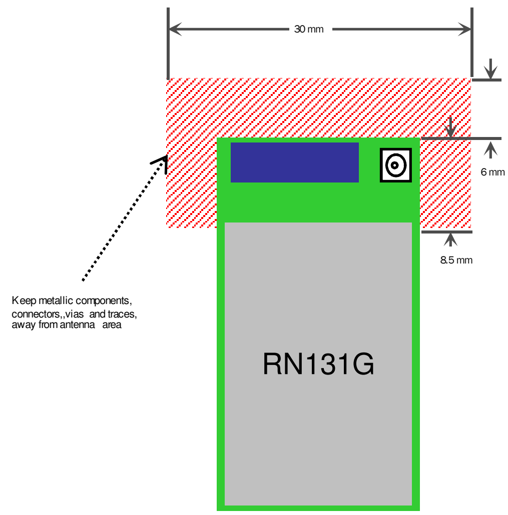


Bottom view

Design Concerns

1. ***Minimizing radio interference.*** When integrating the WiFly module with on board chip antenna make sure the area around the chip antenna end the module protrudes at least 6mm from the mother board PCB and any metal enclosure. If this is not possible use the on board U.FL connector to route to an external Antenna.

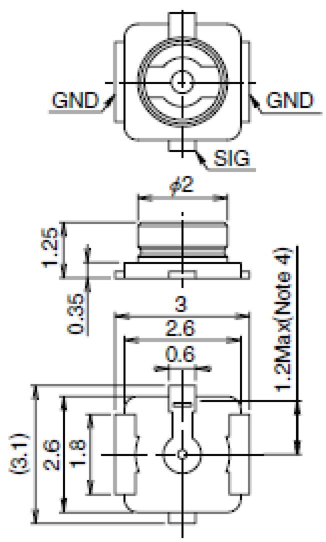
   The 8.5 mm area under the antenna end of the module should be keep clear of metallic components, connectors, vias, traces and other materials that can interfere with the radio signal.



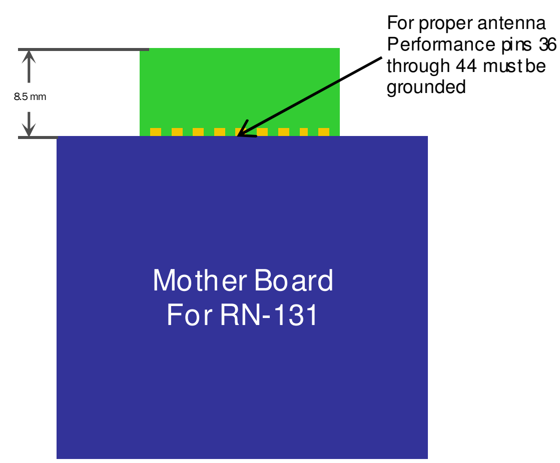
Top view

2. ***Proper grounding.*** For the module antenna to function pins 36- to 44 must be connected to GND. We suggest you place module such that 0.5mm of theses pads is exposed. This provides access for soldiering pins 36 through 44 from below and provides ample clearance of the antenna from the PCB.

3. ***U.FL connector.*** Use Hirose U.FL connector **U.FL-R-SMT** to for connecting external antennas. See Roving Networks U.FL to SMA cable. Part number: RN-UFL-SMA6



U.FL-R-SMT-1



Bottom view

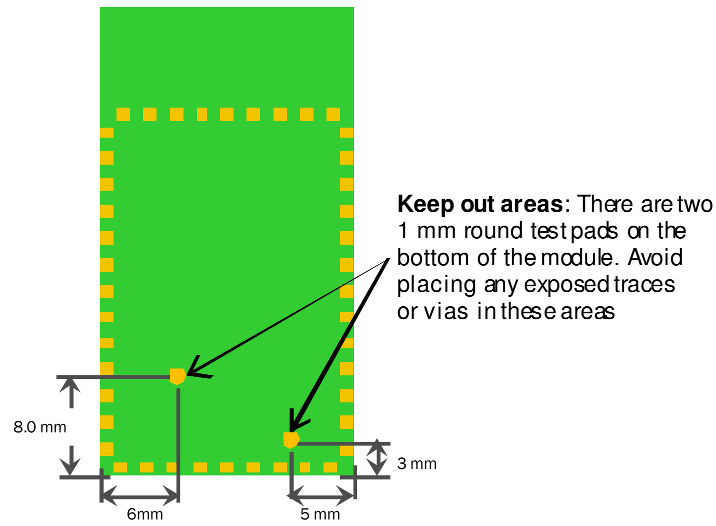
4. ***Connection Status.*** GPIO-4, GPIO-5, GPIO-6 are available to drive a status LEDs. GPIO-4 indicates connection status. When on this indicates an active connection, toggling fast indicates no IP address and toggling slow indicates IP address OK. GPIO-6 indicates association status. On means not associated with a network, Off indicates associated and Internet access is OK. GPIO-5 toggles when data is transferred. NOTE: If LEDs are not being drive by these signals

5. ***Keep out areas.*** When designing your PCB avoid exposed trace and via beneath the module.

6. ***Powering the module.*** The WiFly module can be powered from either 3.0VDC batteries or 3.3VDC regulated power.

   3.0VDC battery power
   - Apply power to pin 20 (VDD-BATT)
   - Short pin 17 (3.3V-REG-OUT) to pin 18 (3.3V-REG-IN)

   3.3 VDC power
   - Apply power to pin 20(VDD-BATT) and pin 21 (VDD-IN)
   - Connect pin 18 (3.3V-REG-IN) to ground and leave pin 17 (3.3V-REG-OUT) un connected.



Bottom view

7. ***Sensor Interfaces.*** Inputs must not exceed 1.2V. Sensitivity saturates at 400 mV.

8. ***Adhoc mode and Restoring Factory Settings.*** Adhoc mode is controlled through GPIO-9. It is a good idea to connect pin 24, GPIO-9 to a switch or jumper connected to a pull up. When GPIO-9 is driven high at power up the module will be in Adhoc mode. If GPIO-9 is then toggled low 5 times, the initial factory default configuration will be RESTORED. This is useful for cases where the module is mis-configured and is no long responding.

Compliance Information

- FCC Certified for us in the United States and CE approved for use in Europe and other countries.
- Environmentally friendly RoHS compliant

Ordering Information

Part Number	Description
RN-131G	With chip antenna
RN-131G-EVAL	Development Kit for the RN-131G (Includes the RN-131G module)
RN-UFL-SMA6	6 inch cable with U.FL connector on one end and SMA on the other
For other configurations, contact Roving Networks directly.	

Visit http://www.rovingnetworks.com for current pricing and a list of distributors carrying our products.

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