Signoff Request - September 7th, 2022 - Navigation (Wireless Access Point)

Tuesday, July 26, 2022 7:35 PM

Navigation Subsystem - Wireless Access Point

Abstract: Wireless Access Point Signoff Takeaways

This signoff request is for the wireless access point device which will be used in the design for the Autonomous Crawl Space Inspection Robot. The wireless access point device resides in the "Navigation Subsystem" on our block diagram. First, for this signoff request, the expectations or specifications of the wireless access point are explained in verbal terms. Then, analysis is performed so that the specifications of the wireless access point can be stated quantitatively as constraints and so that the quantitatively stated specifications can be justified. Finally, two wireless access points are chosen, compared, and analyzed to whether or not they can meet the specifications and constraints of the atomic subsystem.

Specifications:

1. *The device chosen for the Wireless Access Point must allow **at least** Wi-Fi connection from **at least** the controller and the Raspberry Pi 4B (ethernet connection welcomed)*
2. *The device chosen must operate on F.C.C. designated appropriate Wi-Fi bands.*
3. *The device chosen must be modular and allow for "easy" setup that operators or home owners can use and must have a network that remains even if power is lost.*

Constraints:

1. *The device chosen for the Wireless Access Point must be able to be configured as a "wireless access point" or WLAN (Wireless Local Area Network) that is capable of transmitting the summation of at least 8.5 Mbps and 150-200 Kbps, or roughly 9 Mbps (which Microsoft designates as the needed bandwidth when using Remote Desktop Connection (RDP) to watch a 30 FPS and to edit and interact with Microsoft Excel Sheets, which are both the closest estimates to what the user will use to watch live video feed from the robot and interact with the desktop screen to issue command signals).*
2. *The wireless access point must consistently provide the 9 Mbps transmission speed at a distance of at most 70 ft, which is the "hypotenuse" or diagonal distance across the average United States home with an area of 2,200 ft^2. This maximum distance is the absolute maximum distance needed and would allow the user to stand in one spot and communicate with the robot at the farthest point in the crawlspace. The user could walk around the crawlspace to obtain a closer and faster connection.*
3. *The device chosen for the Wireless Access Point must allow for **at least** two devices (besides the wireless access point) to be present on the network at all times which would include the controller and the Raspberry Pi 4B.*
4. *The device chosen for the Wireless Access Point must operate on either the 2.4 GHz or 5 GHz Wi-Fi bands which are license-free bands designated for use by the Federal Communications Commission (F.C.C), wireless protocol 802.11a/b/g/n.*
5. *The device chosen must be able to be powered from the same 5 Volt line feeding into the Raspberry Pi 4B and must have a maximum current of 1 Amp which has been designated by the power draw of the entire inspection robot power system. Additionally, the deivce chosen must have a "static" 802.11a/b/g/n network with a "static" IP-address, such as 192.168.0.1, which can be pinged by other devices and connected to by other devices.*

Analysis:

*Two types of analysis were completed for this signoff request: device comparison (TP-Link N300 vs. ESP-32U) and TP-Link N300 transmission performance from max distances. The team members initially were not able to decide between the TP-Link N300 and the ESP 32-U, so the characteristics, capabilities, and costs of each device were listed so that an informed decision could be made. Then, the team members performed an experiment with the better of the two devices, the TP-Link N300, in order to see what the true transmission speed and maximum transmission distance were under loads determined by the constraints of the subsystem (live video feed and screen interaction). The team members felt that a more in-depth analysis could be performed by examining how the TP-Link N300 performs in terms of max distance and transmission speed in a realistic environment such as a house and crawlspace. Team members found that when using the Wi-Fi connections of the TP-Link N300 for Microsoft Windows Remote Desktop Connection, a 1080p video streaming at 30 fps could be watched while also interacting with the screen . A mobile iPad-Pro device was connected as the controller in one experiment using the Microsoft "RD-Client" application and a PC was connected as the controller in the next experiment using the Windows "Remote Desktop Connection". With both experiments, the total transmission distance was 100 ft with an average transmission speed of 5 Mbps and a maximum transmission speed of 7 Mbps. The TP-Link N300 router supports up to 300 Mbps on Wi-Fi connections and only used on average 5 Mbps, which is well within the constraints specified for inspection robot. It can be noted that the TP-Link N300 supports 100 Mbps **constantly** if connected via the on-board ethernet port.*

Chosen Component:

TPLink - N300 Nano Travel Router - $29.99/Unit - 1 Unit Needed - $29.99 BOM

Expectations (Specifications) and Constraints of Ultrasonic Sensors:

A wireless access point is a hardware-based node which establishes a private, wireless network for devices to connect to and communicate through without the need of an actual internet connection [1]. The wireless access point will be responsible for establishing a wireless communication hub for communication between the raspberry pi (on-board control) and a remote control operated by a user from outside the crawl space. The remote control will be responsible for issuing commands to the raspberry pi over the network established by the wireless access point in the situation where the autonomous inspection robot needs assistance navigating throughout the crawlspace. In this project, the team will be utilizing a wireless access point to communicate across the 2.4 GHz WiFi band, where a license is not required by the Federal Communications Commission (FCC) [2]. While radio frequency signals (RF) can also be used for remotely transmitting information, a traditional WiFi setup allows for a communication hub that can be easily initiated and connected to by users. Additionally, a high data transfer rate can be achieved and will support specific media such as live video feed which require a high channel bandwidth. The wireless access point chosen will need to be able to support data transfer between a Raspberry Pi 4B and a wireless device (i.e. phone, tablet, pc, etc...) with applications such as live video feed and a "remote desktop" control software such as Windows Remote Desktop Connection or VNC Viewer. The wireless access point must be modular, easily set-up by users, and with a static and consistent network so that when the robot is powered back on the wireless access point is ready for operation.

Understanding Quantitative Constraints of the Ultrasonic Sensors Through Analysis of the Expectations/Specifications :

- [ ] The first specification examined for analysis is the transmission speed and transmission distance needed for the wireless access point to allow communication between the Raspberry Pi 4B and the operator outside/inside the crawlspace. The device chosen for the Wireless Access Point must be able to be configured as a "wireless access point" or

WLAN (Wireless Local Area Network). A wireless access point is a hardware-based node which establishes a private, wireless network for devices to connect to and communicate through without the need of an actual internet connection [1]**.** While radio frequency signals (RF) can also be used for remotely transmitting information, a traditional WiFi setup allows for a communication hub that can be easily initiated and connected to by users. Additionally, a high data transfer rate can be achieved and will support specific media such as live video feed which require a high channel bandwidth [3]**.**

The wireless access point will need to be a device that is capable of allowing transmission of the summation of at least 8.5 Mbps and 150-200 Kbps, or roughly 9 Mbps (which Microsoft designates as the needed bandwidth when using Remote Desktop Connection (RDP) to watch a 30 FPS and to edit and interact with Microsoft Excel Sheets, which are both the closest estimates to what the user will use to watch live video feed from the robot and interact with the desktop screen to issue command signals) [4]. Remote Desktop Connection Protocol (RDP) is an application which allows users to remotely observe a computer as well as interact with the device and control the device live over a WLAN or Ethernet connection [4].

The wireless access point must consistently provide the estimated data transmission rate of 9 Mbps at a distance that is the maximum point at which an operator can be from the robot without being able to walk around the house and crawlspace for better connection. In order to calculate this distance, the area of an average home in the United States is considered, which has an average square footage of 2,200 ft^2 [5]. Using equation 1, the Pythagorean Theorem, the width and length (*a* and *b*) can be determined used and then the farthest point across the home (the hypotenuse *c*) can be calcualted. The averge length of a home is roughly 60 feet and the average width of a home is 36 feet [5]. Therefore, it can be determined that the farthest point across the home from the operator would be roughly 70 feet. Therefore, the wireless access point will need to be able to provide at least 9 Mbps transmission speed at a distance of 70 feet.

The device chosen for the Wireless Access Point must allow for **at least** two devices (besides the wireless access point) to be present on the network at all times which would include the controller and the Raspberry Pi 4B. Since the operator will be controlling the inspection robot with a device (phone, pc, etc…) and will be doing so by communicating with the Raspberry Pi 4B over the wireless network, the wireless access point will need to be able to provide the option for at least two device, with the possibility of additional devices being connected for the home owner or for other data historian type protocols.

The device chosen for the Wireless Access Point must operate on either the 2.4 GHz or 5 GHz Wi-Fi bands which are license-free bands designated for use by the Federal Communications Commission (F.C.C), wireless protocol 802.11a/b/g/n [2]. The deivce chosen must have a "static" 802.11a/b/g/n network with a "static" IP-address, such as 192.168.0.1, which can be pinged by other devices and connected to by other devices. By having a static IP-address, users will be able to connect to the wireless access point with the same SSID and password, even after the device loses power and regains power [1]. Finally, the device chosen must be able to be powered from the same 5 Volt line feeding into the Raspberry Pi 4B and must have a maximum current of 1 Amp which has been designated by the power draw of the entire inspection robot power system.

Determining The Appropriate Wireless Access Point Through Analysis of Device Capabilities:

Wireless Access Point – TP-Link N300 Router Vs. Espressif ESP 32U WiFi Module

The two devices being compared in this signoff are the TP-Link N300 Nano Travel Router and the ESP 32U WiFi Module. The N300 router is manufactured by TP-Link and is marketed as a tiny, portable travel WiFi router that is capable of being powered off of everyday household electronics such as cell phone chargers, power banks, and laptop usb ports [6]. The ESP 32U is manufactured by Espressif and is marketed as a tiny and affordable module capable of connecting to and creating WiFi connections for communications [7]. These two devices are capable of establishing an affordable and private wireless local area network (WLAN) for communication between the inspection robot and an external controller operated by a user outside the crawl space. The specifications, cost, and implementation techniques for each device are discussed in the following paragraphs.

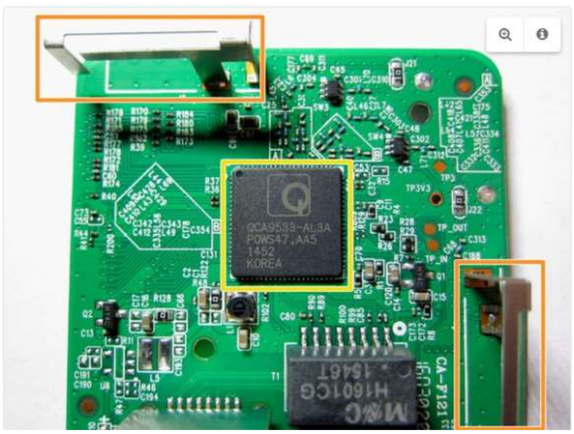
1. TP-Link N300 Nano Travel Router

The N300 Nano Travel Router, manufactured by TP-Link Corporation [6], is shown in figure 1. The TP-Link N300 Nano Router features a single core Qualcomm Atheros QCA9533-AL3A system-on-chip (SoC), shown in figure 2, which has a clock speed of up to 650 MHz and peak wireless transmit speed of 300 Mega-bits-per-second (Mbps) on the IEEE 802.11n WiFi standard [8]. The N300 features two soldered on antennas, also shown in figure 2, which allow for a multiple-input-multiple-output (MIMO) antenna configuration that supports a wider transmission and receiver range [6]. The nano router requires a constant voltage of 5 Volts and a constant current of 1 Amp for operation [6]. Over one hour, the N300 router would use approximately 1 Amp Hours (AH) and 5 Watt Hours (WH). The nano router has two connections, one for the supplied power via a microusb to usb 2.0 cable, and a 1*10/100 ethernet port. While the router is capable of a maximum transmission speed of 300 Mbps, the speed of the 100 Mbps ethernet port does not vary depending on distance and the surrounding environment [6] The N300 has a maximum coverage area of 270 meters (810 feet) with a transmission power less than 30 dBm (decibels with reference to one milliwatt), which adheres to the standards for WiFi transmission set in place by the Federal Communication Commission (FCC) [2]. The TP-Link N300 Nano Travel Router is available via multiple online commerce websites, such as amazon, for an average price of $29.99 [6].

In order to set up the N300 as a wireless access point, a user will need to properly power the device and then connect to the initial WiFi network with the supplied username and password. Next, the user is prompted to a TP-Link webpage which does not require internet access where the user can select "wireless access point" as the behavior protocol for the deivce. The user will then chose a network name and password which will be used for any further connections to the private wireless local area network (WLAN). After completing the previous steps, the 2.4 GHz wireless network will be created and will not be reset if power to the router is lost [6]. In order to assure the fastest connection configuration, the Raspberry Pi 4B can be connected to the router via the 1*10/100 (Mbps) ethernet port so that a constant transmission speed between the Raspberry Pi and the router can be secured. A user would be able to connect a device to be used as the remote control to the WiFi network previously created and would be able to communicate with the Raspberry Pi 4B and therefore communicate with the crawl space inspection robot. As previously mentioned, the range of the WiFi network would vary depending on distance from the robot and the surrounding crawl space environment. It is important to note that the N300 is designed to be a router/WiFi extender and excels at increasing WiFi network range throughout a home containing multiple walls and floor levels [6].

Figure 1 [6]:

Figure 2 [8]:



2. *Espressif ESP-32U Wi-Fi Module*

The ESP-32U Wi-Fi module, manufactured by Espressif Corporation [7], is shown in figure 3. The Espressif ESP-32U Wi-Fi module features a dual core Tensilica L106 32-bit processor, shown in figure 4, which has a maximum clock speed of 160 MHz and a peak, line of sight, wireless transmit speed of 150 Mega-bits-per-second (Mbps) on the IEEE 802.11n Wi-Fi standard [7]. The N300 features an external Subminiature Version A (SMA) connector for an antenna, also shown in figure 3 and figure 4, which allows for users to connect a variety of antennas to the board for increased transmission speed and range [7]. The ESP-32U requires a constant voltage of 3.3 Volts and a constant current of 0.5 Amp, with an additional maximum operation current of 0.080 Amps (80 mA) and a sleep current of 0.000005 Amps (5 uA). Over one hour of constant use, the ESP-32U would use approximately 0.58 Amp Hours (AH) and 1.914 Watt Hours (WH). The ESP-32U has 38 GPIO pins and one cable connection for supplied power via a microusb to usb 2.0 cable, as well as for uploading Arduino or micropython code to the board. The ESP-32U does not have an ethernet port on the stock board. Espressif recommends to utilize an omnidirectional 6 dB antenna with the ESP-32U in order to obtain a maximum coverage area with a transmission power less than 30 dBm (decibels with reference to one milliwatt), which adheres to the standards for Wi-Fi transmission set in place by the Federal Communication Commission (FCC) [2]. Espressif does not state an official range of the ESP-32U, however, many articles online state a range of roughly 100 meters [9]. While some articles state that ranges of up to 10 Km being reached, the tests which were performed are not applicable to the inspection robot project due to the presence of very clear weather, perfect line of sight conditions, as well as with each board being mounted very high up in the air [9]. The Espressif ESP-32U Wi-Fi module is available via multiple online commerce websites, such as digikey, mouser, and amazon, for an average price of $10 [10]. In addition to the ESP-32U, a suggested 6 dB SMA antenna can be purchased for an average of $5, the microusb to usb 2.0 cable can be purchased for an average of $5 [12, 13]. Therefore, the total cost for purchasing and utilizing the Espressif ESP-32U Wi-Fi module is roughly $20.00.

In order to set up the ESP-32U as a wireless access point, a user will need to properly power the device and then create a sketch using the Arduino IDE in order to establish the communicate baud rate, the wireless local area network (WLAN) username and password, and the time for which the network will be active. Next, the user will need to verify and upload the sketch to the ESP-32U using the microusb to usb 2.0 cable. As noted in the datasheet, when uploading a new sketch the ESP-32U requires that the boot button on board be help until the sketch upload is complete, which could be a problem if the sketch is lost from the board somehow. After completing the previous steps, the 2.4 GHz wireless network will be created and will only be lost if the sketch is removed from the ESP-32U board [4]. As with the TP-Link N300, a user would be able to connect a device to be used as the remote control to the WiFi network previously created and would be able to communicate with the Raspberry Pi 4B and therefore communicate with the crawl space inspection robot. As previously mentioned, the range of the ESP-32U WiFi network would vary depending on distance from the robot and the surrounding crawl space environment and no specific transmission distance is stated in the product data-sheet. The dimensions of the ESP-32U are shown in figure 5.

Figure 3 [7]:

Figure 4 [7]

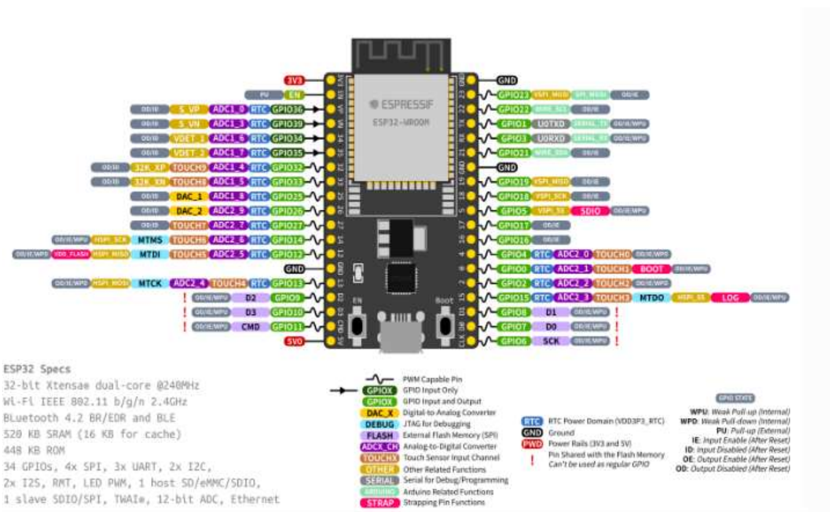
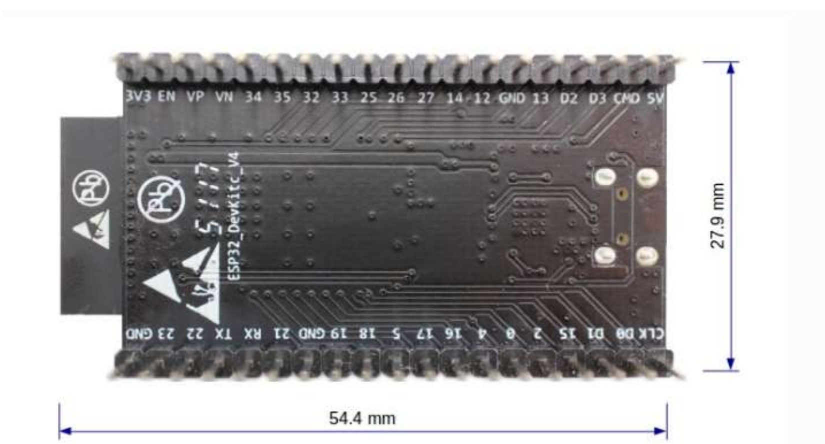


Figure 5 [7]:



3. *Powering the TP-Link N300 and the Espressif ESP-32U*

In order to power the N300 router, a constant 5 Volts and 1 Amp are need to be supplied to the device. In order to power the ESP-32U Wi-Fi module, a constant 3.3 Volts and 0.58 Amps are needed to be supplied to the device. The Raspberry Pi 4B has a total current capacity of 3 Amps, which will be supplied to the device from the power subsystem, and uses 1.5 Amps under normal operation. While the 1 Amps needed for the N300 and the 0.58 Amps needed for the ESP-32U could be supplied by the Raspberry Pi's usb ports, the Raspberry Pi 4B that will be used in the navigation subsystem will have multiple devices already drawing power from the usb ports and the GPIO pins of the device. Before the addition of the N300 router or the ESP-32U, the Raspberry Pi 4B in question will be supplying the following current amounts to the following devices: Raspberry Pi 4b using 1.5 Amps; 360 degree Lidar sensor using 0.6 Amps; four Ultrasonic Sensors using a total of 32 mAmps; an HD USB Camera (not yet decided on) using an estimated 190 mAmps; and Flash Hardware using an estimated 0.6 Amps [14, 15, 16, 17, 18]. Without including the N300 router, the total current drawn by the Raspberry Pi 4B and the connected peripherals totals approximately 2.912 Amps, which is close to the 3 Amp limit of the Raspberry Pi. Therefore, the chosen wireless access point device, either the N300 router or the ESP-32U, would need to be powered separately from the Raspberry Pi 4B in order to ensure that the maximum current draw for the Raspberry Pi and connected peripherals does not exceed 3 Amps [14].

4. TP-Link N300 Nano Travel Router – Wireless Access Point (WAP) That Best Confirms To Specifications and Constraints

The N300 Nano Travel Router, manufactured by TP-Link, has been chosen as the wireless access point (WAP) for the crawl space inspection robot due to the N300 more closely adhering to the specifications given by the capstone team for maximum performance. The N300 router has a higher transmission rate of 300 Mbps, has a higher consistently stated transmission range of 270 meters, has an already included ethernet port for connection to the raspberry pi, is much more modular and structurally sound, and is overall an easier device for users to setup and use than the ESP-32U. While the N300 has a price of $10 higher than the ESP-32U and uses 0.48 Amps more of current, the N300 is an extremely modular device which was designed by TP-Link to provide and extend the Wi-Fi range of a home, a characteristic which the capstone team believes will assist in transmitting through various walls and floors that surround a crawl space environment [6]. Additionally, the N300 has more stated range and transmission specifications by the manufacture than the ESP-32U, therefore, the N300 is a more reliable and predictable device to be included into the design of the crawl space inspection robot. The proposed connections of the N300 router to the Raspberry Pi 4B and external power sources are shown in figure 6. The N300 would most likely be attached to the crawl space inspection robot in the configuration proposed in figure 7, which would allow for proper orientation and area coverage without being in line of sight of the 360-degree Lidar sensor.

Figure 6 [19]:

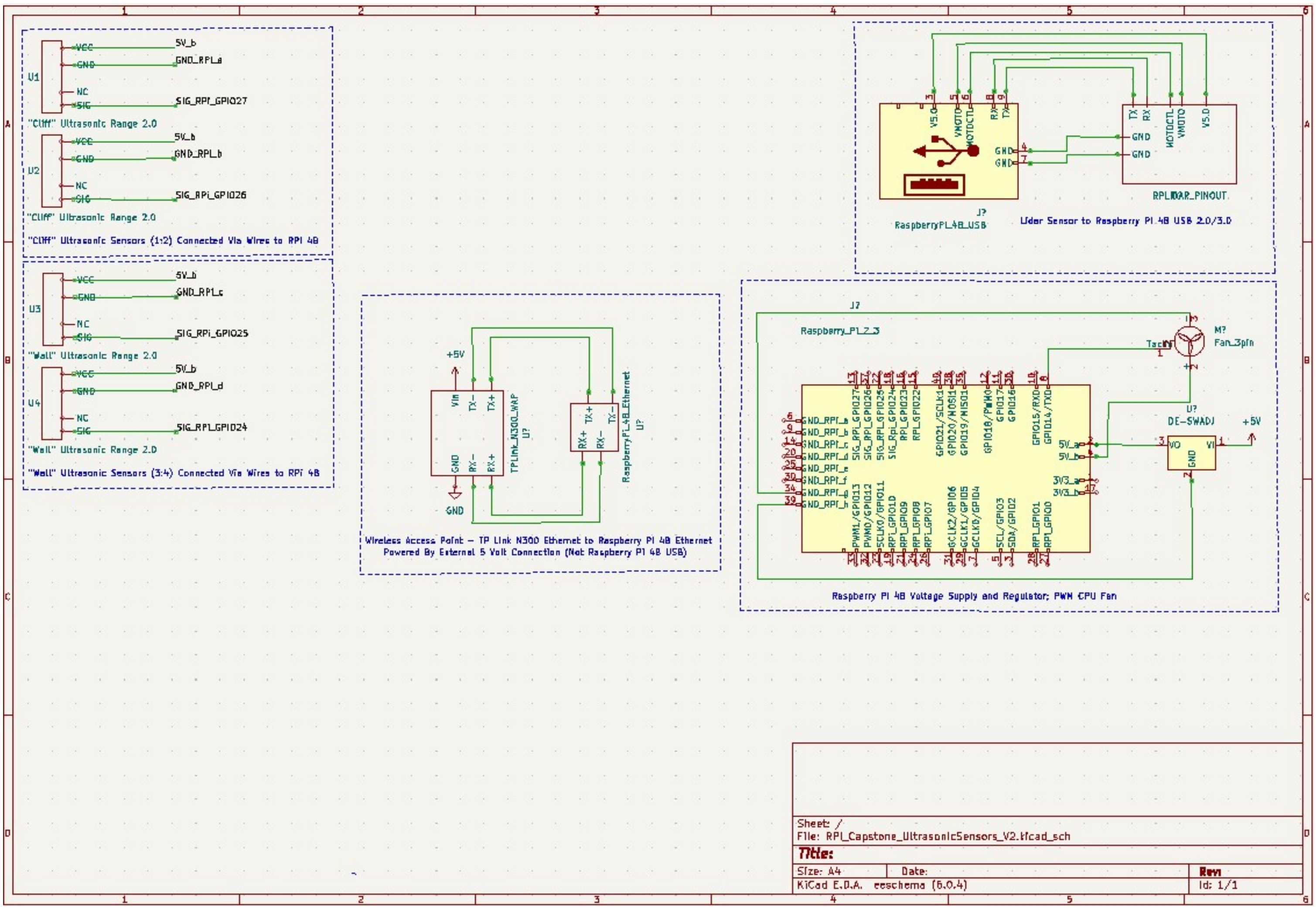
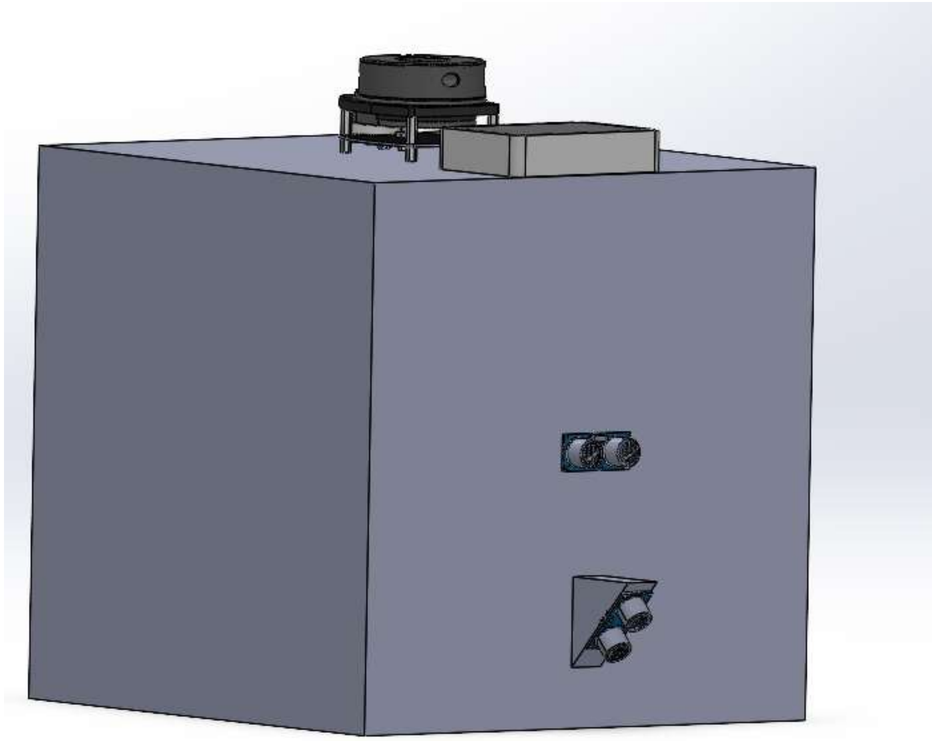


Figure 7 [20]:



Experimentation of the TP-Link N300 Transmission Speed and Distance In A Real-World Environment:

In order to more in depth examine the performance of the TP-Link N300 Nano router, team members obtained the device and developed an experiment to determine how what the transmission speed would realistically be at the maximum distance of 70 feet as defined by the constraints of the subsystem. In order to simulate what the wireless access point would be used for when incorporated into the design of the inspection robot, team members set up the wireless access point and connected two devices to the WLAN network. The TP-Link N300 router is spec'd to have a maximum transmission speed of 300 Mbps over the distance an average house Wi-Fi network [**TP-LINK]**. To test this, team members developed two cases in which one of the devices was remotely controlled using the Microsoft Remote Desktop Connection Protocol and a 1080p 30 fps video was live-streamed from one device to the other while also clicking around on the desktop screen and moving windows from one corner of the screen to the other.

In case 1, a personal computer (PC) was used as the controller and another (PC) was used as the device that was being controlled. Team members mobile device (an iPad Pro) was used as the controller. Team members measured a distance of 70 feet from the Wi-Fi router and placed the "remote control" device (a.k.a PC) at this distance to simulate the maximum distance (hypotenuse) of the average home size as previously discussed in the constraints section. The team members then measured the distance from the additional (PC) to the Wi-Fi router and it was found to be 30 feet (this device is stationary in both cases as it is a desktop computer wirelessly connected to the wireless access point network). Therefore, as with in case 2, the total transmission distance was roughly 100 feet which is well over the proposed transmission distance of 70 feet. While the "remote control" device was 70 feet from the wireless access point the device showed a very strong connection to the WLAN network. In order to measure the current transmission speed the team members utilized the "Resource Monitor" on the device that was being controlled, which allows users to monitor the total current load or stress on the WLAN network and display it as a function of time. The team members connected from the "remote control" device to the device being controlled via the Remote Desktop Connection Protocol and began the 1080p 30 fps video and began moving interacting with the device by applications around on the screen which was estimated to use roughly 9 Mbps [4**]**. The team members found that the wireless access point was able to provide sufficient bandwidth which allowed for the 1080p video to be smoothly seen on the "remote control" deivce as well as the moving of applications across the desktop screen. Additionally, the wireless access point only used a transmission speed on average of 5 Mbps with a peak utilization of 7 Mbps, which is only a fraction of the total allowed bandwidth of 300 Mbps. It is important to note that the average speed of 5 Mbps recorded is only what the wireless access point required to live-stream the video feed over the WLAN at 30 fps. Therefore, the wireless access point only had to use a portion of its bandwidth at a total transmission distance of 100 feet. The results of case 1 and case 2 of the experiment are shown in figures () and figure (). This experiment was repeated with the "remote control" device as the mobile device (iPad Pro) at the same transmission distance but using the mobile version of the Remote Desktop Connection Protocol "RD Client" and obtained similar results. This experiment allowed team members to conclude that the TP-Link N300 Router is a viable option for the design of the crawlspace inspection robot and does in fact meet the constraints and specifications of the subsystem.

Figure 8:

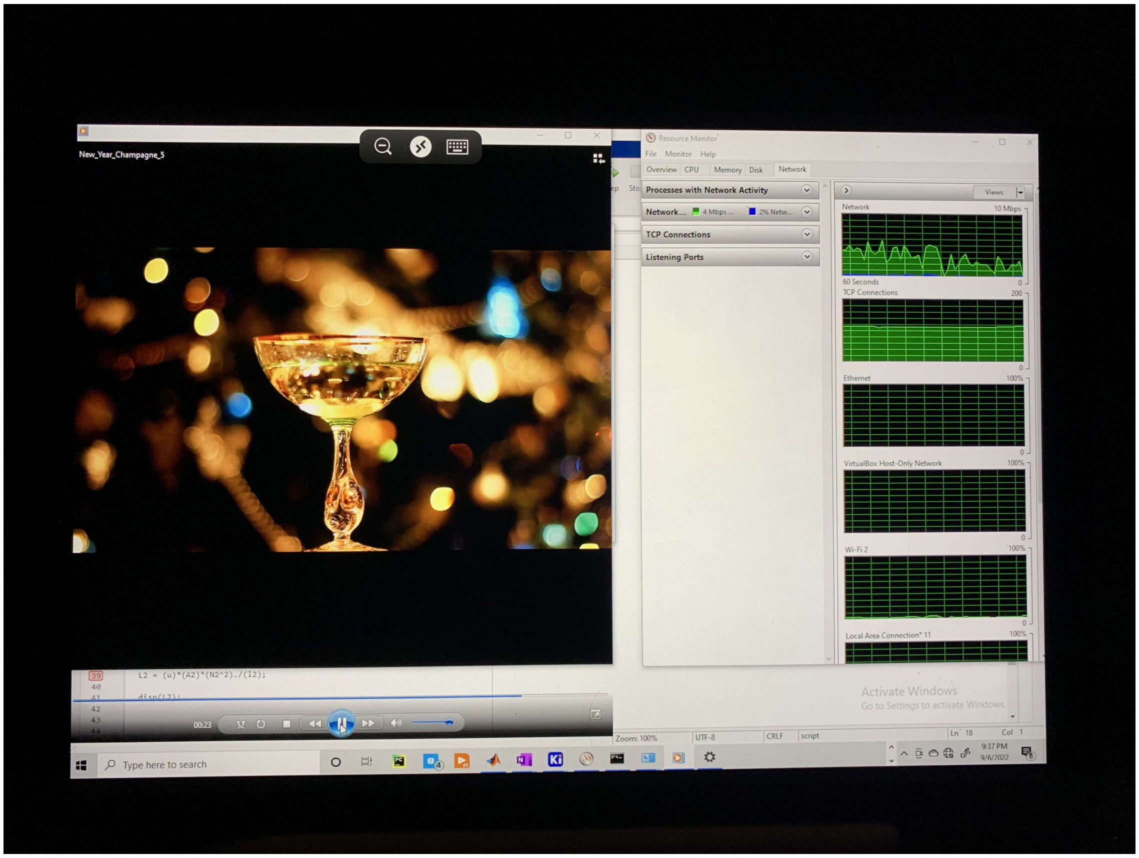
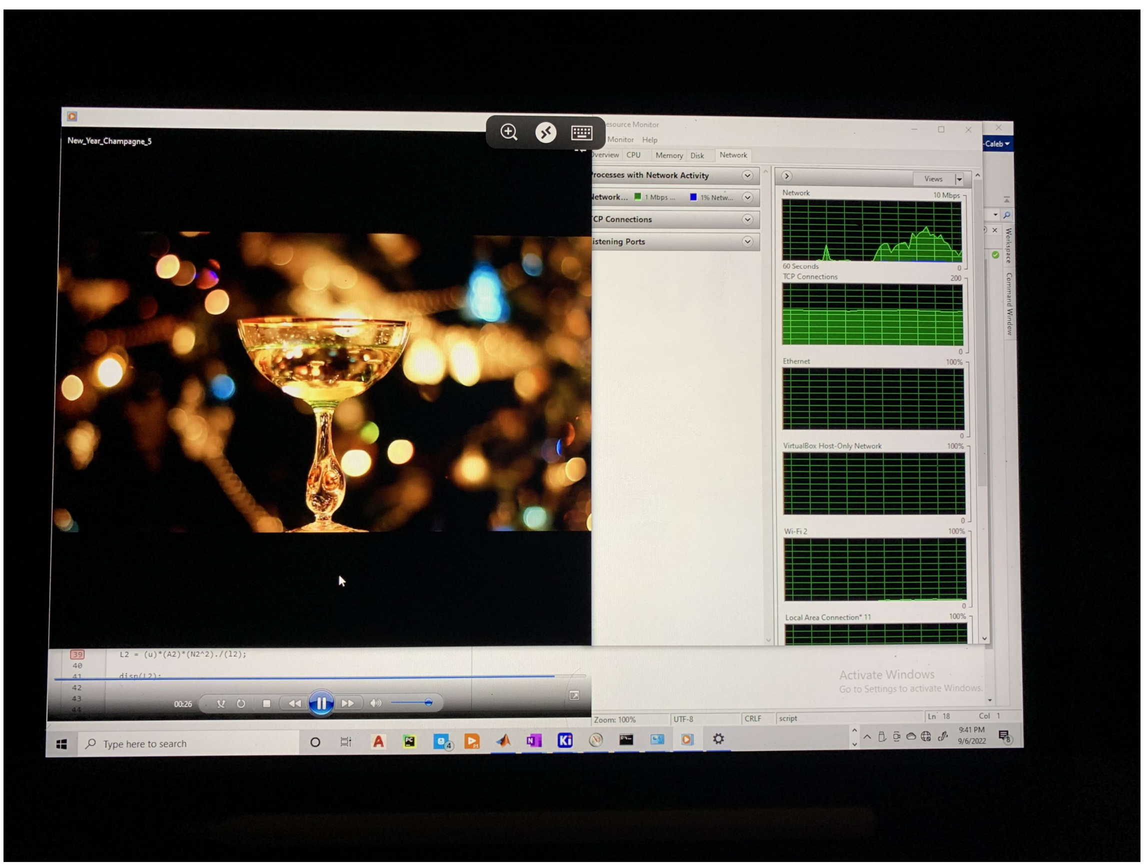


Figure 9:



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