Cleaning and Mapping Robot Laboratory Journal

Beginning 5-27-2020

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Contents

Wednesday, May 27, 2020

Problem Statement:
Various cleaning and mapping (CAM) robots such as the Roomba by iRobot are commercially available today and are able to clean different areas of a home or business. Some of the top of the line robots by iRobot like the Roomba s9+, Roomba i7+, and Braava m6 are able to map rooms with a technology called Imprint Smart Mapping technology. In the app for each robot, a clean map report can be generated[1]. The generated 2D map will show areas that were cleaned by the robot and the white areas that contained obstacles like furniture or appliances. In these robots that support the mapping feature, a camera is mounted at an angle of 45 degrees that takes pictures of a room regularly. These images are then processed using Visual Simultaneous Localization and Mapping (VSLAM)[2]. Multiple alternative techniques for localization and mapping a robot including lidar and RFID technology. In the proposed research, RFID technology will be utilized for the purpose of possibly lowering costs and computational complexity.

Research efforts:
In [1], a probabilistic model for localizing an RFID tag is given for the purpose of localizing a robot in its environment. Given a the position x of the tag and data $z_{1:t}$, the probability of obtaining the correct position of the robot given the observations is

$$p(x|z_{1:t}) = \alpha p(z_t|x)p(x|z_{1:t-1})$$

where α is the normalization constant. The purpose of this study was to determine the locations of RFID tags in an office building using a laser range finder and an RFID reader mounted on the robot. With the RFID tag's locations the path of the robot could be estimated which is known as localization. However, it does not use RFID specifically for mapping an environment. Therefore, techniques must be found for determining how to map the robot's environment. This may only be possible with sensors like a laser range finder, LIDAR sensor, or other digital devices like a camera.

[1] https://homesupport.irobot.com/app/answers/detail/a_id/1467
[2] https://www.thezebra.com/resources/home/how-roomba-works/

Thursday, May 28, 2020

I received the resources for the iRobot Create 2 from Jaden today in his Google Drive. The iRobot Create 2 is a hackable device designed for education rather than commercial use[1]. On iRobot's site, many different projects have been done with this robot such as a Nerf-gun mounted turret modification, nerf-gun dart collector robot, camera bot, pokemon go egg hatching, zcm driver, and path finder. All of them are documented in the provided footnote.

[1] https://www.irobot.com/About-iRobot/STEM/Create-2/Projects.aspx

Monday, June 1, 2020

Today, I did some research on how to implement the mapping feature with a LIDAR sensor as Prof. Miah mentioned that this technology is available in some of the labs. I looked at a tutorial on how to interface the Neato LIDAR sensor with a Beaglebone [1]. By simply connecting the LIDAR sensor to the TX and RX pins of the board, data can be sent to the device or the encoded can be retrieved. The mentioned LIDAR comes with a motor which can be powered with a 3V power supply. To read from the device the device file in the `/dev` directory must be opened. Each packet consists of 22 bytes. The code below:

```
print("Hello")

with open("/dev/ttyO2", "rb") as f:
    byte = f.read(1)
    count = 1
    while byte != "" and count <= 22*100:
        print(byte.encode('hex') + ":")
        byte = f.read(1)
        count += 1

print("Goodbye")
```

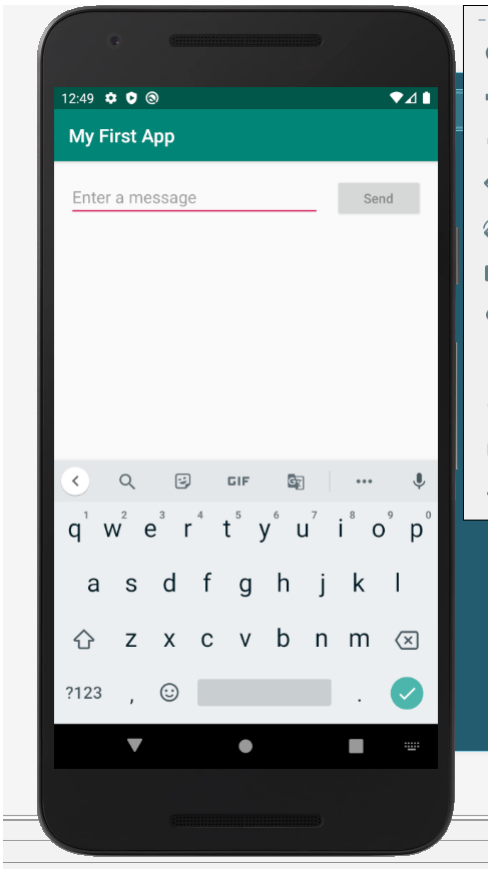
where the LIDAR is located at `/dev/tty02`. However, the LIDAR sensor that Prof. Miah has in his robotics lab is likely different as there are a lot of different options out there.

[1] https://www.alexschimp.com/neato-lidar-data-beaglebone-black/

Tuesday, June 2, 2020

In yesterday's meeting with Jaden, my partner, we agreed that he would focus mostly on the hardware side of things as he has the robot and beaglebone while I work on building an Android app for showing the map. In this way, I will be able to make more of a significant contribution toward the project with the resources I currently have. I have never built an app before so some research will be required before I start developing the app.

I started by following the Android tutorial[1]. The UI for each app is built using a system of layouts and widgets where the layouts are `ViewGroup` objects and the widgets are `View` objects. Objects in the layout like text objects and buttons can be constrained to each other. For each TextView object, a `textSize` and `textColor` variable can be set. The result of the tutorial is shown below:



[1] https://developer.android.com/training/basics/firstapp/creating-project

where after text is entered and the button is pressed, a new activity is shown which displays the text under the top app bar.

Wednesday, June 3, 2020

Today I took a pause on developing the app by looking at the link to the Lidar sensor that Dr. Miah sent us that is available in the robotics facility [1]. The model is a RPiLIDAR S1 360°. According to the datasheet it can perform 2D 360° scan of an area with a 40 meter range. The sampling rate is 9200 samples per second and the sensor can tilt vertically up 0.391°. While scanning, the data output of the sensor over UART includes both the distance between the rotating LIDAR sensor and the sampling point while the heading is the current angle of measurement in degrees. A flag in the data will signal the start of a new scan. Both the distance and heading values will be sent as pairs for data communication for each sample point. The pinout for the device is as follows:

Pin Name	Description
VCC	Power
GND	Power
RX	Serial Input
TX	Serial Output

where there are two pins for VCC and GND each as separate power is needed for the sensor and motor system that rotates the sensor. Because the connector used for the sensor is a SH1.0-6P, some special wires may be needed for connecting to the device. As far as the specification for the serial interface goes, the baud rate is 256000 bps and uses 3.3V TTL logic.

Since I am on my laptop and do not have android studio installed on it, I began installing it. I realized that the Create 2 does not have any sort of internet connectivity, so a web server will be needed on the Beaglebone to communicate with it wirelessly. In the app, some functionality will need to be developed to discover the Roomba on the network.

I created a new project called LidarMap using the bottom navigation bar template.

[1] https://www.robotshop.com/en/rplidar-s1-360-laser-scanner-40-m.html?utm_source=google&utm_medium=surfaces&utm_campaign=surfaces_across_google_usen&gclid=EAIaIQobChMI9JyBto7m6QIVkIbACh3GMwhZEAYYASABEgIebPD_BwE

Thursday, June 4, 2020

I spent some time wireframing the UI for the app on paper today. The app will have a bottom navigation bar with the pages Discovery and Map. The Discovery page will contain the list of discovered robots while the Map page will contain the map similar to the map shown in the Roomba app. Similar to my building energy management project, the robots should be discovered automatically with an "autodiscovery" feature. While waiting for devices to be discovered I want to add an indefinite progress bar spinner. Since I realized that it is possibly going to be more difficult to change the current icons in the current app I decided that I will simply start making the app using a blank template.

I thus created a new Android Studio project named `Create2LidarMap` using Android 4.0.3 (Ice Cream Sandwich) using the empty activity template. I then followed [1] to create a bottom nav bar from scratch.

[1] https://androidwave.com/bottom-navigation-bar-android-example/

Friday, June 5, 2020

I worked on adding the bottom navigation menu from scratch into the app. The icons were successfully added where one is a magnifying glass and the other is a quilt for the map page. The `NavHostFragment` component in the MainAcitity page will provide an area above the nav menu for self contained navigation to occur. Essentially two different fragments will be created for the discovery and map respectively. However after adding the component to the main activity and importing the Android jetpack package `androidx.navigation.fragment`, I got a warning stating that to Replace the tag With FragmentContainerView. I made the change to this View but another issue came up as the navGraph attribute excepts a resource of type String but currently has a navigation resource type (@navigation/mobile_navigation). Inside the onCreate method in the `MainActivity` class, I added the line

```
this.getSupportActionBar().hide();
```

To remove the top action bar with the name of the activity which in my opinion makes the app look a little cleaner.

Monday, June 8, 2020

Because of the issues mentioned previously with adding the navbar from a blank project, I decided to simply take the original LidarMap project and modify it with the appropriate fragment and subtract and add the appropriate navbar elements. In the java directory I created a package`com.example.ui.lidarmap.map` where I created the java file `MapFragment.java` and `MapViewModel.java`. The source code for MapFragment was generated by default and contains the following:

```
package com.example.lidarmap.ui.map;

import androidx.lifecycle.ViewModelProviders;

import android.os.Bundle;

import androidx.annotation.NonNull;
import androidx.annotation.Nullable;
import androidx.fragment.app.Fragment;

import android.view.LayoutInflater;
import android.view.View;
import android.view.ViewGroup;

import com.example.lidarmap.R;

public class MapFragment extends Fragment {

    private MapViewModel mViewModel;

    public static MapFragment newInstance() {
        return new MapFragment();
    }

    @Override
    public View onCreateView(@NonNull LayoutInflater inflater,
    @Nullable ViewGroup container,

                             @Nullable Bundle savedInstanceState) {
        return inflater.inflate(R.layout.map_fragment, container, false);
    }
```

```
    @Override
    public void onActivityCreated(@Nullable Bundle savedInstanceState) {
        super.onActivityCreated(savedInstanceState);
        mViewModel = ViewModelProviders.of(this).get(MapViewModel.class);
        // TODO: Use the ViewModel
    }

}
```

I created a second package named `com.example.lidarmap.ui.discovery` with the files `DiscoveryFragment` and `DiscoveryViewModel` which similar code to the map fragment and view model classes. After adding these files, I generated the layout files. However, the build failed with the exception: `java.lang.RuntimeException`. I thus decided to once again create a new project from scratch in hopes of fixing the previous issues from the `CAMRobotMap` project.

I decided to scrap all my previous ideas and simply follow a tutorial on Youtube at [1]. At the beginning of the tutorial, the speaker mentioned that if only two destinations are needed (map, discovery) then it is better to use a tab layout instead. I deleted the old project with the bottom nav and created a new project with tabbed activity template. Instead I decided the follow the tutorial [2]. In the "Discovery" tab, I added a ListView object

[1] https://www.youtube.com/watch?v=tPV8xA7m-iw
[2] https://www.youtube.com/watch?v=h4HwU_ENXYM

Wednesday, June 10, 2020

What I plan on accomplishing today is creating a github repository for the android app and sharing with Jaden, so that we can both work on the software together as he cannot do much due to hardware limitations with the Roomba. Next I would like to start writing a method to create a TCP/UDP client and send out broadcast messages on the network for the Roomba. First, I asked Dr. Miah for permission before pushing the project to a public Github repository. However, I found that I recent change was made to github that allows for unlimited private repos with fewer than 3 or 4 collaborators. When attempting to the push the changes to the repository I got the error:

```
Push rejected: Push to origin/master was rejected
```

This was fixed after I rebased from master to refs/remotes/origin/master. Thus, I was able to succesfully push the project to the github repo LidarMappingRobot.

Although the priority is to write the TCP/IP client code for the app, I would like to add subitems into the list view for the Discovery fragment.

Thursday, June 11, 2020

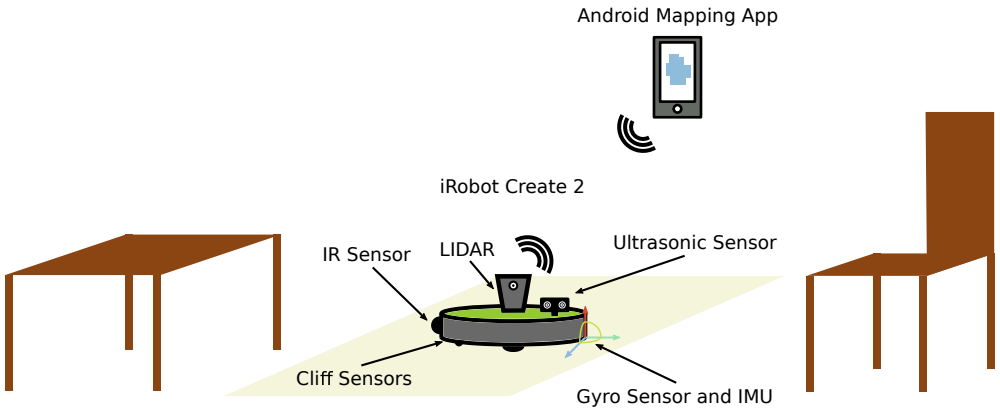


Figure 1: *Diagram representing the working principal of the cleaning and mapping robot*

Description:

The proposed cleaning and mapping robot based off the Roomba vacuum by iRobot will have the ability to collect sensor data from multiple onboard sensors connected to a single board computer (Beaglebone Blue) for the purpose of localization and mapping. IR sensors, ultrasonic sensors, cliff sensors, and LIDAR will help the robot to understand its environment better. The IMU and gyroscope will help to track orientation, velocity, and rotation. With the aid of the computer, the robot will be able to successfully map its environment like a floor of a house or building. The LIDAR sensor will perform a continuous 360° sweep of the environment to generate a 2D map of the environment. For visualizing the fully completed map, an Android app will be developed to display the outcome of the mapping graphically. Built-in WiFi support of the Beaglebone will act as the communication medium between the robot and client. iRobot has developed a technology of their own that can perform mapping of an area and identify areas of high dirt or dust concentration. However, the robot to be developed will seek to use cost effective sensors to clean the floor and build a map of the environment. The robot will exhibit human like reasoning and intelligence including perception and memory through storage of maps on the single board computer. Techniques like artificial intelligence will be deployed for improving the human like perception abilities of the device even further.

Tuesday, June 16, 2020

Brian: I found a blog post on the Internet detailing how to implement a network scanning feature in Android[1]. At the end of section 1, it states that networking code should not run in the UI. In other words, a separate thread of execution must be created for network operations. In this case, scanning all IP addresses on a subnet is the task at hand. I worked on understanding the method `getIpv4Netmask()` which should return the network prefix length or in other words the number of bits in the network portion of the IP address. However I tried the code out in Eclipse and received a `NullPointerException`. This may have to do with passing the wrong IP address as a parameter into the method call. To try and understand what IP address should be passed in an argument, I used the lines

```
WifiManager wifiManger = (WifiManager) getSystemService(Context.WIFI_SERVICE);
DhcpInfo dhcpInfo = wifiManger.getDhcpInfo();
```

in the `onCreate` method of the `MainActivity` class. However, the `getDhcpInfo` call was returning an error as the WifiManager is missing permissions. What I found is that the permission `ACCESS_WIFI_STATE` is required in the Android Manifest file which is accomplished by adding the line.

```
<uses-permission android:name="android.permission.ACCESS_WIFI_STATE" />
```

to the AndroidManifest.xml file. Also, I changed the lines to

```
WifiManager wifiManager = (WifiManager) getContext().getApplicationContext()
.getSystemService(Context.WIFI_SERVICE);
DhcpInfo dhcpInfo = wifiManager.getDhcpInfo();
```

As a test, since the wifi is not enabled on the emulator, I downloaded the app to a test Moto E phone. An added `dhcpInfo.ipAddress` to the the list of items. It displays the integer 318810304 which by using a decimal to IP converter I found the this represents the IP address 192.168.0.19.

[1] https://cheesecakelabs.com/blog/developing-iot-apps-connecting-smart-devices/

Wednesday, June 17, 2020

Since I was having problems with finding the prefix length with the getIpv4Netmask provided in the footnote above, I decided to rather get the localhost of the device and get the network interfaces attached. In this way, hopefully a null reference exception will be avoided. Unfortunately, when I call `Inet4Address.getLocalHost()` the app crashes. I found that this is caused by a `NetworkOnMainThreadException` being thrown by the application as it was trying to perform a network operation on the main thread. I did not realize that it is absolutely required to add in a second thread to perform network operations.

I need to create another class in the `DiscoveryFragment` class that extends from the `AsyncTask` class. However, I discovered that the `AsyncTask` class was deprecated in API level 30. Instead I will use the more up to date `Executor` interface which contains one method: `execute`. In the implementation of the the `execute` method, it creates a new thread and starts it as follows:

```
class TaskExecutor implements Executor {
        public void execute(Runnable r) {
                new Thread(r).start();
        }
}
```

Where `Runnable` is a second interface that adds the `run` method which will be executed when the thread is started. In the `run` method, I would like to get the network prefix of the subnet and add to the ArrayList to be added to the ListView in the android application.

This second issue to be solved is the issue of the `getLocalHost` method returning a `InetAddress` object bound to the IP address 127.0.0.1 rather than the actual address of the device. The network mask prefix of 127.0.0.1 is 8 rather than the expected 24 on my home network. After implementing some more of the code by using an instance of the DhcpInfo object, I was able to successfully display the prefix (24) in the app.

Thursday, June 18, 2020

Today will be detected to searching for all devices under my networks subnet (255.255.255.0). I created a second task titled `ScanNetworkTask`. However, I would like to write a method that will be called in the `ScanNetworkTask` run method for obtaining the network prefix rather than using a separate thread to find the prefix. The purpose for doing this is to prevent a race condition with the class level member variable `mNetworkPrefix`. The problem I am having is that private member variables cannot be accessed from static methods in java. The variable I would like to reference is the instance of `DhcpInfo` which is initialized in the `onCreate` method of the `DiscoveryFragment` class. However, in the end, I just decided to add all the code including the code to determine the network prefix in a single task class titled `ScanSubnetTask`. The code after the network prefix code will loop from 192.168.0.0 up to 192.168.0.254 and ping each of those addresses by calling the `InetAddress.isReachable` method with a timeout of 80 ms. In the task, I decided to update the ArrayList with the list of reachable IP addresses. This causes an `IllegalStateException` because the background thread should not be sending notifications to the UI to update it. Correctly communicating with the UI from backgrounds will be necessary here [1].

[1] `https://developer.android.com/training/multiple-threads/communicate-ui`

Friday, June 19, 2020

Today, I read through some of the android developer resources to determine how to update the UI from a background thread. A line that I found that should be added to the implementation of the `run` method is

```
android.os.Process.setThreadPriority(android.os.Process.THREAD_PRIORITY_BACKGROUND);
```

which moves the thread to the background. Inside the constructor of the `DiscoveryFragment` class I added an instance of an anonymous class which extends the `Handler` class will handle new message added to the task:

```
    private DiscoveryFragment() {
        // This is an anonymous class which extends the Handler class
        handler = new Handler(Looper.getMainLooper()) {
            @Override
            public void handleMessage(Message inputMessage) {

            }

        };
    }
```

The problem is I don't know how the invoke the handler and what type of message will be passed into the `handleMessage` method. It turns out the `sendMessage` method must be used. From the android developer docs [1], the `Message` class is used to define a message containing a description and data object to be sent to a handler. The `setData` must be called on an instance of the Message object in order to add data to the Message instance. When attempting to call the `sendMessage` method on the handler instance, I received the following exception:

```
java.lang.IllegalStateException:
{ when=-14h27m43s520ms what=0
target=com.example.lidarmappingrobot.ui.main.DiscoveryFragment$1 }
This message is already in use.
```

[1] https://developer.android.com/reference/android/os/Message

Monday, June 22, 2020

One of the problems I discovered in my code, is that the `Message.sendMessage(Message)` method was being called inside a for loop. Thus, the same `Message` object was likely being used multiple times causing some issues. After adding the `sendMessage` call after the for loop the exception went away. However, no IP addresses were being listed in the Discovery page. Instead of assigning the `obj` field of the Message object to the ArrayList, I decided to uses `Bundle` and the `putStringArrayList` method to set the data on the message. Now the problem appears to be that `handleMessage` is not being called which I added the single line to

```
mArrayList.add("Null pointer exception here!");
```

I realized I forgot to assign the `Bundle` object which is used for storing the String `ArrayList` and sending to the `Handler` over a `Message` to the output of `Message.getData()`.

A large problem I found in the current implementation of the subnet scanner I have adapted and built is that it takes at least 5-6 seconds in order to finish the call to `getByAddress` on the `InetAddress` object. This leads to the app taking over 10 minutes to finishing scanning all the devices. It turns out the call to `InetAddress.getHostName` takes a long time to call as it performs a DNS lookup under the hood. Therefore, a different approach may need to be taken instead. A solution was quickly found from the Stack Overflow post [1], the `InetAddress.toString` method will simply print a slash and the name of the address instantly without any system call. A problem I am having is the inability to determine if addresses are reachable with the `InetAddress.isReachable` method.

[1] https://stackoverflow.com/questions/10420317/java-inetaddress-gethostname-taking-a-very-long-time-to-execute

Tuesday, June 23, 2020

Since I realized that scanning every single device on the network is not a good idea as it will take a long time, I decided to try to setup the SBC as a wireless access point. Because I don't have a Beaglebone, I will use a RPi instead given directions from stack exchange[1]. For this, I will follow the tutorial at [2] as the link provided in the previous url on stack exchange was returning a 404 error. However, I discovered that the RPi must be connected to the rest of the network via Ethernet, so this may not be a viable option either. A better alternative I found is using multicast sockets over UDP which would be more ideal in terms of speed [3]. The following code should be adapted for android to send data to the receiver (the Beaglebone).

```
import socket
import struct
import sys

message = 'very important data'.encode('utf-8')
multicast_group = ('224.3.29.71', 10000)

sock = socket.socket(socket.AF_INET, socket.SOCK_DGRAM)

sock.settimeout(0.2)

ttl = struct.pack('b',1)
sock.setsockopt(socket.IPPROTO_IP, socket.IP_MULTICAST_TTL, ttl)

sent = sock.sendto(message, multicast_group)
print('sent message')
while True:
    print('waiting to receive')
    try:
        data, server = sock.recvfrom(16)
    except socket.timeout:
        print('timed out')
        break
```

[1] https://raspberrypi.stackexchange.com/questions/66700/tcp-communication-with-android-via-wifi
[2] https://www.raspberrypi.org/documentation/configuration/wireless/access-point-routed.md
[3] https://pymotw.com/2/socket/multicast.html

```
    else:
        print(data)

sock.close()
```

The following receiver code should be added onto for pulling lidar data from the robot that the bone is connected to:

```
import socket
import struct
import sys

multicast_group = '224.3.29.71'
server_address = ('', 10000)

# Create the socket
sock = socket.socket(socket.AF_INET, socket.SOCK_DGRAM)

# Bind to the server address
sock.bind(server_address)
# Tell the operating system to add the socket to the multicast group
# on all interfaces.
group = socket.inet_aton(multicast_group)
mreq = struct.pack('4sL', group, socket.INADDR_ANY)
sock.setsockopt(socket.IPPROTO_IP, socket.IP_ADD_MEMBERSHIP, mreq)
# Receive/respond loop
while True:
    print >>sys.stderr, '\nwaiting to receive message'
    data, address = sock.recvfrom(1024)

    print >>sys.stderr, 'received %s bytes from %s' % (len(data), address)
    print >>sys.stderr, data

    print >>sys.stderr, 'sending acknowledgement to', address
    sock.sendto('ack', address)
```

Luckily, there is a class in the Android SDK specifically for multicast communication, `MulticastSocket`. One of the problems I am running into is how to properly obtain the IP address from the received datagram packet from the remote listener on the RPi. In other words after the call to `DatagramSocket.receive`, the argument passed to the method should receive the message received and have the ip and port of the remote host encoded in it. What I discovered is that a message must be received multiple times in order to properly receive the message from the server. However, when I restart the app, the packet sometimes gets lost and my code gets stuck in an infinite loop. A potential solution is to add a refresh button to look for devices in case the app did not get a response.

Wednesday, June 24, 2020

I altered the code inside the `run` method of the `FindRobotTask` class to only iterate up to 10 times to receive a message from the SBC. This will prevent the infinite loop issue. Next what I would like to do is add in a floating action button to refresh whenever devices don't show up in the list view. The code is fairly simple as all I have to do is call `setOnItemClickListener` on the `FloatingActionButton` object:

```
FloatingActionButton fab = (FloatingActionButton) discoveryView.findViewById(R.id.fab);
fab.setOnClickListener(new View.OnClickListener() {
        @Override
        public void onClick(View v) {
                mArrayList.add("Refreshed");
                new Thread(new FindRobotTask()).start();
        }
});
```

However, the problem I have is the Refreshed string is not being properly added to the array list every time as it is not showing in the ListView. I added the line

```
Snackbar.make(discoveryView, "Replace with your own action", Snackbar.LENGTH_LONG)
                        .setAction("Action", null).show();
```

in the definition of the `onClick` method which creates a pop up at the bottom of the screen whenever the button is clicked. This appears to work but items are still not being added to the listview. I was able to fix the problem of the refresh button stretching across the entire bottom of the screen by switch from using a `RelativeLayout` to a `CoordinatorLayout` in the `fragment_discovery` layout. Because it is in need of an update, I would like to work on the ListView adapter which will show the name of the device in large text and the ip address below in smaller text with the format, ip: [ip address]. I will use the post [1] for the task.

Something I discovered is that the application crashes when I select one of the items in the list view after pressing the refresh button. This is because the attempt to update the array list inside the `onClick` method for the fab is illegal as it is running on a separate thread. Instead a custom adapter class must be written with a definition of `notifyDataSetChanged` which will be called if data has changed or new data is available in order to update the list view.

The problem with the `ListView` not updating was resolved by calling `notifyDataSetChanged` on the `ArrayAdapter` object in the `handleMessage` method.

[1] https://www.vogella.com/tutorials/AndroidListView/article.html

At the end of the day, all issues were resolved and I am able to succesfully discover a RPi on the network with refresh implemented. Changes were pushed to the github.

Bibliography

[1] D. Hahnel, W. Burgard, D. Fox, K. Fishkin, and M. Philipose. Mapping and localization with rfid technology. In *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA '04. 2004*, volume 1, pages 1015–1020 Vol.1, 2004. 5