CS1951R: Introduction to Robotics
Professor Stefanie Tellex

Build, Program, and Fly your very own Drone
Israel Says It Downed Hezbollah Drone Headed Toward Golan

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Jerusalem (AP) -- The Israeli military said it shot down an Iranian-made spy drone operated by the Hezbollah militant group as it approached the Golan Heights on Tuesday, and vowed to take further tough action against any attempts by its archenemies to violate the country's sovereignty.

The aerial showdown took place as Prime Minister Benjamin Netanyahu was preparing to address the U.N. General Assembly, where his speech is expected to focus on concerns of Iran's rising influence across the region, particularly in neighboring Syria.

Lt. Col. Jonathan Conricus, an Israeli military spokesman, said the drone took off from a Damascus military airport and was on a surveillance mission near Israel's border. He said Israel decided to shoot it down after it entered the demilitarized zone between Syria and the Israeli-controlled side of the Golan.
Skydio Guest Lecture

- Tuesday 10/3
Card Access and Flying Space

- 25 students registered on banner and same 25 handed in assignment 1
- We just sent the registration list out to get your swipe cards to work.
- Still need to come to SciLi during open hours.
  - Our office hours.
  - Open lab hours with HCRI staff member: weekdays 1pm-6pm.
Brushless Motors

**Motor Model:** SE1806 (2300KV)

**Motor Outlines:**

- Diameter: 17.5mm
- Thickness: 14mm
- Weight: 21g
- Resistance: 0.19ohm
Electronic Speed Controller (ESC)
Electronic Speed Controller (ESC)
Three-Phase AC
Javascript API

- Just pushed Javascript API to fly the drone.
- Test everything without props before you put props on the drone.
- Networking assignment (coming out Thursday) requires a working Rasberry Pi that you can ssh into.
Updates to Project 1

- Test with Javascript API before you get props.
- Verify each sensor works.
Debugging Strategies

- Decompose the problem.
  - Verify each sensor is sending data.
  - Verify the power chain.
  - Verify motor actuation works.

- Visualize the state.
  - Visualize sensor data.
  - Cleanflight and Javascript API.

- Break the abstraction barriers.
  - Multimeter to check power/connectivity.

- Slow things down.
  - Write sensor logs to a file and graph them.
  - Insert sleep/break statements to pause execution.
Flying Checklist

- Am I connected to my drone, not someone else’s?
- Safety glasses?
- Do I have space to fly?
  - Flyaway possibilities?
  - Collision possibilities?
- Check the kill switch?
- Armed?
Law of Leaky Abstractions

- Examples?
Teleop vs. Autonomy

- Have an idea for autonomous (e.g., dance?)
- Teleoperate the robot to do the task to understand the problem space.
- Program the robot to do the task open-loop.
- Program the robot to do the task closed-loop.
- Gradually increase the amount of closed-loop.
Networking

“Robotics is networking.”
– Liam Paull, co-inventor of Duckietown and professor at University of Montreal
Connecting to Your Robot

Network
Networking Jargon

- TCP (Transmission Control Protocol)
- IP (Internet Protocol)
- UDP (User Datagram Protocol)
- DNS (Domain Name System)
- DHCP (Dynamic Host Configuration Protocol)
- NAT (Network Address Translation)
- Gateway
- IP Address
- MAC Address (Media Access Control Address)
- Port
- Router
- Hub
- Switch
- AP (Access Point)
- Master vs Managed
- SSID (Service Set Identifier)
Problems

- Connect two computers?
- Send data to another network?
- Dropped packets?
- Fast transmission?
- How do we use names instead of IP addresses?
- Obtaining an initial IP address?
- How do we share one IP address?
- How do we talk to the robot?
Ethernet

- Voltage wiggles on the wires correspond to bits.
- Bits represent a packet with a header, MAC address, content, checksum.
- No TTL.
- What does it hide?
  - Voltage wiggles on the wire.
- How does it leak?
  - Broken connections.
  - Noise caused by interference, long cables, etc.
Wifi!

- RF frequency modulation encodes bits. (802.11ac b/g/n)
- Bits represent a packet with a header, MAC address, content, checksum.
- Rasberry Pi has the BCM43438
  - Single-Chip IEEE 802.11ac b/g/n MAC/Baseband/Radio with Integrated Bluetooth 4.1 and FM Receiver
- What does it hide?
  - RF frequency modulation to encode data.
  - Transmission/sending/channel etc.
- How does it leak?
  - Noise from interference.
802.11

- SSID - “Name” of wireless network.
- Network modes
  - Ad-hoc – peer to peer connections
  - Master – you are the master, and connect to other nodes that you manage (you decide SSID, passwords, etc).
  - Managed – you connect to some other access point who is the master.
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IP (Internet Protocol)

- MAC address to IP Address
- Routing

What does it hide?
- Network connectivity graph.
- Routing.
- Disconnection of one route; connecting via a different route.

How does it leak?
- Cycles.
- No path to host.
Connecting to the Interwebs

- Hub
- Switch
- Router
- Gateway
Traceroute

```
steftle10@yawl:~/dev/brown/teaching/2017-fall-robotics/2017-fall-introduction-to-robotics/lectures/2017-09-19-networking
$ traceroute h2r.cs.brown.edu
traceroute to h2r.cs.brown.edu (128.148.36.119), 30 hops max, 60 byte packets
1  10.50.104.1 (10.50.104.1)  9.044 ms  9.091 ms  9.098 ms
2  192.168.101.100 (192.168.101.100)  126.607 ms  137.729 ms  137.675 ms
3  172.16.221.1 (172.16.221.1)  133.147 ms  140.690 ms  140.715 ms
4  border10.tge9-4.nocaddigitalinc-1.wdc002.pnap.net (64.94.31.205)  152.746 ms  138.893 ms  140.079 ms
5  border2.aeo-edgenet.wdc002.pnap.net (66.150.117.21)  72.885 ms  96.584 ms  72.850 ms
6  core2.te5-z-bbnnet.wdc002.pnap.net (216.52.127.72)  72.853 ms  94.229 ms  94.219 ms
7  bb1.aei.laspvox-9.wdc002.pnap.net (64.95.158.246)  105.565 ms  87.411 ms  94.142 ms
8  bb1.ae1.wdc002.pnap.net (64.95.159.33)  117.210 ms  bb1.ae1.wdc002.pnap.net (64.95.159.29)  94.079 ms  117.217 ms
9  eqeq-exchange.tr01-asbinva01.transitrail.net (206.126.236.45)  129.277 ms  132.963 ms  132.959 ms
10  * * *
11  * * *
12  * * *
13  lo-0.rtsw.newy32aapq.net.internet2.edu (64.57.21.235)  129.188 ms  132.835 ms  132.850 ms
14  198.71.47.58 (198.71.47.58)  132.817 ms  224.644 ms  219.469 ms
16  host-198-7-224-118.oshean.org (198.7.224.118)  185.238 ms  185.207 ms host-198-7-224-106.oshean.org (198.7.224.106)  127.991 ms
17  131.109.200.2 (131.109.200.2)  127.977 ms  161.843 ms  126.259 ms
18  * * *
19  * * *
20  * * *
21  * * *
22  * * *
23  * * *
24  * * *
25  * * *
26  * * *
27  * * *
28  * * *
29  * * *
30  *
```

Amtrak
Traceroute

```
$ traceroute h2r.cs.brown.edu
traceroute to h2r.cs.brown.edu (128.148.36.119), 30 hops max, 60 byte packets
1  138.16.161.1 (138.16.161.1)  14.742 ms  15.372 ms  15.676 ms
2  10.1.18.94 (10.1.18.94)  3.431 ms  3.445 ms  3.444 ms
3  vl2062-ddmz-cs-cs5-r.net.brown.edu (10.1.18.2)  2.806 ms  2.817 ms  2.817 ms
4  commodus-ext.cs.brown.edu (138.16.160.252)  1.827 ms  2.073 ms  2.762 ms
```

My Office
Problems

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TCP (Transmission Control Protocol)

- Host-to-host connectivity.
- Ports!
- Open Socket, Close Socket, make it look like a file.
- What does it hide?
  - Lost packets
  - Duplicated packets
  - Out-of-order packets
- How does it leak?
  - Accurate delivery, not timely delivery.
  - Won’t work if you are disconnected.
Problems

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- Dropped packets?
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UDP (User Datagram Protocol)

- Host-to-host connectivity
- Ports
- Checksums
- Lost packets, duplicate packets, out-of-order packets might happen!
- What does it hide?
  - Checksums
- How does it leak?
  - Won’t work if disconnected.
Problems

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DNS (Domain Name System)

- World-wide system for mapping IP addresses to names.
- I pay godaddy.com for the domain name, and pair.com to run a DNS server and host a public website.
- What does it hide?
  - IP addresses are ugly numbers.
- How does it leak?
  - The public internet has a complicated DNS system that you have to buy into. You often want DNS on your LAN but it won’t translate into the public internet. Also setting up a DNS on a LAN is work and many routers don’t do it by default.
Problems

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DHCP (Dynamic Host Configuration Protocol)

- Connect to a new network.
- Ask the world for an IP address
  - Protocol:
- What does it hide?
  - You don’t actually have an IP address at first.
  - You don’t have to configure other network settings, like the gateway or the broadcast mask.
- How does it leak?
  - If no DHCP server, no IP address.
Problems

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NAT (Network Address Translation)

- IP addresses are expensive!
  - My Comcast: $40/month
  - My T-Mobile bill: $57/month
- Lets you share one IP address with lots of people.
- What does it hide?
  - You only have one “real” IP address.
- How does it leak?
  - You can’t be a server on the Internet from behind a NAT.
  - Port forwarding can be used to work around this.
Problems

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ROS (Robot Operating System)

- Application network protocol for
  - Sending messages
  - Remote procedure calls
- Convention for organization of software on the file system for compiling and running (dependency management).
- Library of useful robot software. (Transforms, filters, visualization, etc.).
OSI (Open Systems Interconnection) Model

- Application layer
  - HTTP or XML-RPC or ...

- Presentation layer
  - Convert between different encodings (ASCII vs EBCDIC).

- Session layer
  - Establish, manage, and terminate connections between computers.

- Transport layer
  - Transfer variable-length sequences while maintaining quality-of-service functions.

- Network layer
  - Variable-length data sequences between different “networks.”

- Data link layer
  - Node-to-node data transfer. Error checking and correction. Flow control.

- Physical layer
  - Electrical and physical specifications of the data connection.
Design Scenario

- You want to connect to the drone with your base station.
- Our solution
  - The Pi acts as an 802.11 Master node and advertises a public but password protected network.
  - The Pi runs a DHCP server and allocates IP addresses to anyone who connects to the network.
  - The base station connects to the Pi’s wireless network and uses TCP/IP to communicate.
- Wins:
  - Can start the Pi and connect and don’t need to talk to CIS.
  - Works anywhere!
- Cons:
  - Pi does not have an internet uplink. No “git pull”!
  - Possible network interference.
  - Need to change Wifi settings when setting up a new Pi so there is no name collision.
Design Scenario

- You want to set up a network in your house and enable your cell phone, laptop, and desktop to connect to it.

- My solution
  - Pay Comcast for one IP address and a cable modem.
  - Purchase a WIFI Router.
  - Connect router “uplink” to cable modem.
  - Connect router LAN to desktop.
  - Connect router WIFI link to cell phone and laptop.
  - Router will run DHCP server to allocate IP addresses on LAN.

- Wins:
  - I only pay for one IP address.
  - All “my” machines are behind the NAT and can’t be hacked without first hacking the router.

- Cons:
  - I can’t be a server. Had to do gymnastics to play Minecraft with my brother-in-law.
Open Questions

- The drone has a DHCP server but no Dynamic DNS set up. How do you set up dynamic DNS on the drone so you can ping by hostname as well as by IP address?
- What is the best way for 25 drones and base stations to run at the same time?
- What is the best way to give the drone internet access?