Towards a General-Purpose Cognitive Drone

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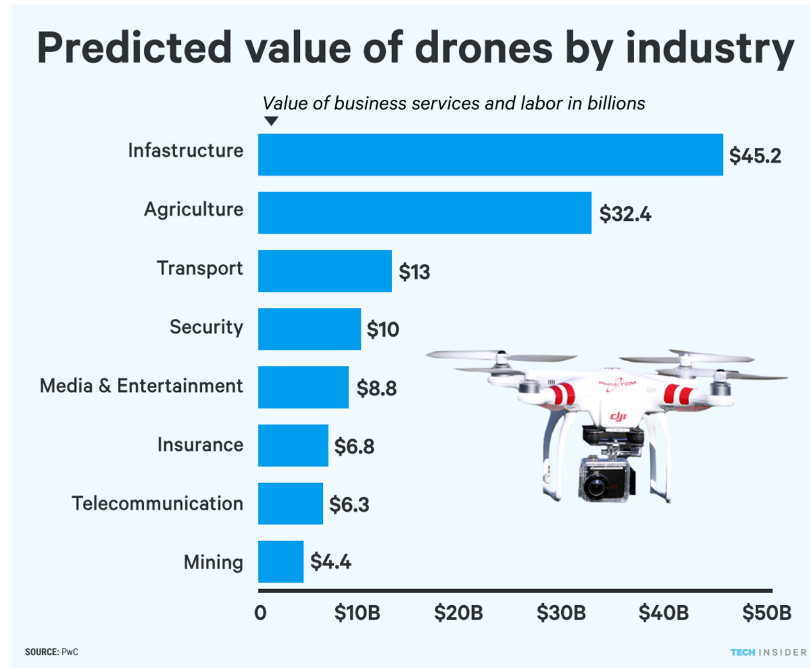
Motivation

- Commercial drone industry will reach 805,000 in sales in 2021, a CAGR of 51% [1]
- Increasing use cases of drones from surveying land to emergency services and national security
- Open-source flight stack to promote innovation through collaboration
- Characterizing underlying architecture and flight stack to achieve high reliability, safety, and performance



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Applications of Drone Technology

- Aerial photography
- Agriculture
- Defense
- Emergency services
- Geographic mapping
- Personal hobby
- Search and rescue
- Shipping

and many more...

Current Drone Technologies

- DJI Commercial Drones [5]
  - Matrice Series (customizable and weight carrying configuration)
- DJI Personal Drones [7]
  - Spark
  - Mavic Series

- Parrot Personal Drones [8]
- Amazon Delivery Drones [6]
- SkyDio Series [9]
  - These drones are specialised for tracking moving objects
  - They heavily rely on Computer Vision and Localisation utilities
- Boeing and Lockheed Martin [10], [11]
  - Drones are oriented more towards defense sector
  - High Altitude Long Endurance (HALE)
  - Stalker XE UAS

Current Technological Shortcomings

- Most drone flight stacks are not open-source
- No access to the autopilot code base
- Weight carrying capacity limitations
- Very difficult to alter hardware due to custom PCBs
- Not cost effective for various types of research projects

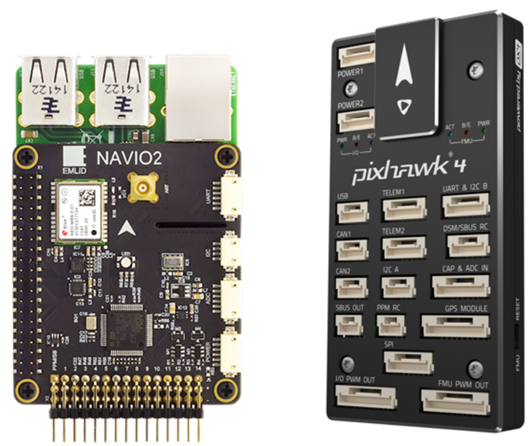
Design Choices

- Open-source drones already exist
  - CrazyFlie [12]
  - PlutoX [13]
- BUT…
  - Limited weight carrying capacity
  - Limited flight time due to battery capacity
  - Microcontroller performance limitation
- We set up a development platform to allow for more sensors and devices to be added in the future
  - Camera for SLAM [14] or OpenCV [15]
  - LIDAR
- So we decided to use a frame kit to build a custom drone

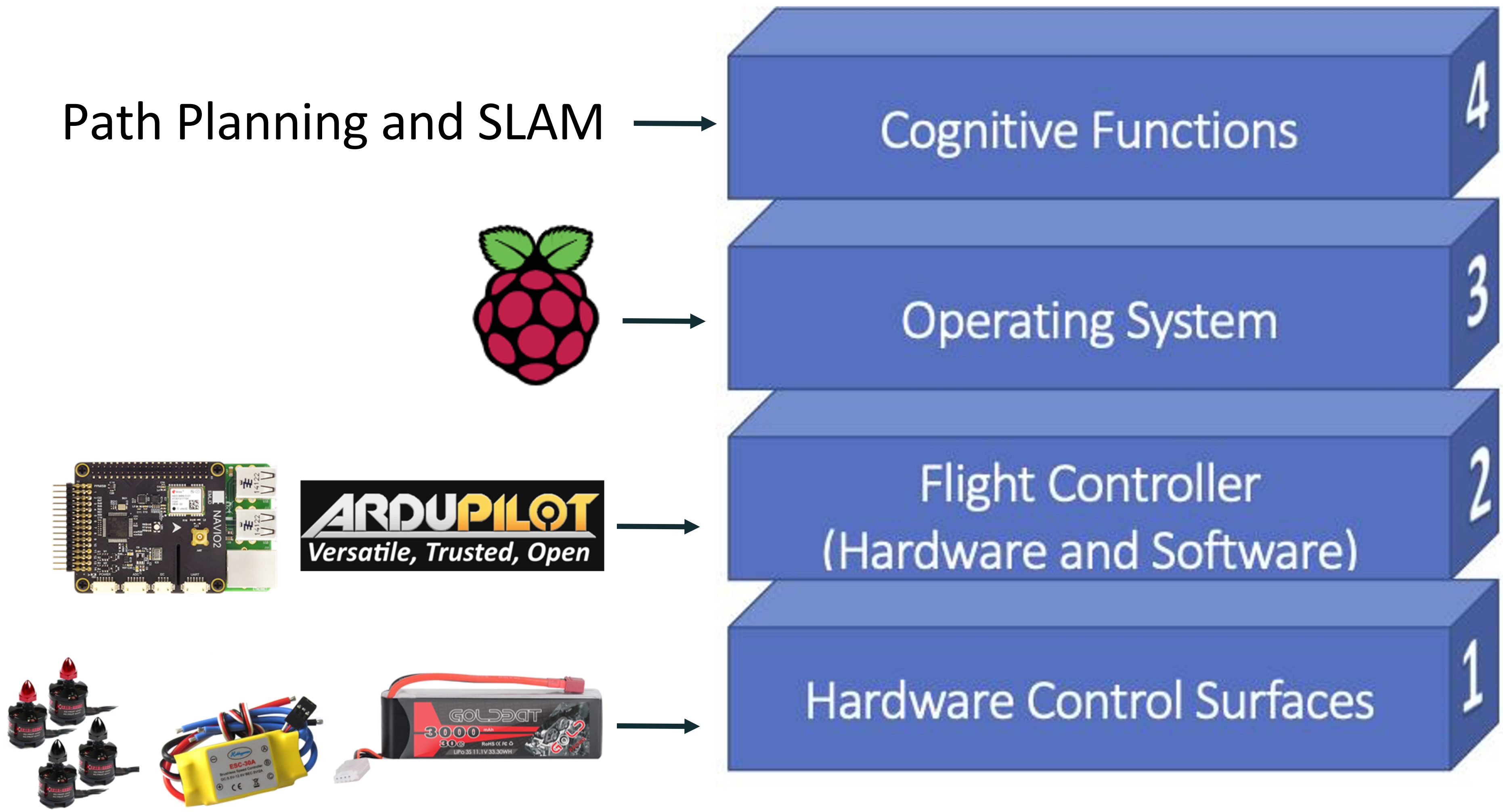
Build Process

Steps:

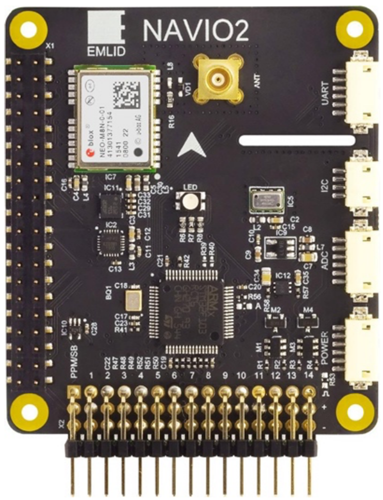
- Component collection and compatibility validation
  - Motor specification calculations
    - Dependent on aggregate weight
    - Weight carrying capacity
    - Motor power calculations
- Choose flight controller
  - Pixhawk 4 [17], Navio2 [16], Pixhawk Pro [17]
  - Based on drone purpose
  - Cost analysis
  - Performance criteria
  - We needed a low latency flight controller which would work with an on-board computer (Raspberry Pi) [18]



Architecture of Drone Flight Stack

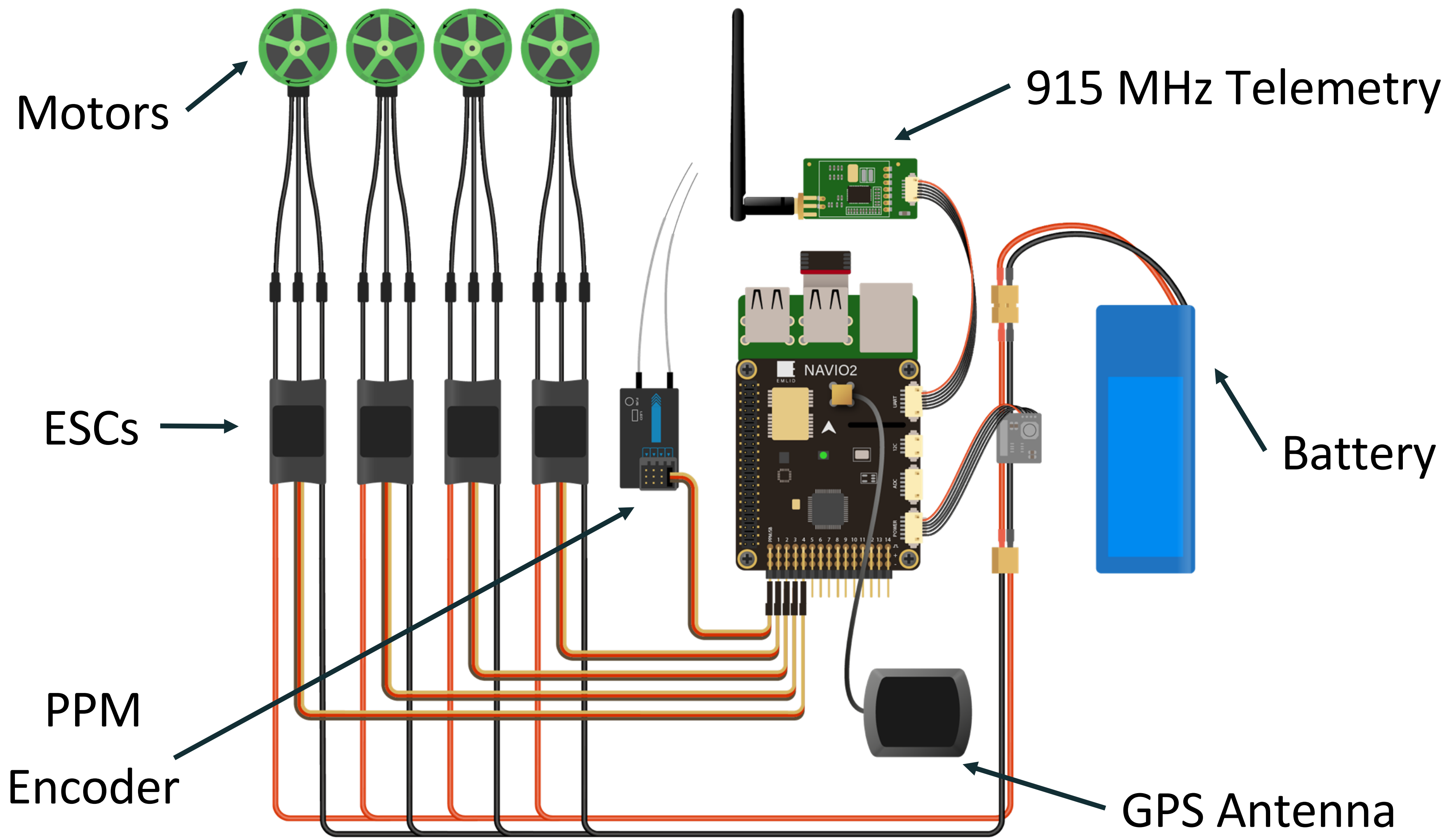


Hardware Overview



- Raspberry Pi 3 Model B +
- Emlid Navio2 HAT for Pi
- ESCs (Electronic Speed Control)
- 935KV motors
- GPS/GLONASS receiver
- 3000 mAh 3S LiPo battery
- 915 MHz Ground-to-Air Telemetry communication
- Features of Navio2:
  - Dual IMU
  - Triple redundant power supply
  - High resolution barometer

Navio2 HAT Setup



Flight Controller - GCS

- Two types of software:
  - Ground Control Station
  - Autopilot firmware
- Ground Control Station (GCS)
  - Executes from laptop
  - Real-time data (altitude, speed, location, battery)
  - Telemetry communication
  - Remote commands to override erroneous behavior
- Most popular GCS is MissionPlanner [20]
  - Open-source
  - Actively maintained

Flight Controller - Autopilot

- ArduCopter (fork of ArduPilot) [21]
  - Executes on board the drone
  - Interfacing between hardware and flight code
  - Autonomous flight capabilities
  - Flight modes (Guided, Auto, Acro)
  - Sensor polling and attribute actuation

Flight Controller - Other

- MAVLink [22]
  - **M**icro **A**ir **V**ehicle **Link**
  - Data packet protocol which enables standardized communication between multiple drones
  - Issuing commands to a drone
- DroneKit API [23]
  - Python and C++ APIs to issue flight commands easily
  - Converts commands to MAVLink protocol
  - Enables use of Python AI libraries with drone

Drone Operating System (1)

- Real Time Operating System (RTOS)
  - RTOSs are used in time critical applications
  - Popular in robotics
  - Minimal, if any, latency in response
  - Kernel tasks can be pre-empted

- Most fully supported RTOSs are not open-source

- We had the choice of using Linux [25] or Robot Operating System (ROS) [24]
  - ROS is a specialized OS for robotics
  - Due to the availability of community support and documentation, we decided to use Linux

Drone Operating System (2)

- Setting up Linux for drone hardware
  - Built Linux with PREEMPT_RT patch to achieve nearly identical performance to a RTOS
  - PREEMPT_RT patch alters kernel scheduler to preempt all processes
  - Interrupt handlers get converted to kernel threads
  - Kernel processes which spin-lock can be preempted
  - Unbounded latency solution
- Stability and customizability of Linux
- Open-source requirement
- Enable a UDP loopback port
  - Used for incoming MAVLink packets

Firmware Switching

- Commercially available drones from Boeing, DJI, and SkyDio are capable of changing their missions mid-flight [26]
  - They are unable to completely shut down their autopilot binary and load a different one since access to their autopilot architecture is limited
- Achieving this ability would open up the field of general purpose drones to the mass consumer and industrial markets

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Due to Space

Flight Testing Methods

- Manual Flying and Testing
  - Weather dependent
  - Battery limitation
  - Approval Process
- Simulations
  - Software in the Loop (SITL)
  - Hardware in the Loop (HITL)
- SITL simulations used to test flight code
  - ArduCopter natively compiles for SITL simulation
  - Less system resource heavy
- Microsoft AirSim [27] for HITL simulation
  - Open-source
  - System resource heavy
  - Provides environment simulation (neighborhood, city)

SITL Simulation

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Conclusion

- Full autonomous flight
  - Pre-programmed
  - On-the-fly computation
  - GPS ALT-Hold
- Waypoint navigation
- Switch firmware mid-flight
  - Useful for general-purpose dev. platform
  - Re-configure attributes on-the-fly
  - Lower maintenance downtime
- AI workloads
  - SLAM workloads in tandem to flight code
  - Path planning enabling drone to decide best approach

Future work

- Performance and Power Analysis
  - We will be presenting our findings at ISPASS 2020 poster session in April
  - Preliminary data suggests room for optimization gains
- Improve reaction time
- Improve flight time and range
- Execute additional secondary AI workloads in tandem
  - OpenCV
  - LIDAR
  - Collaborative missions
- ASIC feasibility assessment
  - Reduce overhead
  - Reduce barrier to entry to custom drone market

Thank You

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