Eye in the Sky – Use of Unmanned Aerial Systems to Monitor Rivers and Associated Ecosystems

Governor's Conference on the Management of the Illinois River System

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Outline

- Introduction
- Riverside Research's recent work using UAS for precision agriculture
- UAS Platforms
- Sensors
- Data processing
- Platform operations

Applying unmanned aerial systems to ecosystem monitoring

Unprecedented opportunities

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- Remote sensing isn't new to river system monitoring
  - Satellites
  - Plane mounted sensors
  - Image capture from shores, river-banks, bridges, poles, etc.
  - Boats dragging sensors
  - Etc.
- Unmanned Aerial Systems (UAS), air vehicles without onboard pilots, offer new imaging and remote sensing capabilities through a change in scale
  - Same types of sensors
    - EO, IR, thermal, hyperspectral, etc.
  - Same types of missions
    - Water depth, flood-level, erosion, polution, etc.
  - Smaller, lower cost platforms at lower altitudes

A Change in Scale

Changes what's possible

- More frequent data collection
  - UAS have low operational costs and rapid mission planning tools
  - Maintenance of many UAS is low
    - Few moving parts
    - Batteries can be charged within hours
- More versatile data collection
  - Many UAS, such as quadcopters, can be launched at the test site
  - Iteratively refine collected data during a single trip to the field
- More detailed data collection
  - Lower altitude operation means higher resolution data with fewer canopy obstructions
  - At 5m AGL, a 12MP sensor provides 2cm resolution

UAS Hurdles

FAA regulations

- The FAA has not issued official rules on the use of UAS, though they are expected in 2015
- Work with your local FAA representative to determine rules of operation
  - May require a Certificate of Authorization (COA)
- FAA Circular 91-57 defines recommendations for *hobby* aircraft; operate:
  - below 400 ft AGL
  - 3 or more miles from airports unless coordinated with airport operator
  - away from full-sized aircraft
  - maintain visual contact with craft at all times

Example Application

UAS as applied to precision agriculture

Riverside Research Experience

Precision agriculture

- Precision agriculture is the application of technology to farming in order to:
  - observe,
  - measure,
  - and make decisions for treating an agricultural product during its production to maximize yield while minimizing inputs
- Remote sensing has been used for precision ag for decades
  - NDVI (normalized difference vegetative index) developed in 70's using satellite imagery
  - Manned aircraft also used to capture images
  - Sensor bearing farm equipment captures additional data
- Platforms for capturing data above the ground and below the clouds have been missing
  - UAS can easily operate in this space
  - One application in this space is Stand Count (newly emerged plant count)

Stand Count Measurement

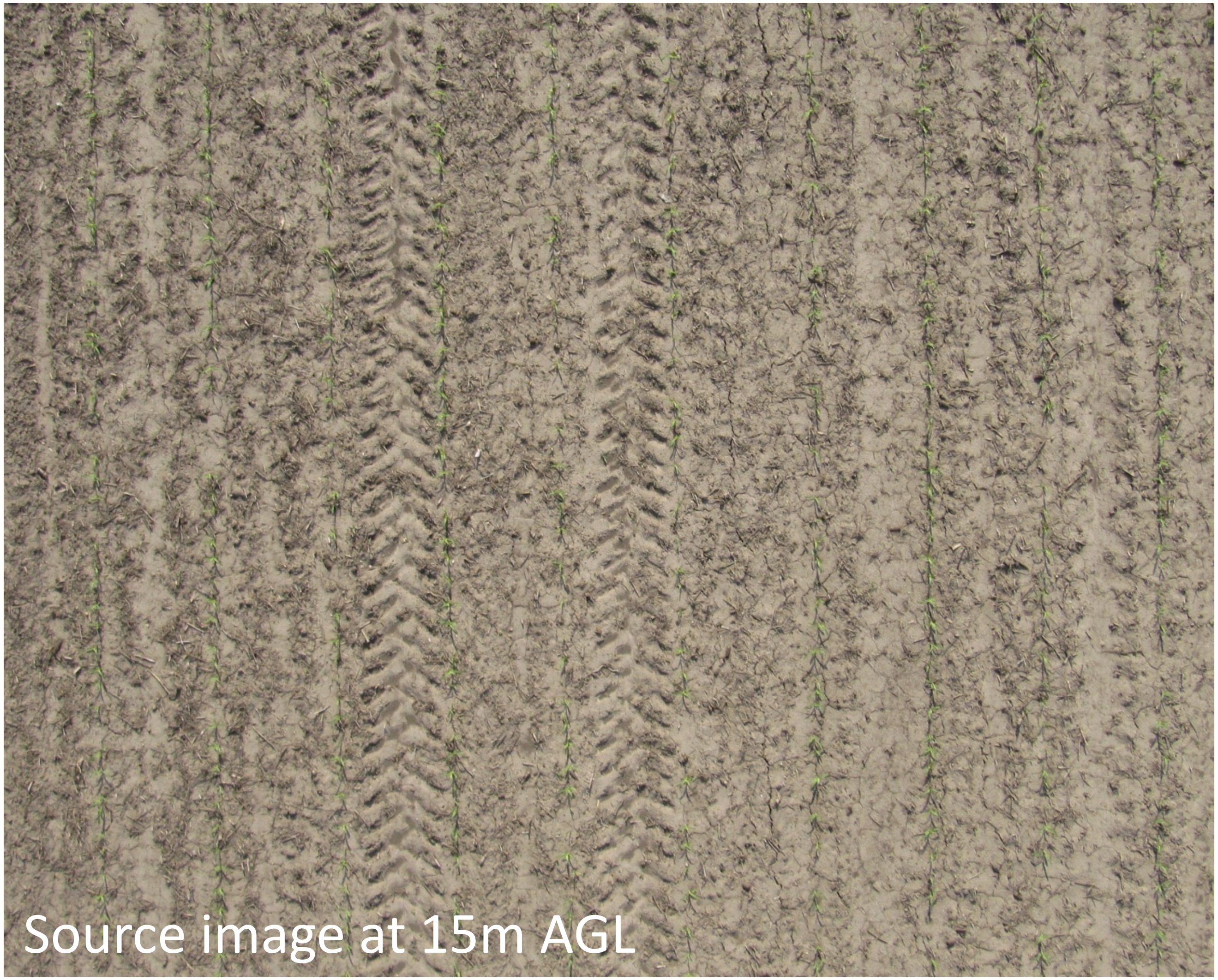
Experiment using low-cost, off-the-shelf components

- Platform: 3DR Hexa
- Flight controller: Ardupilot
- Takeoff Weight: 7 lbs 2 oz
- Flight time: 5 min
- Flight modes: Manual, GPS Waypoints

- Image stabilization: Brushless Gimbal
  - 2-axis stabilization
  - Dedicated inertial measurement unit (IMU)
- Camera: 12MP Canon PowerShot

Captured Imagery

Plant detection and stand count



- University of Illinois (UIUC) fields at Parkland College. UIUC bio-research sponsored by Monsanto
- 5mm resolution

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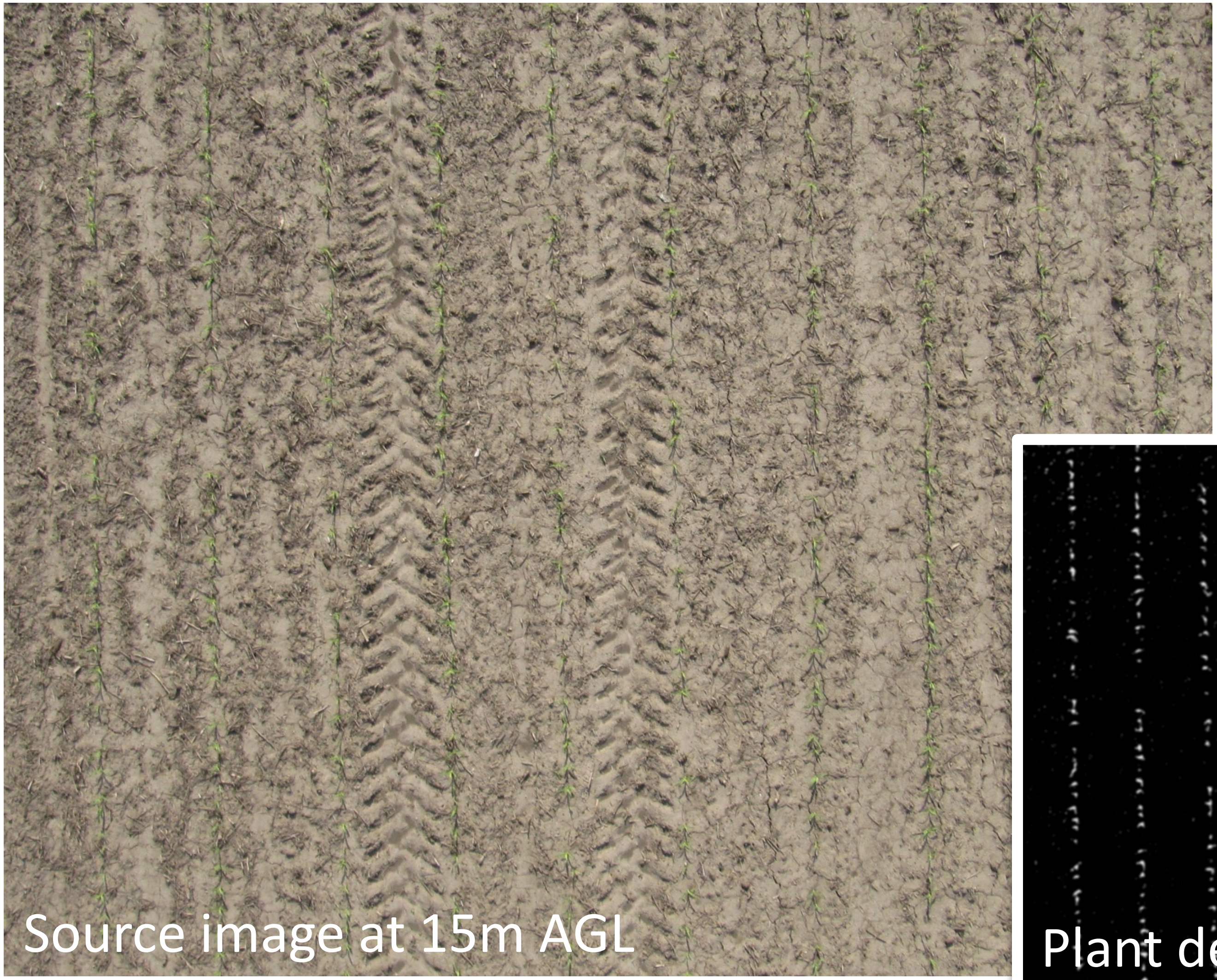

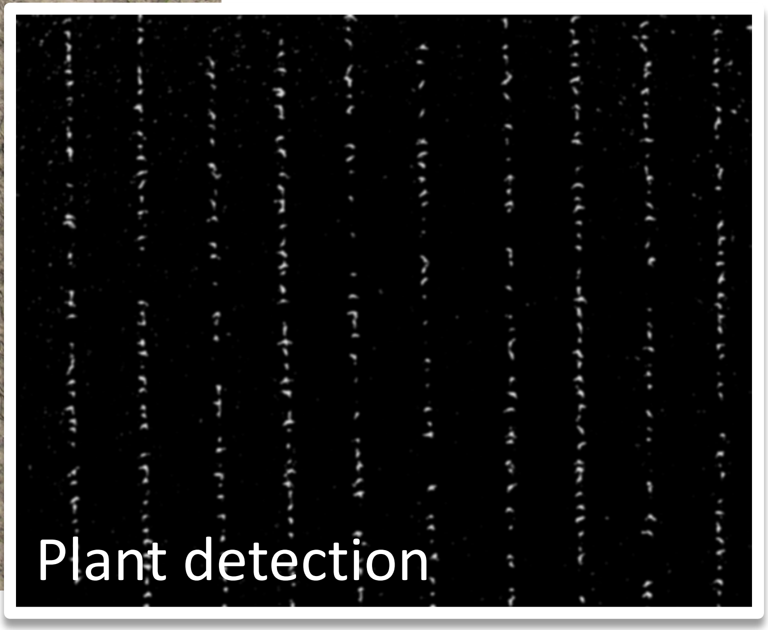

Captured Imagery

15m AGL, 5mm resolution

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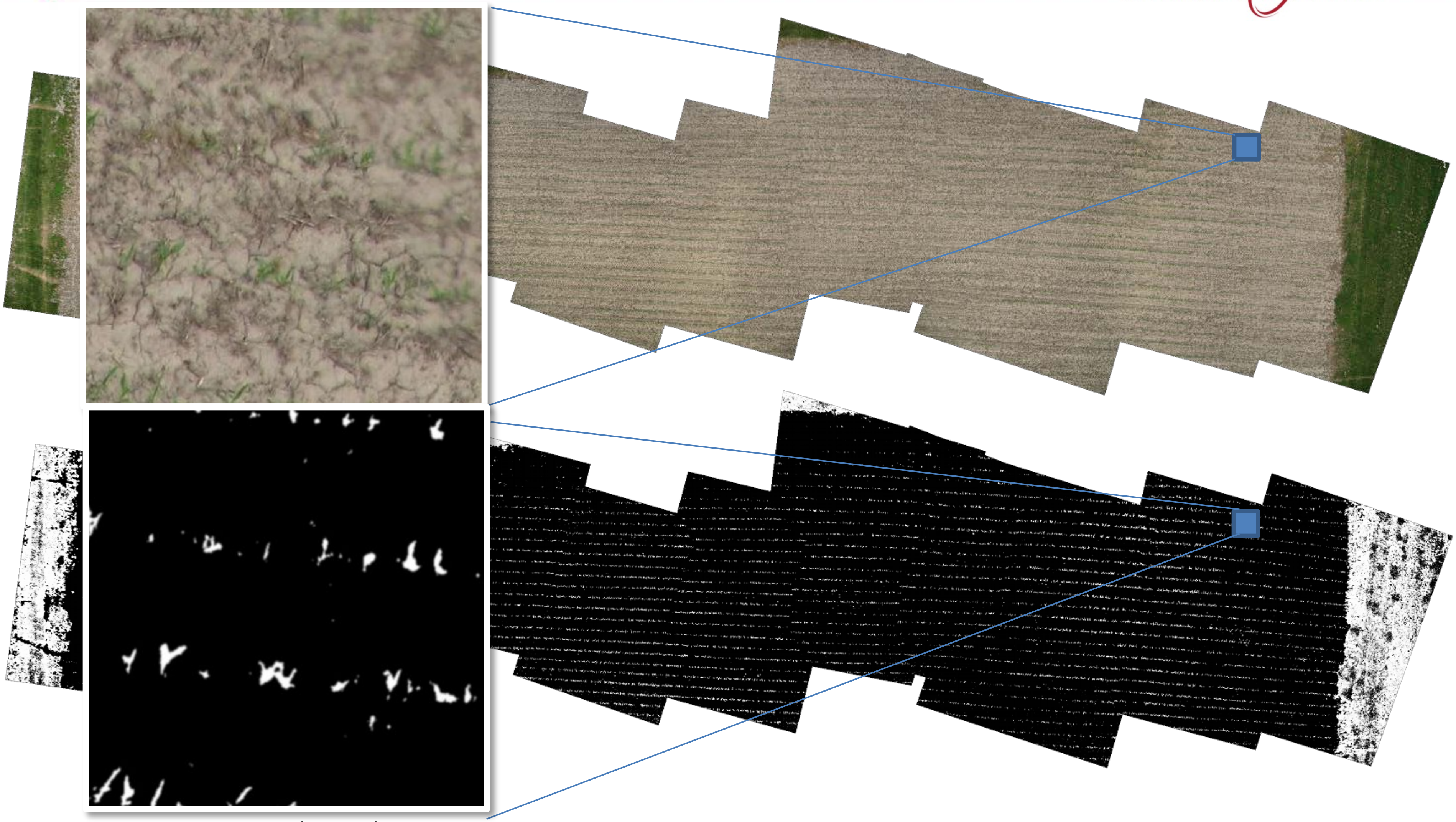
Captured Imagery

15m AGL, 5mm resolution



University of Illinois (UIUC) fields at Parkland College. UIUC bio-research sponsored by Monsanto.

Riverside Research Experience

What we learned along the way

- UAS can provide a platform for gathering amazing data
  - High level of detail unattainable using traditional techniques
  - Creates a new set of data processing challenges
- UAS represent a **huge** subject area
  - Where do I begin?
  - What questions should I be asking?
- Introduction that follows should help to answer these questions

UAS Overview

Platforms, sensors, data processing and operations

Questions to Address

- What type of sensor do I need?
  - How much does it weigh?
  - How long must it dwell on a target for acquisition?
  - How is it triggered?
  - How does it store its measurements?
  - How is it powered?
- What type of UAS platform do I need?
  - Who will be operating the UAS?
    - Researcher?
    - Professional UAS operator?
  - How large is your area of inspection?
  - How high/low must you fly to achieve the desired level of detail?
  - How fast can you fly to satisfy your sensor requirements to avoid motion blur?
  - Is there space for fixed-wing maneuvers?
    - Takeoff and landing?
    - Turning, climbing and descending?
  - What type of autopilot is required?
  - What type of camera stabilization is required?
- What are my regulatory requirements?
  - FAA?
  - State?
  - Local?
- How will I process the data?
  - Can existing techniques support this level-of-detail?
  - Where will it be stored?

UAS Platforms

Categories

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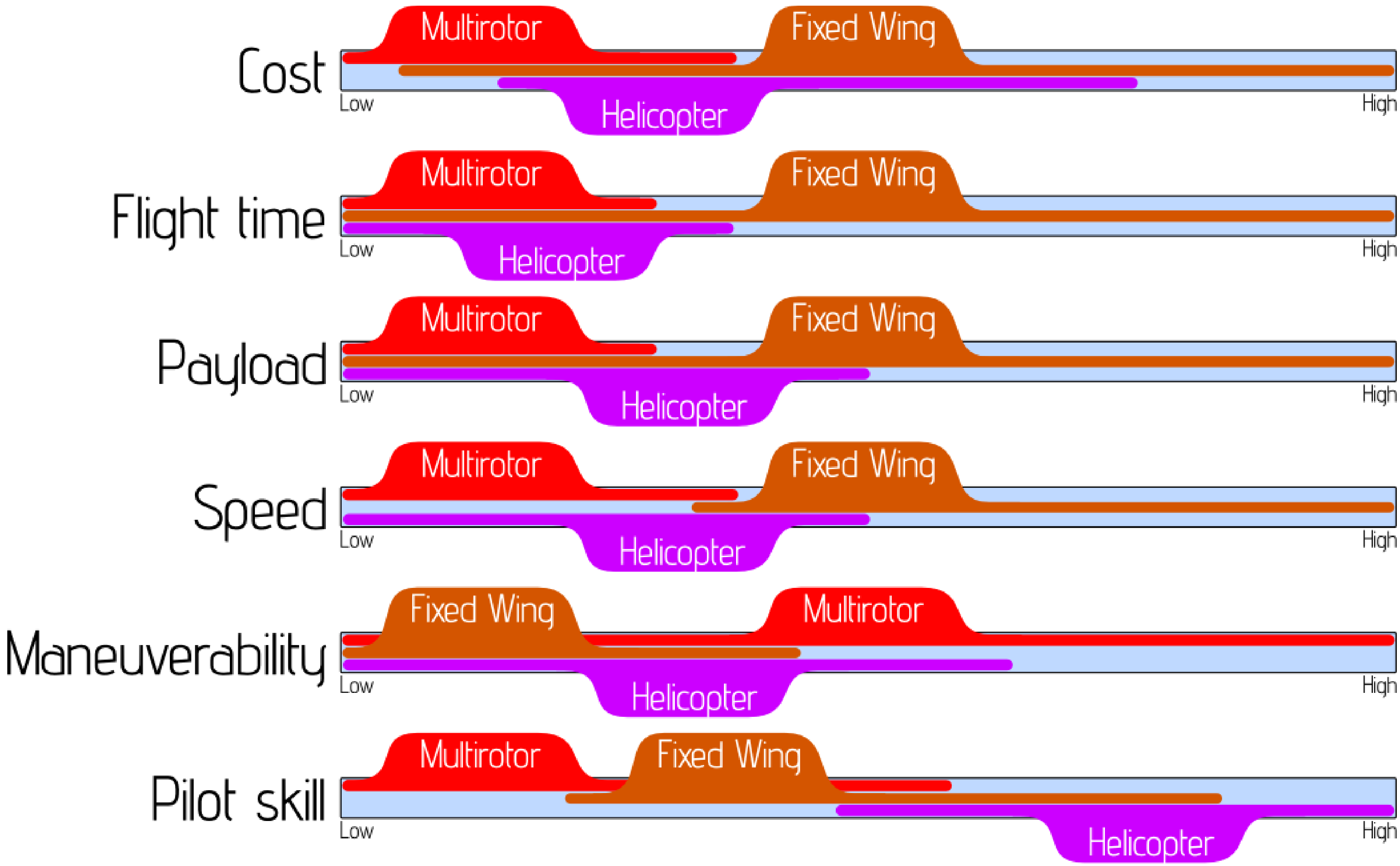
- Three main categories of UAS platforms
  - Fixed wing, traditional rotorcraft, multirotor systems
  - Are other, less common/versatile options: dirigibles, kites, gliders, etc.
- UAS platforms span the gamut of size
  - Palm-sized multi-rotor systems
  - Full-sized aircraft without a pilot
- Remainder of talk will focus on modest sized UAS
  - Craft traditionally qualified as “hobbyist” equipment
  - Readily available on the consumer market

UAS Platforms

A general comparison



UAS Platforms

Example missions

- Autopilots greatly simplify or fully automate fixed-wing and multirotor systems
- Due to their ease of operation and versatility, multirotor systems are Riverside Research's preferred entry-level platform
- Due to the cost, complexity and difficulty to operate helicopters, professional pilots are recommended

Water Depth of River Bend

- Platform: Multirotor
- Flight time: 5 minutes
- Sensor: Hyperspectral
- Flight path: lawn mower

Water Level Along River Segment

- Platform: Fixed wing
- Flight time: 30 minutes
- Sensor: Visible light
- Flight path: straight

Platform Selection

Flight controllers and autopilots

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- Numerous autopilots are available for both fixed-wing and multirotor systems
  - DJI WooKong-M (multirotor)
  - Mikrokopter (multirotor)
  - ArduPilot (multirotor and fixed wing)
  - Many others
- Different autopilots provide varying levels of automation
  - Some provide only flight stabilization (i.e. smoothes control input)
  - Some provide full automation (e.g. waypoint navigation via GPS)
  - Riverside Research has been using ArduPilot on its quad and hexcopter platforms
- All still require an operator at the controls
  - Operator must ensure safety of platform
  - Be ready to take over and safely control the craft

Sensors

Considerations for modest sized UAS

- Sensor Type
  - EO (visible light), IR, Multispectral, Thermal Imaging, Non-contact thermal, LIDAR
- Power requirements
  - Multirotors and fixed-wing can generally provide 11 to 14V power
  - Sensor power requirements reduce flight times
- Data logging
  - Some sensors carry onboard data logging
  - Must budget payload for external data loggers if required
- Triggers
  - Continuous logging
    - Consider platform speed and required dwell time for data acquisition
  - Periodic capture
    - Consider the periodicity vs platform speed to achieve desired coverage
  - Some require external triggers
    - Some flight controllers, such as ArduPilot can trigger a sensor
    - Take care to understand the method of external trigger (electrical, optical, mechanical, radio, etc.)
    - Sensors using electrical trigger are most easily integrated

Sensors

Passive stabilization for vibration mitigation

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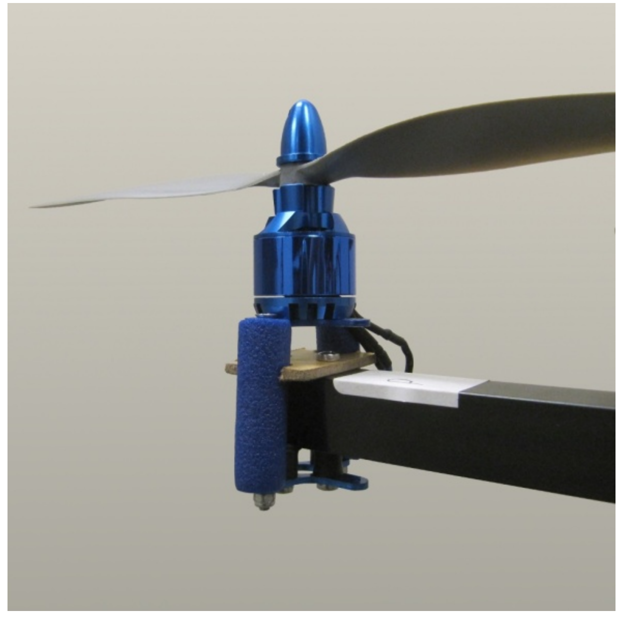
- Vibrations introduce sensor noise
- Caused by unbalanced motors and propellers
  - Vibrations must be reduced through tuning and balancing
- Compensated for by passive stabilization
  - Vibration absorbing materials placed between the sensor and vibration sources
- Motors may be isolated
  - Soft rubber buffers prevent the motor from transmitting vibrations into the hex-copter's aluminum arm.
- The sensor may also be isolated



Sensors

Passive stabilization for vibration mitigation

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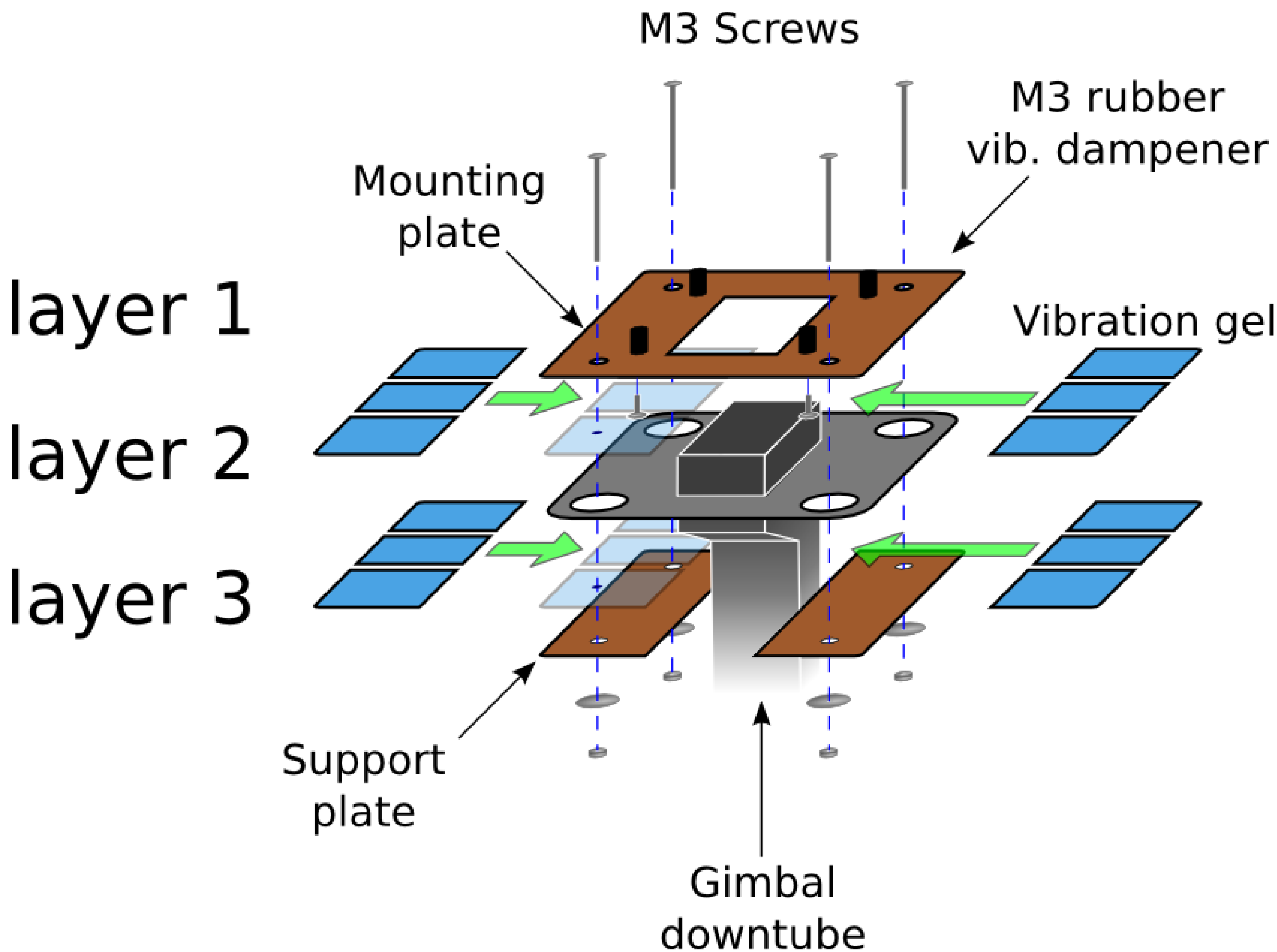


Sensors

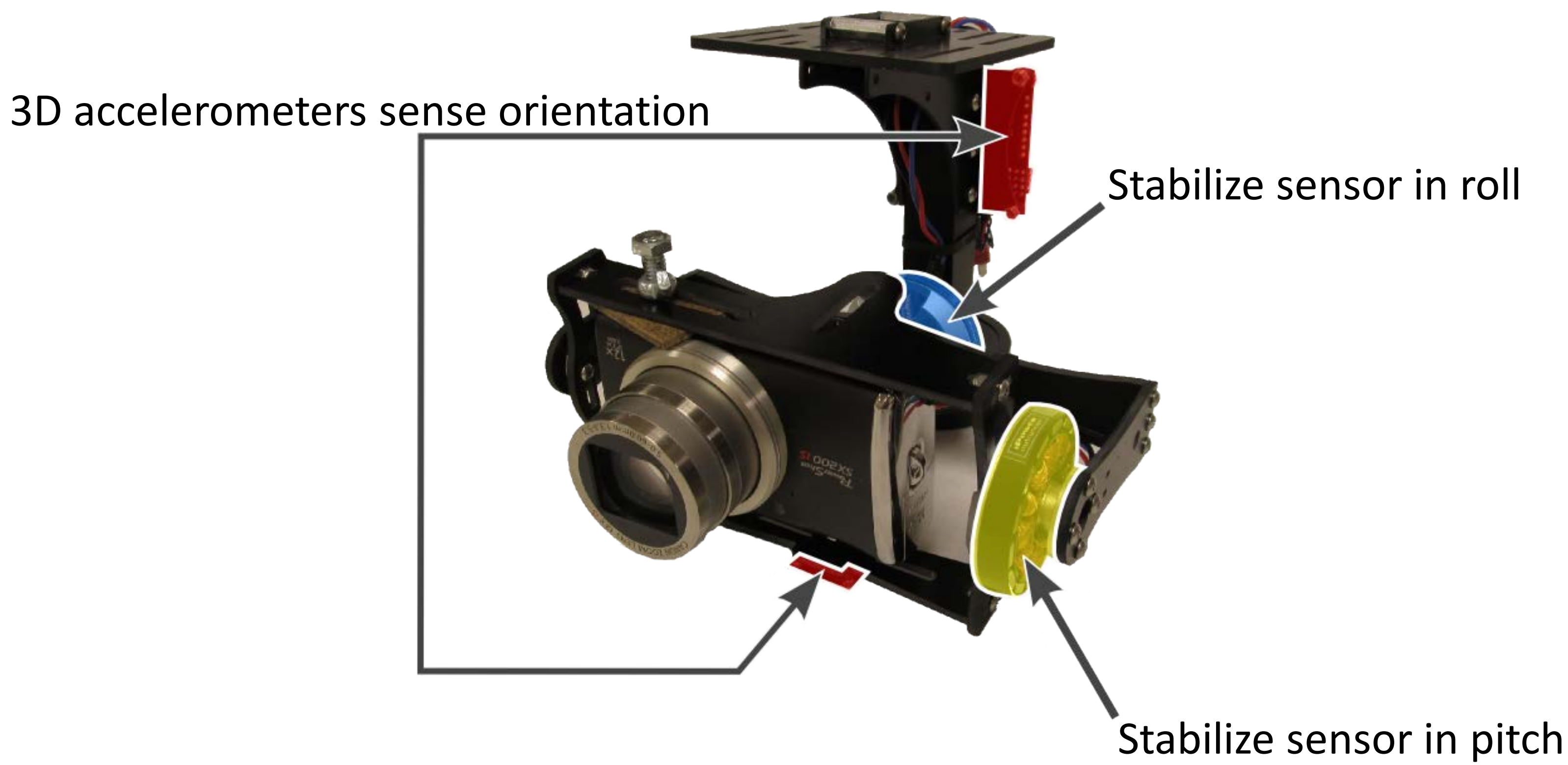
Active stabilization to mitigate orientation errors

- Platform orientation will change with wind
- Causes platform to roll, pitch, yaw, ascend and descend outside the flight plan
- Active sensor stabilization using camera gimbals can mitigate undesirable side-effects in captured imagery

Sensors

Active Stabilization using gimbals

- Gimbaled mounts monitor and maintain sensor orientation, reducing orientation errors
- High speed control boards sense orientation errors and quickly drive brushless motors to compensate



Data Processing

Unique challenges with increased detail

- Individual images likely cover subset of sensed area
  - Many images may be required to cover an entire wetland, stream or river at the desired resolution
- Basic processing stitches captured images together into a mosaic
  - Performs ortho- and georectification
  - Georectification requires ground-control-points
  - Studies over time require georectification
- Higher resolution data gathered by UAS presents new challenges
  - Seamless stitching requires identifiable features
  - Images from the center of a river, with no context, may be lacking features making them difficult or impossible to seamlessly stitch
- Not all applications require seamless maps
  - Simple overlays may be sufficient
  - Overlays can be generated from platform location at capture

Operations

Flight planning and autopilot setup

- Software greatly simplifies mission planning allowing missions to be planned in minutes
- Automated mission planning
  - User defines boundaries of mission by drawing a polygon on satellite imagery
  - Software fills the polygon with waypoints automatically
  - Best suited to large areas such as ponds, marshes, etc.
- Manual mission plans
  - Waypoints entered by clicking on the map
  - Altitudes, dwell times, sensor controls can all be entered through this interface
  - Best suited to linear bodies such as streams and rivers

Conclusions

- UAS is a change in scale that provides the opportunity to capture
  - higher resolution data
  - more often
  - for a lower cost
- The challenges to capturing the data can be overcome with careful
  - planning
  - application of appropriate technologies
- Regulations are the most immediate challenge
  - Technical problems can be overcome
  - Uncertainty in operational regulations complicates research applications