UAS observation of animal movement patterns for early disease detection

Veterinarians are the best doctors

Any other doctor can just ask the patient what the symptoms are!

Long-term goal

Inexpensive **early identification of pen-level illness or stress**, before full disease outbreak aka epidemic aka morbidity.

Hypothesis: **spatial arrangement** correlates with illness.

Weeks-at-a-time autonomous measurement of cattle positions, at a 160 acre feedlot with 40,000 cows.

First *train* a classifier on a few weeks of ground truth (measured positions and known illness).
Then run the classifier to *predict* illness.

Long-term goal: engineering details

- Unattended launch, land, recharge
- One aircraft flies while others recharge
- Ground station analyzes imagery, reports suspicious pens
- Ground station reports when aircraft or payload needs maintenance
- In high gusts or heavy precip, local weather sensors temporarily ground flights (aircraft safety, image quality)

Long-term goal

About 3% of a typical feedlot.

Short-term goal

Preprogrammed waypoint overflight of in-town dairy cattle
Autonomously move images to ground station (Eye-Fi cards)
Autonomously georectify images

Early detection

Example: dairy cows, disease-prone ± 3 weeks from calving.
Measured behaviors correlate with illness:

- Lameness due to sole lesions, **2 week prediction**
  - standing time (h/day)
  - 2 instead of 4 legs inside feeding stall
- Metritis (uterine inflammation), **1 week prediction**
  - dry matter intake (roughage in feed) (kg/day; per hour of day)
  - how often she displaces another cow at the feed trough ($\times$/day)
- Dystocia (obstructed labor), **48 to 24 h prediction**
  - dry matter intake
  - standing bouts ($\times$/day)

Feedlots

Dairies need no aerial monitoring, because each cow is in the milk parlor daily for close observation or measurement.
But **beef feedlot** monitoring can only be aerial.
Pens are like **toddler day-care**: cows from dozens of farms in close proximity.

Optimize the time spent by the few pen riders ("cowboys").
Cowboys evaluate better; robots evaluate faster!

Don't change farmers' habits.
Just give them better results. No culture shock.

Aerial observation doesn't change cattle behavior,
unlike a pen rider on a quad bike.
Such *neutral assessment* is novel to the industry.

Aircraft choice

Impractical

- IC: engine maintenance, fuel storage, refueling
- Fixed-wing: runway maintenance, precise taxi to recharger
- Helis with swashplates: expert inspection and maintenance

Y6 and X8 by 3D Robotics

- Fussy loiter and RTL, ESC sync issues, tech support
- 2.5 kg + 0.5 kg payload
- 11 minutes

Hexacopter by Unmanned Dynamics

- borrowed from Naira Hovakimyan, Dept. of Mech Sci + Eng
- L1 adaptive control: gust-resistant loiter
- 1.5 kg + 0.5 kg payload
- 10.5 minutes

Legality

"Farmers may operate an unmanned aircraft over their own property for personal use."
— FAA spokesman Les Dorr, interviewed 2013 Nov 25 by Oklahoma City's News 9.

sUAS (small UAS) is better accepted outside USA (e.g., DHL Germany's Paketkopter, in service since September).

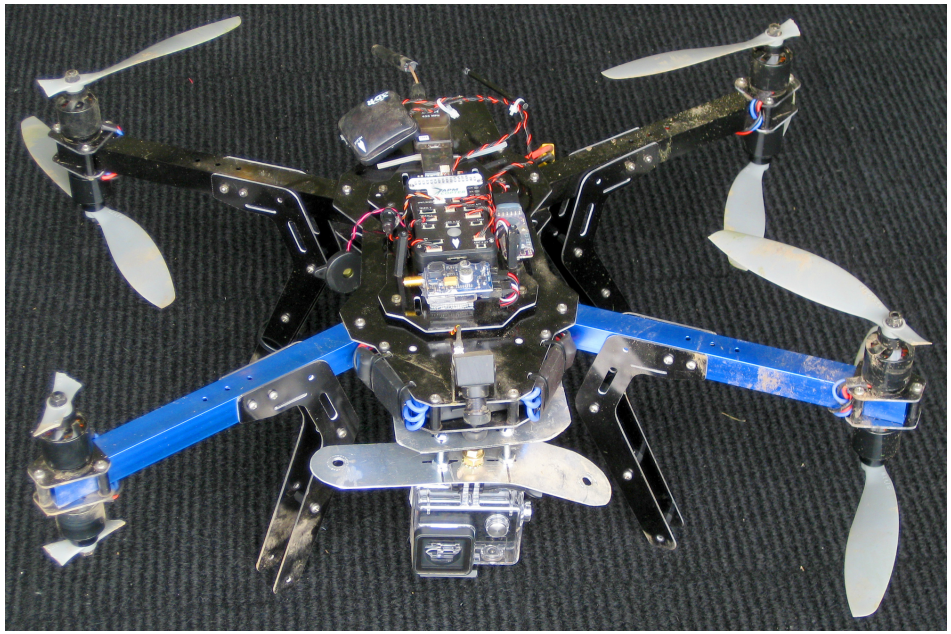
Dairy Cattle Research Unit overflights

www.dairyfocus.illinois.edu

3D Robotics multicopters

Tested limits of Y6 and X8 copters.

- high winds
- large or heavy payloads
- overloaded camera gimbals
- configuring parameters
- semi-autonomous flight modes



Replaced props, standoffs, bolts, antennas.

Replaced GPS mast with EPS foam.

Self-contained imaging payloads

Hi-res stills

- Visible light: GoPro

Synced video

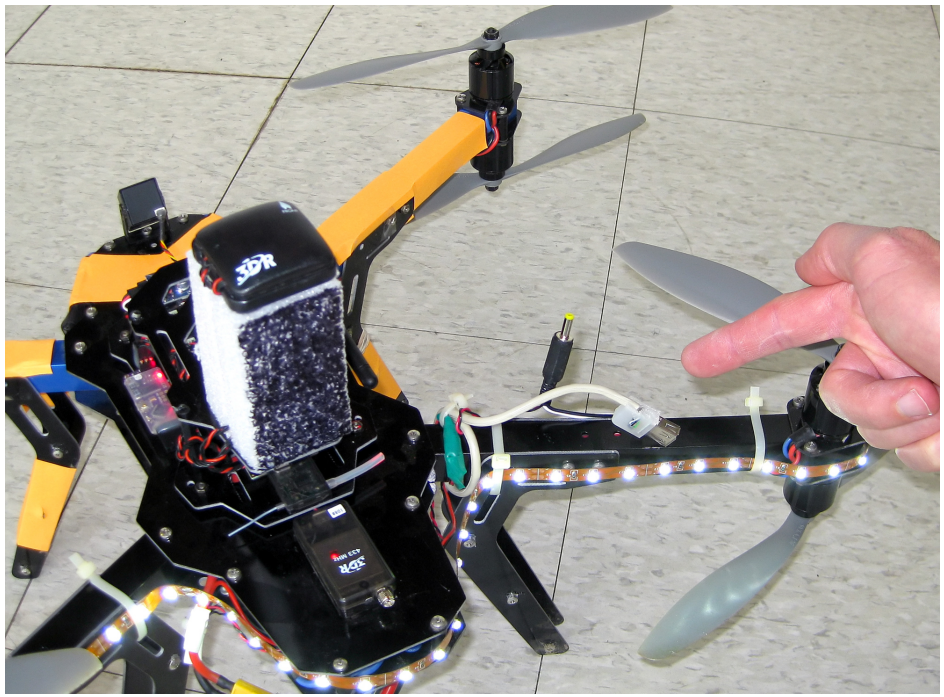
- Visible light: GoPro
- Infrared: Tamarisk 640×480 or 320×240 into mini DVR; 2s LiPo + 7805 5V regulator.

Enclosures

- Orange cardboard, then Coroplast.
- Bolsters whittled from EPS, glued with Goop.

Powering payload

Entire payload powered from copter's battery, to show feasibility of autonomous recharging (recharge/replace 1 battery, not 5).



Reverted to selfcontained power for initial data collection:

- cameras start recording while copter is still unpowered (safer)
- push camera buttons while still outside the box (easier)
- power glitch can't corrupt a recording (more data)
- payload's own batteries last for many flights, anyways

Look straight down

Airplane tests suggested pointing cameras straight down.

- cattle can't occlude each other
- train the cow-detector with images from only one angle
- hide very hot and cold subjects from infrared camera, esp. cold sky, hot pavement, and hot sun.

Sig Kadet Senior
span 2 m
2.8 kg
13 oz/sq ft

6s 4.4 Ah
14×10" prop geared 4:1

Cruises for 37' at 155 W

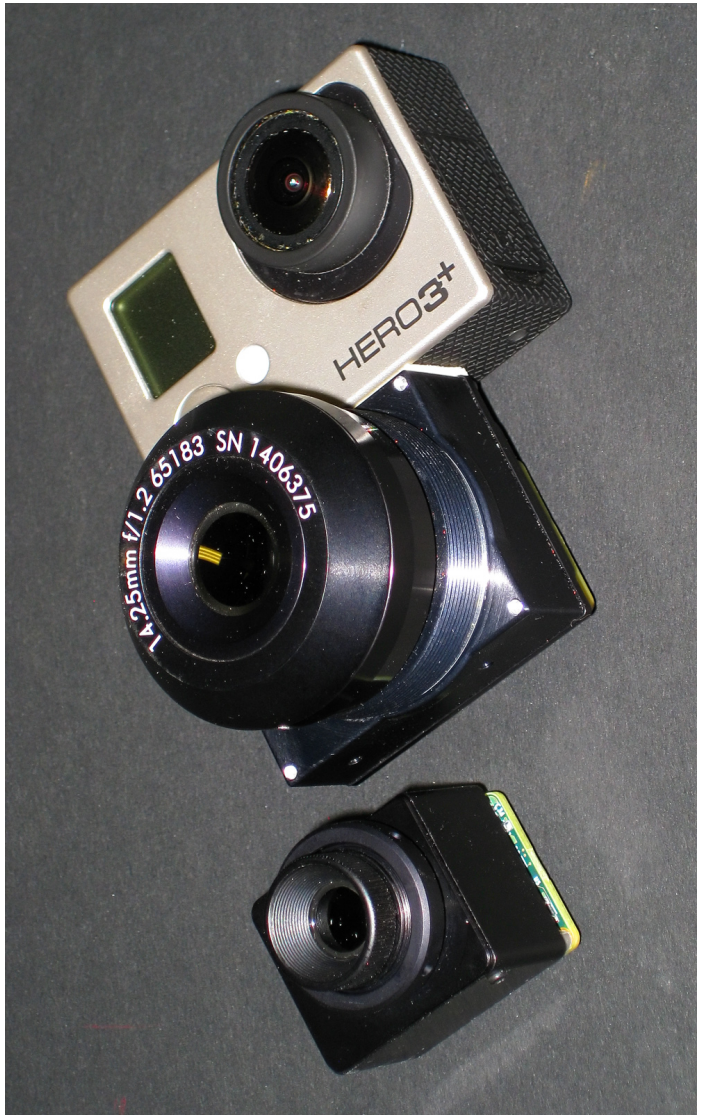
Optimizing camera parameters

Visible light

- number of cameras
- field of view
- frames per second

Infrared

- limits on temperature range
- gain of local contrast enhancement
- AGC adjustments



Manual piloting

Preprogrammed flight path yields many zero-cow images
(little control over their location)

But manual piloting risks orientation loss

- Copters can fly or drift sideways or backwards
- High-contrast coloration works only within 100 ft,
  or low against trees or buildings (not sky, even at dusk)
- Blinking colored LED strips work better

Strategies

- Sun at your back: glinting, not dazzle
- Fly like an airplane: keep moving, preferably forward
- If orientation lost, fly forward to infer which end is the nose

Assisted piloting

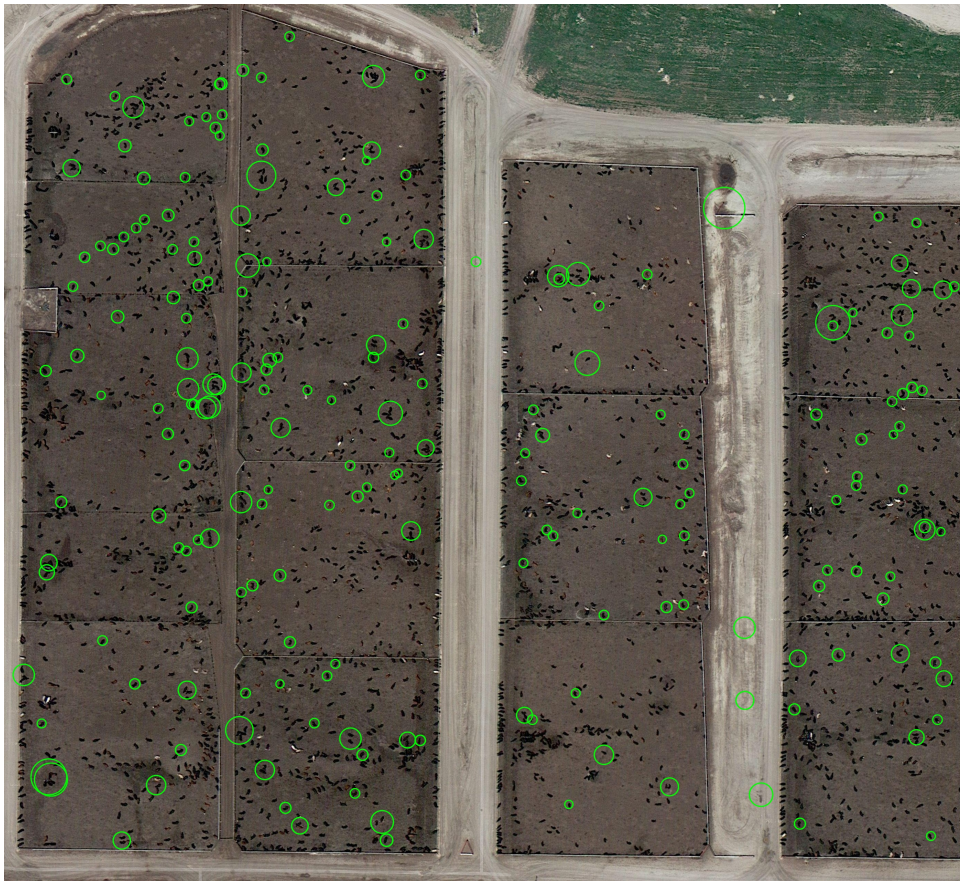
In loiter mode, sticks command:

- climb/descent speed (RoC)
- yaw
- fore-aft speed
- port-starboard speed

How can you keep height steady when throttle doesn't self-center?

- Release right stick to cancel horizontal drift.
- Any visible drift is then vertical.
- Correct that with throttle stick.
- Then keep your mitts off the throttle!

Cow detector



Like a smartphone's face detector, but trained with cows

Software: OpenCV's Haar Feature-based Cascade Classifier for Object Detection (Lienhart's improvement of Viola's detector).

This proof-of-concept example: high altitude, low resolution

Tradeoffs: flying height

Lower:

- more accurate measurement of cow positions
  (more pixels per cow)

Higher:

- less image stitching;
  thus,
- less ghosting (from cow motion or copter motion)
- fewer artifacts (changed exposure across images)
- easier georectifying

But A 12 MP camera, 40-degree lens, 400 ft high, resolves 2 cm per pixel.
So a cow subtends about 16×64 pixels: big enough!
So fly near the FAA-recommended 400 ft AGL limit.
Use images from *only* that height, to improve cow detector.

Tradeoffs: viewing angle

Narrow:

- more pixels per cow (as before)
- less barrel distortion (GoPro sucks)
- excludes cows seen from the side
- excludes cows occluding other cows

All these simplify training the cow detector.

Wide:

- less image stitching (as before)
- less motion blur from camera shake (GoPro rocks)

Very wide angles aren't justified.
Use a lens just narrow enough to avoid excess stitching.

Infrared

Strongly discriminates mammals from terrain!

- bright sun (harsh shadows)
- overcast (no shadows)
- at night (duh)

(Try to spot the brown cows, and the students.)

Tradeoffs: infrared

- can't use alone because it falsely detects "ghost cows"
- lower resolution
- expensive: 640×480 costs \$6K
- needs registration to other cameras
  (tricky: different lenses, different spectra)
- heavier payload (camera, PSU, DVR),
  so shorter flights, so fewer images

Bottom line: machine vision, not human

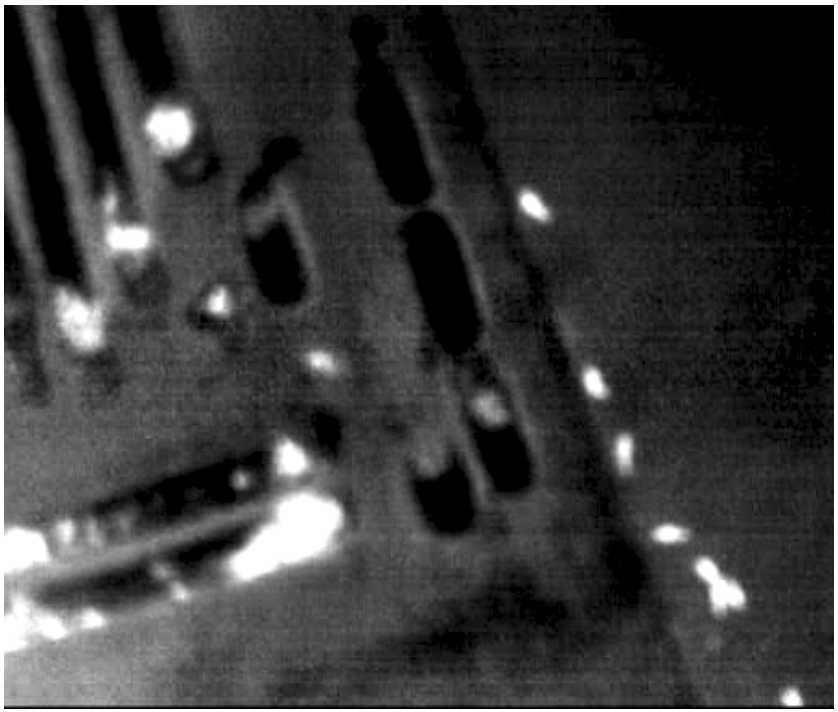
- How much does it improve cow detector
- ~~How cool do the pics look~~

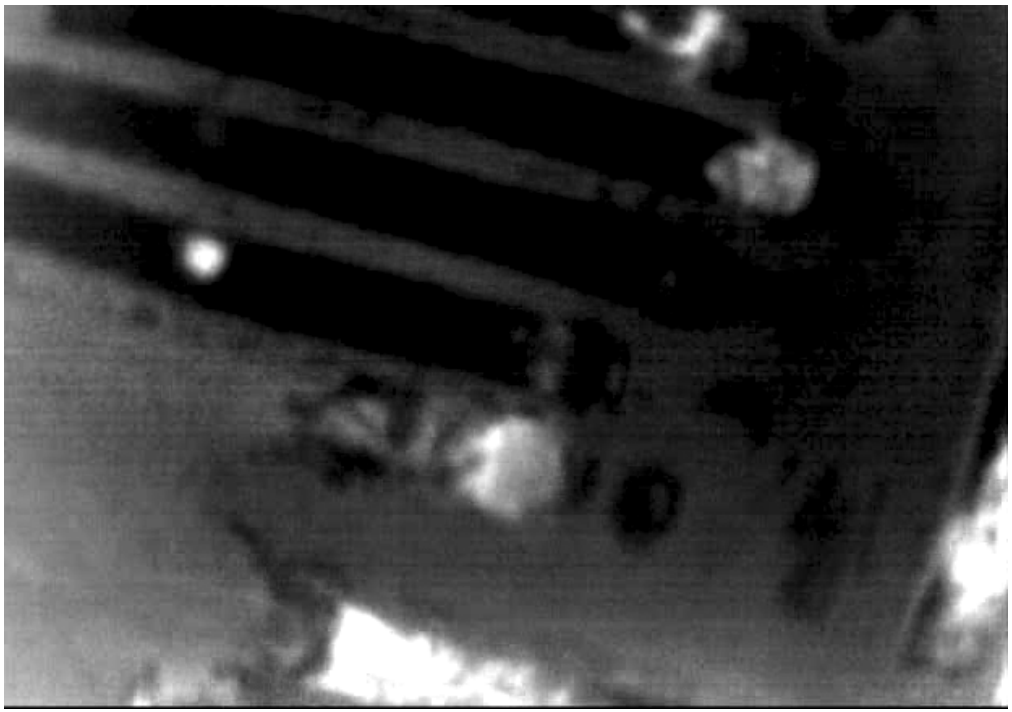
Early detection of spoiling silage

Ferment feed in airtight bag: improves nutrition and digestability.

Early detection of spoiling silage

If the bag rips and lets in oxygen,
then a spot spoils and reaches 100 to 150 degrees F.
(Don't worry: most hot spots here are the bags' open ends.)





Gimbals: more usable imagery?

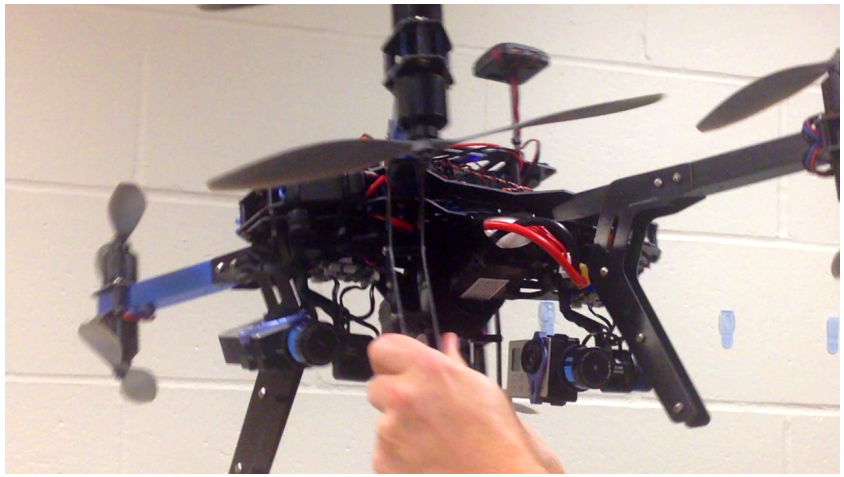
+: Cameras aim down despite gust corrections, despite maneuvers.
−: Doubles payload mass, for payloads from 75 to 1200 g.

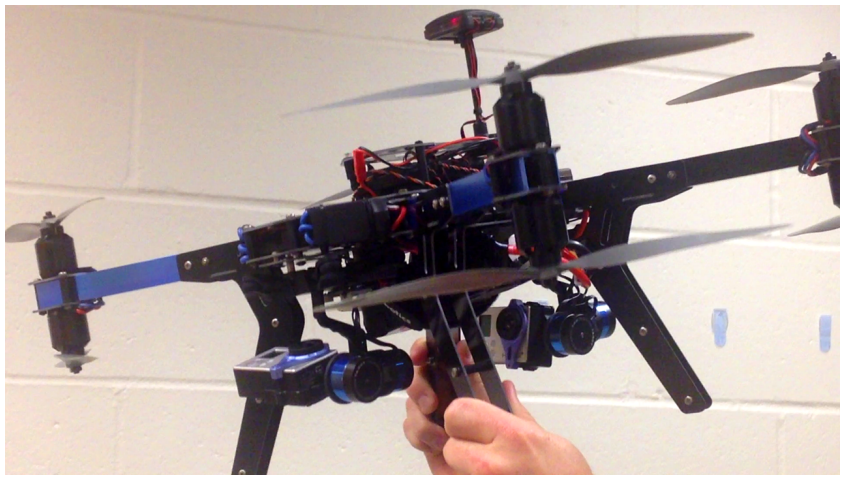
More mass shortens flight, which reduces no. of images, slightly.
On a 2 kg copter, doubling a 500 g payload shortens flight duration from 10 minutes to 8 or 9.
(More mass also reduces wind tolerance and thus flights per year, and thus images per year.)

But even a 20% reduction is small compared to how much more often the camera points where it should (40 to 50%)!

Multiple gimbals

Simple, immediate solution. One for infrared, one for visible light.





Choose feature vector format to train classifier

- Naive: normalized x-y coords of all the cows in a pen.
- Fancy: fit a Gaussian Mixture Model to that set.
- Clever: set of edge lengths of a minimum spanning tree, to heavily weight small isolated groups.

Label each vector with ± 1 indicating ground-truth health or illness.

Labeled vectors train the classifier.

Off-the-shelf classifier: LibSVM, or Adaboost's icsiboost.

Evaluate performance: partition data into a training set and test set

- repeated holdout
- leave-one-out cross-validation (better but slower)

Extract more data: orientation

Before training cow detector, rotate all images head-up. Now it detects only head-up cows.

Train more detectors on the same set, but rotated every 10 degrees. Run all 36 detectors in parallel.

Now we know which end of the cow is its head!

Test hypothesis that illness correlates with orientation:
given two cows within a threshold distance,
are they head-to-head or not?

From local dairy to out-of-state feedlot

Larger-scale feasibility study at a beef feedlot.

Record ground truth: cattle distribution and illness outbreaks.

Analyze imagery on ground station, not in the cloud:

In deep rural areas, sat phones upload only 2 to 120 kbps,
1000× too slow to upload 9 MB of raw imagery for each 10-minute flight.

USDA funding

NSF's National Robotics Initiative.

Robots in symbiosis with humans, augmenting rather than replacing human effort.

This exactly fits copter-based augmentation of a pen rider.

National Robotics Initiative (NRI)
The realization of co-robots acting in direct support of individuals and groups

PROGRAM SOLICITATION
NSF 15-505

National Science Foundation

Directorate for Computer & Information Science & Engineering
Division of Information & Intelligent Systems

Directorate for Engineering

Directorate for Education & Human Resources

Directorate for Social, Behavioral & Economic Sciences

National Aeronautics and Space Administration

Space Technology Mission Directorate, Game Changing Technology Program

National Institutes of Health

National Institute of Biomedical Imaging and Bioengineering

Eunice Kennedy Shriver National Institute of Child Health and Human Development

National Eye Institute

National Institute on Aging

National Institute on Deafness and Other Communication Disorders

National Institute of Neurological Disorders and Stroke

National Institute of Nursing Research

Office of Behavioral and Social Sciences Research

U.S. Dept. of Agriculture

National Institute of Food and Agriculture

Department of Defense

Defense Advanced Research Projects Agency

Others' work: flying

Cattle tracking on ranches: zilch.
(MarcusUAV's Zephyr flying wing has a video downlink, but no image analysis, no cow detector.)

Autonomous recharging and data transfer, from a 10-battery carousel: `skycatch.com`.

Precision Ag has mature use of multispectral imagery,
but on a slower time scale.

Others' work: image processing

Cow detection for *indoor* overhead video cameras (Viola-Jones detector; identify individuals with PCA and SIFT matching):
Martinez-Ortiz, Everson, and Mottram,
"Video tracking of dairy cows for assessing mobility scores."

Georectify (warp into known coords): mature GIS software such as ArcGIS, QGIS, GRASS GIS, ERDAS Image.

Stitching: mature photography tools such as Panorama Tools (+ Hugin or PTgui), AutoStitch, Image Composite Editor.

Acknowledgements

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Questions?