PLANT BREEDING & GENOMICS

Field Phenomics: Developing and Using a Sensor Array

Presented by

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University of Arizona

Hosted by
Shawn Yarnes
Plant Breeding and Genomics

extension

High Throughput Field Phenotyping
Part I: Developing and using a sensor array

Pedro Andrade and John Heun

High Throughput Field Phenotyping
Part I: Developing and using a sensor array

Mike Gore, Jeff White, Andy French, Kelly Thorp, and Bob Strand

USDA ARS

ARID-LAND AGRICULTURAL RESEARCH CENTER

Webinar Outline

1. Platform development – Mechanical components
    - Field vehicle
    - Sensor frame

2. Electronic components – Hardware
    - Plant sensors
    - GPS

3. Data collection – Hardware/software
    - System integration

Field-based High-throughput Phenotyping System

Field-ready system for continuous plant data acquisition

Field-based High-throughput Phenotyping System

High-clearance vehicle

1. Front/back boom w/ parallel bars
2. Hydrostatic transmission
3. Articulated steering
4. Heavy duty engine
5. Hydraulic power
6. Supply of DC power
7. Ample pay load capacity
8. Very high center of gravity

https://www.leeagra.com/high-clearance-tractors/avenger-by-lee/

Field-based High-throughput Phenotyping System

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High-clearance vehicle – Preventing side overturn

Safe operation

- OSH Act → Rollover Protection (ROP) for any tractor over 20 hp
- Seat belts
- Qualified operator
- Frequent inspection (tires and frame integrity in particular)
- Optimal field and road conditions → Even ground
- Wheel spacing (track) as wide as possible
- Avoid high speeds/sharp turns
- Consult with a machinery expert

Field-based High-throughput Phenotyping System

High-clearance vehicle – UA prototype

Front boom: Forward placement of sensors minimize plant disruption

Sensor mounting

Frame adjustment – vertical position

Sensor mounting

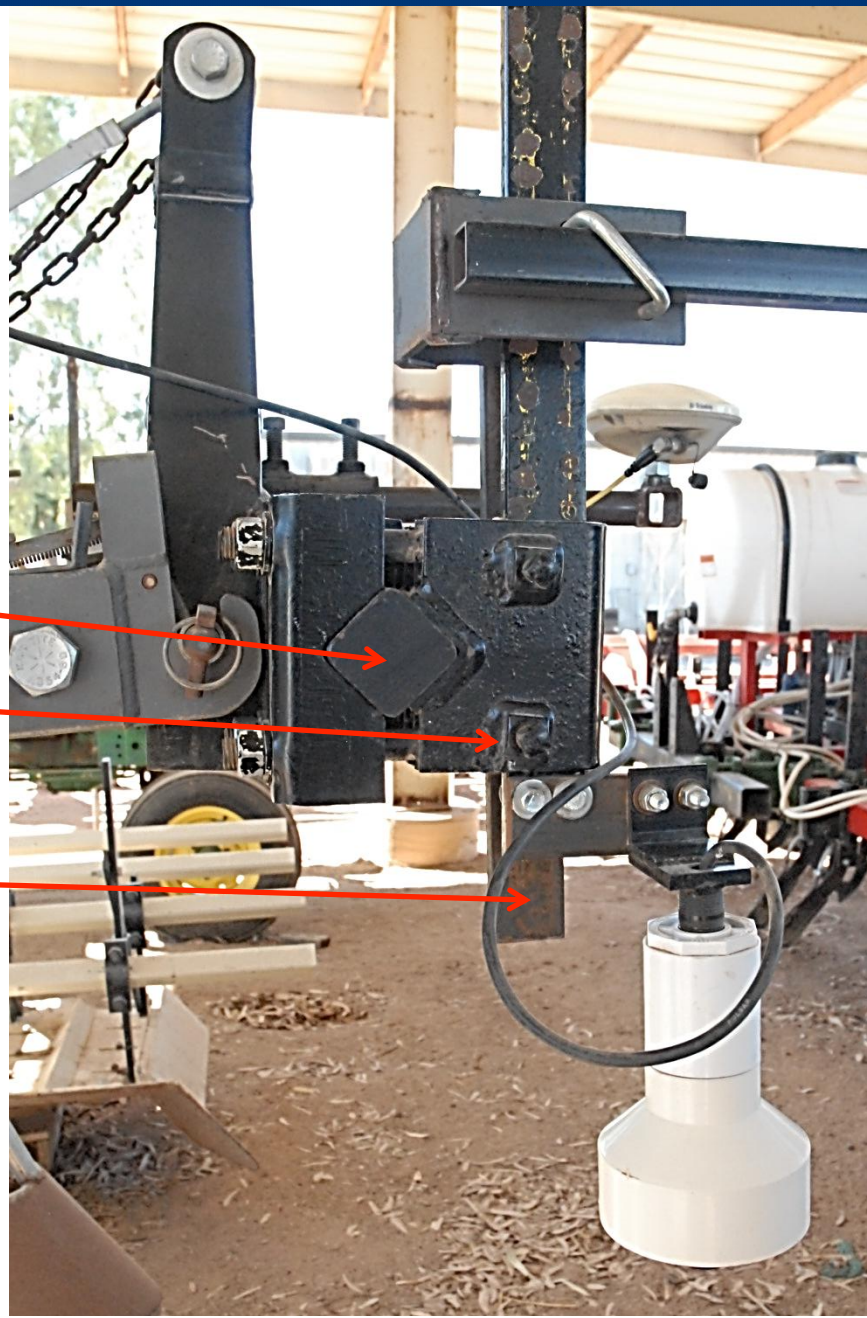
Frame adjustment – vertical position

Field-based High-throughput Phenotyping System

Frame adjustments

Sensor mounting using cultivation tooling

1. 2 ¼” agricultural diamond bar
2. Clamps w/ set bolts
3. Round and flat shanks



Sensor position - vertical adjustment

Sensor position - vertical adjustment

Sensor position - front/back adjustment

Sensor position - front/back adjustment

Sensor position – horizontal adjustment (rotation)

Sensor position – horizontal adjustment (rotation)

Sensor mounting

Sensor adjustment – frame side-ways position

Sensor adjustment – frame side-ways position

Section 2: Instrumentation Hardware

Proximal sensing approach to capture bio-physical characteristics of plants

- Thermal response
  - IRT

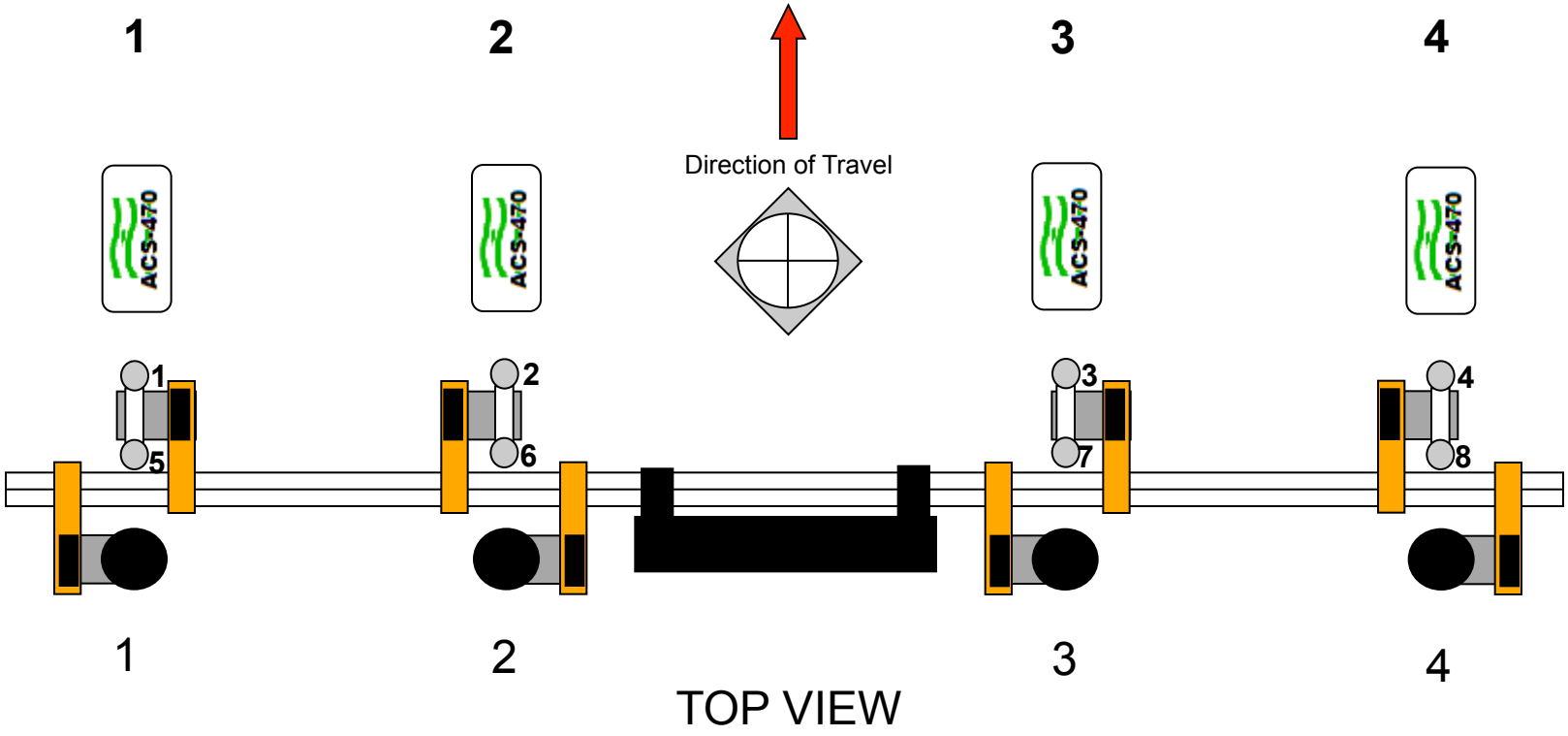
- Light reflectance
  - Active sensors

- Plant size
  - Displacement

Sensor selection: Critically important specs of sensors

- Communications protocol [i.e. serial (RS232, RS485, SDI-12), analog]
- Field of view
- Range of operation
- Input power
- Output format
- Response time
- Rugged design

Field-based High-throughput Phenotyping System



= RTK Antenna

= Sonar Transducer

= IRT Mount

= Crop Circle

Field-based High-throughput Phenotyping System

Plant canopy thermal response – IRT sensors

- Apogee SI-121 Infra-red radiometers
- 8-14 µm window 38° field of view
- Nadir and 30° orientation
- Analog signals
- Response time of “less than one second”

http://www.apogeeinstruments.com/infraredradiometer/

Field-based High-throughput Phenotyping System

Plant canopy spectral response – Light reflectance sensors

- Crop-Circle ACS-470 active-light sensors
- 32° field of view
- Three filters (670, 720, and 820nm)
- RS-485 network
- Fast update (5 Hz)*

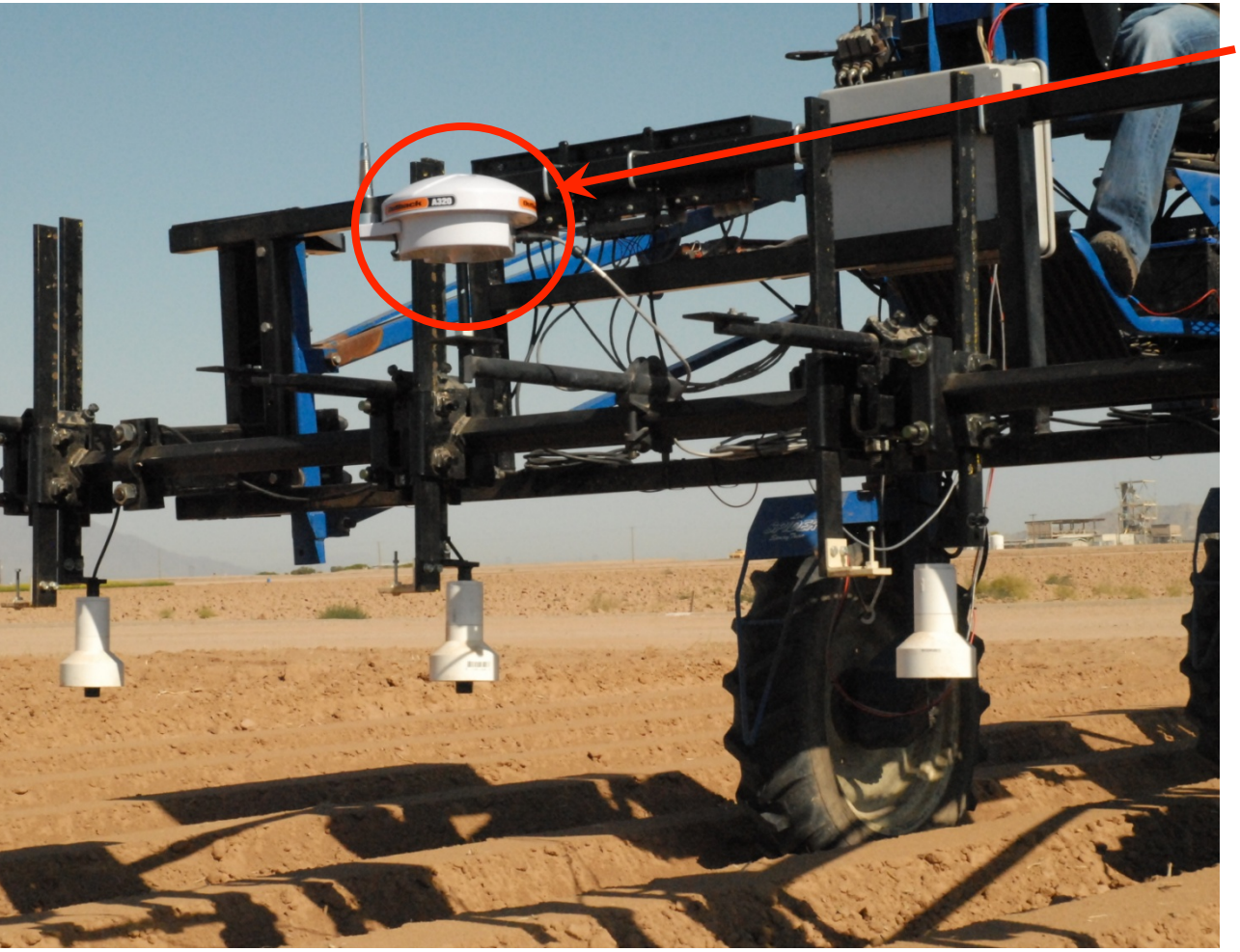
http://hollandscientific.com/crop-circle-acs-470-multi-spectral-crop-canopy-sensor/

Plant height – Displacement sensors

- Pulsar 3dB sonar
- Pulsed ultrasonic transceiver (125kHz)
- 12° beam angle
- Analog output
- Signal update is controlled internally (~ 2 Hz max)*

http://www.pulsar-pm.com/product-types/transducers/db-transducer-series.aspx

Horizontal/vertical position sensor – GPS



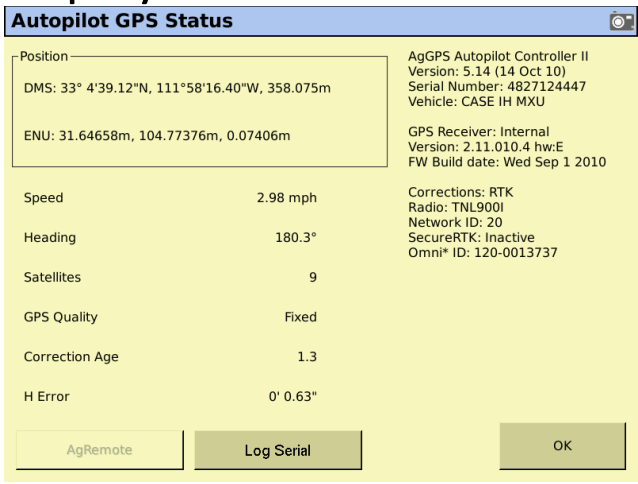
- Outback A320 GPS-RTK receiver (GNSS)
- Serial output
- NMEA GGA and RMC strings at 5 Hz
- Accuracy
  - ~ 1 cm horizontal
  - ~ 2 cm vertical

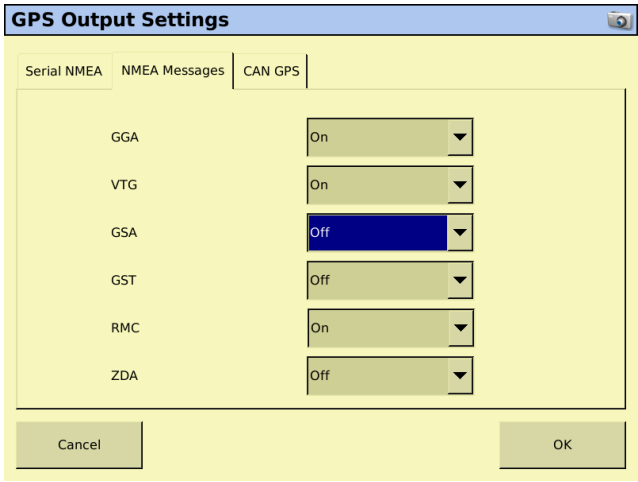
http://www.outbackguidance.com/Products/GNSS/OutbackA320.aspx

Field-based High-throughput Phenotyping System

Horizontal/vertical position sensor – GPS

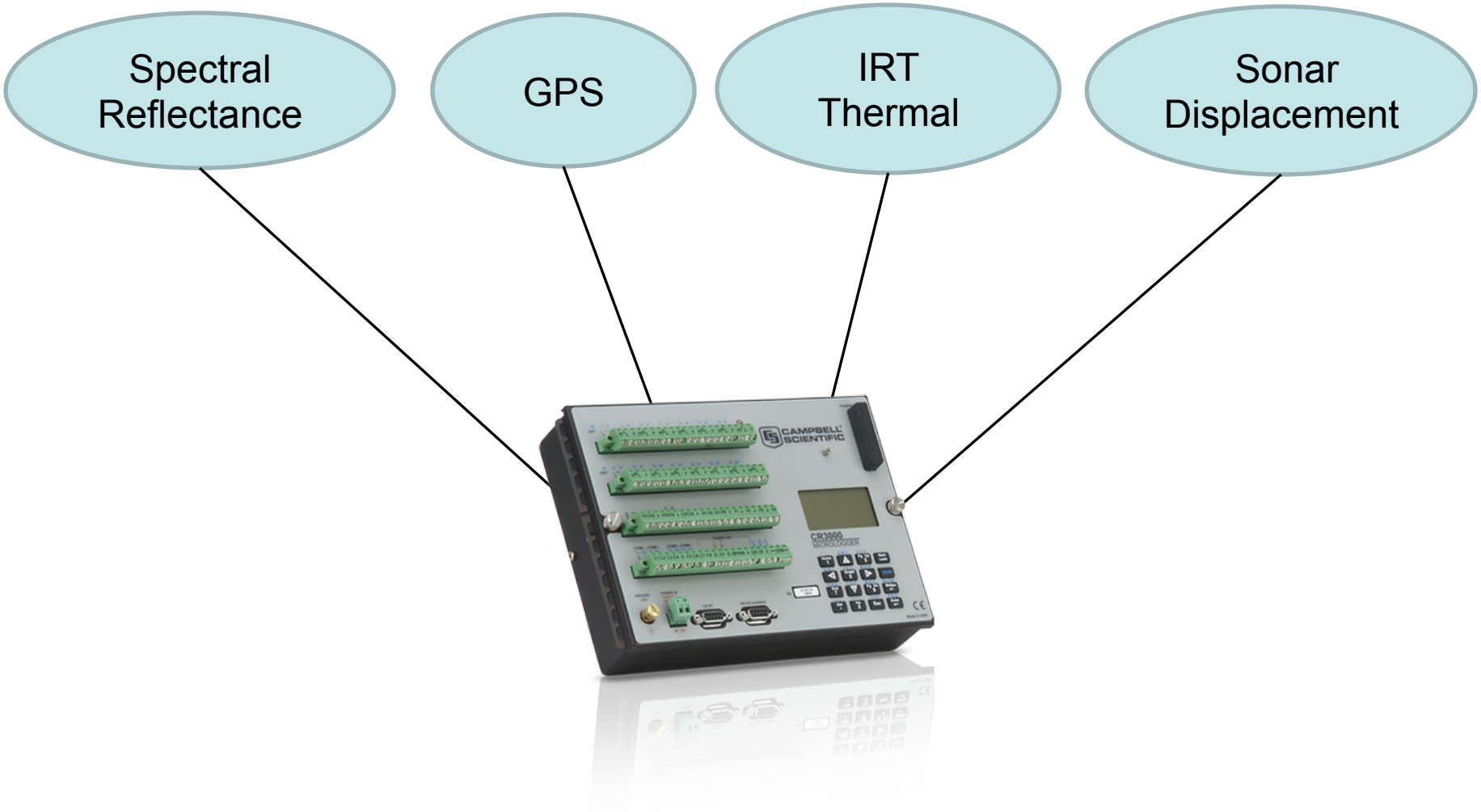
Trimble FMX multi-function display





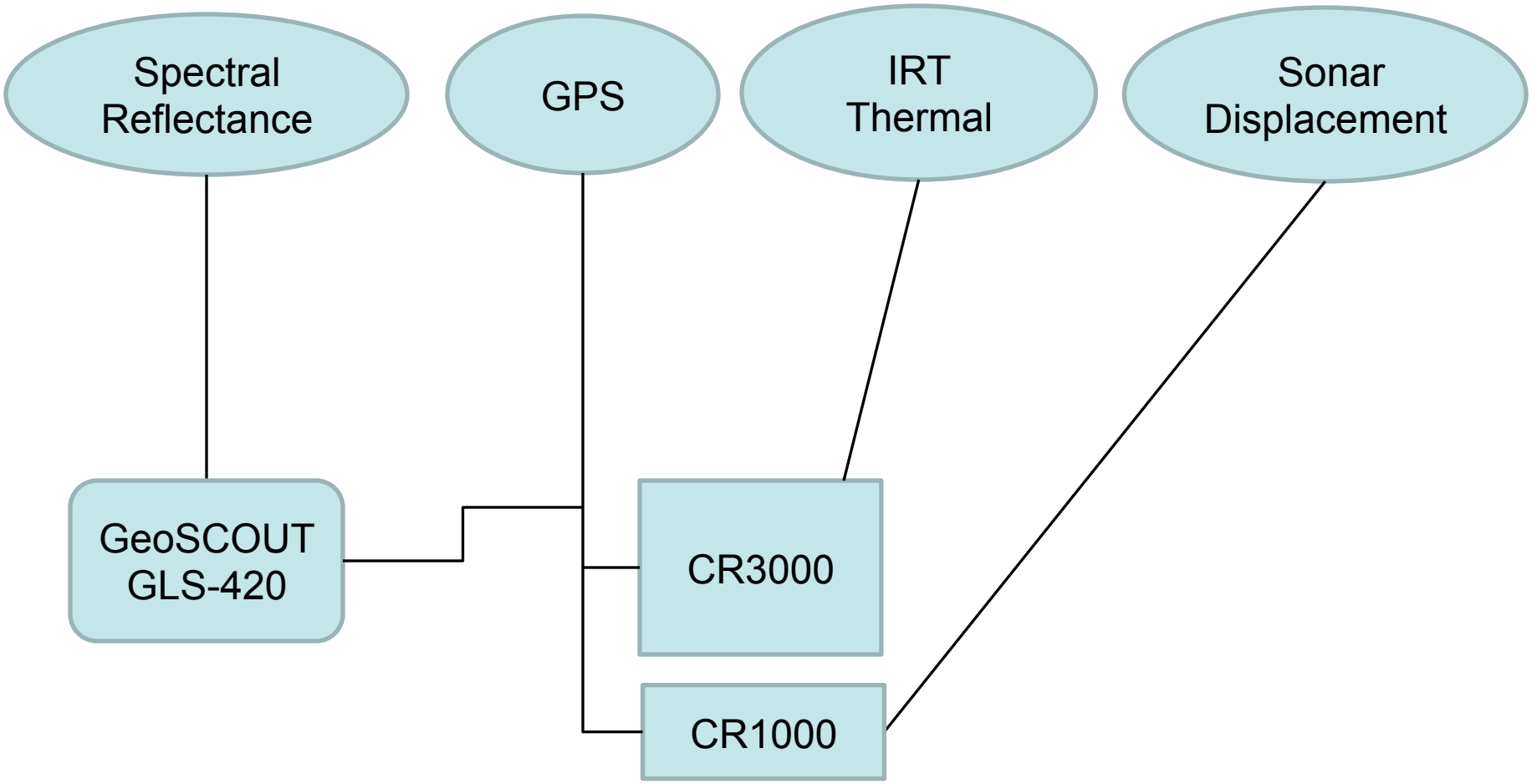
http://www.trimble.com/Agriculture/fmx-display.aspx

Section 3: System Integration



Field-based High-throughput Phenotyping System

System diagram



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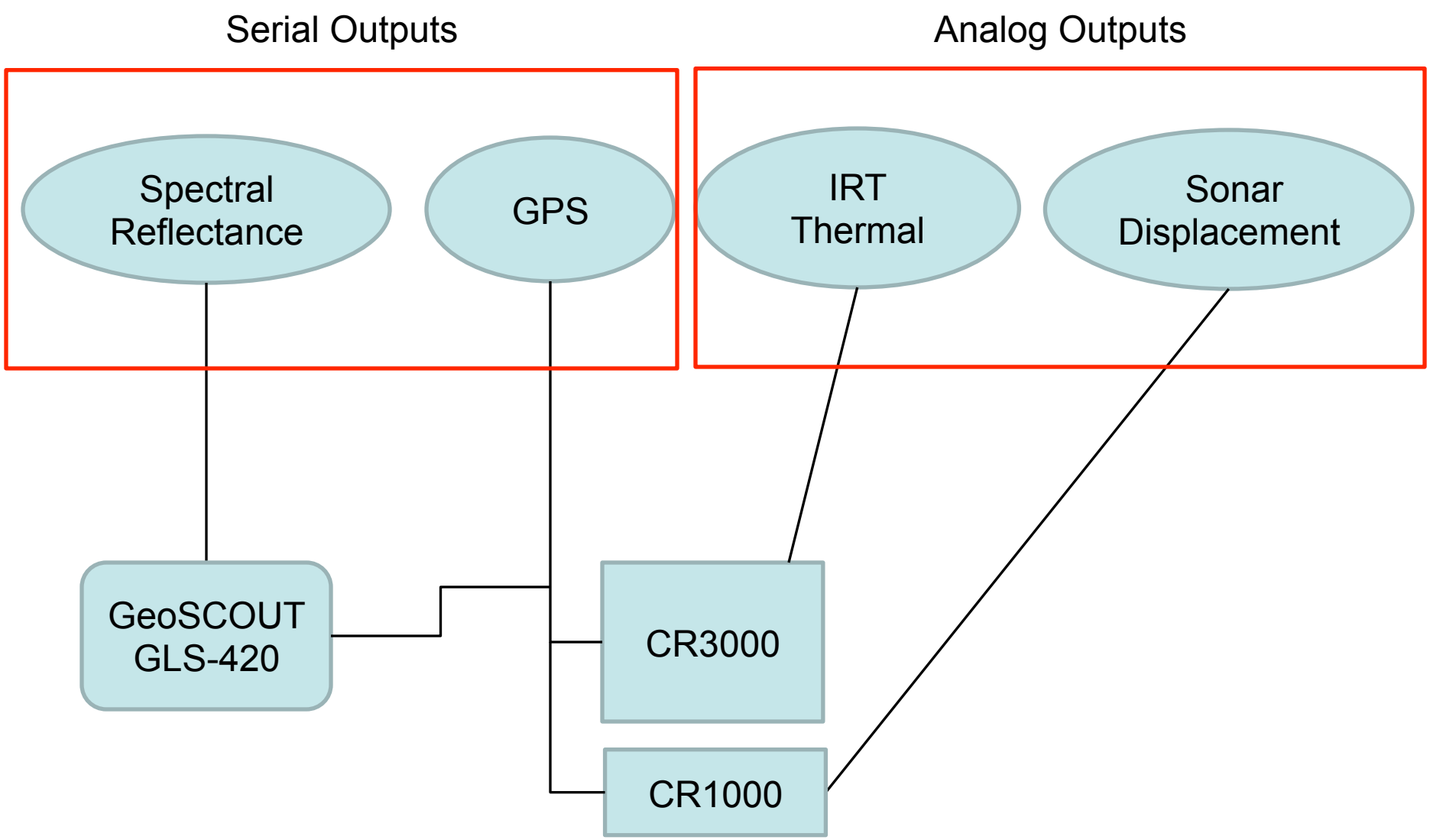
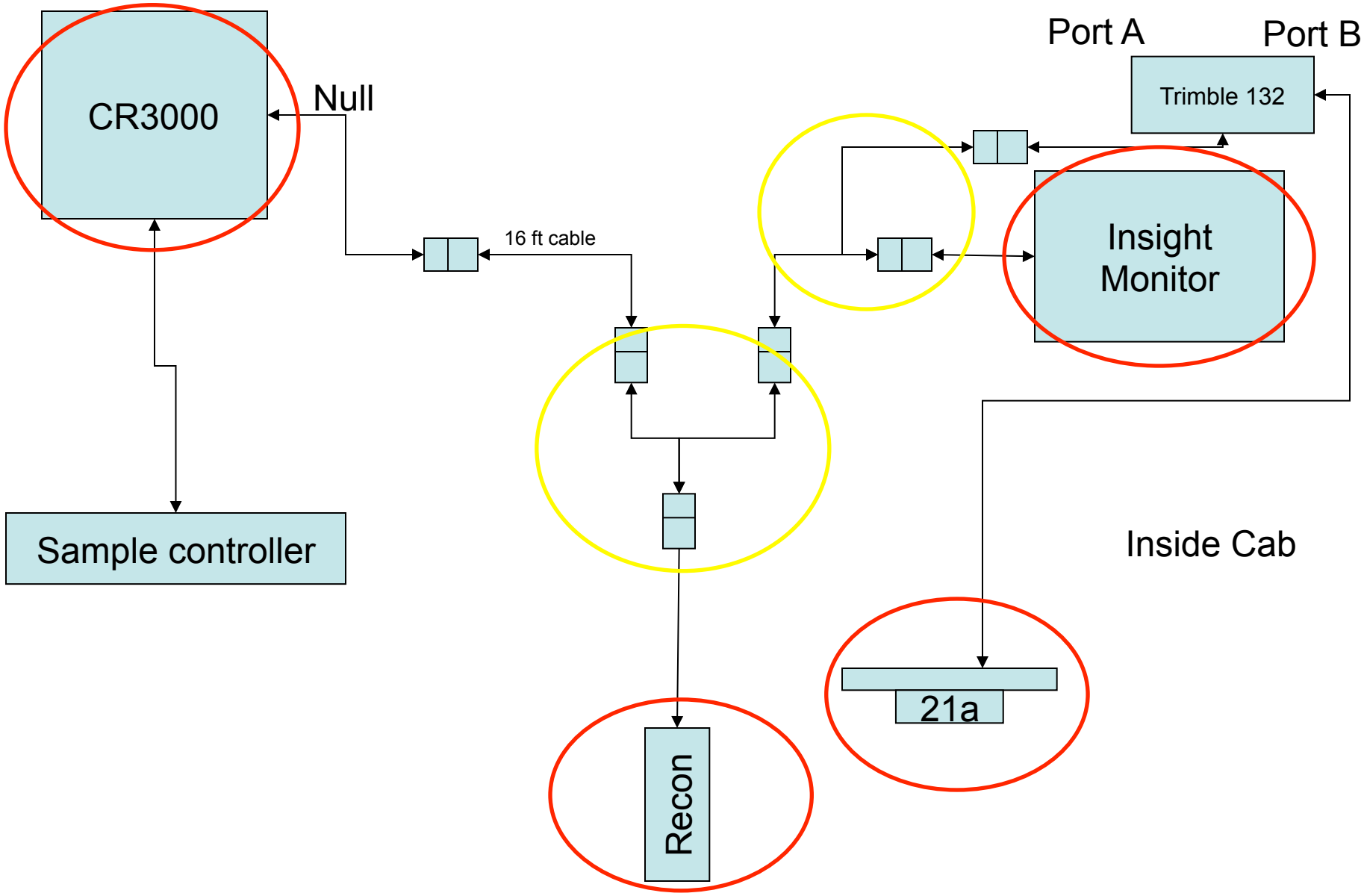
Field-based High-throughput Phenotyping System



Example: Combine RS232 Serial Network



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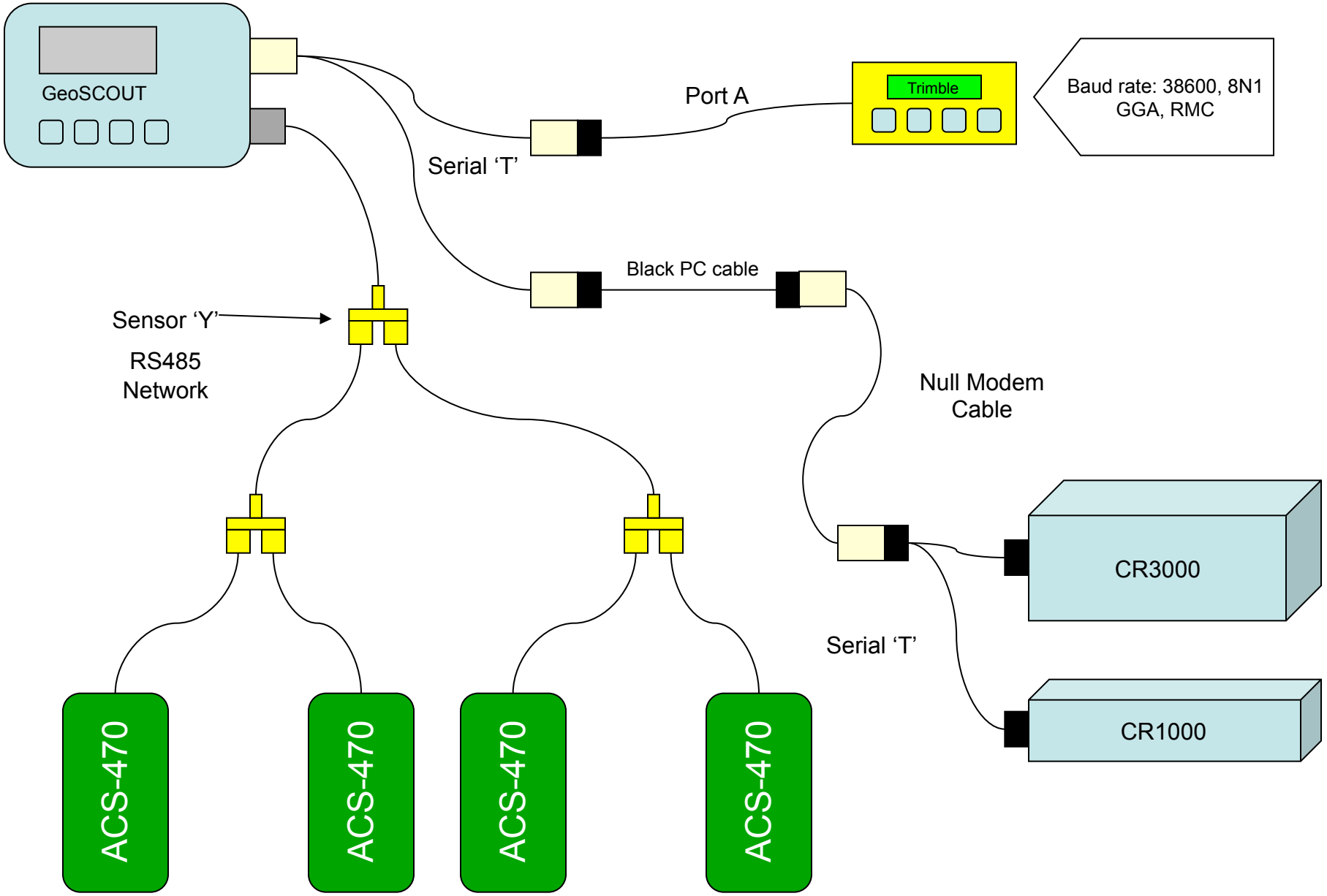
Field-based High-throughput Phenotyping System



NMEA string data - http://www.gpsinformation.org

- Useful pieces of information in common strings

$GPGGA,195124.76,3304.42373723,N,11158.33254617,W,4,12,0.9,358.878,M,-27.208,M,0.4,0000*77

1 2 3 4 5 6

$GPRMC,195124,A,3304.42373723,N,11158.33254617,W,1.7,311.1,181013,12.1,E*5E

8 9 10 11

$GPVTG,311.1,T,,M,1.65,N,3.06,K*65

12 13 14

1. Latitude ddmm.mmmmmmmm
2. Longitude dddmm.mmmmmmmm
3. Quality 2=DGPS, 4=RTK
4. # Satellites
5. Horizontal Dilution of Precision HDOP
6. Elevation, in meters
7. Latitude ddmm.mmmmmmmm
8. Longitude dddmm.mmmmmmmm
9. Speed, in knots
10. Direction in degrees, in reference to geographic north
11. Date, day/month/year
12. Direction in degrees, in reference to geographic north
13. Speed, in knots
14. Speed, in m/s

- CRBasic code example
  - Collects string data and parses to preserve GPS precision

CRBasic Editor - [SensorArray2011.CR3 for the CR3000]

File Edit View Search Compile Template Instruction Goto Window Tools Help

```
Sub Measure
  Scan(1,Se SubName 0)
    'Read in GPS serial data
    compare = 0
    While compare = 0              'No progression until full string is received
      SerialFlush(comRS232)        'Empty current info in the serial buffer
      SerialIn(dest,comRS232,110,"*",81)     'Wait up to 1.1 sec for data
      compare = InStr(1,dest,"$GPGGA",2)      'Checks for $GPGGA in string
    Wend


    'Parse the data components out of the NMEA string - 19 pieces $GPGGA
    'CR3000 receives GPS data and measures IRTS
    SplitStr(SplitResult(),dest,",.",19,6)
     latitude = SplitResult(3)
     latmin = SplitResult(4)
     longitude = SplitResult(6)
     longmin = SplitResult(7)
     qual = SplitResult(9)
     sats = SplitResult(10)
     hdop = SplitResult(11) & "." & SplitResult(12)
     elev = SplitResult(13) & "." & SplitResult(14)
```

Line: 155 Col: 12 C:\Documents and Settings\John Heun\Desktop\Ag Engineering\Data Logger & Software\Data Logger Programs\SensorArray2011.CR3 load Insert

Sampling Frequency & Sensor Response Time

Campbell CR1000 sampling at 5Hz

TOA5	39656	CR1000	39656	CR1000.Std.21	CPU:2011wheatPlantHeight.CR1	57500	Table1									
TIMESTAMP	RECORD	Son_Displacement	Las_Displacement	SonarSig_Avg	LaserSig_Avg	latitude	latmin	longitude	longmin		elev	elevfrac	qual	sats	hdop	
TS	RN	mm	mm	mV		DDMM	.mmmmmm	DDDMM	.mmmmmmm		m	dec m	quality	sv	hdop	
		Smp	Smp	Avg	Avg	Smp	m Smp	Smp	Smp	Elev	Smp	Smp	Smp	Smp	Smp	
3/1/2013 12:00:24	71	669	939	466.5	946	3303	59824276	11158	57281148	362.697	362	697	4	10	0.9	
3/1/2013 12:00:24	72	681.6	912	475.3	918	3303	59824192	11158	57281116	362.691	362	691	4	10	0.9	
3/1/2013 12:00:24	73	681.6	886	475.3	892	3303	59824356	11158	57280872	362.688	362	688	4	10	0.9	
3/1/2013 12:00:24	74	681.6	849	475.3	854	3303	59824320	11158	57280804	362.691	362	691	4	10	0.9	
3/1/2013 12:00:24	75	998	891	696	897	3303	59824332	11158	57281056	362.691	362	691	4	10	0.9	
3/1/2013 12:00:25	76	998	888	696	894	3303	59824412	11158	57281216	362.695	362	695	4	10	0.9	
3/1/2013 12:00:25	77	998	889	696	895	3303	59824408	11158	57280856	362.691	362	691	4	10	0.9	
3/1/2013 12:00:25	78	671.9	962	468.5	968	3303	59824416	11158	57280676	362.688	362	688	4	10	0.9	
3/1/2013 12:00:25	79	670.9	937	467.8	944	3303	59824304	11158	57281004	362.694	362	694	4	10	0.9	
3/1/2013 12:00:25	80	671.9	890	468.5	896	3303	59824344	11158	57281040	362.696	362	696	4	10	0.9	
3/1/2013 12:00:26	81	670.9	888	467.8	894	3303	59824320	11158	57280964	362.695	362	695	4	10	0.9	
3/1/2013 12:00:26	82	670.9	887	467.8	893	3303	59824144	11158	57281012	362.702	362	702	4	10	0.9	
3/1/2013 12:00:26	83	671.9	888	468.5	894	3303	59824348	11158	57281168	362.696	362	696	4	10	0.9	
3/1/2013 12:00:26	84	671.9	889	468.5	895	3303	59824516	11158	57280928	362.695	362	695	4	10	0.9	
3/1/2013 12:00:26	85	671.9	891	468.5	897	3303	59823516	11158	57280816	362.715	362	715	4	10	0.9	
3/1/2013 12:00:27	86	671.9	883	468.5	889	3303	59820628	11158	57280796	362.729	362	729	4	10	0.9	
3/1/2013 12:00:27	87	670.9	922	467.8	928	3303	59816824	11158	57280868	362.68	362	680	4	10	0.9	
3/1/2013 12:00:27	88	854	962	595.8	968	3303	59812024	11158	57283132	362.717	362	717	4	10	0.9	
3/1/2013 12:00:27	89	854	955	595.8	961	3303	59806880	11158	57285528	362.697	362	697	4	10	0.9	
3/1/2013 12:00:27	90	854	977	595.8	984	3303	59801704	11158	57286004	362.703	362	703	4	10	0.9	
3/1/2013 12:00:28	91	867	928	604.6	934	3303	59796028	11158	57285932	362.707	362	707	4	10	0.9	
3/1/2013 12:00:28	92	867	919	604.6	925	3303	59790128	11158	57284412	362.703	362	703	4	10	0.9	
3/1/2013 12:00:28	93	867	997	604.6	1003	3303	59784880	11158	57282368	362.714	362	714	4	10	0.9	
3/1/2013 12:00:28	94	881	1006	614.1	1013	3303	59779356	11158	57281980	362.707	362	707	4	10	0.9	
3/1/2013 12:00:28	95	881	1017	614.1	1024	3303	59774272	11158	57281776	362.726	362	726	4	10	0.9	
3/1/2013 12:00:29	96	881	978	614.1	985	3303	59769316	11158	57283408	362.718	362	718	4	10	0.9	
3/1/2013 12:00:29	97	875	933	610	939	3303	59763948	11158	57284244	362.704	362	704	4	10	0.9	
3/1/2013 12:00:29	98	875	904	610	911	3303	59758732	11158	57284660	362.735	362	735	4	10	0.9	
3/1/2013 12:00:29	99	875	1007	610	1014	3303	59753764	11158	57283736	362.709	362	709	4	10	0.9	
3/1/2013 12:00:29	100	875	1057	610	1064	3303	59748992	11158	57283632	362.701	362	701	4	10	0.9	
3/1/2013 12:00:30	101	849	985	591.7	992	3303	59744332	11158	57283508	362.714	362	714	4	10	0.9	
3/1/2013 12:00:30	102	849	917	591.7	923	3303	59739712	11158	57282504	362.665	362	665	4	10	0.9	

8 digits of precision preserved as a ‘Long’ data type

Quality (4=RTK)

# of satellites

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		Smp	Smp	Avg	Avg	Smp	m Smp	Smp	Smp	Elev	Smp	Smp	Smp	Smp	Smp	
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3/1/2013 12:00:25	76	998	888	696	894	3303	59824412	11158	57281216	362.695	362	695	4	10	0.9	
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3/1/2013 12:00:28	92	867	919	604.6	925	3303	59790128	11158	57284412	362.703	362	703	4	10	0.9	
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3/1/2013 12:00:30	102	849	917	591.7	923	3303	59739712	11158	57282504	362.665	362	665	4	10	0.9	

Sonar updating ASAP ~ 3Hz

Laser updating at 20Hz

Integration considerations:

- Rugged, field ready equipment- solid state HDs/memory cards, vibration proof
- Number of channels- (analog, digital, serial, pulse and frequency measurements)
- Scan rate and sensor response time
- Synchronize with GPS
- Use sensors with analog outputs: 0-20mA current loops or voltage
- Keep program calculations to a minimum. Save complex calculations/ analysis for post processing when possible.
- Number of people to operate systems - driver should have minimal distractions

Final remarks

1. Flexible design
   - Existing equipment and materials
   - Pre-fabricated, interchangeable components
   - Applied to different settings – both research and production
2. Electronic systems integration:
   - Research sensor specs carefully
   - Keep it simple
3. Work in progress:
   - Low-cost platforms (Jeff W.)
   - Lidar 3-D (Andy F.)

Our work in proximal sensing of cotton has been possible by the financial support of CottonInc.

PLANT BREEDING & GENOMICS

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You will be contacted via email.

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