Ultrasonic Proximity Sensors
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I. Introduction

- A. Why measure crop height?
  - 1. Of interest as trait per se
    - a) Lodging
    - b) Mechanical harvest
  - 2. Height indicates overall growth
  - 3. Height often reflects key developmental events
    - a) Bolting indicates onset of flowering (Brassicas)
    - b) End of height growth indicates (cereal crops)
  - 4. Variation in height may relate to canopy architecture
  - 5. Useful as a covariate to enhance interpretation
    - a) Reflectance measurements and sensor distance
- B. Options for measuring height
  - 1. Ruler – with/wo barcode
  - 2. Photogrammetry
  - 3. Lateral profile with image analysis
  - 4. Ultrasonic proximity sensors
- C. Rest of talk on ultrasonic sensors
  - 1. What we are using
  - 2. Very robust
  - 3. Easy to use

II. Ultrasonic basics

- A. Based on sonar
  - 1. Distance is determined by:
    - a) emitting a sound pulse
    - b) listening for echo (reflected sound)
    - c) measuring the time delay t)

d) calculate distance based on speed of sound

(1) s = approximately 346 m s^{-1} in dry air at 25°C

(2) D = 0.5 * t * s

2. Other examples of sonar:

a) Submarines

b) Bats

B. Simple physics

1. Speed of sound

a) Temperature: increases approximately 1% per 5°C rise in air temperature

b) Humidity has a much lesser effect

2. Beam width

a) Decreases as transducer ("speaker") diameter increases

3. Beam strength

a) For a point source: Decreases with 1/(distance^2)

4. Target characteristics strongly affect the echo

a) Best reflection is from a surface that is

(1) Hard – maximizes energy reflected

(2) Flat – avoids multiple paths for echo

(3) Perpendicular to the path of the sound wave – echo returns with least loss of energy

b) Canopies

III. Sensor performance

A. Artificial targets

1. Static tests with rigid target – sensors perform very well (accuracy < 1 cm)

2. Soft targets – some problems arise

3. Soft targets with motion

B. Field performance

1. Cotton

2. Wheat

IV. Sensor characteristics

  A. Examples we have tested (see Table 1)

  B. Beam pattern

  C. Minimum working distance

  D. Maximum range

  E. Response time/refresh rate

    1. As slow as 2 Hz (twice per second)

  F. Voltage and power requirements

    1. MaxBotix:

      a) Analog output is proportional to input voltage

      b) Need a stable input voltage

      c) Campbell logger is very good

    2. Possible issue of peak demand when "firing"

      a) MaxBotix reports 3.4 to 100 mA at 5 VDC (16 to 500 mW)

      b) Pulsar reports 5 W normal with max of 10 W

  G. Mysterious sensitivity and noise filtering

    1. Proprietary

      a) Pulsar Black Box has numerous settings

      b) MaxBotix sells numerous models

    2. Issues

      a) Detection of most important peak with noisy reflections

      b) "Acoustic phase cancelation" (MaxBotix)

      c) Target size compensation (MaxBotix)

      d) Input voltage noise

V. Data analysis

  A. Distribution of heights, not fixed values

  B. Quantiles look promising

    1. Example of quantile regression from Field 105

    2. Possibly related to canopy structure

  C. Analysis of sound envelope

VI. Conclusions

A. Ultrasonic proximity sensors can provide useful data
   1. Height of direct interest
   2. Complement to distance sensitive sensors: IRT, reflectance
   3. Improve estimation of crop growth with reflectance
B. Robust for many crops
C. Don't choose sensors blindly
   1. Working distance
   2. Sensitivity
   3. Refresh rate
D. More advanced analyses may provide additional data
   1. Quantile analysis
   2. "Sound envelope"
E. Many principles and characteristics of ultrasonic sensors apply to other sensors
   1. Field of view
   2. Working distance
   3. Response time/refresh rate
   4. Voltage and power requirements
   5. Sensitivity to environmental conditions (temperature)

References

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Table 1. Characteristics of example ultrasonic proximity sensors.

Manufacturer[1]	Honeywell	MaxBotix	MaxBotix	Parallax	Pulsar
Sensor name	Ultrasonic Distance Sensor	XL- MaxSonar - WR1	HRXL-MaxSonar - WR	PING)))	noncontact ultrasonic transducer
Approximate cost (USD)	$400	$100	$150	$30	$1300
Part number	P43-F4Y-2D-1D0-180E	MB7070	MB7364	28015	dB3 5m FM
Input voltage (V DC)	24	5	5	5	10 to 28
Supply current (mA)	< 40	3.4-100	3.1	30-35	(10 W max., 5 W typical)
Input voltage filtering	NA[2]	None[3]	None	NA	NA
Output	4-20 mA	0-5 VDC	0-5 VDC	5V pulse	4-20 mA
Frequency	180 kHz	42 KHz	42 KHz	40 kHz	125 kHz
Detection range (cm)	20 - 200	20 - 765	30-500	2 to 300	15 - 300
Distance resolution (cm)		1	1		
Response time (ms)	250	100	140	> 30	NA
Beam angle	8°	NA	NA	20°	10°
Air temperature compensation	yes	no	yes	no	yes
Indicator lights	yes	no	no	yes	no
Cable provided	yes	no	no	no	yes
Dimensions	18 mm diam. X 93 mm	44mm diam. x 72 mm	44mm diam. x 72 mm	22H x 46W x 16D mm	86 mm diam. x 98 mm
Housing shape	Cylindrical	Truncated cone	Truncated cone	(none)	Spheroid

[1] Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.
[2] No information available.
[3] Optional filter kit available.

Weight (g)	30	170	170	20	420
Operating temperature (°C)	-15 to 70	-40 to 65	-40 to 65	0 to 70	-40 to 90
Comments	Teach in auto tuning ability.	Real-time auto calibration of temperature, humidity, and noise rejection. Variable gain.	Real-time auto calibration of temperature, humidity, and noise rejection. Variable gain.	Bare circuit board.	Required proprietary datalogger.