A QUICK-INSTALL TRACTOR GUIDANCE SYSTEM RELYING ON COMPUTER VISION

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PROJECT OBJECTIVE

- To design a camera-based automated guidance system capable of guiding an unladen agricultural tractor within a desired path (crop row) at speeds between 1 m/s and the maximum practical operating speed for the tractor (5 m/s).
- The system also has to meet the following requirements:
  - Not restricted to a specific crop or task
  - Compatibility with all agricultural vehicles equipped with power steering
  - Easy to install within minutes
  - Inexpensive

DESIGN REQUIREMENTS

Plant Segmentation

- RGB images must be filtered to distinguish plant matter from soil
- Capability to handle different crops (e.g. soybeans, corn)

Row Detection

- The crop row must be determined after plants have been identified
- Capability to handle high weed density and inconsistent rows

Ground Speed Measurement

- Enough keypoints must be matched to measure progression between frames
- Capability to handle poor lighting (e.g. shadows)

Vehicle Control

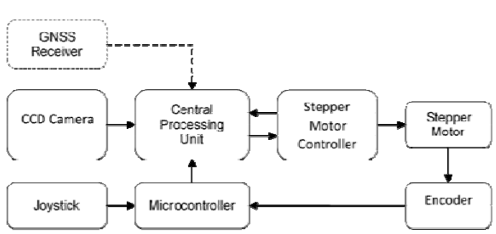
- The guidance adjustments must be smooth and not exhibit hunting oscillations
- Capability to handle rows with 5 cm error

SYSTEM COMPONENTS

- Rugged Camera
- Onboard vehicle computer
- Stepper motor, encoder and mounting hardware
- Joystick and dedicated microcontroller
- HSI band-pass plant detection algorithm
- SURF ground speed estimation
- RTK-level GNSS receiver (for performance evaluation)

Camera, onboard computer, steering wheel hub adapter, and joystick.

SYSTEM DIAGRAM



Steering system diagram.

CAMERA IMPLEMENTATION

(a) (b)

One meter above garden hose on tarmac (a), and above soybeans with the GPS antenna (b)

PLANT SEGMENTATION

- A HSI Band-Pass Plant Detection algorithm (BPPD) was developed to address false-negative and false-positive plant identification in non-diffuse lighting.

$$H_{ij} = \begin{cases} 60 \cdot \left(\frac{G_{ij} - B_{ij}}{I_{ij} - min(R_{ij}, G_{ij}, B_{ij})} \right) & if\ I_{ij} = R_{ij} \\ 120 + 60 \cdot \left(\frac{B_{ij} - R_{ij}}{I_{ij} - min(R_{ij}, G_{ij}, B_{ij})} \right) & if\ I_{ij} = G_{ij} \\ 240 + 60 \cdot \left(\frac{R_{ij} - G_{ij}}{I_{ij} - min(R_{ij}, G_{ij}, B_{ij})} \right) & if\ I_{ij} = B_{ij} \end{cases}$$

$$S_{ij} = \begin{cases} 0 & if\ I_{ij} = 0 \\ \frac{I_{ij} - min(R_{ij}, G_{ij}, B_{ij})}{I_{ij}} & if\ I_{ij} \neq 0 \end{cases}$$

$$I_{ij} = \max(R_{ij}, G_{ij}, B_{ij})$$

$$BPPD_{ij} = \begin{cases} 1 & if\ H_{ij} > H_{min} \wedge H_{ij} < H_{max} \wedge S_{ij} > mean(S) \wedge I_{ij} > mean(I) \\ 0 & otherwise \end{cases}$$

HSI SEGMENTATION ALGORITHM

(a) (b)

Original (a) compared to improved HSI filter (b)

CROP ROW DETECTION

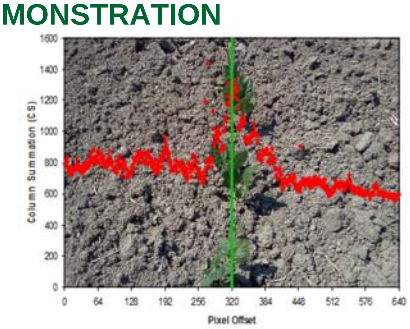
- A statistical band-pass filter for estimating lateral crop offset was developed based on work by Slaughter et al. (1996) and Brivot et al. (1997)

$$CS_i = \sum_{j=0}^{n_j} BPPD_{ij}$$

$$CI_i = \begin{cases} i & if\ CS_i \geq mean(CS) + 2 \cdot std(CS) \\ N/A & if\ CS_i < mean(CS) + 2 \cdot std(CS) \end{cases}$$

$$Offset = \begin{cases} median(CI) - \frac{n}{2} & if\ count(CI) > 0 \\ i_{max\ (CS)} - \frac{n_i}{2} & if\ count(CI) = 0 \end{cases}$$

ROW DETECTION DEMONSTRATION

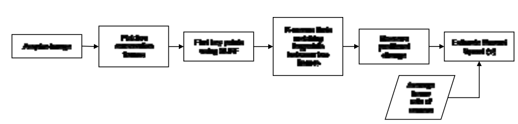


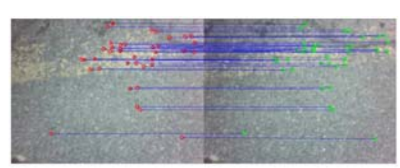
Stanhope et al. 2014

GROUND SPEED MEASUREMENT

- Using two consecutive frames of the video stream to identify keypoints using SURF algorithm (Bay et al. 2006)
- K-means nearest neighbor matching finds matching keypoints
- Average velocity calculated by determining positional change multiplied by average frame rate of camera (Stanhope, 2015)

GROUND SPEED MEASUREMENT





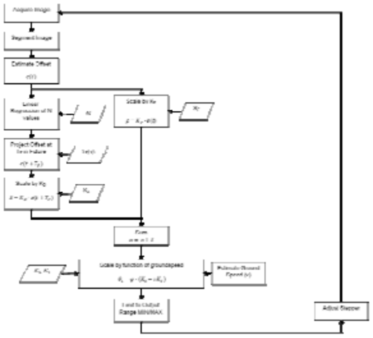
Simplified ground speed estimation flowchart and illustration.

VEHICLE CONTROL

- T5050 New Holland tractor steered by stepper motor and steering wheel hub adapter attached to front window using suction cups
- PD feedback controller design

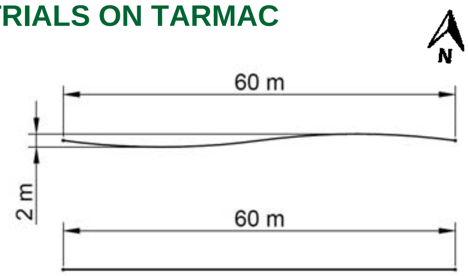
Steering apparatus mounted to the front window of the tractor.

VEHICLE CONTROL ALGORITHM



Simplified control algorithm flowchart.

TRIALS ON TARMAC

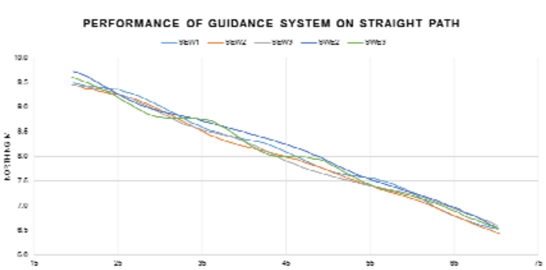


Arrangement of the two test layouts for the garden hose, on tarmac.

TRIALS ON TARMAC AT 2.5 M/S

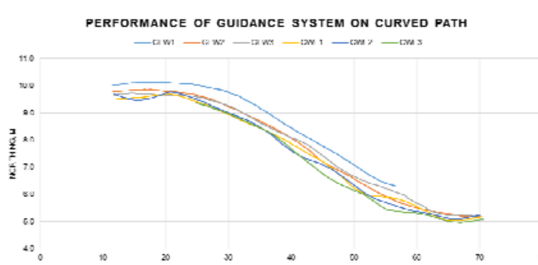
Trajectory	Direction of Travel	Trial	Number of Records	Mean Absolute Error (cm)	RMSE (cm)	95th Percentile (cm)
Straight	East-West	1	110	4.8	6.1	12.5
		2	110	5.9	7.1	13.7
		3	109	7.8	9.6	17.4
	West-East	1	111	10.9	12.5	20.9
		2	112	2.3	2.6	4.4
	Overall		552	6.9	8.6	16.7
Curved	East-West	1	98	15.2	16.4	27.5
		2	127	4.1	5.0	8.9
		3	129	4.6	5.7	10.6
	West-East	1	128	9.1	11.3	20.4
		2	129	9.8	11.8	19.6
		3	98	13.6	14.9	22.0
	Overall		709	9.2	11.3	20.6

RTK TRACKING



Tracking of the test tractor as recorded by GPS, in relation to arbitrarily chosen reference point.

RTK TRACKING CONT'D



Tracking of the test tractor as recorded by GPS, in relation to arbitrarily chosen reference point.

WORK IN PROGRESS

- Higher operating speeds (5 m/s)
- Kalman Filter
- Operator Assisted Reinforcement Learning

  →Q-Learning

Authors next to test tractor.

Q-LEARNING

- Model-free reinforcement learning technique
- The algorithm can be written:
  1. Obtain the current state s_t.
  2. Choose a decision d_t, and execute it.
  3. Obtain the new state s_{t+1} and the immediate reward r.
  4. Update the matrix $Q(s_t,d_t)$ with the equation:
     $$Q(s_t,d_t) = (1-\alpha)\cdot Q(s_t,d_t) + \alpha\cdot\left(r + \gamma\cdot \max_{d_{t+1}} Q(s_{t+1},d_{t+1})\right)$$
  5. Assign $s_t = s_{t+1}$
  6. While $s_t \neq s_{optimal}$ return to 2.

  where α and γ are the learning rate and the discount factor, respectively.

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REFERENCES

- Brivot, R., and J.A. Marchant. 1996. Segmentation of plants and weeds using infrared images. Proceedings of the Institution of Electrical Engineers, Vision, Image and Signal Processing, 143(2): 118–124.
- Slaughter, D.C., and D.K. Giles. 1997. Precision band spraying with machine-vision guidance and adjustable yaw nozzles. Transactions of the ASAE 40(1): 29–36.
- Stanhope, T.P., Adamchuk, V.I. & Roux, J.D., 2014. Computer vision guidance of field cultivation for organic row crop production. *2014 Montreal, Quebec Canada July 13 – July 16, 2014.*