CITRUS MECHANICAL HARVESTING: MACHINE ENHANCEMENT AND IMPROVEMENT

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Machine Enhancement and Improvement

• Yield monitoring
  • Developing a rugged fruit mass flow sensor

• Reducing tree injuries through improved canopy shaking mechanisms
  • Study the parameters that effect fruit removal or causes tree injuries

• Variable rate shaking
  • Measuring canopy size and volume
  • Developing a control system to adjust the optimal shaking parameters
Yield Monitoring System for Citrus Mechanical Harvesting Machines

• Yield monitor can be used to:
  • Quantify the yield variability within or between a citrus orchard block
  • Prevent overloading or under-loading of citrus transportation truck

• Yield monitoring system for citrus mechanical harvesting machines
  • Simple
    • Easy to install and operate
    • Easy to maintain and calibrate
  • Rugged and durable
  • Cost-effective
Components of a Yield Monitor for Citrus Mechanical Harvester

- Tilt Sensor
- Load / Volume Sensor
- GPS
- Ground Speed Sensor
- Belt Speed Sensor
- Signal Control and Conditioning Unit
- Display Unit
Mass Flow Sensor

**SYSTEM COMPONENT/s**
- Two photo interruption layers
  - 20 laser beams per layer
- PIC microcontroller

**ADVANTAGE**
- Absence of defocus problem
- Long life calibration

**DISADVANTAGE**
- Erroneous signals due to vibrations.

**Mass flow sensor with 40 laser beams**

\[
\hat{N} = N_T \left( \frac{\sum_{i=1}^{N_T} \Delta tpc_i}{\sum_{i=1}^{N_T} \Delta tps_i} + 1 \right) = N_T \left( \frac{\sum_{i=1}^{N_T} \Delta tps_i}{\sum_{i=1}^{N_T} \Delta tps_i} + 1 \right) = N_T \left( \frac{\Delta tpc_i}{\Delta tps_i} + 1 \right)
\]

**CONSTRAINT**

Poisson Flow

Dual interruption timing mechanism
Impact Plate

**SYSTEM COMPONENT/s**
- Four (4) Load Cells
- Tern Controller, GPS

**ADVANTAGE**
- Rugged and easy to handle
- Easy to install and maintain

**Plate displacement**

**IMPACT FORCE**

\[ \frac{1}{2} M v^2 = \int_0^{\delta_{\text{max}}} F d\delta + \int_0^{\alpha_{\text{max}}} F d\alpha \]

**PLATE DISPLACEMENT**

\[ \Phi(f) = \frac{|S(f)|^2}{|S(f)|^2 + |N(f)|^2} \]

**FILTER**

\[ \text{Clumps} = \begin{cases} \beta(x-T) & \text{for } (x-T) > \alpha, \\ (x-T) & \text{otherwise.} \end{cases} \]

\[ \text{Pr. Weight} = \begin{cases} \text{Clumps} & \text{for } x > T, \\ 0 & \text{otherwise.} \end{cases} \]
LABORATORY & FIELD TEST
Field Calibration

\[ y = 1.3567x + 411.31 \]

\[ R^2 = 0.9725 \]
Yield Monitoring System in Action
Reducing Tree Injuries & Improving Fruit Removal
Force Distribution in the Tree Canopy during Mechanical Harvesting

Tine design variables
- Forward Speed
- Amplitude
- Frequency
- Inclination (α)

Shaking force
- High
- Medium
- Low

Inclination

Tine movement
Reducing Tree Injuries & Improving Fruit Removal

• Study the force distribution in a canopy of citrus trees and determine the best shaking parameters for each type and size of tree
  • Study the force distribution in an individual branch in the tree when harvested by a canopy shaker
  • Study the effects of frequency of shaker, angle of tines and tree size on the force distribution

• Variable rate shaking
  • Measuring canopy size and volume
  • Developing a control system to adjust the optimal shaking parameters
## Independent Variables

- **Tree size**
- **Angle of tines**
- **Frequency of the canopy shaker**

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Size</td>
<td>1</td>
<td>Large</td>
</tr>
<tr>
<td>(2 Levels)</td>
<td>2</td>
<td>Medium</td>
</tr>
<tr>
<td>Angle of Tines</td>
<td>1</td>
<td>5°</td>
</tr>
<tr>
<td>(3 Levels)</td>
<td>2</td>
<td>20°</td>
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<tr>
<td></td>
<td>3</td>
<td>35°</td>
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<tr>
<td>Frequency of canopy shaker</td>
<td>1</td>
<td>200 cpm</td>
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<tr>
<td>(3 Levels)</td>
<td>2</td>
<td>250 cpm</td>
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<tr>
<td></td>
<td>3</td>
<td>300 cpm</td>
</tr>
</tbody>
</table>

![Diagram showing tree with different angles and shaker movement](image)
Methodology

**Instrumenting the branch:**

- Instrumenting the selected branch starts from the base of the branch where it is joined with the main trunk.

- A sensor is placed at the base.

- From the base of the branch, the sensors are placed at distances of multiples of 50 cm.

- The last sensor is placed such that the diameter of the branch at that location is about 15 cm.
Images of a Tested Tree
Videos of Experiment
PRELIMINARY RESULTS

Large Tree

Graphs showing the relationship between proportional force and frequency for different angles and cpm values.
Preliminary Results

Medium Tree
Variable Rate Shaking of Trees According to Size by Canopy Shakers
Tree Canopy Volume Measurement

\[ x_k = TD - d_k \cdot \sin(\theta_k) \]
\[ y_k = SH + d_k \cdot \cos(\theta_k) \]

Volume of slice \( V_i \) = \( A_i \cdot \Delta t \cdot S \)
Volume of tree \( V \) = \( \sum_{i=1}^{n} V_i \)
where, \( \Delta t = \) scanning time per cycle
\( S = \) vehicle speed
\( A_i = \) area of polygon
Tree Canopy Volume Measurement

### Tree Geometric Characteristics

<table>
<thead>
<tr>
<th>Tree Geometric Characteristics</th>
<th>Travel Speed of the Vehicle = 1.0 (m/sec)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Meas-True</td>
</tr>
<tr>
<td>Height (cm) (True=240)</td>
<td>-0.991</td>
</tr>
<tr>
<td>Volume (m³) (True=11.286)</td>
<td></td>
</tr>
<tr>
<td>Raw data</td>
<td>-1.580</td>
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<tr>
<td>Convex hull</td>
<td>0.665</td>
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<tr>
<td>Hull fit</td>
<td></td>
</tr>
<tr>
<td>P=0.15</td>
<td>0.010</td>
</tr>
<tr>
<td>P=0.30</td>
<td>0.409</td>
</tr>
<tr>
<td>P=0.60</td>
<td>0.585</td>
</tr>
</tbody>
</table>

### Tree Height / Volume

<table>
<thead>
<tr>
<th>Tree Height / Volume</th>
<th>Raw Data / Roll Angle Correction</th>
<th>Travel Speed of the Vehicle = 1.0 (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meas-True</td>
<td>Error (%)</td>
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<tr>
<td>Height (cm) (True=240)</td>
<td>Raw data</td>
<td>-43.510</td>
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<tr>
<td></td>
<td>Roll angle correction</td>
<td>-6.770</td>
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<tr>
<td>Volume (m³) (True=11.286)</td>
<td>Hull fit (P=0.15)</td>
<td>-0.610</td>
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<tr>
<td></td>
<td>Roll angle correction</td>
<td>-0.060</td>
</tr>
</tbody>
</table>
Thank You
Any Questions?