Cable logging operation supported with sensor fusion

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Outline

Aims

Introduction

Methods
    System setup
    Data preparation
    Multivariate data analysis

Results
    Video
    Transfer rates
    PCA Biplot
    PLS results

Conclusions
Aims

Development and test a standalone communication platform for capturing and processing cable-yarding operations data

1. Integration of IMU, GPS and camera data to support automatic work phase recognition.

2. Quantification of the phase prediction success of the method.
Introduction

Finite state machine can be depicted as a graph, whose nodes represent possible system states, and whose arrows represent possible transitions from state to state.
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System setup

This setup was tested on self propelled Woodliner with Konrad KMS tower yarder. Whole tree harvesting was used with downhill extraction in a 160m long corridor.

1. Tower
2. TP Link access point
3. TP Link repeater
4. Computer 1 (slave)
5. Cable carriage
6. Camera 1
7. Camera 2
8. Computer 2 (master)
9. Android device (IMU,GPS)
10. Battery pack 1
11. Battery pack 2
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Data preparation

1. IMU (orientation, angular velocity, linear acceleration)
2. GPS (elevation, velocity)
3. Camera (optical flow - motion vectors)
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### Multivariate data analysis

1. Variables recorded from different sensors were collected as rows in Matrix X
2. 6 phases were manually classified were collected in corresponding matrix Y
3. Responses in Y consisted of 6 categorical binary dummy variables

**Table:** Test verification responses (TP, FP, FN, TN) for PLS model classification of work phases where A is the true phase.

<table>
<thead>
<tr>
<th>Condition</th>
<th>A</th>
<th>Not A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test says &quot;A&quot;</td>
<td>True positive (TP)</td>
<td>False positive (FP)</td>
</tr>
<tr>
<td>Test says &quot;Not A&quot;</td>
<td>False negative (FN)</td>
<td>True negative (TN)</td>
</tr>
</tbody>
</table>
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# Transfer rates

**Table:** Data packets size (kilobytes) and data transfer rates (kilobytes/s) test results for the different sensor devices used on the communication platform.

<table>
<thead>
<tr>
<th>Data source</th>
<th>size min (KB)</th>
<th>size max (KB)</th>
<th>frequency min (Hz)</th>
<th>rate min (KB/s)</th>
<th>rate max (KB/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>0.12</td>
<td>0.12</td>
<td>0.96</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>IMU</td>
<td>0.32</td>
<td>0.32</td>
<td>0.01</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Camera 2 (RaspiCam) compressed image</td>
<td>57</td>
<td>112</td>
<td>0.04</td>
<td>1425</td>
<td>2800</td>
</tr>
<tr>
<td>Camera 1 (USB cam) compressed image</td>
<td>59</td>
<td>73</td>
<td>0.085</td>
<td>694.11</td>
<td>858.82</td>
</tr>
<tr>
<td>Total (including compressed images only)</td>
<td>116.44</td>
<td>185.44</td>
<td></td>
<td>2151.23</td>
<td>3690.94</td>
</tr>
<tr>
<td>Camera 1 (USB cam) raw image</td>
<td>942.08</td>
<td>942.08</td>
<td>0.1</td>
<td>9 420.8</td>
<td>9 420.8</td>
</tr>
<tr>
<td>Total (all data)</td>
<td>1 058.52</td>
<td>1 127.52</td>
<td></td>
<td>11 572.03</td>
<td>13 111.74</td>
</tr>
</tbody>
</table>
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PCA Biplot

Biplot of validation data

- Variables
- GSPZ
- ROLL
- GPS_velocityXY
- Optical Flow
- ANGULAR VELOCITY
- ACCELERATION X
- ACCELERATION Y
- ACCELERATION Z
- lateral in
- inhaul
- outhaul
- stop
- unhook

NIBIO
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# PLS results

**Table**: Prediction results for classification success per work phase.

<table>
<thead>
<tr>
<th>Class</th>
<th>TP</th>
<th>FP</th>
<th>TN</th>
<th>FN</th>
<th>N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>outhaul</td>
<td>0.767</td>
<td>0.018</td>
<td>0.981</td>
<td>0.232</td>
<td>56</td>
<td>0.843</td>
</tr>
<tr>
<td>choking</td>
<td>0.947</td>
<td>0.076</td>
<td>0.923</td>
<td>0.052</td>
<td>133</td>
<td>0.818</td>
</tr>
<tr>
<td>lateral in</td>
<td>0.795</td>
<td>0.041</td>
<td>0.958</td>
<td>0.204</td>
<td>88</td>
<td>0.804</td>
</tr>
<tr>
<td>inhaul</td>
<td>0.738</td>
<td>0.038</td>
<td>0.961</td>
<td>0.261</td>
<td>111</td>
<td>0.845</td>
</tr>
<tr>
<td>unhook</td>
<td>0.721</td>
<td>0.066</td>
<td>0.933</td>
<td>0.278</td>
<td>61</td>
<td>0.602</td>
</tr>
<tr>
<td>stop</td>
<td>0.450</td>
<td>0.033</td>
<td>0.966</td>
<td>0.549</td>
<td>51</td>
<td>0.605</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predicted</th>
<th>outhaul</th>
<th>choking</th>
<th>lateral in</th>
<th>inhaul</th>
<th>unhook</th>
<th>stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>outhaul</td>
<td>43</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>choking</td>
<td>12</td>
<td>126</td>
<td>15</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>lateral in</td>
<td>0</td>
<td>6</td>
<td>70</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>inhaul</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>82</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>unhook</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>44</td>
<td>19</td>
</tr>
<tr>
<td>stop</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>7</td>
<td>23</td>
</tr>
</tbody>
</table>
Conclusions

1. Study showed promising method for enabling machine communication with max latency of 0.16s.
2. WLAN has a potential for cable yarding with defined spatial range.
3. Data fusion from different sensors resulted in 78 % of correct classification.
4. Further implementation of this concept is considered a starting point for further development of autonomous routines in cable yarding.