GRAPH-BASED FORMATION WITH REAL E-PUCKS

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GENERAL OVERVIEW

APPLICATIONS

- Security patrolling
- Search and rescue in hazardous environment
- Lawn mowing
- Vacuum cleaning
OUR FORMATION

\[ W = \begin{bmatrix} 2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \]

Weight matrix defines importance of each edge

\[ L = \begin{bmatrix} 6 & -2 & -2 & -2 \\ -2 & 6 & -1 & -3 \\ -2 & -1 & 3 & 0 \\ -2 & -3 & 0 & 5 \end{bmatrix} \]

Laplacian matrix:
\[ L = I * W * I^T \]

\[ B = \begin{bmatrix} 0 & 14.14 & 10 & 10 \\ 14.14 & 0 & 10 & 10 \\ 10 & 10 & 0 & 14.14 \\ 10 & 10 & 14.14 & 0 \end{bmatrix} \]

Bias matrix defines the desired formation

LEADER
RELATIVE MEASUREMENTS

PROBLEM
• Lack of absolute reference frame, especially on real e-pucks

SOLUTION
• Each robot has two matrices of relative range and bearing values
• Fills only its line

\[
\text{rangeMatrix} = \begin{bmatrix}
R_{00} & R_{01} & R_{02} & R_{03} \\
R_{10} & R_{11} & R_{12} & R_{13} \\
R_{20} & R_{21} & R_{22} & R_{23} \\
R_{30} & R_{31} & R_{32} & R_{33}
\end{bmatrix}
\]

\[
\text{bearingMatrix} = \begin{bmatrix}
B_{00} & B_{01} & B_{02} & B_{03} \\
B_{10} & B_{11} & B_{12} & B_{13} \\
B_{20} & B_{21} & B_{22} & B_{23} \\
B_{30} & B_{31} & B_{32} & B_{33}
\end{bmatrix}
\]
# THE CONTROLLER

1. \( \dot{x}(t) = -L \cdot (x(t) - B_x) \)
   \( \dot{y}(t) = -L \cdot (y(t) - B_y) \)

2. \( \bar{e}_i = \sqrt{\bar{e}_{x,i}^2 + \bar{e}_{y,i}^2} \)
   \( \bar{\alpha}_i = \text{atan2}(\bar{e}_{y,i}, \bar{e}_{x,i}) \)

3. \( \bar{e}_{x,i} = \frac{1}{\Delta_i+1} \sum_{j=1}^{\Delta_i} [-L_{i,j} \cdot (e_{i,j} - b_{i,j}) \cdot \cos(\alpha_{i,j})] \)
   \( \bar{e}_{y,i} = \frac{1}{\Delta_i+1} \sum_{j=1}^{\Delta_i} [-L_{i,j} \cdot (e_{i,j} - b_{i,j}) \cdot \sin(\alpha_{i,j})] \)

4. \( u = K_u \bar{e}_i \cos(\bar{\alpha}_i) + K_I \int_0^t f(\bar{\alpha}_i) \bar{e}_i dt \)
   \( w = K_w \bar{\alpha}_i \)

**Laplacian Expression**

**Global Relative Error**

**Expression**

**Transformation**
main
Declare and initialize variables

for (infinite)
    Send ping message
    Process received ping message

    if (robot_id != 0)
        Speed = compute speed using Laplacian expression
    else
        Speed = pre-defined speed
    end if

    Set speed
    Advance 1 time step

end for
end main
WEBOTS VIDEO
REAL E-PUCKS

First trial of pseudo-code on real hardware

Physical quantities more consistent

Limitations in IR Sensors range
WEBOTS TO REAL E-PUCKS ADJUSTMENTS

COMMUNICATION

- Robot ID = selector
- Communication protocol
- Filtering in measurement

PERFORMANCE

- Tuning of parameters
- Synchronized departure
- Discretized angles problem
ANGLE CORRECTION

Algorithm proposed by J. Pugh et al in «A Fast Onboard Relative Positioning Module for Multirobot Systems. »

\[
a = \frac{r_1 + r_{-1} + 2r_0}{2 \cos(\beta_1) + 2 \cos(\beta_{-1}) + 2}
\]

\[
b = \frac{r_1 - r_{-1}}{2 \sin(\beta_1) + 2 \sin(\beta_{-1})}
\]

\[
\theta_{\text{correction}} = \arctan\left(\frac{b}{a}\right)
\]

\[
\theta_{\text{corrected}} = \theta_0 + \theta_{\text{correction}}
\]
REAK E-PUCKS VIDEO
\[ F = \alpha \sum_{i=0}^{2} range_{error}(i, i + 1) + \beta \sum_{i=1}^{3} angle_{error}(i, i + 1) \]

\[ range_{error}(i, i + 1) = |range_{i,k} - bias_{i,k}| \]

\[ angle_{error}(i, i + 1) = |\sin(\theta_i - \frac{\pi}{2})| \]
CORRECTED vs NON-CORRECTED ANGLE

- Non-corrected performance divergence
- Overall best fitness of corrected angle

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<th>CORRECTED</th>
<th>NON-CORRECTED</th>
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<tbody>
<tr>
<td>MIN</td>
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<td>8.9260</td>
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<tr>
<td>AVG</td>
<td>9.2279</td>
<td>17.4468</td>
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P-CONTROLLER COMPARISON

- Trend
- Noise due to indirect measurement
- Time of convergence

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<td>MIN</td>
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<td>FINAL</td>
<td>3.6109</td>
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PI-CONTROLLER COMPARISON

![Fitness PI controller graph](image)

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- Trend
- Noise due to indirect measurement
- Initial best performance of real e-pucks
- Time of convergence
CONCLUSION

Consistent gap between working with simulated and real e-pucks
Sensor and actuator noise
Webots performance outperforms the real e-puck

POSSIBLE IMPROVEMENTS:
◦ Implement out of line-of-sight algorithm presented in J. Pugh et al.
Thanks for your attention!

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