Influence of PWM on Trajectory Accuracy in Mobile Robot MOTION
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Abstract:
The paper compares simulation results for direct and PWM control of DC motors in a tri-wheel mobile robot with a castor sliding wheel. Our aim was to determine to what extent PWM control changes the trajectory accuracy. For this purpose, we compare kinematic and dynamic control. To make the model more realistic, we considered the impact of viscous and rolling friction of driving wheels on the motion along the trajectory. We conclude that dynamic control is of higher quality as compared to kinematic control, and that there is a significant impact of PWM control on the trajectory accuracy.

Keywords: mobile robot control, kinematic and dynamic control, castor sliding wheel, pulse width modulation.

1. Introduction
The issue of trajectory accuracy has not been yet resolved for mobile robots with to a satisfactory extent. The regulator is incapable to determine the trajectory accurately enough given surface irregularities impacting the behaviour of wheels. For this reason, the theoretical and empirical trajectories might deviate from each other significantly. The impact of slips on the trajectory has been considered in [1, 2, 3, 4] for tri-wheel robots, in [5] for four-wheel robots and in [6] for unicyles. Not considering wheel slips might lead to significant trajectory errors [7, 8, 9, 10]. Yet, for simulation of trajectory of tri-wheel robots, the castor free wheel is assumed to be passive [11] and not to have any impact on the trajectory.

In this paper, we consider a tri-wheel robot with a castor sliding wheel [12]. The innovation is that the castor wheel does exert an impact on the entire mobile robot. Viscous and rolling frictions do influence the motion of the castor wheel. Friction coefficients are assumed to have normal distribution N(0.001, 0.00058). The simulation was carried out for an example trajectory as in [12] rotation around a fixed axis (Fig. 5), i.e. around a characteristic point A (Fig.1). For simulation purposes, we assumed the parameters of a Dunkermotoren GR63x25 motor with a PLG52 1:36 transmission.

Next, we compared the kinematic and dynamic control for both direct (without any modulation) and PWM control types [13]. [6] contains a comparison between kinematic and dynamic control, though without any restriction imposed on torques and forces. Kinematic [14] and dynamic control are still applied in robotics [10], though they are increasingly often combined with adaptive [11] and robust control.

2. Mobile robot model
Simulations were carried out for the model presented in Fig. 1:

\[ M(q)\ddot{q} + C(q, \dot{q})\dot{q} = B(q)\tau + J^T(q)\lambda, \]

where:
\[ \dot{\mathbf{q}} = \begin{bmatrix} \dot{\beta} & \dot{\psi} & \dot{\phi} & \dot{\alpha}_3 \end{bmatrix}, \]
\[ \mathbf{q} = \begin{bmatrix} \beta & \psi & \phi & \alpha_3 \end{bmatrix}, \]
\[ \mathbf{M} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & 0 \\ a_{21} & a_{22} & a_{23} & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \]
\[ \mathbf{C} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 \\ c_{21} & c_{22} & c_{23} & 0 \\ c_{31} & c_{32} & c_{33} & 0 \\ 0 & 0 & 0 & c_{44} \end{bmatrix}, \]
The elements of matrix \( M \) are described as:

\[
a_{11} = m_{1e} (l_1^2 + l_2^2 + 2l_1 l_2 \cos(\phi)) + I_{1s} + 2h_{1i} (m_{2r_1}^2 + I_{2s}) + 2l_1 r_1^2 + m_{2r_1}^2 + I_{2s}, \quad a_{12} = a_{21} = -m_{2r_1} r_1 \sin(\phi), \\
a_{22} = a_{33} = m_{2r_1}^2 + I_{3s}, \quad a_{32} = a_{23} = m_{2r_1}^2 + 2m_{2r_1}^2 + 2l_1 r_1^2 + m_{2r_1}^2, \\
a_{33} = a_{13} = -m_{2r_1} (l_1^2 + I_1) \sin(\phi) - I_{3s}.
\]

The elements of \( C \) matrix are calculated as follows:

\[
c_{11} = m_1 (-3\phi_1 l \sin(\phi) + \beta \phi_1 l \sin(\phi)) + (N_1 f_1 + N_2 f_2) h_1^2, \\
c_{12} = m_1 (-r_1 l \cos(\phi) - \beta r_1 l \cos(\phi)) + (N_1 f_1 - N_2 f_2) h_1, \\
c_{13} = m_1 \phi_1 l \sin(\phi) + D_{\phi}, \\
c_{21} = m_1 (\beta l \sin(\phi) - \phi_1 l \sin(\phi)) + (N_1 f_1 - N_2 f_2) h_1, \\
c_{22} = -m_{r_1} l \cos(\phi) \beta + r_1 l \cos(\phi) + D_{\phi}, \\
c_{23} = m_1 \beta l \sin(\phi), \\
c_{31} = m_1 \beta r_1 l \sin(\phi), \\
c_{32} = m_1 \beta r_1 l \sin(\phi), \\
c_{33} = D_{\phi}, \\
c_{44} = D_{3r_1}^2 \cos(\phi) + D_{\alpha_3},
\]

where \( \phi_1 \) is the natural (non-sliding) angle of the castor wheel with sliding being exempted, \( R \) is the current radius of the trajectory and \( V \) is the desired velocity of the castor sliding wheel. \( N_1, N_2, N_3 \) are the pressure wheels of the ground, respectively, \( M_1, M_2 \) are DC torques, \( f_1, f_2, f_3 \) are wheels coefficients friction of the ground, respectively and \( D_{\phi}, D_{\alpha}, D_{3r} \) are damping factors. Variables \( V, R \) and \( \phi \) are calculated from the formulas below:
To make the model more realistic, we also modeled two transistor bridges H, each consisting of four transistors and four diodes. The algorithm which sets the instantaneous value of PWM voltages was presented in Fig. 2., where $K$ is the duty cycle, $DT_k^{-1/20}$ of PWM impulse duration, $V_{d1}, V_{d2}$ – voltages set by the regulator based on the set-torque $M_{d1}$ and $M_{d2}$, $V_{max}$ – maximum voltage ($V_{max} = 24V$), $V_{min}$ – minimum voltage ($V_{min} = 0V$). Moreover, we assumed that the duration of a single PWM impulse $Tc$ is 2 ms and that we do not take commutation process into account, $dt$ – timestep.

The voltages $V_{d1}$ and $V_{d2}$ are calculated as follows:

$$V_{d1} = R_{a1}M_{d1} / (k\Psi) + k\Psi \alpha_1,$$

$$V_{d2} = R_{a2}M_{d2} / (k\Psi) + k\Psi \alpha_2,$$

where $\Psi_1, \Psi_2$ – exciting flux, $k$ – gear, $\alpha_1 = \psi + \beta h_1$ and $\alpha_2 = \psi - \beta h_1$ – driving wheels velocities.

To the robot dynamics equations (1) described above we added equations describing DC motors [15]:

$$\bar{Q}_1 = (V_1 - R_{a1} \bar{Q}_1 - e_{a1}) / L_a,$$

$$\bar{Q}_2 = (V_2 - R_{a2} \bar{Q}_2 - e_{a2}) / L_a,$$

where $\bar{Q}_1, \bar{Q}_2$ – currents, $e_{a1}, e_{a2}$ – inducted voltages, $L_a$ – armature inductance.

Inducted voltages are equal to:

$$e_1 = k\Psi_1 \alpha_1, \quad e_2 = k\Psi_2 \alpha_2,$$

(4)

The motor armature resistances and voltages are calculated as:

$$R_{d1} = R_d + R_{c1},$$

$$R_{d2} = R_d + R_{c2},$$

(5)

$$R_{c1} = \sum_{i=1}^{4} \delta_i R_n + \sum_{j=1}^{4} \delta_i R_{b_j},$$

(6)

$$R_{c2} = \sum_{i=1}^{4} \delta_i R_n + \sum_{j=1}^{4} \delta_i R_{b_j},$$

(7)

$$\Delta V_{c1} = \sum_{i=1}^{4} \delta_i V_c(TO) + p \sum_{j=1}^{4} \delta_j V_f(TO),$$

(8)

$$\Delta V_{c2} = \sum_{i=1}^{4} \delta_i V_c(TO) + p \sum_{j=1}^{4} \delta_j V_f(TO),$$

(9)

$$V_1 = V - \Delta V_{c1}, \quad V_2 = V - \Delta V_{c2},$$

(10)

where $R_{d1}$ – resultant resistance of motor 1, $R_{d2}$ – resultant resistance of motor 2, $R_d$ – armature resistance, $R_{c1}$, $R_{c2}$ – 1st and 2nd H-structure inverter resistance, $V_{c1}, V_{c2}$ – forward and second H-structure inverter voltage reduction, $V$ – voltage value at source, $V_{c(TO)}$ – forward voltage of transistor, $V_{f(TO)}$ – forward voltage of diode, $\delta$ – Kronecker delta, $i, j$ – indexes, $T$ – transistor, $D$ – diode, $V \in \{0, 24\}$ where $V = 24V$ while two transistors or two diodes conducting (factor $p = -1$) and $V = 0V$ in other cases (factor $p = 1$). If any $\delta_i = 1$ or $\delta_j = 1$, that means transistor or diode conducted.
The torques used in (1) are calculated as:

$$M_1 = k_1 \dot{\Psi}_1, \quad M_2 = k_2 \dot{\Psi}_2.$$  \hspace{1cm} (11)

For dynamic and kinematic control (Fig. 4 and Fig. 5), $\dot{x}_A, \dot{y}_A$ are desired velocities of the characteristic point A as in Fig. 1, $\dot{x}, \dot{y}$ are output velocities of the characteristic point A, $x_A, y_A$ are desired positions of the characteristic point A, $\omega$ is the vector of general coordinates, $\omega_{ref}$, $\omega_{ref}$ are reference values vectors of general coordinates, $I$ is the vector of currents of DC motors, $u_{ref}$ is the vector of reference voltages of the motor and $\Theta$ is the vector of disturbances (vector of varying coefficients of the friction between wheels and ground).

Figures 3 and 4 present the controllers structure for dynamic and kinematic control, respectively. Kinematic controller is assumed to be as in [14].
3. Simulation

The model calibration was inspired with Pioneer 2DX [16] technical parameters:

\[ m_1 = 113.4 \text{ kg}, \quad m_2 = 1.5 \text{ kg}, \quad m_3 = 1.5 \text{ kg}, \quad m_4 = 0.5 \text{ kg}, \]
\[ I_{1} = 3.08 \text{ kg} \cdot \text{m}^2, \quad I_{2} = 0.052 \text{ kg} \cdot \text{m}^2, \quad I_{3} = 0.052 \text{ kg} \cdot \text{m}^2, \]
\[ I_{4} = 0.163 \text{ kg} \cdot \text{m}^2, \quad I_{5} = 0.163 \text{ kg} \cdot \text{m}^2, \quad I_{6} = 0.07 \text{ kg} \cdot \text{m}^2, \]
\[ r_1 = 0.0825 \text{ m}, \quad r_2 = 0.0825 \text{ m}, \quad r_3 = 0.0211 \text{ m}, \]
\[ h_1 = l_1/r_1, \quad l = 0.217 \text{m}, \quad l_2 = 0.163 \text{m}, \quad l_3 = 0.07 \text{m}, \]
\[ l_4 = 0.06 \text{m}, \quad f_1 = 0.001, \quad f_2 = 0.001, \quad f_3 = 1.0. \]

For variable \( f_1 \) and \( f_2 \), they are assumed to have normal distribution \( N(0.001, 0.00058) \). The simulation is carried out for an example trajectory as in [12] and for the robot platform (Fig. 1) moving around the characteristic point A (Fig. 5).

In the first second, the robot accelerated and then next 20 seconds it was moving with the constant velocities.

We also analyze for both control types in direct torque or voltage control (as exemplary testing base) and the widely known PWM control. This control (with H Transistor Bridge) is the most popular for changing voltages in DC motors.

Figures 6, 7 and 8 show cases when PD controller with gains \( K_d = 141.0 \) and \( K_p = 473.0 \) is applied. These gains were calculated by means of Hooke-Jeves optimization of the trajectory accuracy [12]. Fig. 7 and Fig. 8 show the movement of the characteristic point A.

4. Simulation results

The errors of the trajectory as in [12] and, for the trajectory with the robot platform moving around the characteristic point A (Fig. 5), were presented in Tables 1 to 4. The errors for the whole trajectory are calculated as follows:

\[ \Delta \beta = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\beta_i - \beta_d)^2}, \quad \Delta \psi = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\psi_i - \psi_d)^2}, \]  \tag{13}
\[ \Delta \dot{\beta} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\dot{\beta}_i - \dot{\beta}_d)^2}, \quad \Delta \dot{\psi} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\dot{\psi}_i - \dot{\psi}_d)^2}, \]  \tag{14}

where: \( \Delta \beta \) – root mean square (RMS) errors of angle \( \beta \), \( \Delta \psi \) – RMS error of angle \( \psi \), \( \Delta \dot{\beta} \) – RMS error of velocity \( \dot{\beta} \), \( \Delta \dot{\psi} \) – RMS error of velocity \( \dot{\psi} \), \( i \) – an individual step, \( n \) – number of steps, index \( d \) stands for desired values. The maximum errors were calculated as H – errors, i.e. as a maximum absolute error for the whole trajectory. Angles \( \beta \) and \( \psi \) and their angle velocities are equal to:

<table>
<thead>
<tr>
<th>Kind of control</th>
<th>( \Delta \beta ) [rad]</th>
<th>( \Delta \psi ) [rad]</th>
<th>( \Delta \dot{\beta} ) [rad/s]</th>
<th>( \Delta \dot{\psi} ) [rad/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic direct</td>
<td>9.19 \times 10^{-2}</td>
<td>3.62 \times 10^{-2}</td>
<td>9.58 \times 10^{-3}</td>
<td>2.61 \times 10^{-1}</td>
</tr>
<tr>
<td>Dynamic direct</td>
<td>5.70 \times 10^{-4}</td>
<td>1.47 \times 10^{-4}</td>
<td>5.52 \times 10^{-3}</td>
<td>2.84 \times 10^{-3}</td>
</tr>
<tr>
<td>Kinematic direct</td>
<td>9.19 \times 10^{-2}</td>
<td>3.62 \times 10^{-2}</td>
<td>9.58 \times 10^{-3}</td>
<td>2.61 \times 10^{-1}</td>
</tr>
<tr>
<td>Dynamic direct</td>
<td>5.71 \times 10^{-4}</td>
<td>1.48 \times 10^{-4}</td>
<td>5.52 \times 10^{-3}</td>
<td>2.86 \times 10^{-3}</td>
</tr>
<tr>
<td>Kinematic PWM</td>
<td>9.97 \times 10^{-2}</td>
<td>3.63 \times 10^{-2}</td>
<td>1.02 \times 10^{-3}</td>
<td>2.62 \times 10^{-3}</td>
</tr>
<tr>
<td>Dynamic PWM</td>
<td>8.08 \times 10^{-4}</td>
<td>2.49 \times 10^{-3}</td>
<td>5.70 \times 10^{-3}</td>
<td>4.13 \times 10^{-3}</td>
</tr>
<tr>
<td>Kinematic PWM</td>
<td>9.97 \times 10^{-2}</td>
<td>3.63 \times 10^{-2}</td>
<td>1.02 \times 10^{-3}</td>
<td>2.62 \times 10^{-3}</td>
</tr>
<tr>
<td>Dynamic PWM</td>
<td>6.55 \times 10^{-4}</td>
<td>1.76 \times 10^{-3}</td>
<td>5.70 \times 10^{-3}</td>
<td>4.27 \times 10^{-3}</td>
</tr>
</tbody>
</table>
\[
\Delta \beta_{\text{max}} = |\Delta \beta|, \quad \Delta \beta'_{\text{max}} = |\Delta \beta'|, \\
\Delta \psi_{\text{max}} = |\Delta \psi|, \quad \Delta \psi'_{\text{max}} = |\Delta \psi'|,
\]
where index \(\text{max}\) denotes the maximum value. Index \(f\) in tables 1 to 4 means that in this simulation we analyzed the varying wheel friction of the ground.

### Table 2. Maximum errors for given in [12] trajectory

<table>
<thead>
<tr>
<th>Kind of control</th>
<th>Maximum errors</th>
<th>(\Delta \beta) [rad]</th>
<th>(\Delta \psi) [rad]</th>
<th>(\Delta \beta) [rad/s]</th>
<th>(\Delta \psi) [rad/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic direct <em>f</em></td>
<td>1.45·10^{-1}</td>
<td>5.94·10^{-1}</td>
<td>2.50·10^{-1}</td>
<td>3.70·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic direct <em>f</em></td>
<td>2.16·10^{-3}</td>
<td>1.39·10^{-3}</td>
<td>2.50·10^{-1}</td>
<td>1.08·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Kinematic direct</td>
<td>1.45·10^{-2}</td>
<td>5.94·10^{-1}</td>
<td>2.50·10^{-1}</td>
<td>3.69·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic direct</td>
<td>2.16·10^{-3}</td>
<td>1.39·10^{-3}</td>
<td>2.50·10^{-1}</td>
<td>1.08·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Kinematic PWM</td>
<td>1.57·10^{-3}</td>
<td>5.95·10^{-1}</td>
<td>2.50·10^{-1}</td>
<td>3.76·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic PWM</td>
<td>3.06·10^{-3}</td>
<td>6.21·10^{-3}</td>
<td>2.50·10^{-1}</td>
<td>1.08·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Kinematic PWM <em>f</em></td>
<td>1.57·10^{-1}</td>
<td>5.95·10^{-1}</td>
<td>2.50·10^{-1}</td>
<td>3.75·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic PWM <em>f</em></td>
<td>2.23·10^{-3}</td>
<td>5.19·10^{-3}</td>
<td>2.51·10^{-1}</td>
<td>1.10·10^{-1}</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3. Root mean square errors for trajectory of robot moving around the characteristic point

<table>
<thead>
<tr>
<th>Kind of control</th>
<th>Root mean square errors</th>
<th>(\Delta \beta) [rad]</th>
<th>(\Delta \psi) [rad]</th>
<th>(\Delta \beta) [rad/s]</th>
<th>(\Delta \psi) [rad/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic direct <em>f</em></td>
<td>1.64·10^{-1}</td>
<td>5.47·10^{-1}</td>
<td>1.39·10^{-1}</td>
<td>3.87·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic direct <em>f</em></td>
<td>8.36·10^{-3}</td>
<td>3.67·10^{-3}</td>
<td>1.91·10^{-3}</td>
<td>8.51·10^{-3}</td>
<td></td>
</tr>
<tr>
<td>Kinematic direct</td>
<td>1.64·10^{-1}</td>
<td>5.47·10^{-1}</td>
<td>1.39·10^{-1}</td>
<td>3.87·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic direct</td>
<td>8.36·10^{-3}</td>
<td>3.67·10^{-3}</td>
<td>1.73·10^{-3}</td>
<td>7.67·10^{-4}</td>
<td></td>
</tr>
<tr>
<td>Kinematic PWM</td>
<td>1.65·10^{-1}</td>
<td>3.64·10^{-1}</td>
<td>1.39·10^{-1}</td>
<td>8.26·10^{-1}</td>
<td></td>
</tr>
<tr>
<td>Dynamic PWM</td>
<td>8.36·10^{-3}</td>
<td>6.68·10^{-3}</td>
<td>1.81·10^{-3}</td>
<td>1.60·10^{-3}</td>
<td></td>
</tr>
<tr>
<td>Kinematic PWM <em>f</em></td>
<td>1.65·10^{-1}</td>
<td>3.71·10^{-1}</td>
<td>1.39·10^{-1}</td>
<td>8.26·10^{-4}</td>
<td></td>
</tr>
<tr>
<td>Dynamic PWM <em>f</em></td>
<td>8.34·10^{-3}</td>
<td>6.47·10^{-3}</td>
<td>1.98·10^{-3}</td>
<td>1.84·10^{-1}</td>
<td></td>
</tr>
</tbody>
</table>

Large errors achieved for simulations with the kinematic control indicate that this control type is insufficient for the mobile robot. As shown in Tables 1 and 3, there is also a significant difference between PWM and a direct voltage control. However, in real models we can use only PWM, as direct control is strictly theoretical. The index _f_ indicates that in the given simulation we analyzed the varying wheel friction of the ground.

### Table 4. Maximum errors for trajectory of robot moving around the characteristic A point

<table>
<thead>
<tr>
<th>Kind of control</th>
<th>Maximum errors</th>
<th>(\Delta \beta) [rad]</th>
<th>(\Delta \psi) [rad]</th>
<th>(\Delta \beta) [rad/s]</th>
<th>(\Delta \psi) [rad/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic direct <em>f</em></td>
<td>2.88·10^{-0}</td>
<td>8.03·10^{-2}</td>
<td>1.72·10^{-1}</td>
<td>4.95·10^{-3}</td>
<td></td>
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<tr>
<td>Dynamic direct <em>f</em></td>
<td>8.69·10^{-3}</td>
<td>3.83·10^{-3}</td>
<td>1.46·10^{-2}</td>
<td>6.34·10^{-3}</td>
<td></td>
</tr>
<tr>
<td>Kinematic direct</td>
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<td>8.03·10^{-2}</td>
<td>1.72·10^{-2}</td>
<td>4.22·10^{-3}</td>
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<tr>
<td>Dynamic direct</td>
<td>8.57·10^{-3}</td>
<td>3.77·10^{-3}</td>
<td>1.47·10^{-2}</td>
<td>6.01·10^{-3}</td>
<td></td>
</tr>
<tr>
<td>Kinematic PWM</td>
<td>2.89·10^{-0}</td>
<td>5.32·10^{-3}</td>
<td>1.74·10^{-1}</td>
<td>1.17·10^{-2}</td>
<td></td>
</tr>
<tr>
<td>Dynamic PWM</td>
<td>8.60·10^{-3}</td>
<td>6.91·10^{-3}</td>
<td>1.70·10^{-2}</td>
<td>1.52·10^{-2}</td>
<td></td>
</tr>
<tr>
<td>Kinematic PWM <em>f</em></td>
<td>2.89·10^{-0}</td>
<td>5.46·10^{-3}</td>
<td>1.74·10^{-1}</td>
<td>1.18·10^{-2}</td>
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</tr>
<tr>
<td>Dynamic PWM <em>f</em></td>
<td>8.66·10^{-3}</td>
<td>6.79·10^{-3}</td>
<td>1.73·10^{-2}</td>
<td>1.51·10^{-2}</td>
<td></td>
</tr>
</tbody>
</table>

Results shown in Table 3 and 4 are encouraging, because, for the robot moving around the characteristic point A, the varying friction does not influence the trajectory. In figures below, \(M_1\) _direct_, \(M_2\) _direct_ stand for torques for theoretical direct voltage control. \(M_1\) _PWM_ and \(M_2\) _PWM_ denote torques for PWM voltage control.

Even though the simulation results for mobile robot moving along the trajectory as in [12] seem to be almost identical as presented Fig. 9-11, results presented in tables 1 and 2 leave no doubt that the kinematic control causes greater deviations compared to dynamic control. For comparison, we present the set torques (Fig. 10).

Fig. 12, 13 and 14 show the torque of mobile robot when rotating around its a fixed axis (characteristic point A).
Fig. 12 and 13 depict theoretical torques for kinematic and dynamic control, from which, when compared to Fig. 14 showing the set torques, we can conclude that for kinematic control the torques are less oscillatory as compared to dynamic control. The reason for this is the impact of angle velocity regulation in dynamic control, which causes a greater sensitivity of the automatic regulation system.

5. Conclusion

In Fig. 9 to 14, we show torques for kinematic and dynamic control types, with and without PWM. We also show the impact of the varying friction coefficient on the trajectory accuracy.

The kinematic controller is not suitable for high accuracy control of the mobile robot, because in our model with a castor sliding wheel the kinematic controller cannot stabilize the motion, as the errors in kinematic control are too large. Such magnitude of errors might have been triggered with too large time constant of the regulator. Given this, the kinematic control should not be applied for mobile robots, as it brings about significant trajectory errors. Our results are conductive for improving the robot simulation procedure so as to achieve results closer to robot behavior in reality.

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