SYNTHESIS OF QUADROTOR POSITION CONTROL SYSTEM

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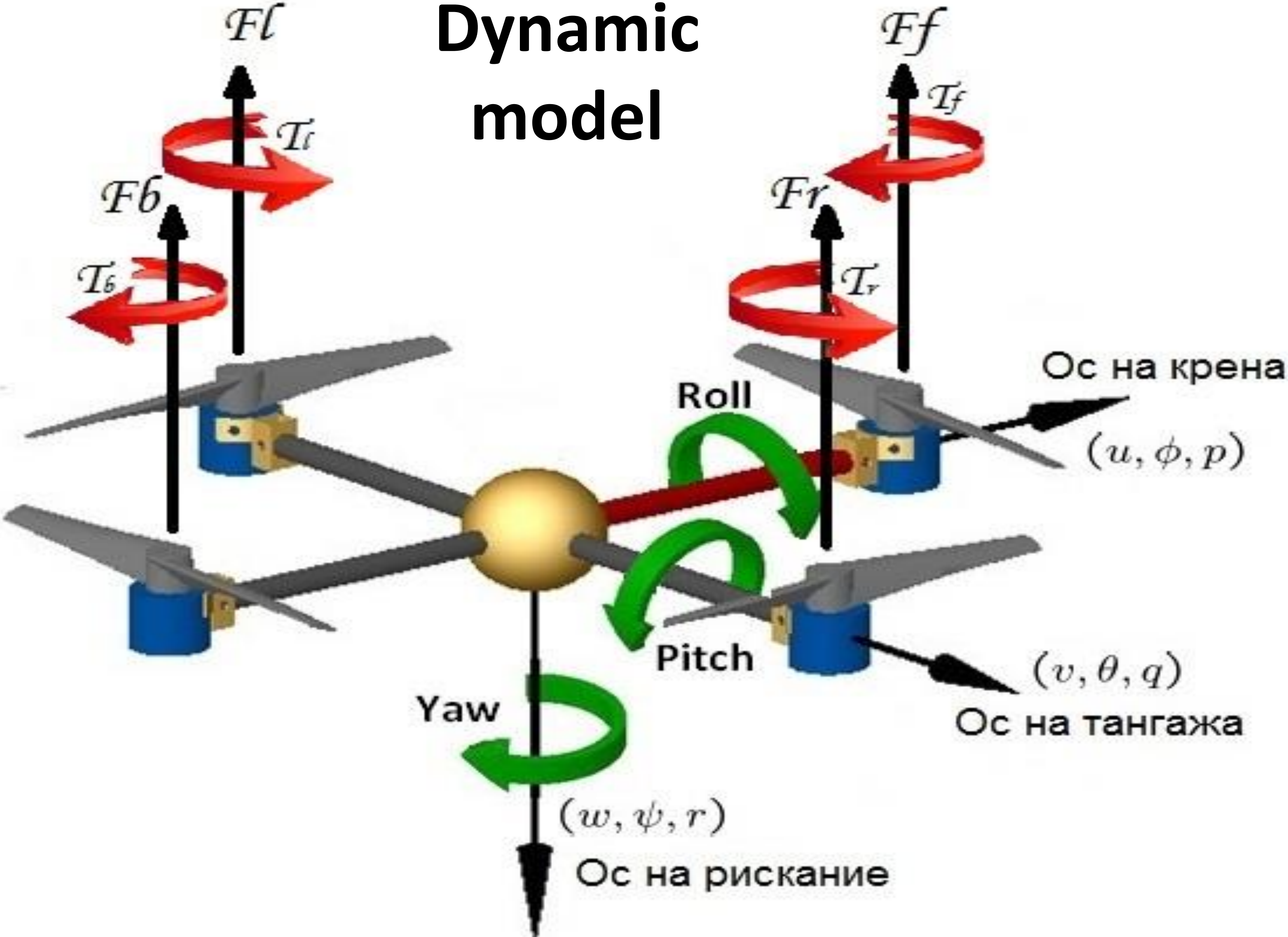
Unmanned aerial vehicles

- The advantages of rotary wing UAVs are achieving a higher degree of freedom, flight on place, vertical takeoff and landing, and low-speed flying.

Dynamic model



Kinematic model

$$\begin{pmatrix} \dot{p}_n \\ \dot{p}_e \\ \dot{h} \end{pmatrix} = \begin{pmatrix} \cos\theta\cos\psi & \sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi & \cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi \\ \cos\theta\sin\psi & \sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi & \cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi \\ \sin\theta & -\sin\varphi\cos\theta & -\cos\varphi\cos\theta \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

$$\begin{pmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{pmatrix} = \begin{pmatrix} rv - qw \\ pw - ru \\ qu - pv \end{pmatrix} + \begin{pmatrix} -g\sin\theta \\ g\cos\theta\sin\varphi \\ g\cos\theta\sin\varphi \end{pmatrix} + \frac{1}{m}\begin{pmatrix} 0 \\ 0 \\ -F \end{pmatrix}$$

- It is assumed that the angles φ и θare too small.
- Coriolis relations are ignored.

$$\ddot{p}_x = \cos\varphi\sin\theta\frac{F}{m}$$

$$\ddot{p}_y = \sin\varphi\frac{F}{m}$$

$$\ddot{p}_z = g - \cos\varphi\cos\theta\frac{F}{m}$$

Dynamic model

$$\begin{pmatrix}\dot{\varphi}\\ \dot{\theta}\\ \dot{\psi}\end{pmatrix} = \begin{pmatrix} 1 & \sin\varphi\tan\theta & \cos\varphi\tan\theta \\ 0 & \cos\varphi & -\sin\varphi \\ 0 & \dfrac{\sin\varphi}{\cos\theta} & \dfrac{\cos\varphi}{\cos\theta}\end{pmatrix}\begin{pmatrix}p\\ q\\ r\end{pmatrix}$$

$$\begin{pmatrix}\dot{p}\\ \dot{q}\\ \dot{r}\end{pmatrix} = \begin{pmatrix} \dfrac{J_y - J_z}{J_x} qr \\ \dfrac{J_z - J_x}{J_y} pr \\ \dfrac{J_x - J_y}{J_z} pq \end{pmatrix} + \begin{pmatrix} \dfrac{1}{J_x}\tau_\varphi \\ \dfrac{1}{J_y}\tau_\theta \\ \dfrac{1}{J_z}\tau_\psi \end{pmatrix}$$

$$\ddot{\varphi} = \frac{1}{J_x}\tau_\varphi$$

$$\ddot{\theta} = \frac{1}{J_y}\tau_\theta$$

$$\ddot{\psi} = \frac{1}{J_z}\tau_\psi$$

- It is assumed that the angles φ и θ are too small.
- Coriolis relations are ignored.

The six degrees of freedom model of kinematics and dynamics of quadrotor

$$\ddot{p}_x = \cos\varphi \sin\theta \frac{F}{m}$$

$$\ddot{p}_y = \sin\varphi \frac{F}{m}$$

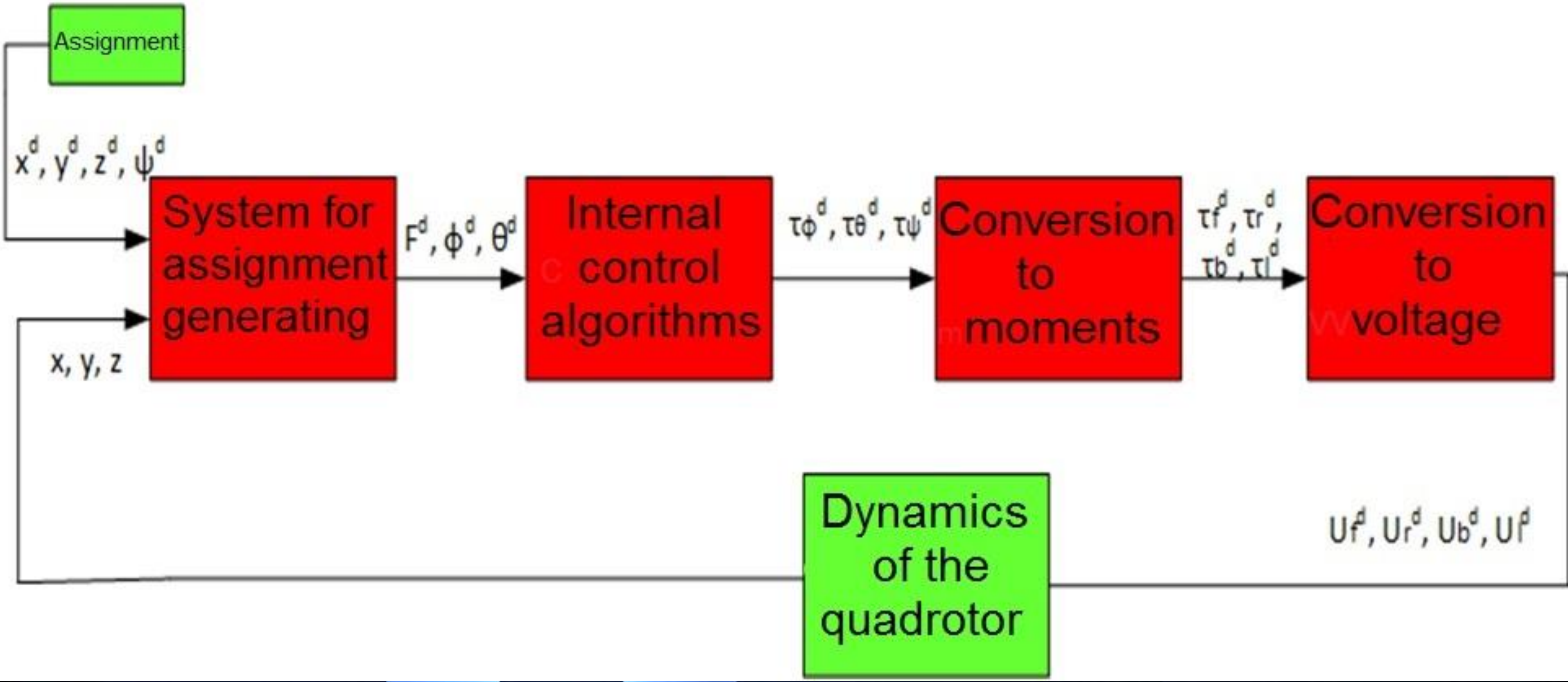
$$\ddot{p}_z = g - \cos\varphi \cos\theta \frac{F}{m}$$

$$\ddot{\varphi} = \frac{1}{J_x} \tau_\varphi$$

$$\ddot{\theta} = \frac{1}{J_y} \tau_\theta$$

$$\ddot{\psi} = \frac{1}{J_z} \tau_\psi$$

Structural block diagram of the control system



System generating assignments

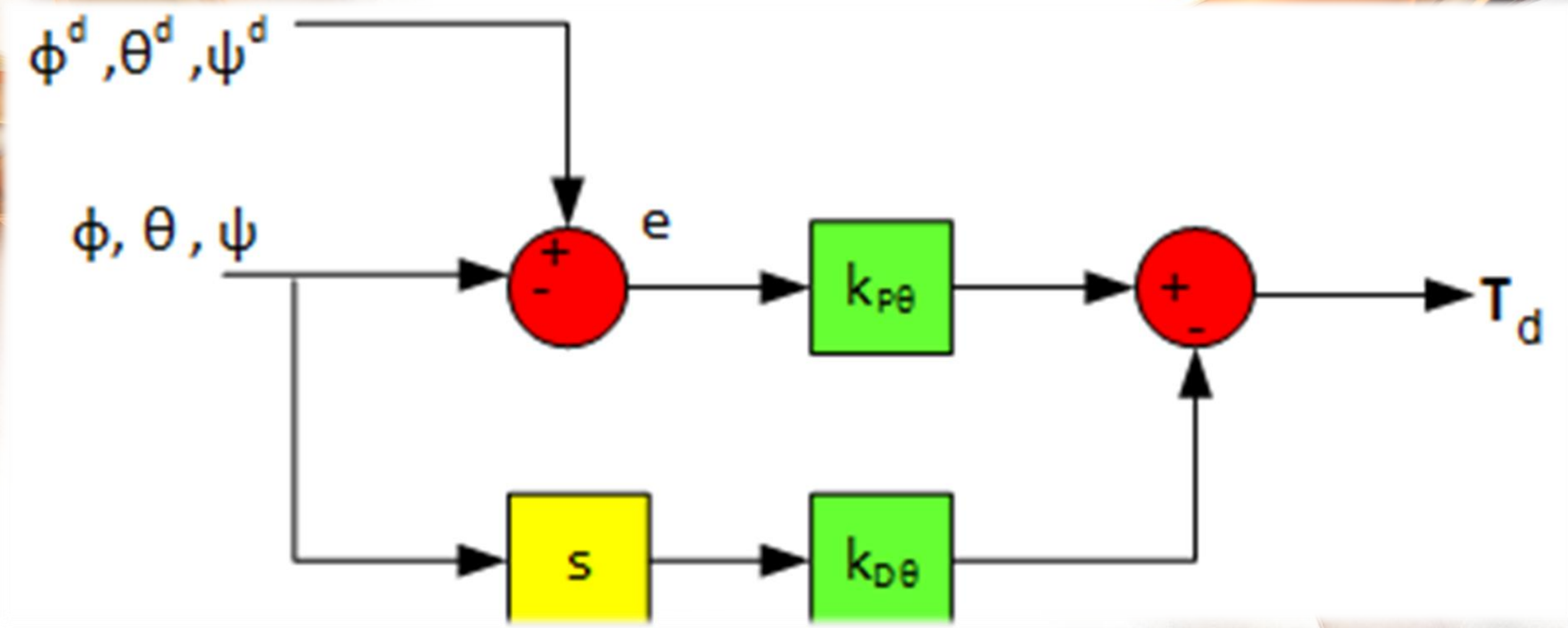
- System generating assignments is the basis of the control algorithms. It processes the task and data by the dynamics of quadrotor and generates the desired angles, necessary for the performance of all the major movements, which balanced the position error.

$$\ddot{e}_x = -k_1\dot{e}_x - k_2 e_x$$

- The movement control at the three axes is achieved by linearization feedback type of input-output.
- It’s obtained the desired total force F, and the desired angles of roll and pitch.

Internal control algorithms

- At the input are submitted the desired roll, pitch and yawn angles and the actual state of the angles. The output of the PD controller gives the desired moments of roll, pitch and yawn angles.



Converting to moments

- The individual moments of each of the motors is obtained from the following relationship:

$$\begin{bmatrix} \tau_f \\ \tau_b \\ \tau_r \\ \tau_l \end{bmatrix} = \begin{bmatrix} l/4 & -1/4 & 1/2 & 0 \\ l/4 & -1/4 & -1/2 & 0 \\ l/4 & 1/4 & 0 & -1/2 \\ l/4 & 1/4 & 0 & 1/2 \end{bmatrix} . \begin{bmatrix} F \\ \tau_\psi \\ \tau_\theta \\ \tau_\varphi \end{bmatrix}$$

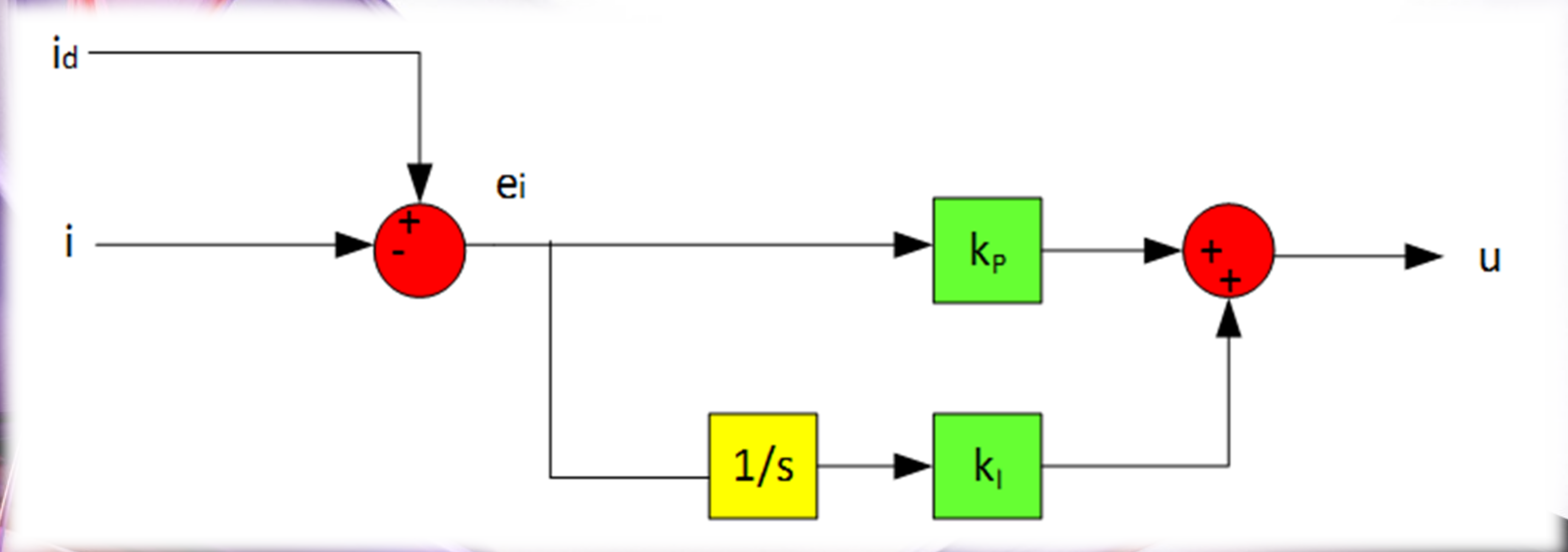
- After calculating the individual desired moments they are converted into current by the formula:

$$\tau_d = k_T i_d \qquad i_d = \frac{\tau_d}{k_T}$$

- Where k_T is a constant torque of the motor

Converting to voltages

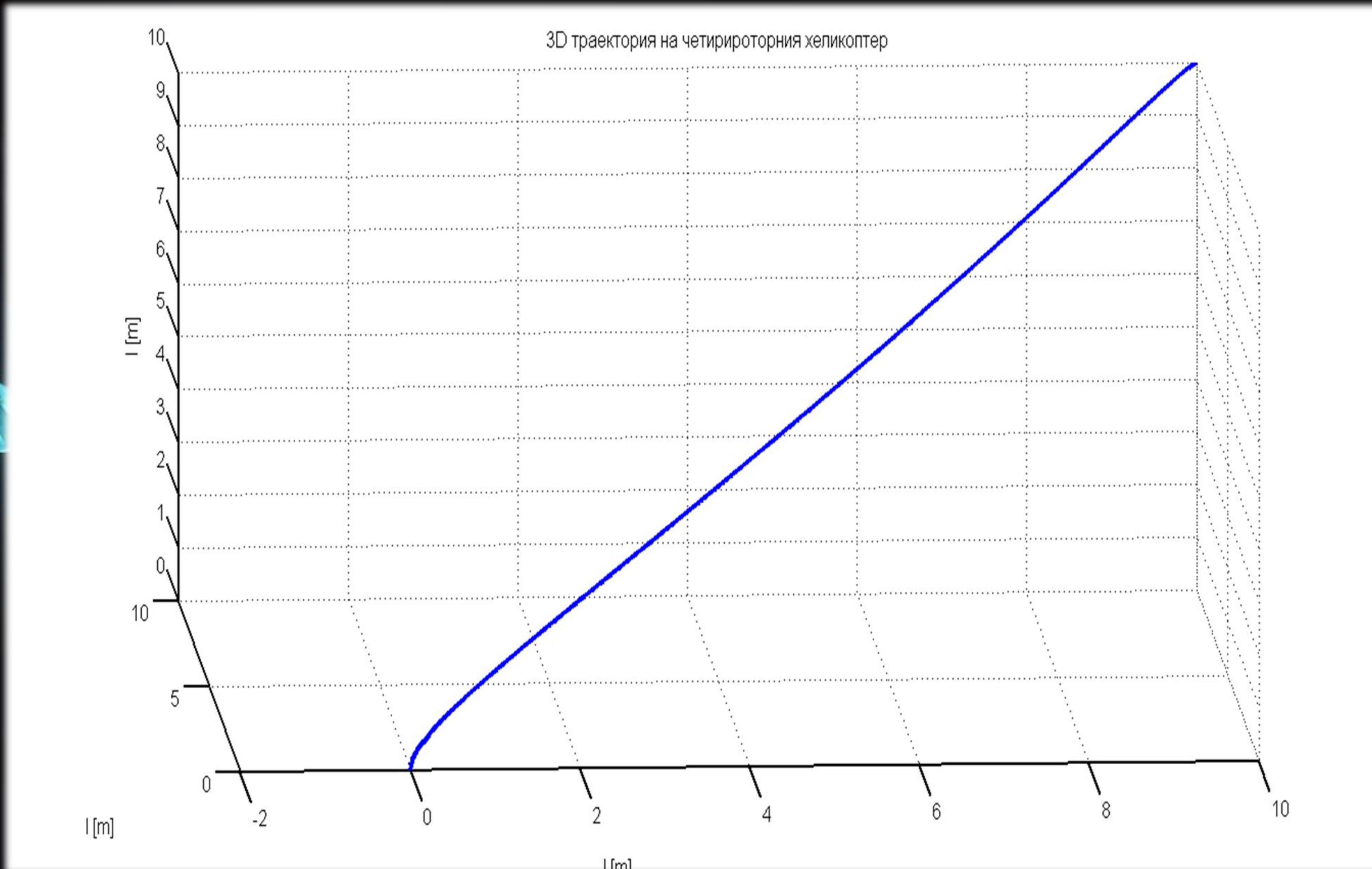
- The desired currents are submitted to the PI regulator that generates the desired voltages of each of the motors.



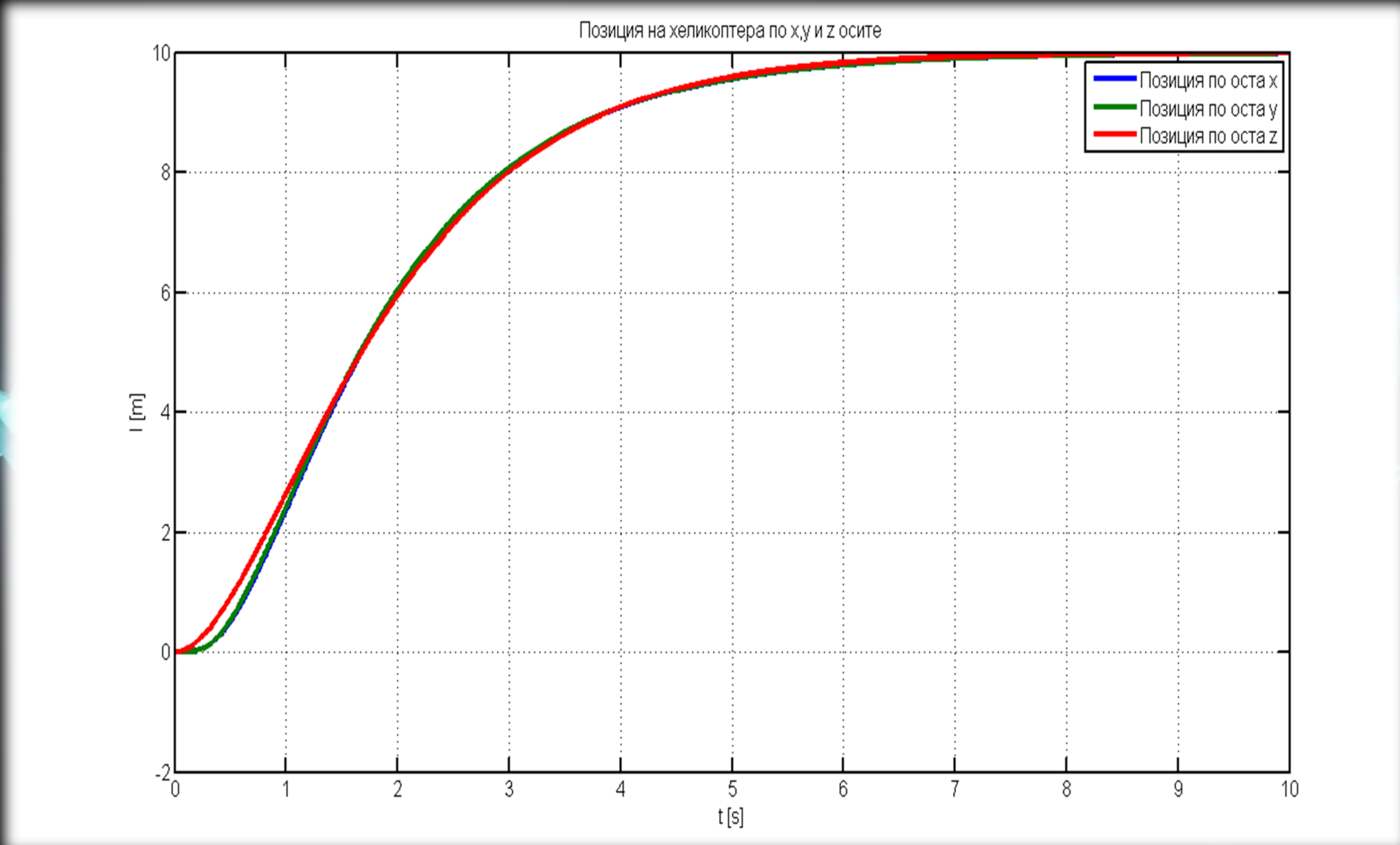
Simulation experiments

- The assignment of the quadrotor is positioning at a point into the space with coordinates x, y and z respectively [10,10,10] meters.

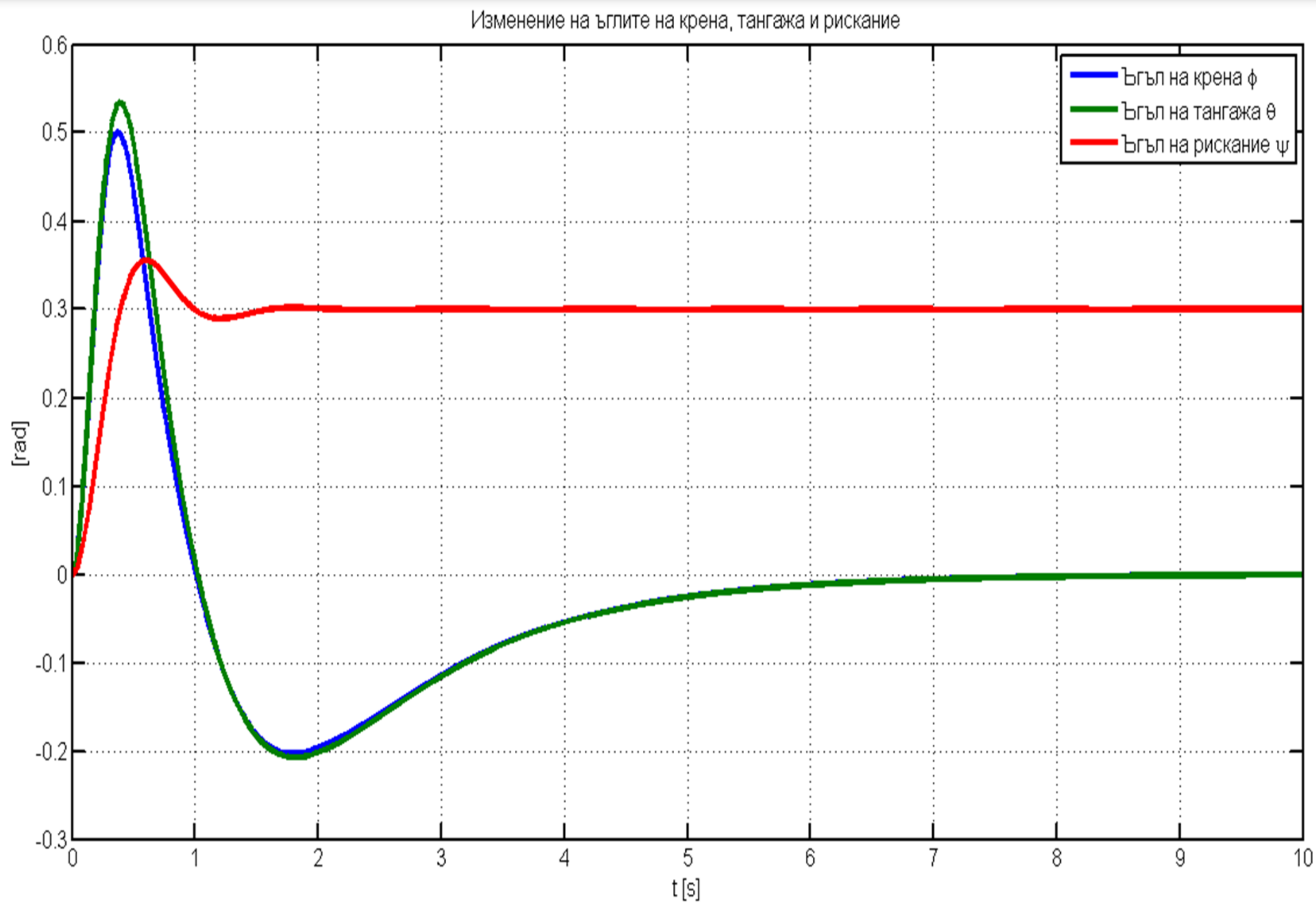
pxd [m]	pyd [m]	pzd [m]	psid [rad]	Ti [s]
10	10	10	0.3	10



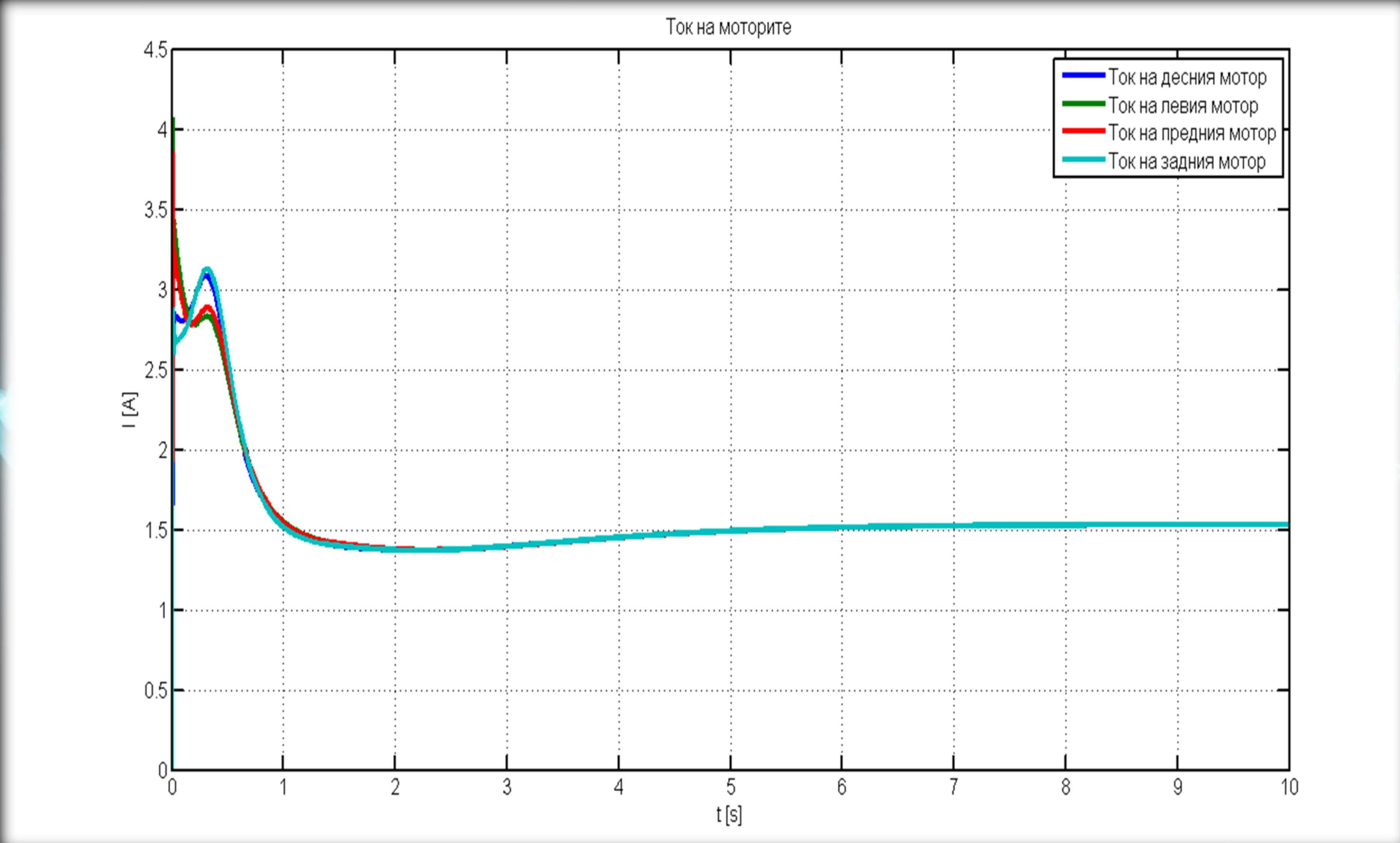
• The system performs pre-defined control objectives with high accuracy.



• It is achieved a stable autonomous behavior of the helicopter at the stabilization in space mode, with high quality transients and smoothly execution of movements.



• The transitional process again performed relatively smoothly and with high quality.

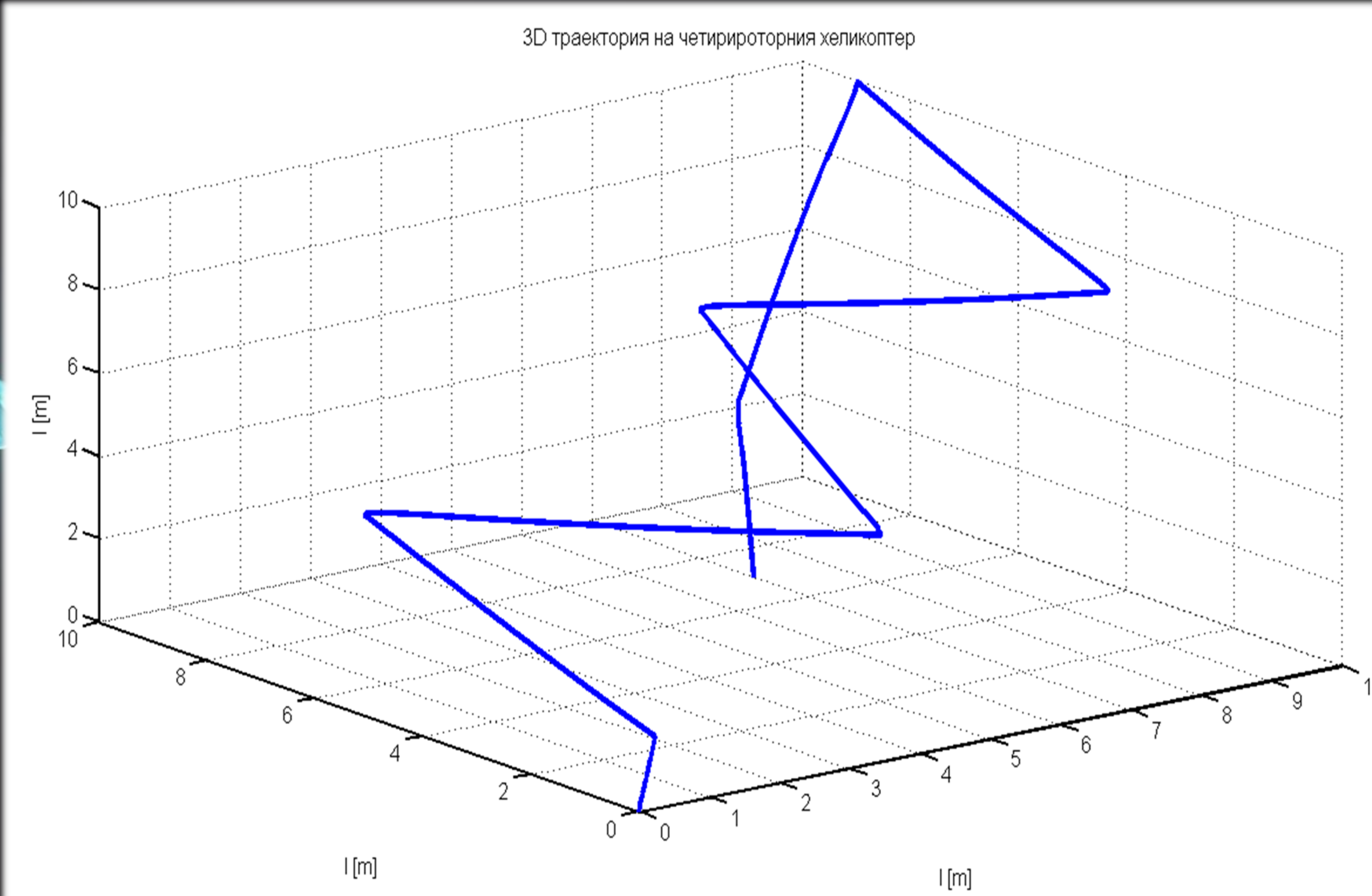


• Currents and voltages of the quadrotor does not exceed 4 A and 5.5 V, which presents the system in good condition for realization in real time.

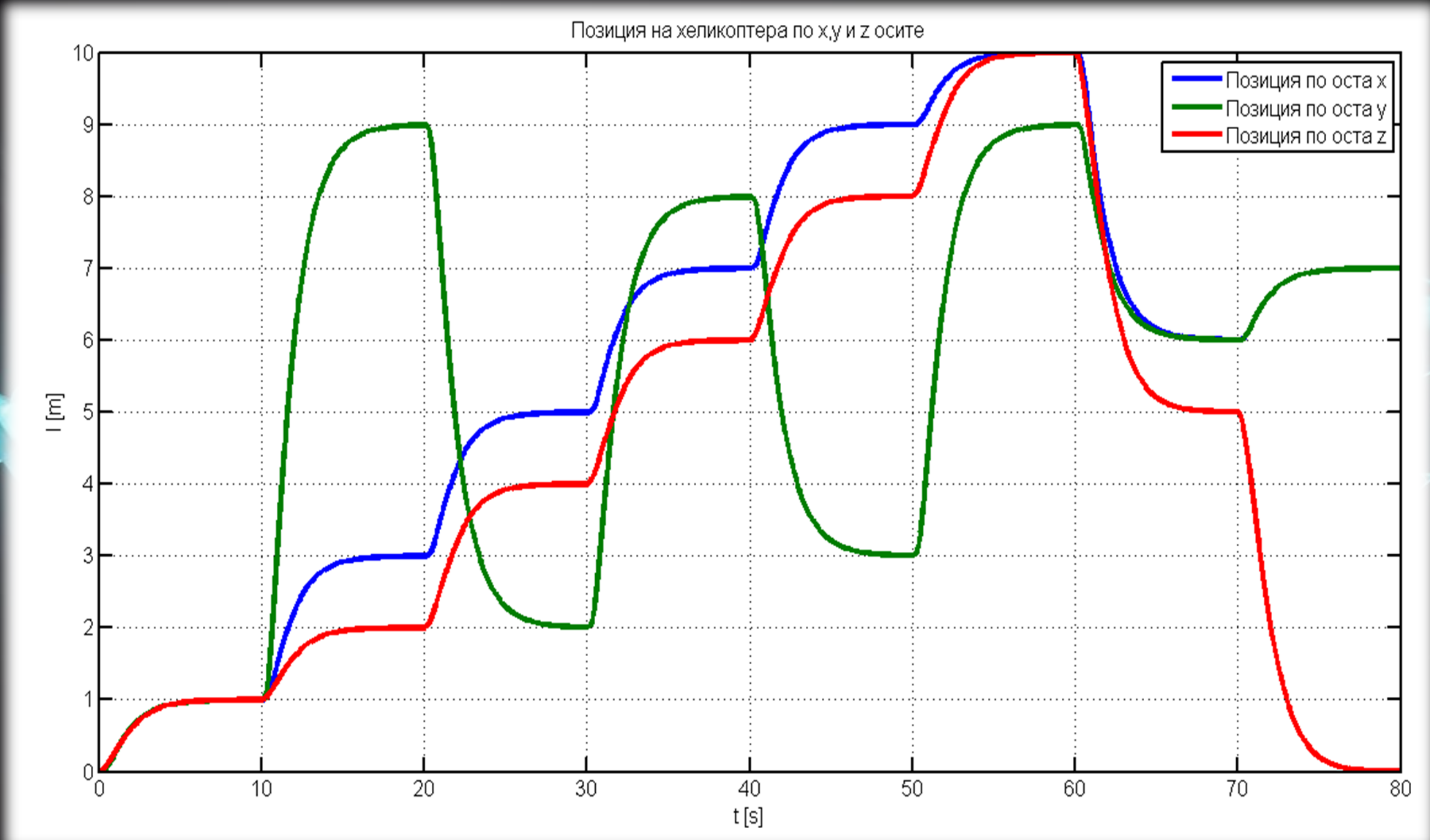
Simulation experiments

- Experiment with a few changes of assignment. Chetirirotorniyat helicopter aims to be positioned at several different points in space at an interval of 10 seconds and landing.

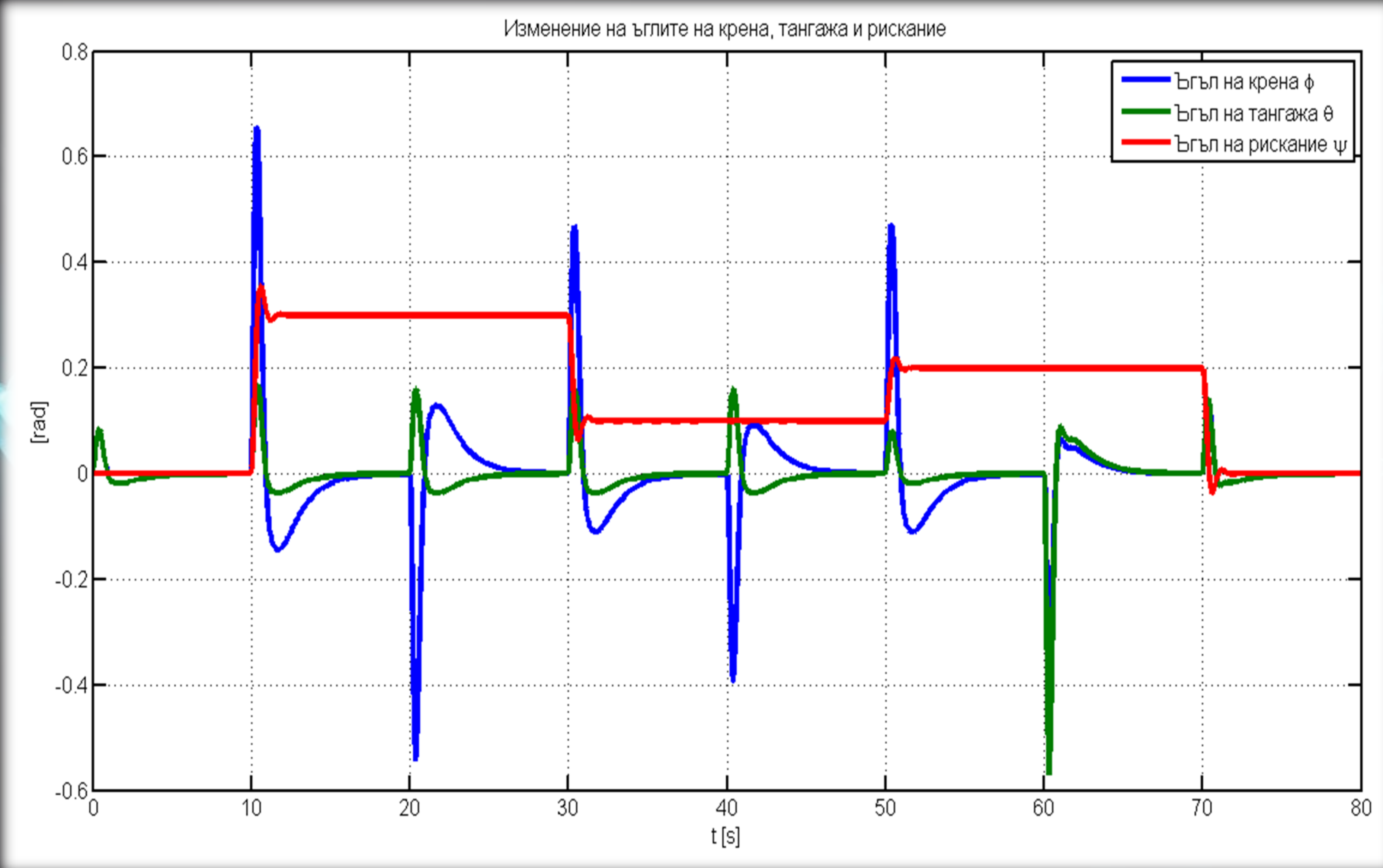
	pxd [m]	pyd [m]	pzd [m]	psid [rad]	Ti [s]
Задание 1	1	1	1	0	10
Задание 2	3	9	2	0.3	20
Задание 3	5	2	4	0.3	30
Задание 4	7	8	6	0.1	40
Задание 5	9	3	8	0.1	50
Задание 6	10	9	10	0.2	60
Задание 7	6	6	5	0.2	70
Задание 8	7	7	0	0	80



• The system performs pre-defined control objectives with high accuracy.



- It is achieved a stable autonomous behavior of the helicopter at the stabilization in space mode, with high quality transients and smoothly execution of movements.



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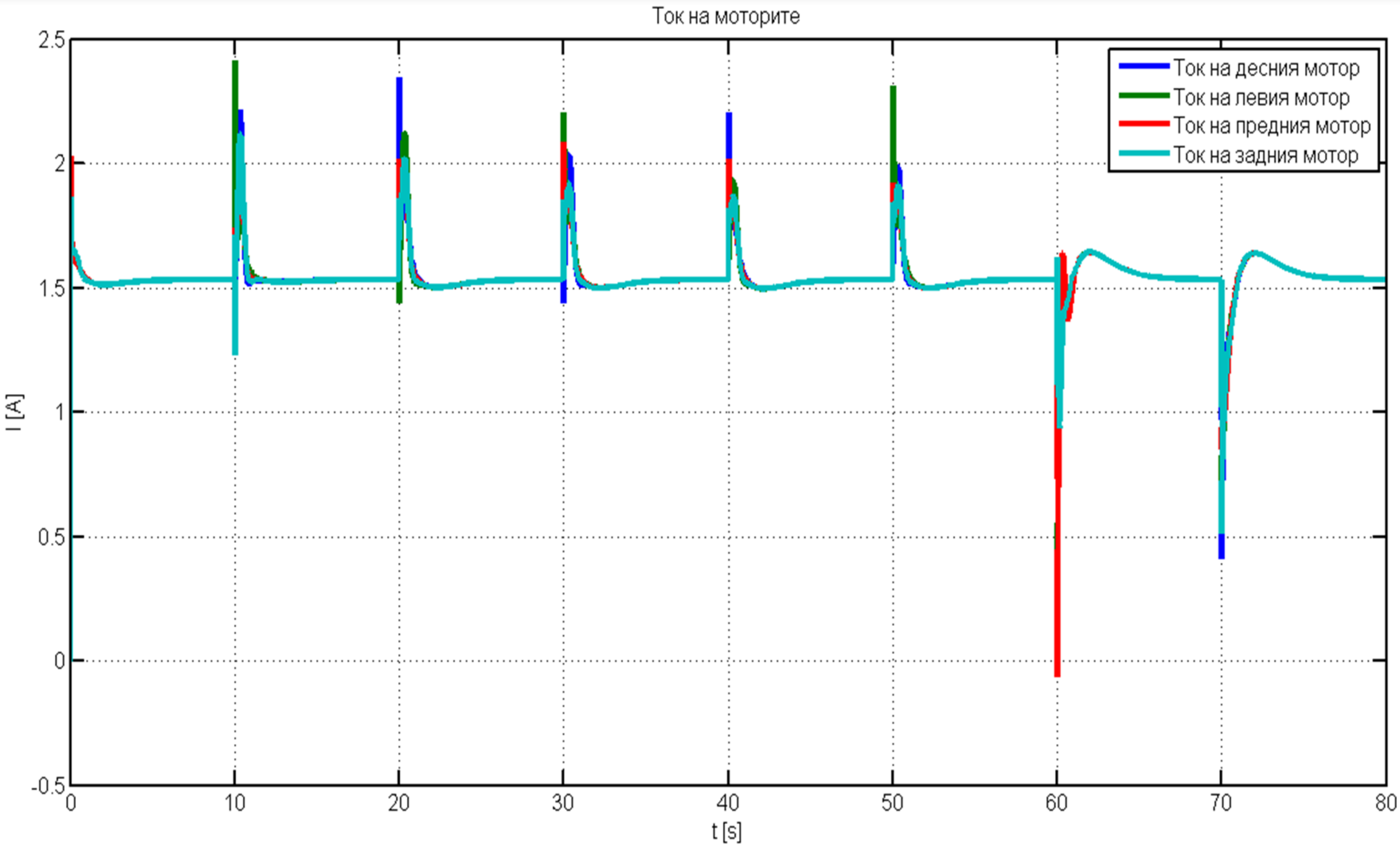

• Currents and voltages of the quadrotor does not exceed 2.5 A and 3 V, which presents the system in good condition for realization in real time.

Conclusions

- Based on the results it can be argued that the purpose of the thesis – system synthesis for position control of quadrotor is executed as results are confirmed by dynamic simulation of nonlinear closed control system.