POTENTIOMETER SENSORS OF AN ANGULAR ACCELERATION FOR RESEARCH ROBOTS TO BENCHMARK SMART CITIES APPLICATIONS

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Annotation**:** The estimations of angular accelerations by means of the potentiometer sensors are considered in the context of the applications in small-scale research robotics prototypes for benchmarking of automation engineering's solutions to support full-scale implementations related with smart cities. It is proved, that potentiometer sensors are possible for instrumental estimations of angular accelerations, but it requires defining the first and second derivatives on the time of the measured voltage incorrect in Adamar's sense, so that it is necessary to propose the suitable regularisation approach to have reliable estimations for angular accelerations.

Key words: smart cities, automation benchmarks, angular acceleration, potentiometer` sensors.

RELEVANCE. Different robotics are involved in smart cities applications to exclude people from monotonous continuous operations and to provide the improved controls of different processes for energy and resource efficiencies to achieve sustainable prosperity and competitiveness of the EU next decades through implementations of green and digital technologies [1]. Automation engineering's solutions providing such improved controls require the suitable small-scale prototypes for reliable benchmarks, and these prototypes must be provided by the correspondent measuring systems, including to measure the angular accelerations of the rotating parts widely represented in the robotics. So, this research related with measurements of angular accelerations is relevant due to necessities in developments of suitable small-scale robotics prototypes for benchmarks of automation engineering's solutions before implementations in full-scale smart cities applications.

A benchmarking of engineering solutions for robotics is the relatively separate problem related including with the development of the suitable prototypes, as it is discussed in the research [2] for an example. The potentiometer sensors are widely discussed in scientific publications like in [3], and they are suitable to develop robotic prototypes for benchmarking of automation engineering solutions due to the accessibility and simple usages, and due to wide possibilities in simulations of digitalised products, whose are discussed in the research [4]. The purpose of this research is in developments of crucial principles for measurements of angular accelerations by means of the potentiometer sensors for applications in small-scale robotics prototypes to support benchmarking of solutions in automation engineering.

RESULTS. To measure angular accelerations, potentiometers with a circular resistive element and the rotated sliding contact are proposed to use in research robotics prototypes for benchmarking of solutions in engineering automation. Such potentiometer is indeed the variable voltage divider, providing the value of the divided voltage as the given function of the supplied voltage and the angle of the rotation of the potentiometer's shaft:

$$U = U_s K(\alpha), \tag{1}$$

where α is the rotation angle of the shaft of the potentiometer; U is the divided voltage; U_s is the voltage supplied for operating the scheme; $K(\alpha)$ is the function defining the dependence between the divided voltage and rotation angle of the shaft of potentiometer.

To measure the angular acceleration of some part of robotics, it is necessary to join this part with the shaft of the potentiometer. Suitable mechanical joints of the shaft of potentiometer with the rotating part of the robotics allow to have the relations between the corresponding angles:

$$\alpha = \alpha(\varphi), \tag{2}$$

where φ is the rotation angle of the part, whose angular acceleration must be measured by the potentiometer sensor with the divided voltage (1).

The relations (1) and (2) prove, that the variable divided voltage on the potentiometer is the composite function of the rotation angle of the considered part of robotics. The derivatives of the composite function (1), (2) have the following views:

$$\frac{dU}{dt} = U_s \frac{dK}{d\alpha}\frac{d\alpha}{d\varphi}\frac{d\varphi}{dt}, \quad \frac{d^2U}{dt^2} = U_s\left(\frac{d^2K}{d\alpha^2}\left(\frac{d\alpha}{d\varphi}\right)^2 + \frac{dK}{d\alpha}\frac{d^2\alpha}{d\varphi^2}\right)\left(\frac{d\varphi}{dt}\right)^2 + U_s\frac{dK}{d\alpha}\frac{d\alpha}{d\varphi}\frac{d^2\varphi}{dt^2}. \quad (3)$$

The measured angular acceleration of the part is the second derivative of the rotation angle:

$$\varepsilon = \frac{d^2\varphi}{dt^2}. \quad (4)$$

The first derivative of the rotation angle φ can be defined from the first relation (3), and taking into account the relation (4), it is possible to use the second relation (3) to find the angular acceleration:

$$\varepsilon = \frac{1}{U_s}\left(\frac{dK}{d\alpha}\frac{d\alpha}{d\varphi}\right)^{-1}\frac{d^2U}{dt^2} - \frac{1}{U_s^2}\left(\frac{dK}{d\alpha}\frac{d\alpha}{d\varphi}\right)^{-3}\left(\frac{d^2K}{d\alpha^2}\left(\frac{d\alpha}{d\varphi}\right)^2 + \frac{dK}{d\alpha}\frac{d^2\alpha}{d\varphi^2}\right)\frac{dU}{dt}. \quad (5)$$

To simplify the relation (5) it is recommended to use the linear potentiometer and the linear joints of the shaft of potentiometer with the rotating part:

$$\frac{d^2K}{d\alpha^2} = 0, \frac{d^2\alpha}{d\varphi^2} = 0 \Rightarrow \varepsilon = \frac{1}{U_s}\left(\frac{dK}{d\alpha}\frac{d\alpha}{d\varphi}\right)^{-1}\frac{d^2U}{dt^2}. \quad (6)$$

The divided voltage (1) can be easily measured, but the results (5) and (6) shows that estimations of angular accelerations of the rotating part by means the joined potentiometer (1), (2) require first and second derivatives on the time of the measured voltage. At the same time, even high-quality measuring devices provide low errors to measure voltage do not allow defining the derivatives on the time for the measured voltage, because of differentiating a function is incorrect operation in Adamar's sense. Due to these circumstances, the relations (5) or (6) cannot be used directly, and it is necessary to develop the suitable regularisation procedure.

CONCLUSIONS. The potentiometer sensors are possible for instrumental estimations of angular accelerations due to the inherent opportunities in representing the estimated value through the related electrical voltage, which can be easily measured directly. At the same time, the principal difficulties in estimation of angular accelerations exist due to that it is required to define the first and second derivatives on the time of the measured voltage, so that the relation between the measured voltage and the estimated angular acceleration is incorrect in Adamar's sense, and cannot be used directly. So, to provide reliable estimations of angular accelerations by potentiometer sensors, it is necessary to propose the suitable regularisation approach, and further research is envisaged for it.

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