РОЗДІЛ ІІІ. ЕНЕРГЕТИКА, ЕЛЕКТРОТЕХНІКА ТА ЕЛЕКТРОМЕХАНІКА

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EXPERIMENTAL IDENTIFICATION OF SENSITIVITY OF TILT SENSOR

Urgency of the research. *Robots and vehicles which locomote on high slope ground has tendency to overturning and they lost stability during the locomotion. The problem also occurs in area of automotive industry.*

Target setting. *All vehicles moving on the rough and inclined ground has a problem with stability. Emergency system for warning before dangerous tilt angle can be mounted inside the vehicles and robots as prevention of side overturning.*

Actual scientific researches and issues analysis. *The problem is to find the reliable sensor for detection of dangerous tilt angle. Task is to identify the sensor properties as sensitivity, zero shift and also uncertainty of measurement. Before using it is necessary to identify sensor properties.*

Uninvestigated parts of general matters defining. *The questions of the filtering of data acquisition by tilt angle sensor are uninvestigated, because the next research will be focused to this topic.*

The research objective. *Sine bar is used for verification and testing of tilt sensor. Sine bar angle is adjusted using the parallel length gauge blocks. Sensor reacts to the changed tilt angle proportionally with pulse width on output pulse width signal. Indication of sensed data is made via using the microcontroller and LCD display. Also all calculations are executed inside the microcontroller.*

The statement of basic materials. *The tilt sensor can be mounted inside the problematic vehicles to detect dangerous tilt angle and also automatic system for change the center of gravity position can be designed. The system will compensate the dangerous tilt angle.*

Conclusions. *Evaluated uncertainties are related to overall sensing system and not only for sensor. Only sensor alone cannot be tested, because the sensor has no indication module. Expanded uncertainty of the system for measurement of tilt has been obtained and it is value should be taken into account before the sensor using.*

Keywords: *Mobile robot; locomotion; pipe; cleaning; parallelogram; chimney.*
Fig.: 8. References: 17.

Introduction. Service robots use a various sensors for detecting of internal state quantities and also quantities of outside world. On the base of these sensors data, control system of robot reacts to any situation. Tilt sensor can be used for the measurement of inclination of robot body as prevention of stability lost. It can be used for wheeled, tracked and also legged robots [1-10].

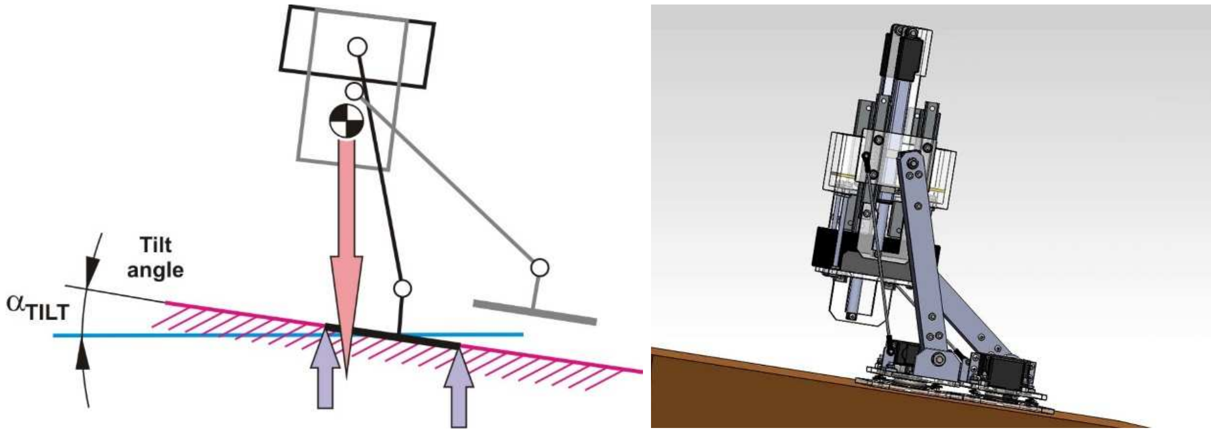

Fig. 1. Tilt stability of legged robot

Off-road vehicles also locomote on inclined ground and in this situation also they can lost stability and overturning of vehicle can occurs. Sideways overturning has to be checked. Also the tilt sensor can be used for monitoring of actual tilt of vehicle.

Analysis of stability needs to know the position of center of gravity of vehicle (CoG). Center of gravity Vehicle will roll over in case when the center of gravity is placed outside of its base of stability. Base of stability is an area between points, where vehicle has contact with ground.

Roll-over protection system can be installed in vehicle as prevention of sideway stability lost. System includes the sensors for detection of dangerous vehicle tilting.

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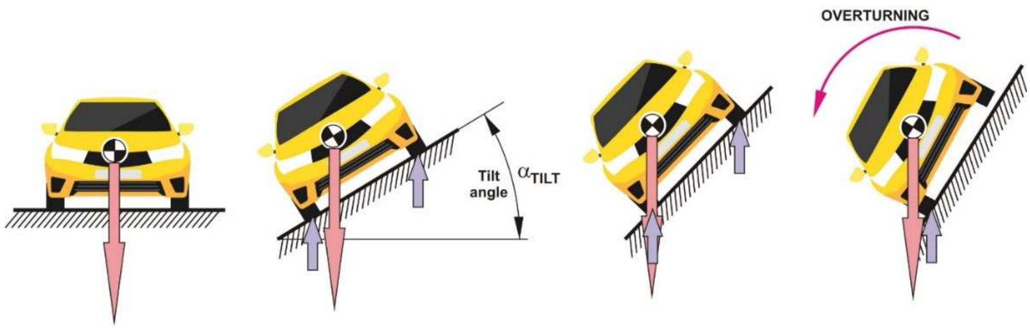

Fig. 2. Sideway stability of vehicle

Actually there are several used sensors for this purposes which uses mechanical parts as pendulum with inertial mass or ball system, which has frequently malfunction and limited life. This work explored the using of sensor without any mechanical parts. Main contribution of this work is verifying of usability of the proposed system for the tilt measurement.

The paper deals with testing of tilt sensor probably useful for the roll-over protection system. The precision of the sensor system should be known, because of evaluation, how we can believe to the sensing system. Using of the unreliable sensor will cause the vehicle accident [11-17].

1. Tilt sensor principle. Tilt sensor is working on principle based on heat temperature array (fig. 3). It includes heat chamber with source of heat in the middle of chamber and four temperature sensors place in corners of the chamber.

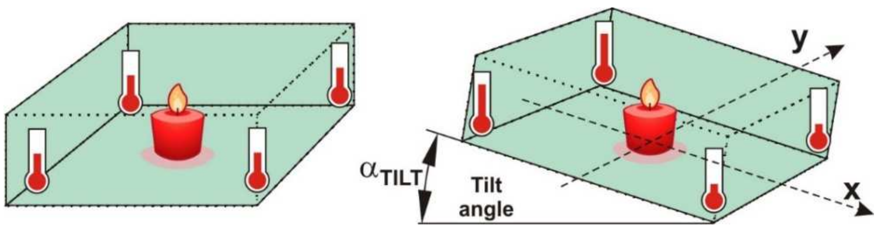

Fig. 3. Heat temperature array chamber of sensor

If sensor is in horizontal position in both axes, then all four sensors will detect equal temperature. If sensor is tilted, then measured temperatures differ in accordance with tilt angle. Tilt angle in both axes can be calculated from measured temperatures. Output quantity is pulse with modulation signal, which represents the searched tilt angle. The sensor is able to obtain tilt angle in both axes X and Y and also there are independent two pulse with modulation signals for tilt angles. Duty cycle of pulse with modulation signal changes linearly with tilt angle in both axes.

The sensor is produced via using the MEMS technology and there is no moving parts inside the sensor, so the sensor has better resistibility against the damaging.

The technology used for producing does not enable to produce tilt sensors with equal properties (sensitivity, zero shift etc.). For this reason it is necessary to identify the sensitivity of each sensor to obtain maximum accuracy of measurement.

Output signal (fig. 4) which is on sensor output is rectangular pulse with modulated signal with constant period T and duty cycle D is holding the information about tilt angle. Consequently, there is a need to measure of duration time logical high state t_H.

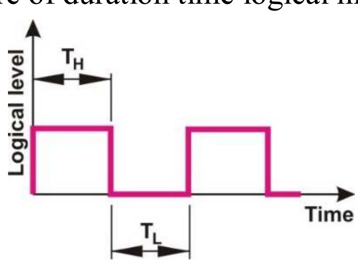

Fig. 4. Output signal from tilt sensor

Producer of sensor provides the math model for tilt angle measurement α_{TILT}:

$$\alpha_{TILT} = arcsin\left(\frac{t_H - 5}{C_S}\right), \quad [18] \tag{1}$$

where t_H is duration time of logical high state in pulse with modulation signal (ms).

C_S is a sensitivity of sensor and producer provides only an interval of possible values of sensitivity. For accurate measurement, it is necessary to experimentally identify the value of sensor sensitivity.

2. Experimental identification of sensor sensitivity. Experimental system (fig. 5) has been built for this purpose. It consist of sine bar and parallel gauge blocks placed under one end of sine bar. Sine bar has rectangular body fixed on two cylinders at the both ends. Axis distance between the cylinders is known. Top surface of bar is parallel to the line composed through the centres of cylinders. Tilt sensor is placed on top surface of sine bar. Inclination is adjusted via using of suitable parallel gauge length blocks. Tilt angle can be calculated from sine rule in rectangular triangle.

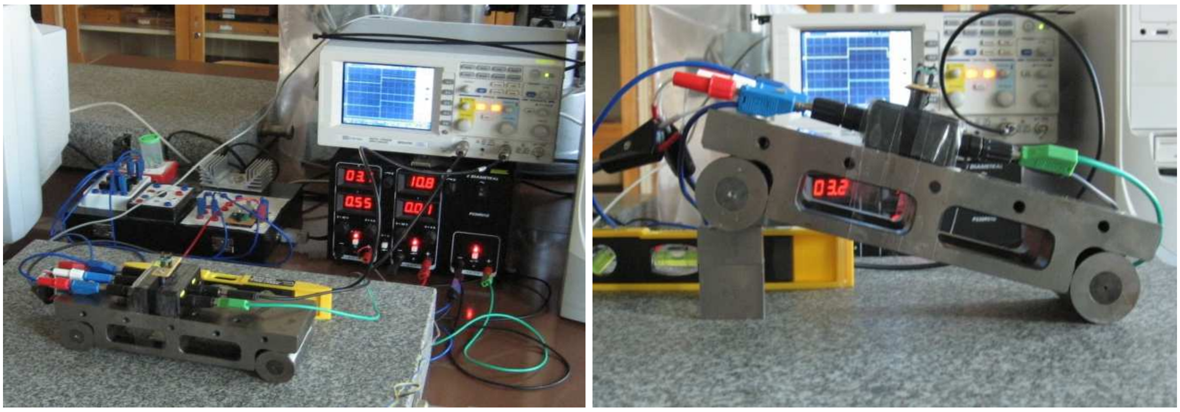

Fig. 5. Experimental system for testing of tilt sensor

Duration time of logical high state (pulse width of pulse modulated signal) is measured via using the oscilloscope and also microcontroller with LCD display which is currently used for this purpose.

From the model (1), it is possible to derive static characteristic model:

$$t_H = C_S \cdot \sin(\alpha_{TILT}) + 5, \ [18] \tag{3}$$

Figure 6 shows measured data and its linear approximation. After regression analysis the new linear model is obtained.

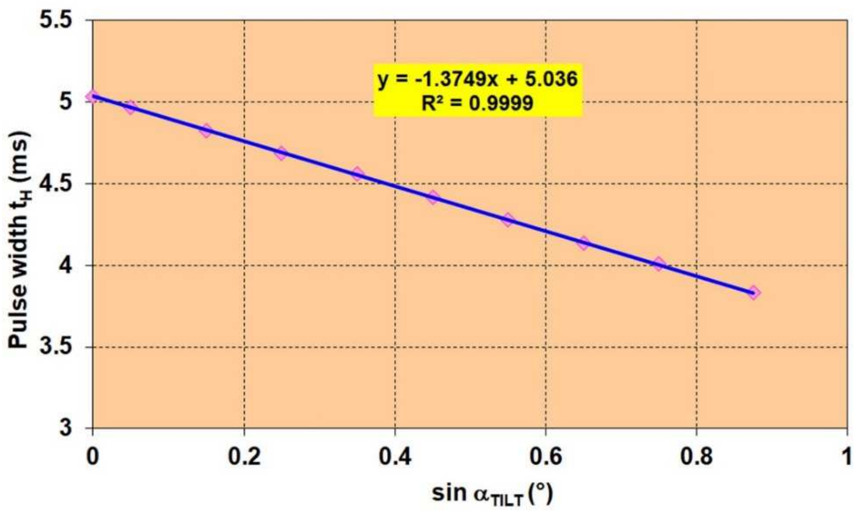

Fig. 6. Experimental data from measurement on sine bar setup

Linear model (fig.6) shows that sensitivity has value C_S = -1.3749 ms and also zero shift has different value Z_S = 5.036 ms. Model (3) includes zero shift with value 5 ms.

From experimental data it is possible to write new modified math model of measurement with corrected coefficients:

$$\alpha_{TILT} = arcsin\left(\frac{5.036 - t_H}{1.3749}\right) \quad (4)$$

Corrected math model will provide more accurate results from measurements. After derivation it can be obtained an uncertainty of coefficients determined on math model (fig. 6):

$$u_{Cs}^2 = \frac{n}{n \cdot \sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)^2 - \left(\sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)\right)^2} \cdot \sigma^2 \quad (5)$$

$$u_{Zs}^2 = \frac{\sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)^2}{n \cdot \sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)^2 - \left(\sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)\right)^2} \cdot \sigma^2 \quad (6)$$

where σ is standard deviation of duration time measurements t_H and it can be obtained from selected residual dispersion:

$$\sigma_{MSE}^2 = \frac{1}{n-2} \cdot \sum_{i=1}^{n}\left[t_{Hi} - \left(C_S \cdot sin(\alpha_{TILT} + Z_S)\right)\right] \quad (7)$$

Covariance is a characteristic, which defines the joint variability of our coefficients sensor sensitivity C_S and sensor zero shift Z_S:

$$u_{Zs}^2 = \frac{-\sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)}{n \cdot \sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)^2 - \left(\sum_{i=1}^{n}\left(sin(\alpha_{TILT})\right)\right)^2} \cdot \sigma^2 \quad (8)$$

Obtained model (4) can be implemented into microcontroller for recalculation of measured time into requested tilt angle. Also after verification it is possible to identify standard uncertainty of measurement of tilt angle realised using the tested tilt sensor (fig. 7). Ten measurement have been executed for every values of tilt angle. All standard uncertainties are less than 1° or 0.017 radians.

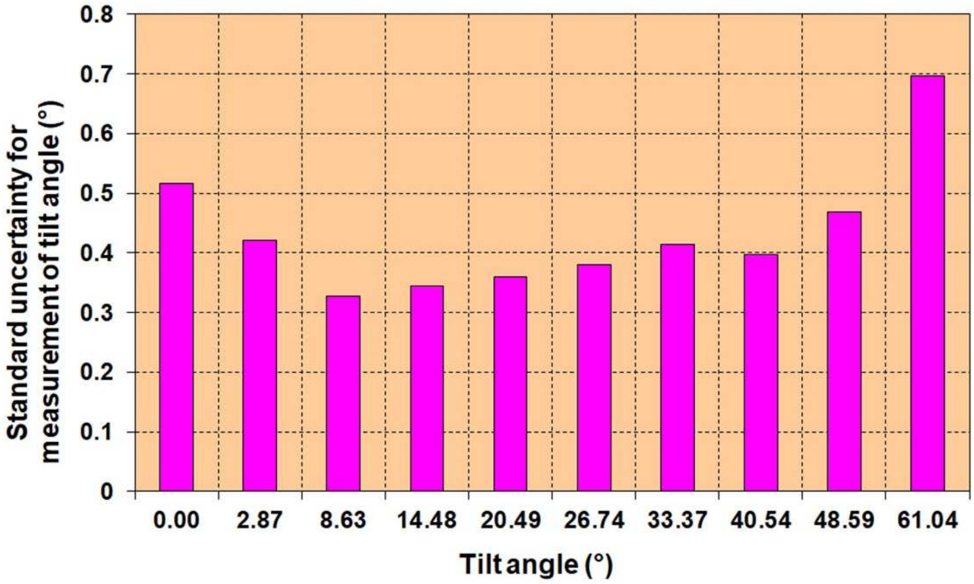

Fig. 7. Standard uncertainty of measurement of tilt angle

Before final evaluation it is necessary to analyse also errors of used sine bar and parallel length gauge blocks (fig. 8). As it is visible, the maximum inaccuracy of sine bar with gauge blocks is 0.5°. Overall uncertainty of tilt angle measurement is affected also with accuracy of sine bar with gauge blocks. For the better results and knowledge of uncertainty of tilt sensor is necessary to use etalon with better accuracy value. Duration time has been measured via using the microcontroller counter and also this inaccuracy should be used for final evaluation.

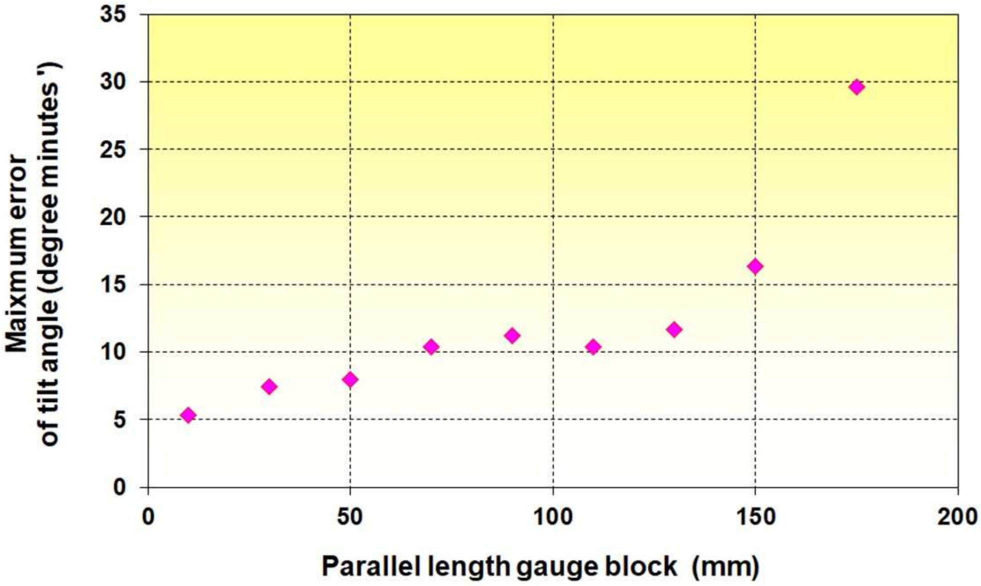

Fig. 8. Maximum inaccuracy of sine bar with parallel length gauge blocks

Expanded uncertainty is calculated and maximum values is 1.2° and it is for rectangular distribution with coverage factor $\sqrt{3}$ at probability level 95%. This uncertainty also includes contribution from microcontroller. Required expanded uncertainty is under 2°, but it depends on concrete applications.

Conclusion. Purpose of this research was to test commercial tilt sensor and identify the sensitivity and zero shift of the sensor. It is necessary to do it, because of variability of the sensor properties produced by manufacturer. Producer provides the interval for sensitivity coefficient in range between the values from 1.18 ms to 1.32 ms. Our sensor sensitivity is out of this range and it confirms the necessity of testing the sensor. Also producer defines zero shift to value 5ms, but for our sensor the values of zero shift is 5.036 ms. These identified coefficients for sensors help to decrease the overall uncertainty of tilt measurement.

Sensor was included into measurement system which also includes microcontroller and LCD display module. It is necessary to say, that also microcontroller brings any contribution overall uncertainty of measurement. Consequently, all evaluated uncertainties are related to overall sensing system and not only for sensor. Only sensor alone cannot be tested, because the sensor has no indication module. Expanded uncertainty of the system for measurement of tilt angle is 1.2° and its value should be taken into account before the sensor using.

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УДК 004.4

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ЕКСПЕРИМЕНТАЛЬНЕ ВИЗНАЧЕННЯ ЧУТЛИВОСТІ ДАТЧИКА НАХИЛУ

Актуальність теми дослідження. *Роботи та транспортні засоби, які рухаються на крутих схилах, мають тенденцію до перекидання, коли вони втрачають стійкість під час руху. Проблема також виникає в галузі автомобільної промисловості.*

Постановка проблеми. *Усі транспортні засоби, що рухаються по нерівній і похилій землі, мають проблеми зі стабільністю. Аварійна система попередження перед небезпечним кутом нахилу може бути встановлена всередині транспортних засобів та роботів для запобігання бічному перекиданню.*

Аналіз останніх досліджень і публікацій. *Проблема полягає у пошуку надійного датчика для виявлення небезпечного кута нахилу. Завдання – визначити властивості датчика, такі як як чутливість, зсув нуля, а також похибку вимірювання. Перед використанням необхідно визначити властивості датчика.*

Виділення недосліджених частин загальної проблеми. *Питання фільтрації збору даних датчиком кута нахилу не досліджені, тому дане дослідження буде зосереджено на цій темі.*

Постановка завдання. *Для перевірки та випробування датчика нахилу використовується блок для дослідження кута нахилу. Кут повороту самого блоку для дослідження кута нахилу регулюється за допомогою вимірювальних* *блоків паралельної довжини. Датчик реагує на змінений кут нахилу пропорційно ширині імпульсу на вихідний сигнал імпульсу. Індикація отриманих даних здійснюється за допомогою мікроконтролера та РК-дисплея. Також всі розрахунки виконуються всередині мікроконтролера.*

Виклад основного матеріалу. *Датчик нахилу може бути встановлений всередині проблемних транспортних засобів для виявлення небезпечного кута нахилу, а також може бути розроблена автоматична система для зміни положення ваги. Система компенсує небезпечний кут нахилу.*

Висновки відповідно до статті. *Оцінені похибки вимірювання, пов'язані не лише з датчиком, але й із загальною системою вимірювання. Датчик окремо не може бути протестований, оскільки він не має модуля індикації. Отримана розширена невизначеність системи для вимірювання нахилу, тому її значення слід враховувати перед використанням датчика.*

Ключові слова: *мобільний робот; пересування; труба; очищення; паралелограм; джерело вогню.*

Рис.: 8. Бібл.: 17.

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