THE MACHINE LEARNING CONCEPT FOR AN INCLINATION SENSOR

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ABSTRACT: In this study, it is aimed to create a sensor which may be able to learn with artificial intelligence. The sensor constituted is an industrial inclination sensor. Due to centrifugal force and/or shocking impacts, inclination sensors may have incorrect measurements. Decree of action that causes this error however has been measured by an acceleration sensor. It has been intended to remedy and correct the error of inclination and obtain a usable inclination data. Acceleration sensor, inclination sensor, data logger card have been installed on a platform. Inclination and acceleration values have been simultaneously observed and recorded. Data have been analyzed with WEKA Machine Learning Program. Rules obtained have been used as code in "Arduino". Thus, using the machine learning technique, and with the support of arduino programming card, a system which transforms measurements of inclination and acceleration sensor to utilizable inclination measurement value has been achieved.

Keywords – Machine learning, Inclination sensor, acceleration sensor, Arduino, Weka, Inclination balancing system

INTRODUCTION

Inclination sensors perform inclination measurement according to a specified reference position angle. As from the position which was accepted as a reference the inclination sensor gives an analog output pro rata the amount of angle made. This analog output is generally 4-20 mA or 0-10 V for industrial sensors, according to the type of the sensor chosen. Inclination sensors are vital for systems which are specifically mobile and requiring self-balancing. Inclination sensors are used for providing information to the operators working at fixed positioned construction machines, concrete pumps, drilling platforms (rigs), military platforms, etc. which are prone to tipping risk due to gradient. In the more widespread manner, however, they are used at industrial automation systems in such sectors as space, aviation, agriculture, production and construction machines, etc. (*Bayrakçeken and Yeşilırmak, 2009*). Inclination balancing systems however are very important for military vehicles, construction machines. Inclination sensors beside protection of tipping inclination limits of military vehicles and construction machines have been used for operation at construction machines (*Köse et al., 2012*). Preference of inclination balancing/stabilization systems in agricultural equipment and machinery, in combined harvester (Figure 1) with over 4,20 m work width, in agricultural pesticide machines and specifically in sensitive ground leveling machines is popular and common.

Figure 1. Combined harvester.

Likewise, in ground leveling machines, in controlling the scraper blade, it is also common to use the inclination sensors (Figure 2).

Figure 2. Ground leveling with grader.

In such kind of machines which do not make circular movements inclination sensors have been usually supported with oil and spring reinforced dampers. Response times are adequate for longer and general utilization purposes. Nevertheless inclination sensor's behaviors in much sensitive works robot control or for a sensitive ground leveling must be within a specified tolerances. Success of automation systems has a direct relation with the achievement of sensors. For an item which can be measured incorrectly in an automation system the decision given by the automation system will not be correct in this respect.

In this study, it is aimed to create a sensor system which may be able to learn with artificial intelligence. The sensor system will be used to measure the precise inclination in an automation system. In order to correct the errors of inclination sensor, an acceleration sensor is added into the system. The variables of acceleration and inclination sensors are obtained by ARDUINO sd module and then analized by WEKA. The rules used to correct inclination errors are obtained by WEKA and these rules are used as a software in the system.

MATERIALS AND METHODS

In this study it is intended to correct an erroneous measurement which was performed by an inclination sensor under the effect of centrifugal force. The inclination sensor is a system made up of pendulum, potentiometer and damping components. The damping components cause small vibrations to lead measurement error and help prevent shocking impacts. However if at the axis (Z) where inclination is measured the sensor is moved laterally at axis X (Figure 3), pendulum of the sensor cannot preserve its inertia against this movement. The sensor gives an erroneous output value under the impact of centrifugal force (*Kubat and Kiraz, 2012*). Moreover, if the pendulum preserves its inertia, then it cannot measure the inclination under the normal conditions.

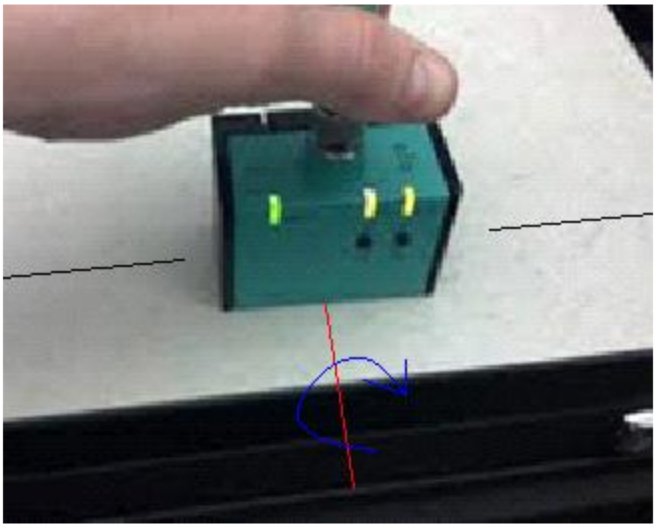

Figure 3. Centrifugal force impact to which the inclination sensor was exposed.

Centrifugal Force Effect causes measurement error in the inclination sensor and the automation system gives a response by considering such erroneous measurement as a real inclination value (*Çalışkan, 2007*). Consequently, the incorrect gradient causes to access to a response of another automation system which is different from the desired one.

A lot of studies have been carried out for filtering measurement values for general sensor errors. However the most known is Kalman filter. In a dynamic system shown with state space model, it is such a filter that conditions of the system can be forecasted from input and output information together with the previous data and information of the model. It was found by Rudolf Kalman who was Hungarian origin, American mathematical system theorist.

Observation theory, based on a decided point of view, is a path to be followed for the system's condition forecast. If the system's stochastic or random noisy aspect is taken into account, minimum variance estimate or Kalman filter is convenient. Kalman Filter, as is the same for the conventional estimators, despite its filtering feature, is very powerful and talented in order to estimate non-measurable conditions of the system. It is an algorithm which has been used especially in car navigation (despite the aviation typical, other fields of application are also available) since 1960s, providing an estimation optimized on the system's state. Algorithm, operating as recursive real time on noisy, input observation data flows (typically sensor measurements) filters errors by least square curve fitting method and optimize according to the mathematical estimate of the future state generated by modeling of the system's physical characteristics.

Model estimation is compared with the observation and this difference is scaled with a multiplier known as Kalman's gain, which later on is feedback to the mode as an input in order to improve the next coming estimates. The gain can be "adjustable" for improved performance. With a high gain the filter follows the observations more closely. With a lower gain, it follows the filter model estimates more closely. The method converges to produce closer estimates than the estimates that may be obtained on the basis of the real unknown values, a single measurement or solely model estimates. At each time step, Kalman filter produces the estimates of real unknown values together with their uncertainties. When the result of the next measurement is observed, these estimates are updated with weighted mean, by giving much more weight onto the estimates whose uncertainty is low.

From a theoretical point of view, the main hypothesis of Kalman filter is that the underlying system was a linear dynamic system and all errors and measurements have got Gaussian distribution (often multivariable Gaussian distribution). In this system however what effects behavior of the sensor is the impact of a centrifugal force whose time is not known. This system is not a linear dynamic system. A centrifugal force whose time is uncertain and its size is uncertain affects this system as an external force. To make a long story short, Kalman filter is not also a solution for this system.

Such size which affects inclination sensor with acceleration sensor. Data of inclination sensor and data of acceleration sensor have been recorded simultaneously. However, thousands of data must be assessed in order to examine this relationship. Manually processing of huge amount of data and making their analysis are impossible. For the purpose of finding solution machine learning methods have been developed.

Artificial intelligence technology has been developing more every passing day. New products have been produced and they have appeared mostly in daily life. Automation systems however have been equipped with artificial intelligence and eventually users have been benefiting from computer’s decision making power. Brand new commercial systems have been emerging every passing day and functional features of systems have been increased. The present technology has been making contribution to people for producing useful products in daily life of people. Artificial neural networks ensure computer’s learning (*Öztemel, 2012*).

Machine learning is a method paradigm making inferences from existing data by using mathematical and statistical methods, making estimations on the unknown through these inferences and it is also defined as the improvement of behaviors in time. The purpose of machine learning is to create systems that think like human beings, behaves like human beings, conduct logic/reason and act rational/wisely (*Pirim, 2006*).

Machine learning, specifically in case of absence of human experience, when space duties, imitation of our inexplicable skills, facial recognition, speech recognition, solutions depending on situation (time) become necessary, in a computer network orientation operation, special applications, biometry, diagnosis in the field of health, in the fields of automatic problem solving can be used.

Machine learning methods try to find the best suitable model to the data by using the previous data. They analyze new data also in accordance with this model and get result. Different applications have had expectations different from analyses. Thus, a problem can be solved by making inference from previous existing examples. Machine learning methods may be classified as classification, clustering, regression and curve fitting.

RESULTS AND DISCUSSION

Empirical study method includes that in addition to the inclination sensor, at the direction of axis X of the inclination sensor an acceleration sensor is to be involved in the system. At the same direction data of sensor is observed on Arduino LCD screen and is recorded with Arduino sd card module. Choice of sensor is as follows: PEPERL FUCHS make acceleration sensor and inclination sensor were chosen for the empirical study. Code of the inclination sensor is INY360D-F99-2I2E2-V17, complete with double axes measuring feature. In this study it was used at one-way measurement (Figure 4).

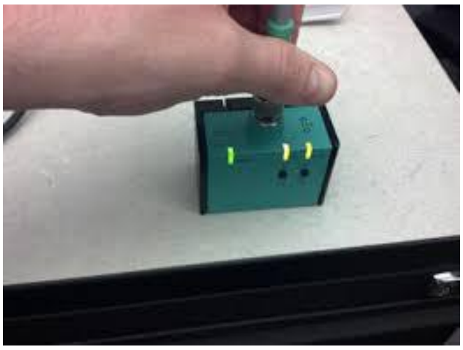

Figure 4. Inclination sensor reference position.

Inclination Sensor Technical Data

General specifications

- Type Inclination sensor, 2-axis
- Measurement range 0 ... 360°
- Absolute accuracy ≤ ± 0,5 °
- Response delay ≤ 25 ms
- Resolution ≤ 0,1 °
- Repeat accuracy ≤ ± 0,1 °
- Temperature influence ≤ 0,027 °/K

Electrical specifications

- Operating voltage UB 10 ... 30 V DC
- No-load supply current I0 ≤ 25 mA
- Time delay before availability tv ≤ 200 ms

Analog output

- Output type 2 current outputs 4 ... 20 mA
- (one output for each axis)
- Load resistor 0 ... 200 Ω at UB = 10 ... 18 V
- 0 ... 500 Ω at UB = 18 ... 30 V
- Mass 240 g

While inclination sensors' being two or single axis do not affect measurement of individual inclinations at axes, axes interact on the acceleration sensors. This is a great problem. Therefore, a single axis acceleration sensor with Code No: ACX04-F99-I-V15 was chosen (Figure 5).

Figure 5. Single axis acceleration sensor.

Acceleration Sensor Technical Data

General specifications

- Type 1 axis
- Measurement range -2 ... 2 *g*
- Resolution ≤ 5 m*g*
- Repeat accuracy ≤ ± 5 m*g*
- Frequency range 0 ... 100 Hz

Electrical specifications

- Operating voltage UB 10 ... 30 V DC
- No-load supply current I0 ≤ 25 mA
- Time delay before availability tv ≤ 100 ms

Analog output

- Output type 1 current output 4 ... 20 mA
- Zero signal 12 mA
- Slope of output characteristic 4 mA / *g*
- Linearity error ± 1,2 %
- Load resistor 0 ... 200 Ω at UB = 10 ... 18 V
- 0 ... 500 Ω at UB = 18 ... 30 V
- Mass 240 g

The two sensors were fixed together on a metal plate (Figure 6). This plate can rotate around axis 1° +/-45°. It can be fixed at a specified position with a bolt.

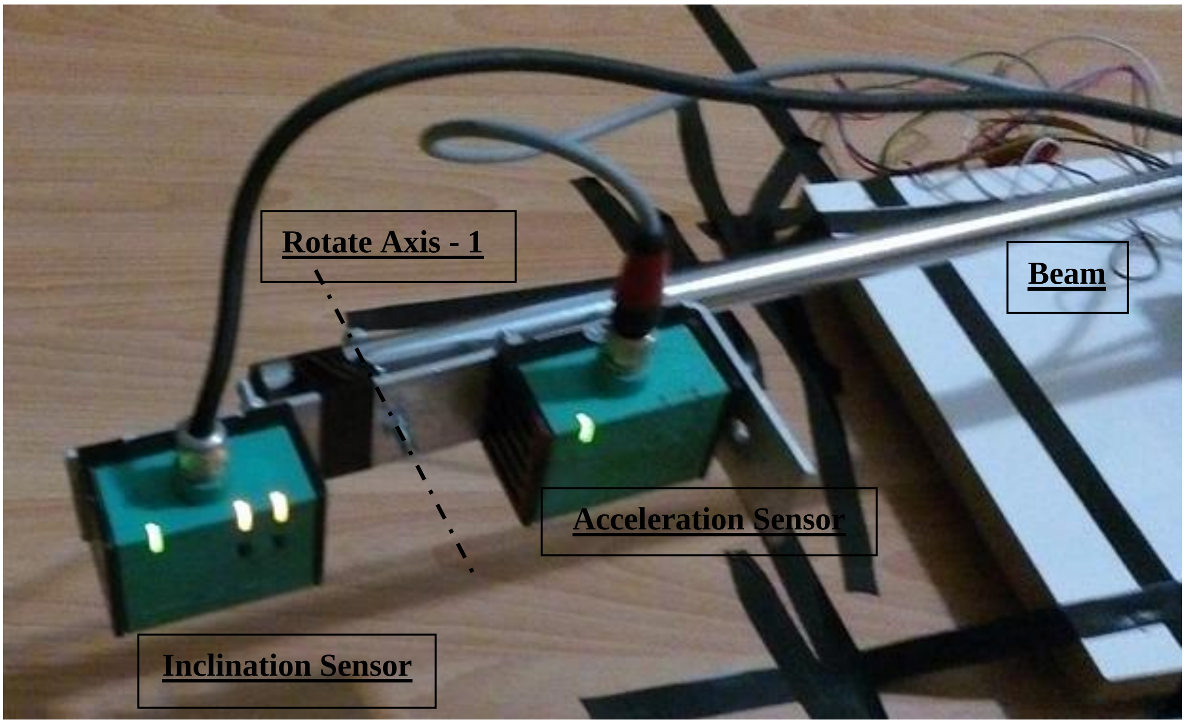

Figure 6. Positioning of inclination and acceleration sensors on a metal plate.

The two sensors have been mounted to the tip of a 1,2 m long rod with this metal plate. The long carrier bar can be moved by a step motor at different speeds. Several tests were conducted consecutively at different rotational speeds of step motor. While the fixed inclination sensor's measurement value should not change, a change was observed on the inclination and acceleration with the rotational movement of the long bar (Figure 7).

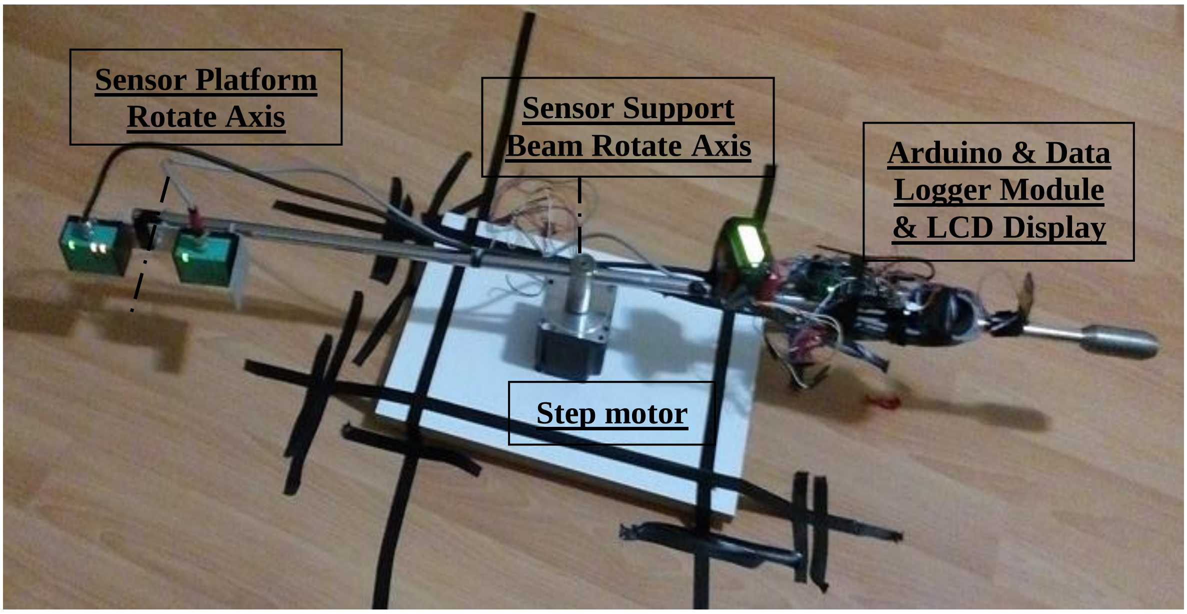

Figure 7. Test system.

Plate, while the long bar was not rotating, was moved at (-45°/+45°) angles and values were recorded. Additionally, for 17 different random angle values (-45°/+45°) at which the plate was fixed, instantaneous acceleration and inclination values were also recorded with the rotation of the long carrier bar at different speeds (Table 1).

Table 1. Measured inclination values and data numbers

330	3936
427	8228
480	9743
482	10753
507	12263
534	18604
535	19590
795	21611
303	26118
387	30194
407	31807
518	37763
522	38878
524	41176
529	43200
555	45966
593	47863
0-1023	53672

In the present study the simultaneous data were recorded with Arduino sd Card module. A certain part of the data is shown on Table 2:

Table 2. Simultaneous data values recorded with Arduino sd Card module.

Instantaneous Inclination	Instantaneous Acceleration	Inclination Required to be Measured	Inclination Error	Acceleration Difference to the Reference (544-544)
534	544	534	0	0
544	552	534	-10	-8
551	549	534	-17	-5
545	540	534	-11	4
511	529	534	23	15
465	518	534	69	26
415	506	534	119	38
363	504	534	171	40
341	504	534	193	40
544	552	534	-10	-8
551	549	534	-17	-5
545	540	534	-11	4
511	529	534	23	15
465	518	534	69	26
415	506	534	119	38
434	523	534	100	21
386	524	534	148	20
392	513	534	142	31
313	500	534	221	44
316	497	534	218	47
318	499	534	216	45
322	504	534	212	40
392	513	534	142	31
395	521	534	139	23

Upon analyzing the table, in the relation between acceleration difference and inclination difference, Equation 1 may be obtained. However, whenever the acceleration difference gets higher, then it is seen that the coefficient of 2.24 rises up to 4.68.

Inclination Error = (Acceleration Difference) x 2.24 (2.24.....4.68) (1)

Inasmuch as the fact that our purpose is to protect and preserve the measured inclination value against centrifugal force and to obtain a useable inclination value, it is not necessary that we should reveal and indicate the relationship between the inclination and the acceleration by means of a formulation. We will use the relationship in Arduino as code. Therefore the relationship may be expressed in all manners as multi-formulation, classification and clustering, etc. Data can be analyzed with WEKA which is a data mining program. WEKA which has got a completely modular design and with its specifications is capable of doing such operations as visualization, data analysis, business intelligence applications, data mining, etc. on datasets. WEKA software, as sui generis, has come with the support of ARFF extension. However WEKA software contains tools that may be used for converting CSV files to ARFF format. Basically the following 3 Data Mining transaction may be performed by WEKA:

- Classification
- Clustering
- Association

WEKA is one of the most used 10 software in the field of business intelligence, likewise ranks among the top three in the most used free software ranking on the issue of business intelligence. With WEKA you can use artificial neural networks algorithms, classification and clustering algorithms, regression algorithms and association algorithms, even if you do not know their content. It covers almost all known data mining algorithms. Moreover, graphical presentation of the consisting outputs is rather satisfactory.

In this study data for WEKA was prepared in Excel file and saved as WEKA file. While performing examination, for the choice of filter, unsupervised - attribute -Numeric to Nominal was preferred (Figure 8).

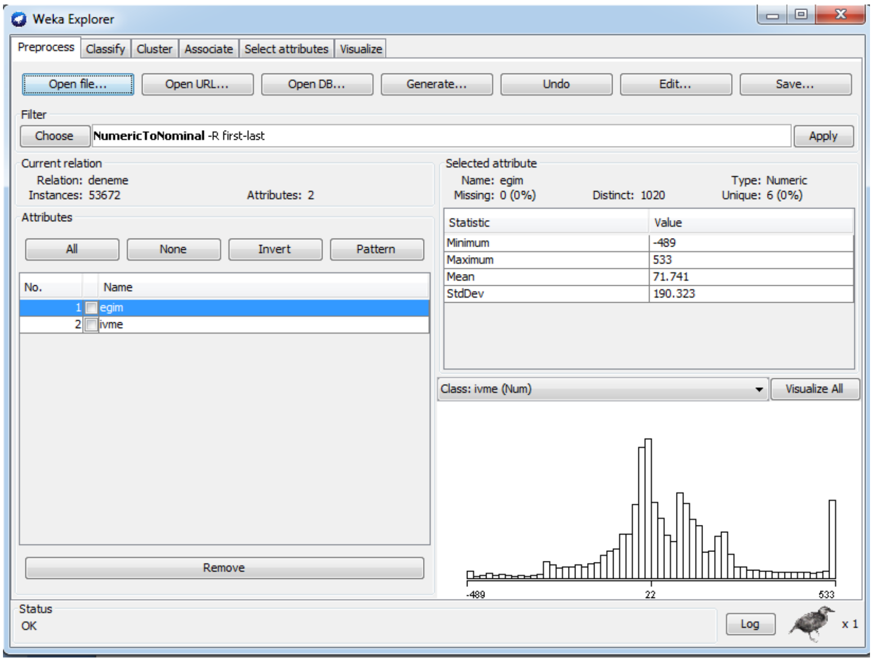

Figure 8. WEKA user interface filter choice and breakdown of data.

Classify - OneR is chosen. Inclination difference values related with the acceleration difference were thus obtained. A certain part of data obtained, are shown in Table 3.

Table 3. Inclination correction values due to the acceleration difference

Acceleration Difference	Inclination Difference
-205 <	=AccDiff * 2.5
-205	-448
-204	-444
-203	-442
...	
-3	-11
-2	-11
-1	-5
0	0
1	0
2	14
3	15
...	
141	526
142	529
143	529
144	530
AccDiff >= 145	(AccDiff * 4)

… the datum between the top and bottom values continue.

All of Data shown in Table 3 were converted to Arduino codes. Arduino codes calculate the correction inclination value related to the acceleration difference size with the instantaneous inclination value. Thus inclination error based on the centrifugal force has been eliminated.

CONCLUSIONS

Machine learning is crucial and most important issue for humanoid machines and it has been developing and improving day by day. Sensor system arranged with the machine learning application can be improved further by means of new data. The probability of risking the automation system at taught sensors is rather low in reference to a non-processed sensor with direct connection. Acceleration sensor has been reflected to this system as an additional cost. However, net and reliable inclination measurement has been ensured. Sensor - Arduino system yields 0-5V analog output. It can be connected to an automation system as inclination sensor. Machine Learning is efficient and reliable method in order to be able to evaluate and assess a lot of effects simultaneously in systems consisting of inclination sensor or combination of several sensors.

WEKA which is machine learning software, is included in the top ten machine learning program which has been preferred because of its process success and being satisfactory. Supporting of sensors with the machine learning protects automation systems and operators against bad and unexpected surprises and a more stable automation system is obtained.

Measurement success of the sensor affects directly the success of automation system. Inclination sensors have been used widespread at such sectors as agriculture, industry, space, robot, aviation, etc. It is impossible for a person to examine and analyze thousands of data and to establish a relationship among data. The system that obtained in this study can be successfully used specifically in precision ground leveling machines, robots, agricultural pesticide machines and agricultural machines such as combine harvester, etc. which are in need of balancing system. Total cost of the system is USD 320.

Arduino, with its best economic cost and ergonomic usage, is one of the most preferred programming cards. In the system so created sensor reading speed, Arduino data output speed can be adjustable. The system is able to give 0-5v analog output and 0-5v digital output.

In this study a sensor which can make successfully an inclination measurement at the moment of linear progressing in a circular orbit, the sensor which made incorrect measurement due to the effect of centrifugal force in addition to affect of centrifugal force along with the gravity force to the sensor pendulum was examined. It has been aimed that affect of the centrifugal force has been specified with the acceleration sensor, and eventually that the sensor should make measurement as if sensor was making measurement only under the affect of gravity.

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