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Development of Arduino Uno Based Multispectra Colorimeter For Formaldehyde Determination

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Abstract: Formalin is a hazardous substance that is often misused as a food preservative, so routine formalin analysis is very necessary for public safety. Formalin analysis generally uses spectrophotometry and also a simple colorimeter. Currently, many Arduino-based colorimeters are being studied and development with RGB (Red, Green, Blue) LED (Light Emitting Diode) light sources. This research is also in this field with a focus on the use of multi-spectral RGB LED lights with 16 colors that are already commercially available. The multispectral colorimeter is designed by integrating an LED light source, a photodiode module as a detector, and controlled by an Arduino Uno R3. The LED light module circuit, cuvette and detector photodiode are then arranged and packaged in an X8 project box. Optimization of the circuit is studied including the distance between the LED lamp and the cuvette and the photodiode with the cuvette. A feasibility study of the use of multispectral RGB LEDs is also carried out by looking at the stability of the response of each color. The performance test of the multispectral colorimeter is carried out by analyzing formaldehyde oxidized with hydrogen peroxide using methyl red as an indicator under the alkaline condition. The results showed no significant difference when viewed from the linearity, Limit of Detection, Limit of Quantitation, sensitivity, and precision values calculated from the calibration curve. The difference in linearity values was 0.0013, Limit of Detection = 0.17, Limit of Quantitation = 0.57, sensitivity = 0.0001, and precision (SD = 0.001 and %RSD = 0.11).

Keywords: arduino, colorimetry, formaldehyde, photodiode, and spectrophotometric visible.

INTRODUCTION

Formalin is a colorless and pungent-smelling liquid with the main content of 37% formaldehyde, 15% methanol, and the rest is water. Formaldehyde has the formula HCOH which is generally used as a disinfectant, antiseptic, or corpse preservative [1]. Formalin can cause irritation, respiratory problems, and even cancer if exposed in significant amounts [2]. The widespread misuse of formalin as a food preservative can endanger public health, so it is necessary to detect the presence of formalin as a routine activity of a commercial product.

Formaldehyde analysis usually uses color changes as an indicator using specific reagents such as chromatophic acid [3], $KMnO_4$ [4], H_2O_2 and Bromothymol Blue in basic conditions [5], and H_2O_2 and methyl red in basic conditions [6]. Determination of formaldehyde is generally carried out using a visible spectrophotometer, where the equipment is large, expensive, less flexible, and must be carried out in a laboratory. The limitations of this tool can delay analysis, especially on the spot analysis, so an alternative tool is needed that is more flexible, handy and easy to operate.

A simpler method compared to spectrophotometry is colorimetry with the characteristic of using one light source that represents one particular wavelength region. The colorimeter works based on the Lambert-Beer law, which satisfies the linear relationship between concentration and the intensity of light transmitted by the solution [7]. Simple colorimeters generally use LEDs (Light Emitting Diodes) as a light source and use detectors in the form of photodiodes or photoresistors, where the detector will respond in the form of a voltage that is proportional to the light intensity [8].

Currently, various simple Arduino-based colorimeters have been developed. Several researchers have succeeded in designing portable colorimeters such as Yohan et al., (2021) who designed a colorimeter using a light source from one LED with a wavelength of 467 nm and a Light Dependent Resistor (LDR) detector, and integrated it with Arduino Uno [9]. The colorimeter was tested for its feasibility on the determination of ammonium samples. Rahmawati and Yohandri (2023) also developed the same instrument using four LED light sources (RGB and white) using the BH1750 color sensor and tested the analysis of congo red solution [10]. Yohan et al., (2018) also studied the use of four LEDs as light sources, and focused on the violet color and used an LDR detector. The designed colorimeter was used for the analysis of brilliant blue and tartrazine food coloring compounds [9]. Meanwhile, Magro et al., (2020) developed an RGB colorimeter with an LDR detector to test methylene blue, methylene orange, and cobalt chloride samples [12]. The use of detectors in RGB-Arduino Colorimeters is not limited to LDR, Wulandari and Yulkifli (2018) have designed an RGB colorimeter with a photodiode detector, white LED as a light source. The performance of the colorimeter was then tested on the determination of green food coloring samples. The results show that the photodiode detector is very sensitive to light and responds very quickly. The disadvantage of this study is the light source used so that it has limitations in analyzing various substances [7].

The current development of LEDs is not limited to RGB and White colors, but also to the use of 16-color LED lights controlled by a remote and are already commercially available. This provides an opportunity for researchers to be able to develop colorimeters with various light sources with varying colors. Thus, this study aims to develop a multi-spectral colorimeter based on Arduino Uno whose performance is compared to a spectrophotometer.

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METHODS

Design Multi spectra Colorimeter

The materials used in assembling the multispectral colorimeter are Arduino Uno R3 clone version China, China photodiode module, Multicolor RGB LED CARCOB China, jumper cables, X8 project box, foam, DC socket, and glue. The multispectral colorimeter is designed by placing a cuvette between the light source box (Multi color RGB LED) and the photodiode module box. The light source box is given a hole of about 0.5 cm in diameter for light transmission to the cuvette. Likewise, the photodiode box is given a hole that is in line with the hole in the light source. The distance between the light source module to the cuvette and the cuvette to the photodiode detector body can be varied. The color setting of the light source is done using a remote control, with a 3.3 Volt power source coming from an Arduino Uno, and the remote control is placed right above the light source box. The photodiode is connected to the Arduino Uno. via the GND pin, the VCC pin on the diode module with the 5V pin on the Arduino and the A_0 output pin on the photodiode is connected to the A_0 pin on the Arduino Uno module. Arduino Uno serial communication with the computer via USB and the data reading and processing process through the simple ARDUINO IDE application. All the component was placed on Box Project X8.

Reagent and Procedure

Optimization of the multi-spectral colorimeter design was carried out by testing commercial food coloring solutions (Rajawali brand) of carmine red, tartrazine yellow, and chlorophyll green. These food coloring solutions were prepared by diluting one drop into 10 mL of distilled water. All of these solutions were scanned and their absorbance was measured using both spectrophotometer and a multi-spectral colorimeter. While, the performance of multi-spectral colorimeter was studied by analysing a standard formalin solution on the range concentration of 1.0; 2.5; 5.0; 7.5; and 10.0 ppm (Merck, MW: 30.03 g/mol). The oxidiator used was 2% hydrogen peroxide (Merck, MW: 34.01 g/mol). The reaction took place under basic conditions of 0.1 M NaOH (Merck, MW: 40 g/mol) and using 0.06 M methyl red indicator (Merck, MW: 269.3 g/mol) dissolved in ethanol (Merck, MW: 46.07 g/mol).

The reaction was carried out by adding 1 drop of methyl red, 4 drops of 0.001 M NaOH, and 2.0 mL of 2% H_2O_2 into 2.0 mL of standard formalin solution. Furthermore, scanning using a spectrophotometer was carried out in the wavelength range of 400-700 nm using a standard formalin solution concentration of 5.0 ppm, while scanning with a multispectral colorimeter was carried out using an optimized color light source. Performance testing was carried out by calibrating the multi-spectral colorimeter using standard solutions in the concentration range of 1.0; 2.5; 5.0; 7.5; and 10.0 ppm and the optimized color light source. The performance parameters measured included linearity and linear range, standard error, limit detection and limit of quantification. The results were then compared with the measurement of standard solutions in the same concentration range using a spectrophotometer at the maximum wavelength of the scanning results. The experiment was carried out with five repetitions.

Method

Statistical approach is used to evaluate the performance of multi-spectral colorimeters such as standard error of the using standard deviation equation (1),

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{n}(X_i-\bar{X})^2}{n-1}} \quad (1)$$

SD = Standar deviation
xi = absorbance value of measurement results
$\bar{x}$ = average absorbance value of measurement results

while the reproducibility of the measurement is carried out using the relative standard deviation of five measurement replication of the standard solution in accordance with equation (2).

$$\mathrm{RSD} = \frac{\mathrm{SD}}{\bar{x}} \times 100 \quad (2)$$

RSD = Relative Standard Deviation
$\bar{x}$ = average absorbance value of measurement results

Meanwhile, the measurement of the detection limit and quantification limit are in accordance with equations (3) and (4) respectively.

$$\mathrm{LOD} = 3\frac{\mathrm{SD}}{slope} \quad (3)$$

$$\mathrm{LOQ} = 10\frac{\mathrm{SD}}{slope} \quad (4)$$

The comparative test of the measurement by spectrophotometry and multi-spectral colorimeter is carried out by determining the Pearson's correlation coefficient, in accordance with equation (5). The correlation coefficient is determined by plotting absorbance colorimeter versus commercial spectrometer absorbance with the help of data-processing software (Microsoft Excel).

$$r = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2}} \quad (5)$$

r = correlation coefficient
x_i = absorbance values measured using a multispectral colorimeter
$\bar{x}$ = average absorbance value measured using a multispectral colorimeter
y_i = absorbance values measured using a spectrophotometer
$\bar{y}$ = average absorbance value measured using a multispectral colorimeter.

RESULT AND DISCUSSION

Multi-spectral Colorimeter

Multi-spectral colorimeter was developed by combining software and hardware. The hardware circuit consists of a Multi color RGB LED module placed in a REM 2 project box measuring 4.8 x 3 x 2.5 cm and given a hole for light transmission with a diameter of 0.55 cm. The photodiode module is placed in the REM 2 project box and also has a hole that is in line with the light transmission hole of the Multicolor RGB LED box. While the cuvette is placed in the REM 1 Project box measuring 3.5 x 2.0 x 3.0 cm with holes on two sides facing the light source hole with a distance of 1.0 cm and a photodiode hole without a distance. Arduino Uno R3 is connected to the photodiode to receive analog signal input and convert it into a digital signal so that it can be processed with simple Arduino IDE software. In the Arduino IDE software, a command has been created where the resulting voltage change is proportional to the light intensity, then the absorbance value is calculated according to the Lambert-Beer law. Arduino is also used to supply a voltage of 3.3 Volts for the light source remote control. The connection between hardware uses a jumper cable equipped with serial communication using USB. All hardware is placed in a 16 x 12.9 x 4.0 cm X8 project box, and a remote control is placed on the top of the box to adjust the color of the light source, The multi-spectral colorimeter is shown on Figure 1.

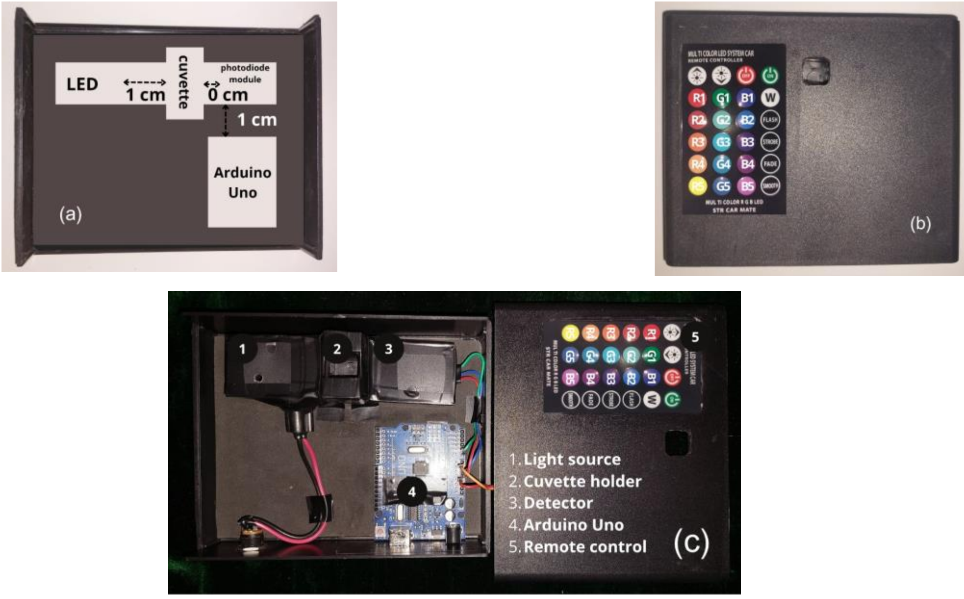

Figure 1. (a) Placement of the main components of the Multi-spectra Colorimeter (b) Exterior View of Multi-spectra Colorimeter (c) Multi-spectra Colorimeter Circuit

Multi-spectral Colorimeter Performance Optimization

Optimization of the Distance of the Cuvette to the Light Source and to the Photodiode Detector

Optimization was carried out by measuring the intensity of light transmitted after passing through a red carmine solution with 5 repetitions. Meanwhile, the light source used is a green LED light source with the code G1. The distance of the light source was varied as far as 1.0, 2.0 and 3.0 cm from the cuvette. The results showed that the red carmine solution could absorb green light source as indicated by a decrease in light intensity read in voltage. At a distance of 1.0 cm for the cuvette with the light source, the average of transmitted light intensity was 2.96 Volt, and decreased to 1.55 Volts at a distance of 3.0 cm as shown in Figure 2.a. Based on these results, the optimum condition for using a light source is at a distance of 1.0 cm from the cuvette, which is indicated by an average voltage value of 2.96 Volts with a low error of ±0.0028 Volts from five repetitions.

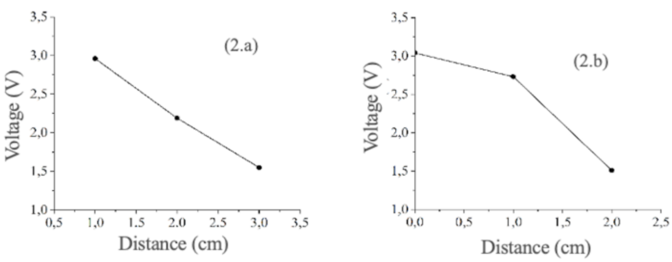

Figure 2. Relationship between the distance and the measured voltage on (a) Optimization of the distance of the light source to the cuvette and (b) Optimization of the distance of the detector to the cuvette

The similar trend is also observed in the experiment of the cuvette to the photodiode detector distance. The closer the distance between the cuvette and the detector, the greater the transmitted intensity after passing through the red carmine solution. The results show that at a distance of 2.0 cm between the cuvette and the detector, the average transmitted light intensity is 1.51 Volts with an error of 0.0008. The intensity value increases when the distance is reduced, as seen at a distance of 1.0 cm and no distance or 0 cm, where the average transmitted light value is 2.73 + and 3.04 + Volts respectively (Figure 2.b). These results also suggest that in further experiments the position of the cuvette close to the photodiode detector will be used.

Feasibility study of LED Light Source

The feasibility of LED lamps was studied by observing the stability of the transmitted light intensity and qualitatively the accumulated color of the light produced. The experiment was carried out using optimum conditions for the distance of the cuvette to the light source of 1.0 cm and the distance of the cuvette to the photodiode of 0 cm or without distance and measurements were carried out using a blank cuvette.

The test results of LED lamps as a light source with codes R1, R5, G1, G5, B1, and B5 show that high stability. This is indicated by the value of the transmitted light intensity in volts. The average values of transmitted light intensity lamp, namely R1 = 3.78 V, R5 = 4.81 Volts, G1 = 4.74 Volts, G5 = 4.84 Volts, B1 = 4.83 Volts, and B5 = 4.84 Volts with a Relative Standard Deviation value below 0.2%. Furthermore, the six light sources produce a unified light color. However, unstable responses are also obtained for light sources with codes R2, R3, R4, G2, G3, G4, B2, B3, and B4. This is also indicated by the separate RGB light colors. Stable are simplified in Figure 3.

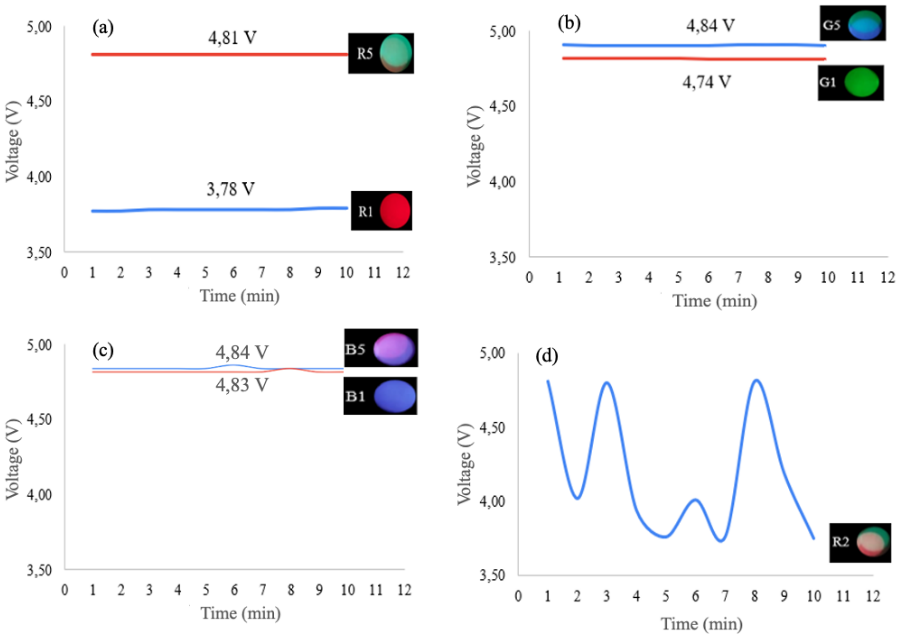

Figure 3. (a) Stable response for light sources with codes R1 and R5, (b) Stable response for light sources with codes G1 and G5, (c) Stable response for light sources with codes B1 and B5, and (d) unstable response profile represented by the response of the light source with code R2.

Six stable light sources with codes R1, R5, G1, G5, B1, and B5, were then used to test three food colorings, namely red carmine, yellow tartrazine and green chlorophyll. The results of the red carmine solution are quite effective in absorbing light produced by light sources in the green range. Six stable light sources with codes R1, R5, G1, G5, B1, and B5, were then used to test three food colorings, namely red carmine, yellow tartrazine and green chlorophyll. The results of the red carmine solution were quite effective in absorbing light produced by light sources in the green range indicated by its absorbance value. Likewise, the green chlorophyll solution absorbed red light indicated by a high absorbance value. The yellow sample solution gave a high absorbance value when given blue light. It can be concluded that six Multicolor LED RGB light sources can be used to detect colored solutions, especially red, yellow and green. The results of observations of the absorbance of red, green and yellow solutions are presented in Figure 4.

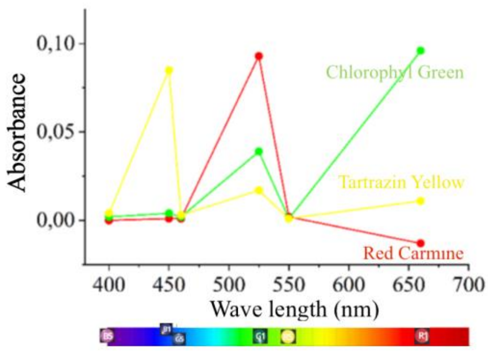

Figure 4. Scanning profile of red carmine, tartrazine, and chlorophyl solution using six stable light sources with codes R1, R5, G1, G5, B1, and B5.

Scanning Color changes in formaldehyde oxidation reactions

Observation of the spectra results was carried out using the reaction results between formalin and H_2O_2 in a basic atmosphere and using methyl red indicator. The reaction product in the form of formic acid is indicated by the formation of color and is monitored by visible spectrometry in the wavelength range of 460 nm to 550 nm, and is also scanned with a multispectral colorimeter using lamps with codes G5, G1 and R5. The scanning results of the reaction show the same absorbance profile, and the maximum wavelength is obtained at 525 nm. The result is described in Figure 5. This position is comparable to the green LED light G1. However, there is a difference in the absorbance value, where the absorbance value of the spectrometric measurement is greater than the absorbance value of the measurement using colorimetry. This may occur, where the green LED light has a slightly different wavelength with l max = 525 nm.

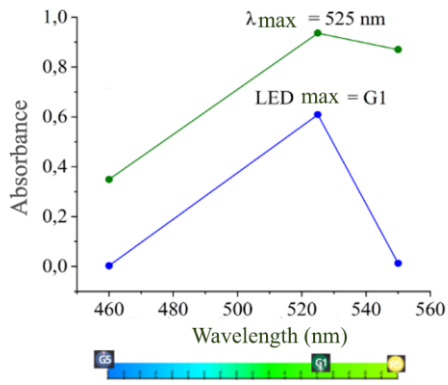

Figure 5. Scanning profile of the red solution resulting from formaldehyde oxidation using spectrophotometer and the multi-spectra colorimeter.

Comparison of the performance of a multispectral colorimeter with a spectrophotometer in the calibration of formaldehyde standard solutions

Calibration curves were generated by measuring the absorbance of standard solutions of 1.0; 2.5; 5.0; 7.5; and 10.0

ppm using a multispectral colorimeter and spectrophotometer. The results showed that colorimetric measurements met the Lambert Beer equation as indicated by a linear relationship between concentration and absorbance values with the equation y = 0.0106x + 0.6972, while spectrophotometry produced y = 0.0107x + 0.8651. Those results are presented in Figure 6.

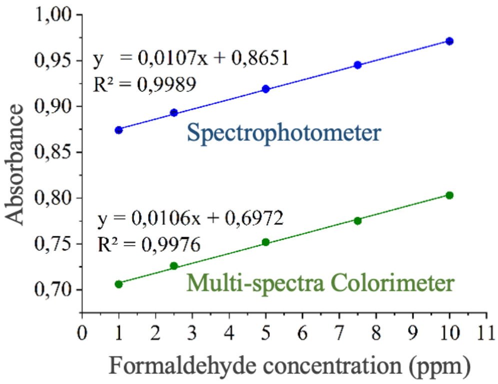

Figure 6. Calibration curves of the formaldehyde standard solution using the multi-spectra colorimeter and spectrophotometer

Figure 6 also shows that the sensitivity of the measurements using the spectrophotometer and multispectral colorimeter does not show any significant difference where the difference is in the range of 1%. The spectrophotometer shows 0.0107 abs/ppm, while the multispectral colorimeter is 0.0106 abs/ppm. However, in terms of the ability to detect formaldehyde, the spectrophotometer is better where the LOD and LOQ values based on the standard error of the calibration curve are smaller than the LOD and LOQ obtained by measuring using the multispectral colorimeter. The LOD measurement results are 0.37 ppm and 0.54 ppm and the LOQ is 1.23 ppm and 1.80 ppm which are measured by spectrophotometry and colorimetry respectively.

The measurement performance using a spectrophotometer is not significantly different from the measurement using a multi-spectral Colorimeter, this is based on the relationship between the absorbance values of the two measurements indicated by a correlation coefficient value of 0.999. These results indicate that the two measurements are not different or with a similarity level of 99.9%. This relationship is simplified in Figure 7.

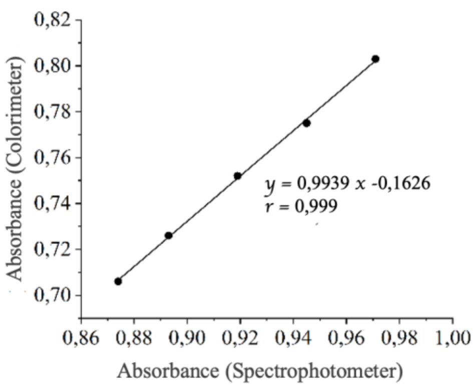

Figure 7. Correlation of the measured absorbance using the spectrophotometer and the multi-spectra colorimeter of standard formaldehyde solutions 1.0 ppm - 10.0 ppm.

CONCLUSION

The conclusion that can be drawn from this study is that the multispectral colorimeter was successfully developed based on Arduino and using Multicolor LED RGB as a light source.

Six light sources from Multicolor LED RGB with codes R1, R5, G1, G5, B1 and B5 have good stability and can be used as a light source in the Colorimeter. The performance of the multispectral colorimeter was evaluated and the results showed that the Colorimetry worked to fulfill the Lambert Beer equation with the equation y = 0.0106 x + 0.6972 in a working range of 1.0 ppm to 10.0 ppm. The Multi-spectral Colorimeter also has a sensitivity of 0.0106 abs / ppm with a LOD of 0.54 ppm and a LOQ of 1.80 ppm.

The comparison test of the multispectral colorimeter with the spectrophotometer also showed no significant difference as indicated by the correlation coefficient value of 0.999, and it can be concluded that the similarity level of the two methods is 99.9%.

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