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Characteristics of Tin Oxide Gas Sensors for Human Vital Signs during Sleep

Takashi Oyabu, Takeshi Onodera[1], Haruhiko Kimura[1] and Teruaki Katsube[2]

Kanazawa University of Economics, Kanazawa 920-8620, Japan
[1]Faculty of Engineering, Kanazawa University, Kanazawa 920-8667, Japan
[2]Faculty of Engineering, Saitama University, Urawa 338-8570, Japan

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Daily human behavior in an indoor environment is identified, and activities are defined using outputs from four kinds of tin oxide gas sensors installed in the living room of a house. The beginning and end of indoor human activities and the ignition of an oil heater in the monitoring room can be recognized by analyzing the output patterns of the sensors. A frequency analyzing method is useful to recognize human behavior clearly. The sensor's output patterns while a person sleeps are also changed by the attributes of the subjects. The patterns fluctuate frequently for a young person but show no variation for an aged individual. A person generates some gases while sleeping; these gases have an effect upon the sensor output.

1. Introduction

Both homes for the aged and the number of aged living alone are increasing in Japan. In these homes, it is difficult to provide adequate nursing. If aged persons become ill, they can lapse into a serious condition. Monitoring systems to improve living conditions for the aged must be specially constructed.

Various gases are generated according to human activities in a domestic environment. Most of the gases are reducing gases. A day of domestic life begins upon waking and ends upon sleeping. Many gases are generated along with human activities, namely preparation of meals, making tea, heating with an oil heater and so on. Indoor air quality (IAQ) deteriorates upon waking and improves during sleeping.[(1)] Gases are also generated by the human body and even by breathing during sleep. The gases generated in a domestic environment are monitored by four kinds of tin oxide gas sensors.[2] Daily periodical patterns in the sensor outputs differ from household to household. The patterns also differ from day to day. The standard pattern of a day of the week in a household can be defined by accumulating many daily patterns.[3] The sensors detect many gasses generated by human activities, but not carbon dioxide. This investigation has been carried out to clarify the relationship between the output of the sensor and indoor human activities and to construct a support system using four kinds of gas sensors for an elderly person's house and for a generic house. It is not an aim to examine the kinds of gases generated by indoor human activities.

The four sensors are designed to detect a combustible gas, ammonia, carbon monoxide gas and nitrogen oxide gas. The sensors, however, do not have much gas selectively. The outputs of the four sensors fluctuate according to indoor human activities. The combustible gas sensor responds sensitively to these activities, including sleep. First, these phenomena are examined. The sensor output pattern has some peaks, and the number of peaks changes with the age of a subject. There are many peaks in the patterns of a younger person. These patterns may be affected by the depth of sleep and by the basal metabolism (BM) of the subject. Frequency analysis of the sensor output pattern is also useful to distinguish the beginning and end of human activities.

2. Sensory System

Four kinds of tin oxide gas sensors are used to monitor an indoor environment. These sensors include combustible gas (CGS, TGS800), ammonia (AMS, TGS826), carbon monoxide (COS, a type of TGS) and nitrogen oxide gas sensors (NXS, TGS211). These four sensors do not show good gas selectivity. The CGS responds sensitively to various reducing gases.[4] A temperature sensor (TMS, TY7203A1000), relative humidity sensor (RHS, HY7200A2004), absolute humidity sensor (AHS, TGS2180) and carbon dioxide sensor (CO2S, 5577) are sometimes adopted in the system for references. The outputs of these eight sensors are input into a computer through an A-D converter. A schematic of the system is shown in Fig. 1. The sensor output range is 0 to 5 V. The CGS is sensitive to various reducing gases; namely, the sensor outputs a signal which contains various information on human activities. The sensitivities of CGS to four gases are shown in Fig.

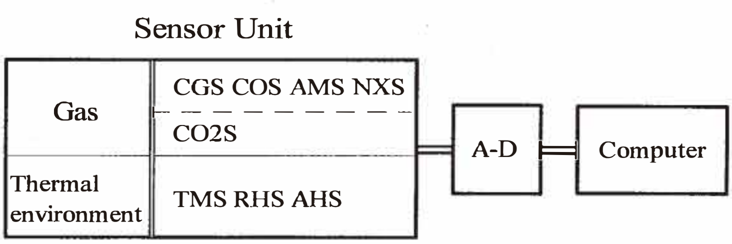
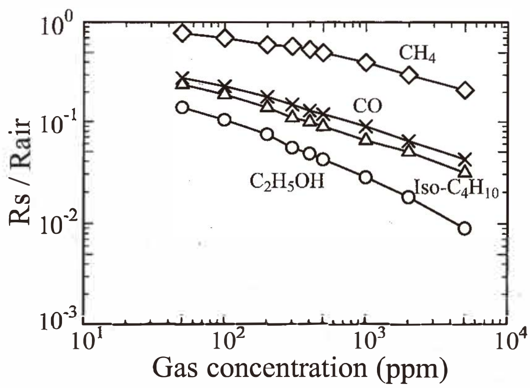


Fig. 1. Schematic diagram of the sensory system.

2(a), and the sensitivities of AMS are shown in Fig. 2(b). In Fig. 2 (a), the vertical axis indicates sensor sensitivity R_s/R_{air}. The term R_s is the sensor resistance in various gases, and R_{air} is the sensor resistance in air. The horizontal axis gives the concentration of four gases. Both CGS and AMS are highly sensitive to ethanol. However, they do not have good gas selectivity. CGS is sensitive to formaldehyde, ammonia, propane, and cigarette smoke in addition to the four gases in Fig. 2(a). AMS is sensitive to carbon monoxide, propane and cigarette smoke.

The sensitivity to gases is summarized in Table 1. The number 1 means that the sensor has the highest sensitivity to the gas. The number 2 means that the sensor has the second highest sensitivity to the gas. The number 3 indicates the sensor has the third highest sensitivity to the gas. All of the gas sensors except AHS are highly sensitive to cigarette smoke. This system can estimate the presence of a gas using the sensor-gas patterns in Table 1. The types of responding sensors and sensitivity numbers are very important.

(a)



(b)

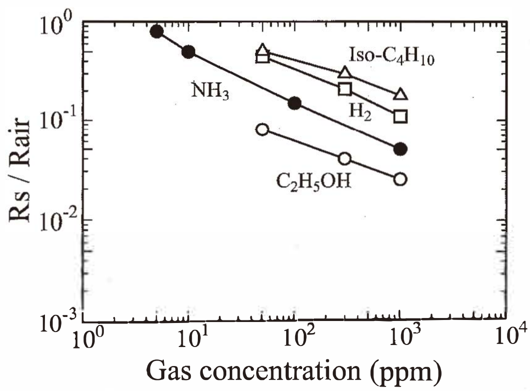


Fig. 2. Sensitivities of CGS and AMS to typical gases. (a) CGS and (b) AMS.

3. Monitoring Results

3.1 *Daily pattern of sensor output*

Human activities in an indoor environment begin at waking and end with sleep. A typical monitoring pattern for a generic house is shown in Fig. 3. In this figure, one of the family members wakes up at about 6:45 and the indoor activity in the house begins. The activity ends at about 21:00. Indoor air quality (IAQ) improves as human activity ceases, namely, output levels of CGS and COS decrease remarkably until rising the next day. An oil heater was turned on upon awakening, and the output of NXS decreased. The output of NXS decreases when nitrogen dioxide gas is generated and increases when nitrogen monoxide gas is generated. If the output of NXS decreases rapidly, we can deduce that an oil heater was ignited. Output level of NXS also decreases at about 18:30 in the evening; the heater was also ignited at this time. The CGS output level fluctuates markedly at about 13:30 in the daytime. At that time, a woman in the family was preparing and eating a

Table 1
Sensitivities of five types of tin oxide gas sensors and a dioxide sensor (CO2S) to eight gases. Numbers in the table indicate orders of sensitivity.

	CO	CO_2	C_2H_5OH	CH_4	NH_3	HCHO	Cigarette smoke	C_3H_8
CGS	2		1	1	3	1	1	1
AMS			2		1	2	2	
COS	1						3	
NXS					2		4	
CO2S		1					5	
AHS				1				

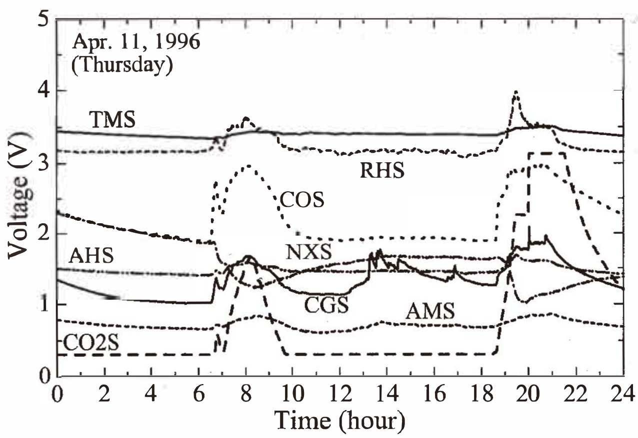


Fig. 3. Periodical patterns of eight sensors observed on April 11, 1996.

lunch. After that, she was at a desk in the monitoring room. The output of CO2S saturates at about 3 V in the evening. The level of 3 V is equivalent to 3000 ppm of carbon dioxide. The CO2S can only measure up to 3 V (3,000 ppm). On this day, all family members slept in their own rooms on the second floor. Sensors were installed in a living room close to the dining room and kitchen of the first floor. The IAQ increases from 0:00 until the time the family wakes up because there is no human activity. Ignition of the oil heater, eating a meal, opening a window and so on are included in human activity. A ventilation fan operated from 6:45 to 7:00 decreases the outputs of CO2S, CGS, COS and RHS. Indoor human behavior and activity can be recognized roughly by examining the sensor patterns. The CGS always responds to various human activities among the five gas sensors, and the sensor plays an important role in the system.[5–7] The output voltages of TMS and RHS can be converted to real temperature and humidity , respectively, using the following equations.[6]

$$t(^\circ\mathrm{C}) = V(\mathrm{TMS}) \times 22.53 - 60.39 \quad (1)$$

$$h(\%) = V(\mathrm{RHS}) \times 24.57 - 27.21 \quad (2)$$

A daily periodical pattern on June 12, 1996 is shown in Fig. 4. The data in this figure were measured two months after the data in Fig. 3 were measured. The temperature and humidity are high in June in Japan, and the oil heater is not used in this season. Therefore, CGS changes considerably and the level of CGS is higher than in Fig. 3. The output of CGS is affected by temperature and humidity, and hence by season. Neither CGS nor COS decreases greatly after 21:00. A boy (twelve years old) slept in the monitoring room on that day. The sensors are installed one meter above the floor and about one meter away from the head of the sleeping subject.

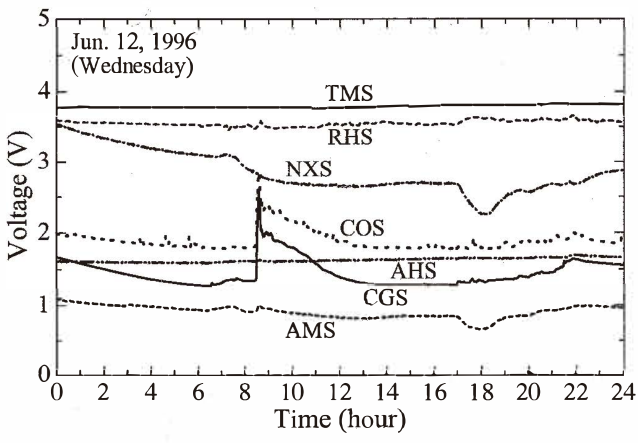


Fig. 4. Periodical patterns of seven sensors observed on June 12, 1996.

The output patterns of four tin oxide gas sensors during sleeping, namely CGS, AMS, COS and NXS, are shown in Fig. 5. The patterns indicate the outputs of the four sensors from 20:00 in the evening to 8:00 in the morning of the next day. The boy went to bed at about 21:30 and woke up at 7:00. There are eight peaks in the CGS pattern, and COS pattern also has small peaks during that interval. The CGS pattern fluctuates greatly. These patterns include information about the gases generated from the body during sleep. There was no other human activity at all at that time. The CGS is not sensitive to carbon dioxide. The CGS has a sensitivity to other gases and AMS does not have a sensitivity to the gases generated from the body, namely the gases not listed in Table 1.

3.2 *CGS pattern in sleeping*

People sometimes produce gases during sleep. Some output patterns of CGS during sleep are shown in Fig. 6. These patterns are measured in the same season. The patterns have some peaks, except for (c), the pattern of a woman 69 years of age. Her pattern does not have a peak and increases gradually in the middle of the night. The pattern of no person (d) only decreases at that time. On the other hand, an aged male sometimes has some peaks in his pattern.[8] The patterns show a tendency to increase in the number of peaks when a younger person is sleeping; the interval from peak to peak is short in a younger person's pattern. The period from peak to peak as a function of the sequential order of peak intervals is shown in Fig. 7. The pattern of B (female, 39 years old) in the figure has three peak intervals. The first interval is about 2.8 hours, the second interval is 2.5 hours and the third is 1.9 hours. The intervals in B become shorter as time passes. These intervals are relatively long. The pattern in C is a boy's pattern. He is 13 years old. His first interval is 0.84 hours and second is 0.57 hours. The average of his intervals, except for the last interval, is about 0.64 hours. The last interval is 1.18 hours. It is probable that the appearance of peaks has to do with bowel gas and turning over in sleep.

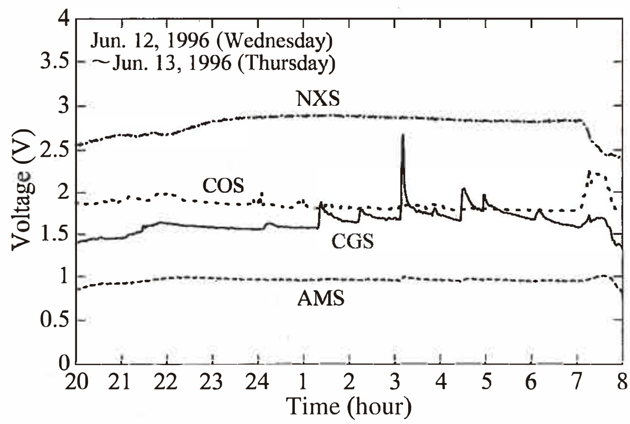


Fig. 5. Output pattern of four kinds of gas sensors in the sleeping state.

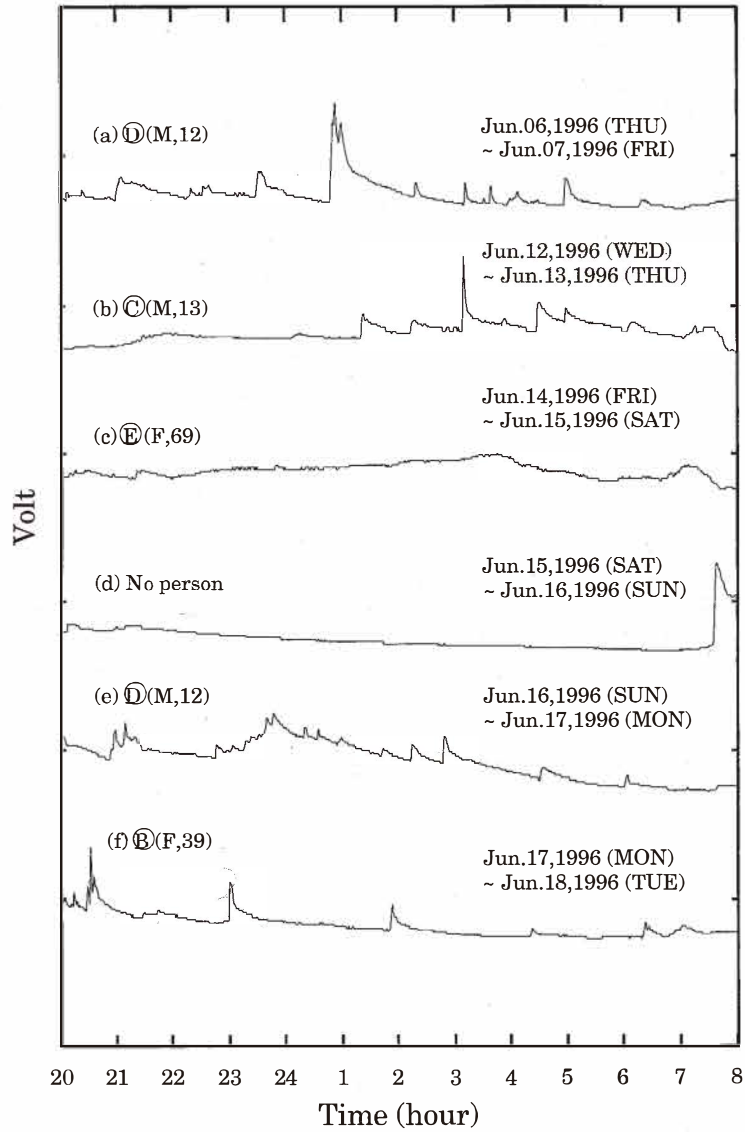


Fig. 6 Various CGS patterns in the sleeping states.

The features become more intense for younger subjects. A younger person has shorter intervals. In Fig. 6, E does not have a peak and the pattern changes slowly. She is 69 years old. These patterns may be affected by the depth of sleep and by the basal metabolism (BM) of the subject.

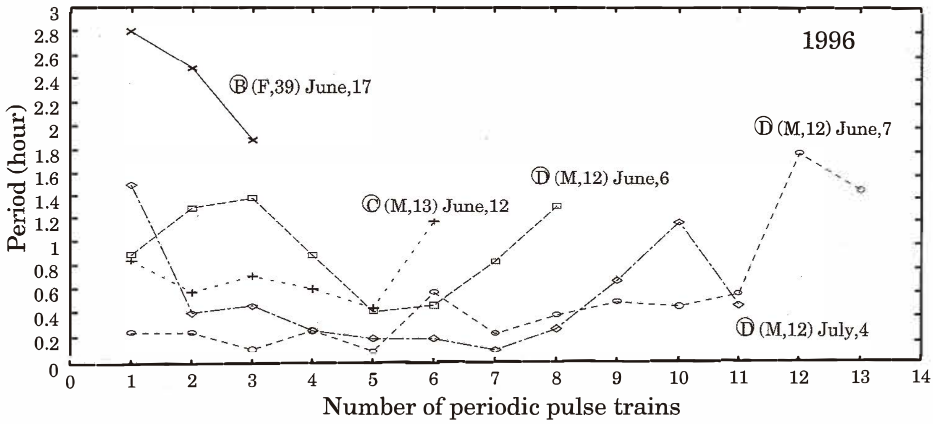


Fig. 7. Period of time from peak to peak as a function of sequential order of peak intervals.

Frequency analysis is effective to judge whether there is indoor human activity in the morning and evening. It is thought that this analysis is useful for an elderly person's house. Using this method, this system can judge whether the subject is spending an ordinary day. The result is shown in Fig. 8. Figure 8(a) indicates a typical daily periodical pattern $\Phi(t)$, which shows the CGS sensor output signal as a function of time. Figure 8(b) shows the result when a low-pass filter (LPF) is applied to the data in Fig. 8(a). The pattern of CGS for one week is divided into 10,080 parts (60 min × 24 h × 7 days). One day is equivalent to 1,440 parts. Figure 8 is the pattern of the second day of a week; the divided number is from 1,441 to 2,880 which is indicated on the horizontal axis. A fast fourier transform (FFT) method is applied to the observed CGS outputs of the 10,080 points, and high-frequency components which exceed 8.25×10^{-4} (Hz) are removed (see eq. (3)). Then, the data are filtered by an ideal LPF, and a reverse FFT is applied to the data. Figure 8(b) shows as the result. Frequency resolution is 1.65×10^{-6}, which is derived from the equation, 1/(60 s × 60 min × 24 h × 7 days). To separate high- and low-frequency components, the frequency spectrum number is set at 500, which corresponds to about 20 min (=10,080/500), that is, frequency components over 20 min are cut off as noise. The value of 8.25×10^{-4} indicates a cutoff frequency.

$$1.65 \times 10^{-6}\,(\text{Hz}) \times 500 \approx 8.25 \times 10^{-4}\,(\text{Hz}) \tag{3}$$

Figure 8(c) is obtained using the difference method of the second order of $d\Phi(t)/dt$ of Fig. 8(a). This figure shows a fluctuation from the stationary distribution of generated gases in an indoor environment. The vertical axis corresponds to a grade proportional to a quantity of fluctuation. Figure 8(d) is also derived in the same way as Fig. 8(c). In the figure, high-frequency components are removed from Fig. 8(c). It is obvious that there were significant human activities in the morning and evening in the monitoring house. Figure 8(d) is used to judge roughly whether there is indoor human activity. Figure 8(c) is

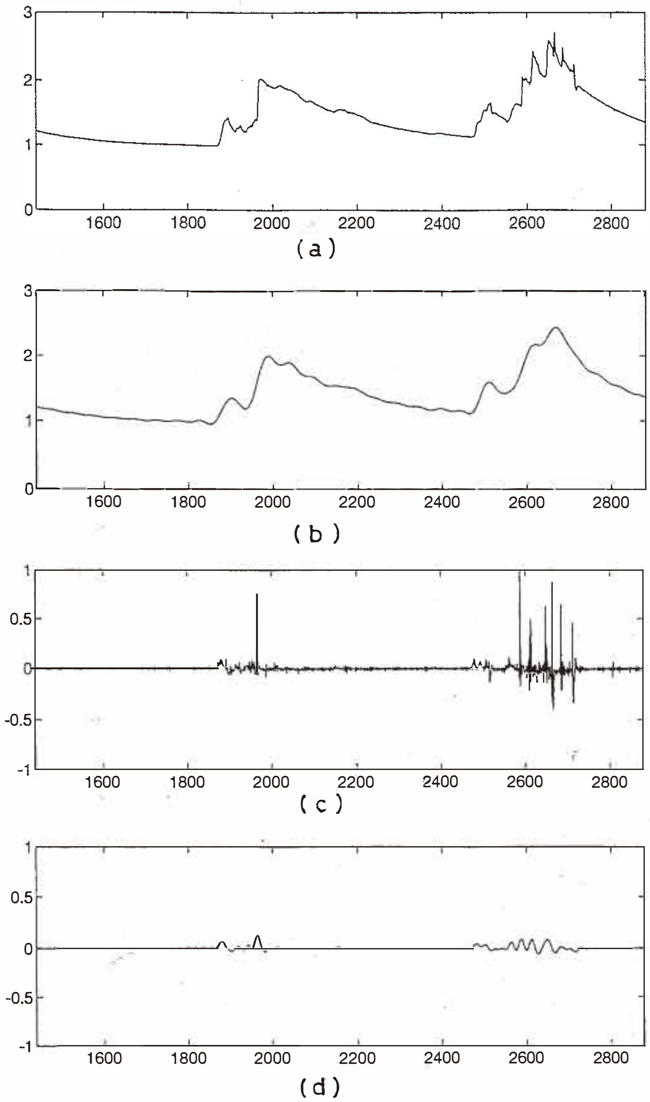


Fig. 8. The results of three-point numerical differentiation (TPND) pattern. (a) is an original CGS pattern. (b) is the pattern after LPF process for (a). (c) is the result of TPND pattern for (a). (d) is the result of TPND pattern for (b).

effective for examine trivial actions, for instance the operation of a ventilation fan and the preparation and consumption of a meal. It is, however, necessary to investigate the characteristics.

We can judge roughly whether the monitored family has spent a typical day or not using this method. The data can be transferred to a remote place and processed, and the processed data can be viewed through a communication cable from various places. There is not an invasion of privacy in this method as there is with the use of a TV camera and microphone, and it is effective for monitoring an elderly person's house.

4. Conclusions

Basic human activity in an indoor environment are examined using tin oxide gas sensors. First, the data from five gas sensors and three thermal environmental sensors are accumulated. The beginning and end of human activity and ignition of an oil heater can be recognized using the pattern of a combustible gas sensor (CGS). The frequency analyzed pattern of a CGS is useful for the examination of human activity in the morning and evening. The combustible gas sensor responds during sleep, and the sensor's pattern has some peaks. Humans generate some gases and carbon dioxide during sleep. The interval between peaks is shorter for a younger subject. A younger person has a high basal metabolic rate (BMR) and the pattern changes fractionally.

This system will be effective in accumulating information in an indoor environment, especially in an elderly person's house, and the system can judge roughly whether the person spends a typical day or not. The information can be gathered and processed easily in a control center. We can view the data from a remote place. A chemical sensor can be used to accumulate indoor information because human activity involves the generation of reducing gases or odors.

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