Industrial Health 2016, **54**, 542–549

Original Article

Investigation of human body potential measured by a non-contact measuring system

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Received January 21, 2016 and accepted June 10, 2016
Published online in J-STAGE June 16, 2016

Abstract: A human body is occasionally electrified in a room. This charged object will be a source of electrostatic accidents, including the malfunction of electronic equipment. Hence, prevention of these accidents is required. Accidents occasionally occur, even though antistatic clothes and shoes are used. One of the causes for these accidents is that there is a lack of the preventive measures. This situation occurs when using, for example, unconductive wax. In this study, human body potential (voltage) is measured using a non-contact measuring system. An investigation of the human body's voltage when using this system is conducted. The result demonstrates that the voltage of a human body wearing antistatic clothes and shoes or light clothes and slippers exceeds a malfunctioning voltage of a microelectronics device when the body walks on floors. Thus, accidents may occur even if a human body wearing the antistatic clothes walks on flooring. These results will be useful in estimating determination whether electrostatic accidents occur or not.

Key words: Non-contact measuring system, Induced voltage, Floating potential, Charged human body, Malfunction and failure

Introduction

A charged human body, a charged human object, and an electrostatic induced voltage generated by the electrostatic induction from the body cause a malfunction and failure of electronic equipment[1−20]. This type of the accident cannot be ignored for microelectronics[21−29]. A discrimination of whether a human body is electrified is also important for determining the probability of an accident but also a confirmation of the existence of the body. The electrification of the human body occurs occasionally even if a human body wears antistatic clothes and shoes and light clothes and slippers in a room with an air conditioner.

Thus, some electric accidents occasionally occur even the antistatic clothes and shoes are used in a room. This type of accident is caused by a lack of preventive measures for electrostatic accidents. For example, when a human body wearing antistatic clothes and shoes walks on a floor, the voltage of the body increases and its voltage is changed by each motion. This topic of study has not been discussed when using a non-contact measuring system as far as the authors know. In general, a microelectronic device causes an error and malfunction for a few voltages. Therefore, considerations of how high voltages are generated for an antistatic human body and a human body wearing light clothes and slippers are important. The antistatic human body implies the human body wearing antistatic clothes and shoes.

Discrimination of a charged object is required in a room with an air conditioner. If the discrimination of the charged object is sufficient, we can determine the motion of the charged object in the room. This information can be used to determine whether a charged object exists and moves and whether accidents occur. However, finding the charged object is not easy when the object does not approach a sensor because the voltage of a charged human body changes

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and the body moves all over the room. If a voltage measurement of the charged human body is performed directly, then the motion of the charged body also becomes available. This direct measurement of the charged body cannot be performed when the wire of an electrostatic voltmeter is not connected to the charged body. Thus, the determination becomes difficult when a direct measurement is not performed.

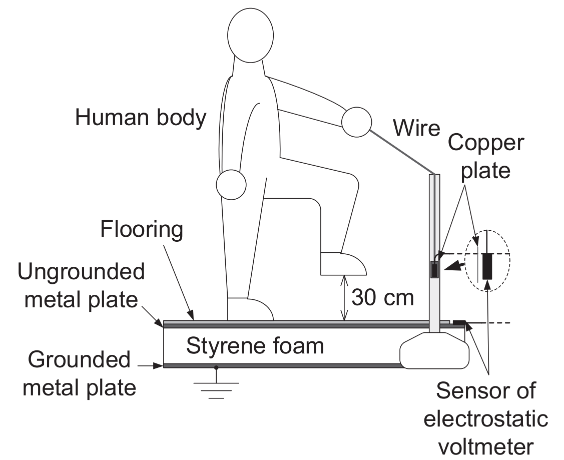
For example, there are several discrimination methods for a charged body with a metal mesh electrode near the ceiling[30], an electrode placed on the floor, and a wire electrode placed along the direction of human walking[31]. On the other hand, the non-contact measuring system of this study is different from these methods. The difference is that an induced voltage generated by the motion of a charged human body is measured by an ungrounded metal plate that is placed under the flooring[32]. We will discuss this topic for the measuring system.

In this study, when a human body wears antistatic clothes and shoes and light clothes and slippers and then moves on some floors, which are generally used with different surface resistances on an ungrounded metal plate of the experimental floor, the relation between the voltage of a charged human body and the induced voltage generated on the ungrounded metal plate is studied experimentally by using the non-contact measuring system. The results show that the charged human body in this situation can be determined by the system, and the body voltage exceeds the voltage for malfunction and failure of electronic equipment. The results of this study will be useful for considering the error and malfunction of a microelectronic device.

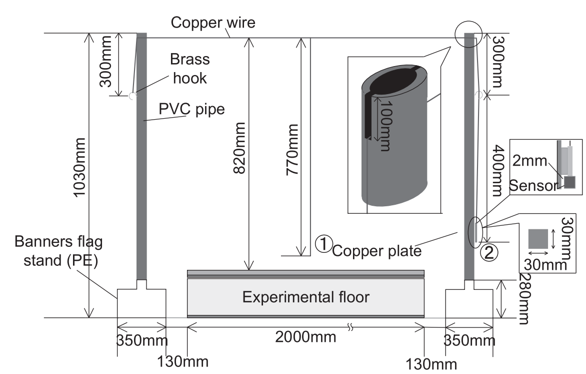
Experimental Setup

Figure 1 (a) shows the arrangement of the experimental setup. The experimental setup consists of an experimental floor, a direct measuring part for the voltage of a human body, and measuring instruments.

The experimental floor consists of a grounded metal (copper) plate, styrene foam, an ungrounded metal (copper) plate, and a floor. A sensor for the surface voltmeter (Model 347, Trek Co.) is arranged on the ungrounded metal plate. The experimental floor represents the floor in a room. Four floors are used with a PMMA acrylic plate, a multi-layer vinyl floor sheet, carpet, and a polyvinyl chloride sheet. Thus, a human body wearing antistatic clothes and shoes or a T-shirt, knee trousers (made of 100% cotton), and slippers is modeled on the general floor. The slippers of the polyvinyl chloride (PVC) are used because a human body often wears this type of slippers in the room. The surface resistances of the four floors are shown in Table 1. The value of the surface resistance in the table represents the average surface resistance of five measurements. The surface resistances are measured by Model 152-1 and Model 152P-CR-1 instruments from Trek Co. The measurements of the surface resistance of four floors are performed on an insulated plate. The walking motion of stepping is performed on the experimental floor. The dimensions of the grounded metal plate and the ungrounded metal plate are 2 m in length, 1 m in width, and 1 mm in thickness. The dimensions of the styrene foam are 2 m in length, 1 m in width, and 19.6 cm in thickness. The thickness of the four floors is approximately 2 mm.



(a) Side view of human walking



(b) Dimension of setup (front view)

Fig. 1. Arrangement of experimental setup.

Table 1. Surface resistance of flooring used in experiments

Type of flooring	Surface resistance (Ω)
PMMA plate	1.18×10^{12}
Multi-layer vinyl floor sheet	5.24×10^{11}
Carpet	3.30×10^{8}
Polyvinyl chloride sheet	1.53×10^{9}

The direct measuring part for the voltage of a human body consists of a fine wire, which is supported by two PVC pillars, with a small copper plate and a sensor for the surface voltmeter (see Fig. 1 (b)). The PVC pillars are supported by the bases of polyethylene. The sensor for the surface voltmeter is arranged on the small copper plate. A wire is connected to the center of the horizontal wire between the two pillars. A human body contacts a tip of the wire. Thus, the human body's voltage is measured by the direct measuring part. The total length of the horizontal wire between the pillars is 3.6 m, and the distance between the two pillars is 2.6 m[32].

The measuring instruments consist of two surface voltmeters, an oscilloscope, and a notebook computer with the PC Link Software installed. The induced voltage generated on the ungrounded metal plate of the experimental floor and the human body's voltage are measured by using two surface voltmeters with sensors. The two surface voltmeters connect the oscilloscope and the notebook computer. Thus, the induced voltage on the ungrounded metal plate generated by the walking motion and the human body's voltage are measured automatically.

Experimental Method

When the walking motion of stepping is performed, the induced voltage generated on the ungrounded metal plate of the experimental floor and the human body's voltage are measured. The walking motion can be explained as follows.

When a human body moves by marching in place on the experimental floor, the time interval of each step is approximately 1 second. First, the right foot rises from the experimental floor and then the left foot rises. The initial voltage of the human body is approximately zero before the walking motion starts. The height between the shoe sole and the experimental floor is nearly constant and is 30 cm for each step.

A human body is a man of general size. The experiments are conducted in a room of 28°C to 29°C and 50% to 58% R.H.

Experimental Results

Human body with antistatic clothes and shoes

Three measurements for each condition are performed because we need to consider whether the results are correct or not. A representative result of three measurements is used since the similar results are obtained repeatedly under same condition.

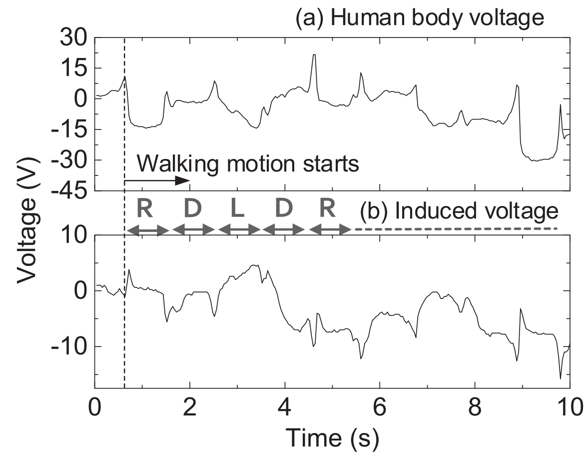


Fig. 2. HBV and induced voltage of ungrounded metal plate when human body wearing antistatic clothes and shoes walks on PMMA plate.

Figure 2 (a) shows the human body's voltage (HBV) when a human body wearing antistatic clothes and shoes walks on a PMMA plate on the experimental floor. The results in Figs. 2 (a) and (b) are measured simultaneously. In these figures, the symbol of "**R**" implies that the human body raises a right foot, "**D**" the body downs the foot, and "**L**" the body raises a left foot. A human body's voltage is −14 V when the right foot rises. The human body's voltage decreases when the foot is lowered. The human body's voltage changes when the walking motion repeats. The largest induced voltage is −30 V.

Figure 2 (b) shows the induced voltage generated on an ungrounded metal plate of the experimental floor when a human body wearing antistatic clothes and shoes walks on the floor of a PMMA plate on the experimental floor. The induced voltage increases when the right foot rises, and the first peak value is 4 V. The induced voltage is −0.5 times the human body's voltage in Fig. 2 (a). When the right foot is lowered, the induced voltage changes. The induced voltage changes when the walking motion repeats.

Figure 3 (a) shows the human body's voltage (HBV) when an antistatic human body walks on the multi-layer vinyl floor sheet on the experimental floor. The human body's voltage increases when the right foot rises, and its peak value is 13 V. The human body's voltage decreases and increases immediately to 7 V when the right foot is lowered. The largest human body voltage is 17 V.

Figure 3 (b) shows the induced voltage generated on an ungrounded metal plate of the experimental floor when an antistatic human body walks on the multi-layer vinyl floor sheet. The induced voltage increases up to −7 V

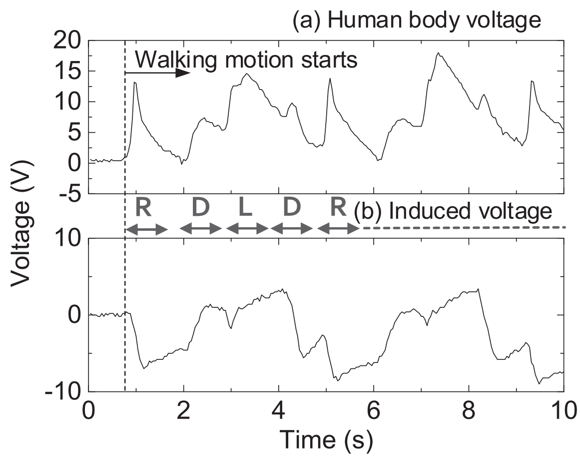


Fig. 3. HBV and induced voltage of ungrounded metal plate when human body wearing antistatic clothes and shoes walks on multi-layer vinyl floor sheet.

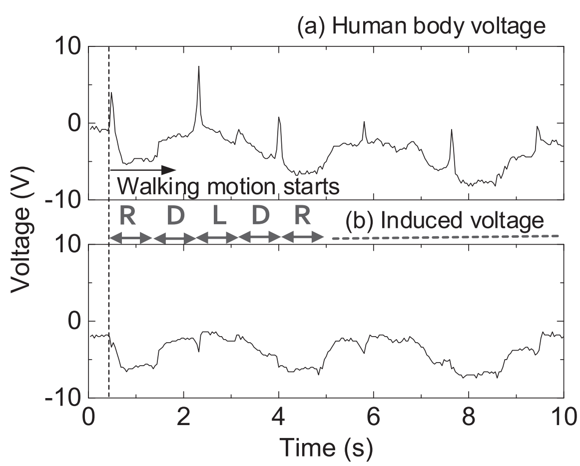


Fig. 4. HBV and induced voltage of ungrounded metal plate when human body wearing antistatic clothes and shoes walks on carpet.

when height of the right foot increases. The induced voltage decreases when the right foot is lowered. The induced voltage becomes the inverse polarity of the human body's voltage in Fig. 3 (a).

Figure 4 (a) shows the human body's voltage (HBV) when an antistatic human body walks on carpet. The human body's voltage changes when the right foot rises, and its negative peak value is −5 V. The human body's voltage decreases to −1 V when the right foot is lowered. The human body's voltage decreases rapidly even though the voltage increases positively when the height of the left foot increases.

Figure 4 (b) shows the induced voltage generated on the ungrounded metal plate of the experimental floor when an antistatic human body walks on carpet. The induced voltage is −7 V when the right foot rises. The peak value of the induced voltage is similar to that of the human body's voltage in Fig. 4 (a).

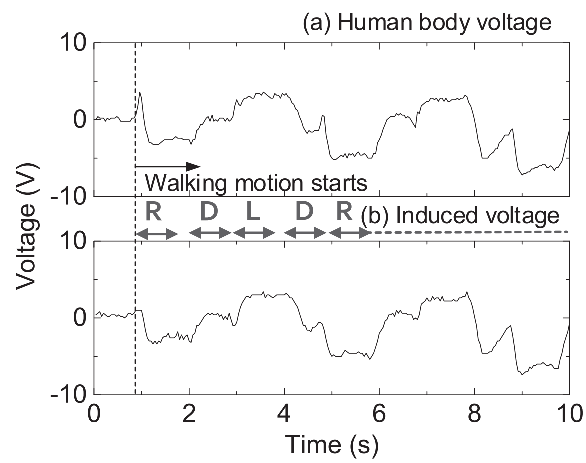


Fig. 5. HBV and induced voltage of ungrounded metal plate when human body wearing antistatic clothes and shoes walks on polyvinyl chloride sheet.

Figure 5 (a) shows the human body's voltage (HBV) when an antistatic human body walks on a polyvinyl chloride (PVC) sheet. The human body's voltage is −3 V when the right foot of the body rises. The human body's voltage decreases to approximately zero when the right foot is lowered. The largest human body voltage is −7 V.

Figure 5 (b) shows the induced voltage generated on the ungrounded metal plate of the experimental floor when an antistatic human body walks on a PVC sheet. The induced voltage is similar to the human body's voltage in Fig. 5 (a). The largest induced voltage is −7 V.

Human body with light clothes and slippers

Figure 6 (a) shows the human body's voltage (HBV) when wearing a T-shirt, knee trousers and slippers walks on a PMMA plate on the experimental floor. The human body's voltage increases up to −25 V when the right foot rises. The human body's voltage decreases to approximately zero when the right foot is lowered. The human body's voltage changes when the walking motion repeats. The largest human body voltage is −63 V.

Figure 6 (b) shows the induced voltage generated on an ungrounded metal plate of the experimental floor when a human body wearing light clothes and slippers walks on the PMMA plate. The induced voltage increases when the right foot rises, and its peak value is 9 V. The induced voltage is −0.4 times the human body's voltage in Fig. 6 (a). The induced voltage decreases to approximately zero volts. The induced voltage changes when the walking motion

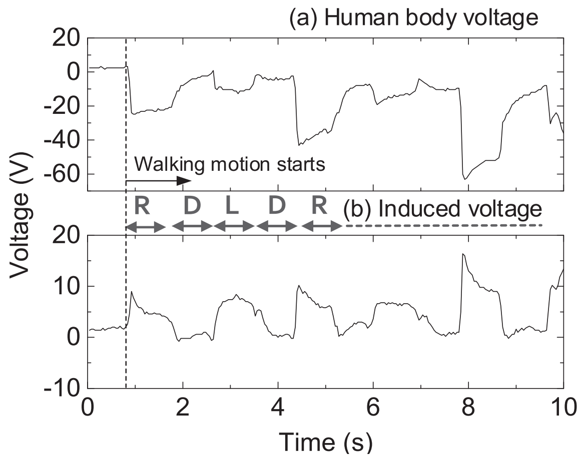


Fig. 6. HBV and induced voltage of ungrounded metal plate when human body wearing light clothes and slippers walks on PMMA plate.

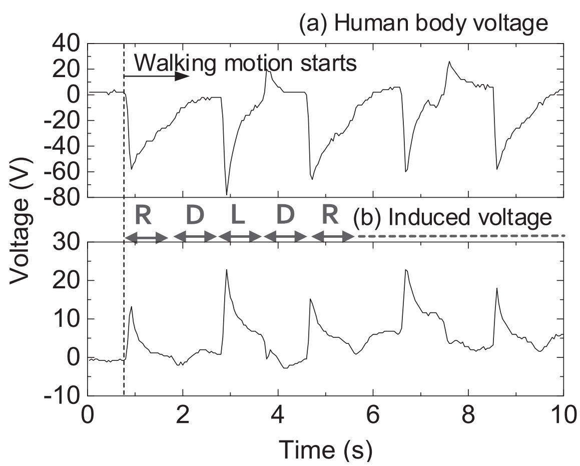


Fig. 7. HBV and induced voltage of ungrounded metal plate when human body wearing light clothes and slippers walks on multi-layer vinyl floor sheet.

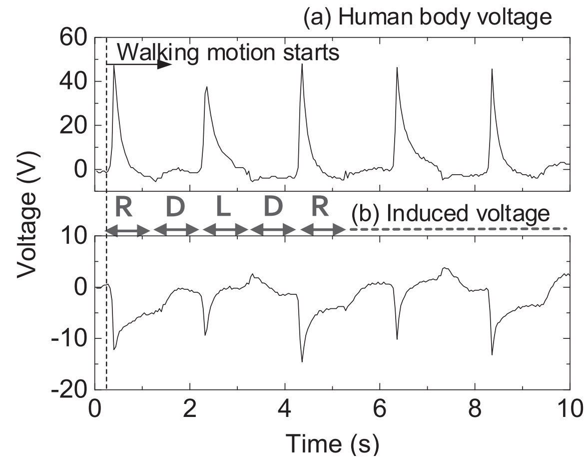


Fig. 8. HBV and induced voltage of ungrounded metal plate when human body wearing light clothes and slippers walks on carpet.

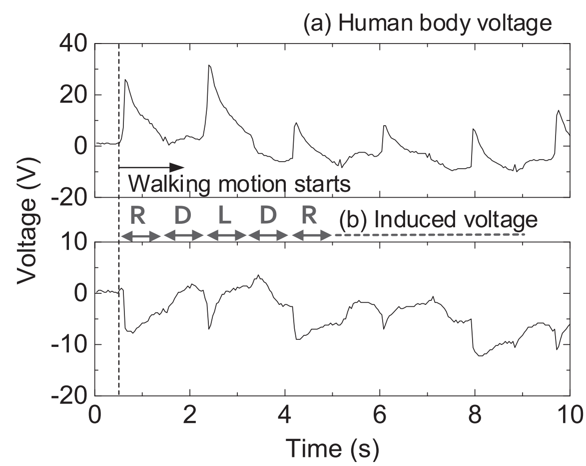


Fig. 9. HBV and induced voltage of ungrounded metal plate when human body wearing light clothes and slippers walks on polyvinyl chloride sheet.

repeats. The largest induced voltage is 16 V.

Figure 7 (a) shows the human body's voltage (HBV) when a human body wearing light clothes and slippers walks on the multi-layer vinyl floor sheet of the experimental floor. The human body's voltage increases up to −58 V when the right foot rises. The human body's voltage decreases to approximately zero when the right foot is lowered. The largest human body voltage is −78 V.

Figure 7 (b) shows the induced voltage generated on an ungrounded metal plate of the experimental floor when a human body wearing light clothes and slippers walks on the multi-layer vinyl floor sheet. The induced voltage increases up to 13 V when the right foot rises. The induced voltage is near zero volts when the right foot is lowered. The largest induced voltage is 23 V.

Figure 8 (a) shows the human body's voltage (HBV) when a human body wearing light clothes and slippers walks on carpet on the experimental floor. The human body's voltage increases up to 47 V when the right foot rises. The human body's voltage indicates a value near zero volts when the right foot is lowered. The human body's voltage is generated regularly when the walking motion repeats. The largest human body voltage is 48 V.

Figure 8 (b) shows the induced voltage generated on an ungrounded metal plate of the experimental floor when a human body wearing light clothes and slippers walks on carpet. The induced voltage increases up to −12 V when the right foot rises. The largest induced voltage is −15 V.

Figure 9 (a) shows the human body's voltage (HBV) when a human body wearing light clothes and slippers walks on a PVC sheet on the experimental floor. The human body's voltage increases up to 26 V when the right foot rises. The human body's voltage decreases when the right foot is lowered. Overall, the human body's voltage decreases as the walking motion repeats. The reason is that the human body is electrified negatively by the repetition of the walking motion.

Figure 9 (b) shows the induced voltage generated on an ungrounded metal plate of the experimental floor when a human body wearing light clothes and slippers walks on the PVC sheet. The induced voltage increases up to −7 V when the right foot rises. The induced voltage is −0.3 times the human body's voltage in Fig. 9 (a). The induced voltage decreases when the right foot is lowered.

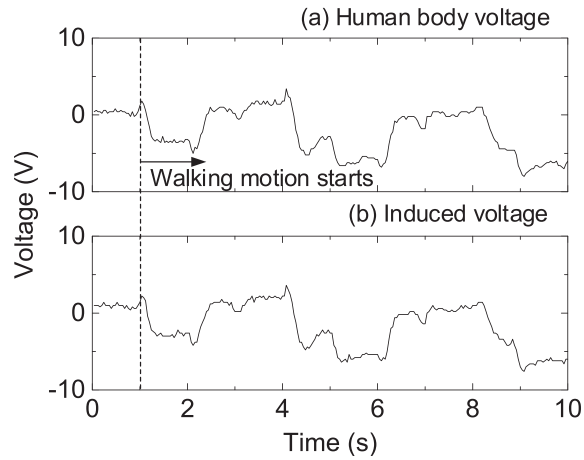


Fig. 10. HBV and induced voltage of ungrounded metal plate when human body wearing antistatic clothes and shoes walks on ungrounded metal plate.

Discussion

When an antistatic human body walks on a PMMA plate or a multi-layer vinyl floor sheet on the experimental floor, the antistatic human body is electrified in a range from −30 V to 22 V for the PMMA plate or from 0 V to 17 V for the multi-layer vinyl floor sheet. Thus, the electrification of an antistatic human body occurs with a contact and a separation between an antistatic shoe sole and the flooring. On the other hand, the induced voltage generated on an ungrounded metal plate of the experimental floor indicates a voltage of opposite polarity against the human body's voltage. The reason is that the voltage induced by the polarization of the flooring and generated by the surface charge on the flooring appears[32].

When the antistatic human body walks on carpet or a polyvinyl chloride sheet, the voltage of the antistatic human body is similar to the induced voltage generated on the experimental floor. Similar voltages are generated between the human body's voltage and the induced voltage of the experimental floor because an antistatic human body is connected electrostatically to the ungrounded metal plate similar to the results of Fig. 10. Figures 10 (a) and (b) show the human body's voltage and the induced voltage generated on the ungrounded metal plate when an antistatic human body walks on the ungrounded metal plate of the experimental floor without a floor.

When a human body wearing light clothes and slippers walks on each type of floor on the experimental floor, the voltage polarities of the human body have a negative polarity for the PMMA plate and the multi-layer vinyl floor sheet and a positive polarity for carpet. We can consider that the difference in voltage occurs because of the combination between the flooring on the experimental floor and the slippers. The induced voltage of the experimental floor becomes the opposite polarity against the human body's voltage because the induced voltage is generated by induction when the right foot or left foot rises.

Table 2. Capacitances between human body and ungrounded metal plate of experimental floor

Flooring	Capacitances (pF)					
	Antistatic clothes and shoes			Light clothes and slippers		
	Stop	Right foot rises	Left foot rises	Stop	Right foot rises	Left foot rises
PMMA plate	86	54	54	90	58	53
Multi-layer vinyl floor sheet	93	60	58	90	59	54
Carpet	91	59	57	87	58	53
Polyvinyl chloride sheet	93	59	57	88	58	53

The human body's voltage changes because of the walking motion. The change in the human body's voltage occurs from $q=cv$, and the capacitances between the human body and the ungrounded metal plate of the experimental floor change as shown Table 2. The capacitances of each motion represent the averaged value of the three measurements. We can understand the change of the human body's voltage from the measured results of Table 2. The human body's voltage increases positively or negatively if the electric charges of the human body are almost constant as the capacitance between the human body and the ungrounded metal plate decreases. The induced voltage of an ungrounded metal plate of the experimental floor changes by the change of the human body's voltage.

Conclusions

A human body is occasionally electrified, and this charged object causes a malfunction and failure of electronic equipment. The malfunction and failure are caused by the occurrence of approximately 5 V or less for the microelectronic device. These accidents occur when the human body wears antistatic clothing and shoes or light clothes and slippers in a room with an air conditioner.

In this study, the motion of a charged human body is determined by the non-contact measuring system. The human body's voltage is measured directly to determine how high the human body's voltage is and whether the human body's voltage exceeds the malfunctioning voltage of the electronic equipment.

The results show that the human body's voltage exceeds the malfunctioning voltage of the electronic equipment even if the human body wears antistatic clothes and shoes and walks on a PMMA plate, a multi-layer vinyl floor sheet, carpet, and a polyvinyl chloride sheet on the experimental floor. The induced voltage generated on an ungrounded metal plate of the experimental floor is measured simultaneously.

The fruits of this study will be useful in determining whether the malfunction and failure of electronic equipment occurs in a room.

Acknowledgment

The authors would like to thank Mr. S. Tajima and Mr. T. Morita for his help with the experiments.

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