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Research Article

Application of Capacitance Proximity Sensor for the Identification of Paper and Plastic from Recycling Materials

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Abstract: The aim of this research is to differentiate recyclable material like papers and plastics using capacitance proximity. Capacitance proximity sensor is one of the most famous systems used in the food industry. The sensor is mainly used to detect the level of liquid in the container. However, this research has found a new alternative of using the capacitance proximity sensor which is to identify paper and plastic from mixed recycling materials. This sensor can detect the target based on the permittivity value of each material. The sensors used in this study have been adjusted according to the values of paper and plastic. Experiments have been done using samples with the combination of plastic and paper with different densities. Results obtain from the experiment showed that the capacitance proximity sensor was able to detect non-metallic materials which were plastic and paper and able to identify paper and plastic with different densities.

Keywords: Capacitance proximity sensor, dielectric, permittivity, plastics, papers, recyclable

INTRODUCTION

Today's system in solid waste management and recycling fields is still weak as there is not a lot of high technology applied to help improve the system and there are not much areas or landfills to cover the waste disposal. This topic is important as it gives potential impacts on human health and safety and also the environment. Solid waste management is needed and relevant to prevent the possible threats to humanity's future with the usage of natural resources including drinking water, agricultural soil and air and so on.

There is clearly a trend made by the government to give more attention toward the recycling of larger amount of waste produced. Hahn and Lauridsen (2011) explained that besides the direct market value of the waste, the problem also stemmed from the lack of proper disposal facilities. These problems have raised the public awareness of the imbalance between consumption and protection of natural environment. For that reason, waste collection and scavenging called recycling are made important and must be applied into the minds of the public.

Monitoring systems in today's technology are famous to be used by the industries in order to make the best product and services including ensuring their product quality and the efficiency of the process. Good and reliable results can be obtained by depending on the good selection of suitable sensor technology. This can be included with the sensor's capabilities, limitations and suitability with the application, regardless of the environment. For sensing capability system, proximity sensors are widely used in many industries including food and beverage (Amft *et al*., 2010; Stevan Jr. *et al*., 2015), chemical processing (Nair *et al*., 2015; Facco *et al*., 2010; Vijayaraghavan *et al*., 2007), pharmaceuticals (Cesarovic *et al*., 2011), building and construction (Lundström *et al*., 2015) because of their versatility and high level of functionality. There are a few types of proximity sensors that are popular such as inductive, capacitive and ultrasonic. A considerable amount of literature has been published on capacitance proximity but in this research, only capacitive sensor is discussed.

Udelhoven (2012) reported that proximity sensors provide an accurate and repeatable operation under high speed conditions as 5,000 Hz and this sensor can fulfill the demands of many fast-paced industrial applications. Because the calculation can be made within 0.001 in., proximity sensor will provide precision in order to maintain efficiency and the effectiveness of the product.

Another study by Puers (1993) noted that capacitive sensing can be defined as non-contact detection device. According to him, this technology is

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suitable to use for detecting metals, non-metals, solids and liquids and mostly used for non-metallic targets because of its characteristics and cost when compared to inductive proximity sensors. Besides that, capacitive sensor can sense motion, chemical composition, fluid level, composition and pressure. Through lower dielectric materials such as plastic or glass, or higher dielectric materials like liquids, the level of numerous materials can be directly detected through glass, plastic or other container's composition (Udelhoven, 2012).

Capacitive sensors have a wide sensitivity band that allows them to perform well in difficult applications like detecting very small metal parts through a tube and this study was done by Elbuken *et al*. (2011). Capacitive sensors are also available in different housing types, with barrel, rectangular (Benniu *et al*., 2007) and probe styles available and are constructed to withstand a variety of demanding environments reliably. Capacitive sensors also detect a wide variety of materials such as liquids of varying viscosities or solids like powders, rocks and metals. As an example, capacitive sensor is used to detect powered materials such as plastic pellet in hoppers of injection-molding machines. Capacitive sensor also allows them to be mounted on grain elevators to detect materials like rice, barley malt, corn and soybeans (Udelhoven, 2012).

This research has tried to find a new application to identify recycling materials which are paper and plastic. There are a few researches that have been conducted to design are liable system of separating solid waste. According to an article published by the Waste Management World 2014, the separation or sorting of waste is done using trommel and manual sorting with an assistance by the filters, magnets, Eddy-current, hydro-crusher and air separator. There is also a system that involves a large tank full of water that uses a tank hydro-mechanic separation by gravity. As the plastic or biodegradable organic materials have equal or lower weight than water, it will float and remain suspended; therefore it will be moving through rotating blades.

More recently, Rogoff (2014) also pointed out that waste disposal companies commonly deal with sorting materials using one or more of five methods. This includes the trommel separator or drum screens, Eddy current separator, induction sorting, near infrared sensors (NIR) and X-ray technology. However, interestingly, manual sorting is still a very popular technique used for separating. Thus, this research has tried to find a new alternative to identify recycling materials using an automation system. By using the capacitance proximity sensor, this research will be able to identify recycling materials automatically.

MATERIALS AND METHODS

According to an investigation carried out by Namco (2013), capacitance is an electrical property between two separate materials, while a capacitive sensor is operated by detecting the change in capacitance between capacitive sensor and the intended target. The strength of capacitance value can be differentiated by the distance and the properties of materials.

Capacitive sensor is widely used in the food industry because of its versatility and range. In this industry, capacitive proximity sensor is used to detect product level inside a hopper or in the storage tank. Moreover, Namco (2013) also said that this sensor is also able to sense the content of a sealed package to ensure the product has a sufficient amount of content. This is because the sensor is able to see through plastic, paper or cardboard boxes in order to ensure the product is in its package.

As explained by Udelhoven (2012), a capacitive sensor's active element is formed by two metallic electrodes positioned to form the equivalent of an open capacitor. The electrodes are located in the feedback loop of a high frequency oscillator. The sensor's capacitance is low when there is no target present as the oscillation amplitude is also small. As the target approaches, the capacitance of the sensor increases along with the amplitude of the oscillation. Then, it will be measured by an evaluating circuit that generates a signal for whether to turn the output to "on" or "off".

Besides that, Rockwell Automation (2014) explained that there are a few basic components of capacitive sensors including capacitive probe, oscillator, threshold detector and the output circuit. Figure 1 shows the operation method for the capacitive proximity sensor. Capacitive proximity will generate an electrostatic field and react to the changes of the capacitance. It occurs when a target is approaching the electrostatic field. The detector circuits will check the amplitude output from the oscillator. When the target is outside of the electrostatic field, the oscillator is inactive. A capacitive coupling is developed between the target and capacitive probe when the target approaches. The oscillator will activate, triggering the output circuit to switch states between "ON" or "OFF" when the capacitance reaches a specified threshold.

Moreover, this sensor is able to detect the target based on the target's size, dielectric constant or permittivity and the distance from the sensor. Rockwell Automation (2014) also highlighted that as the target's size increase, the capacitive coupling between the probe and the target also becomes stronger.

According to an investigation by Rockwell Automation (2014), materials have different values of dielectric constant. It is easier to detect materials that have a higher dielectric constant value than materials with lower values. Water and air are examples of dielectric extremes. Water has higher dielectric constant which is 80, making the sensor sensitive to it but not for air which has a lower value of only 1. As mentioned by

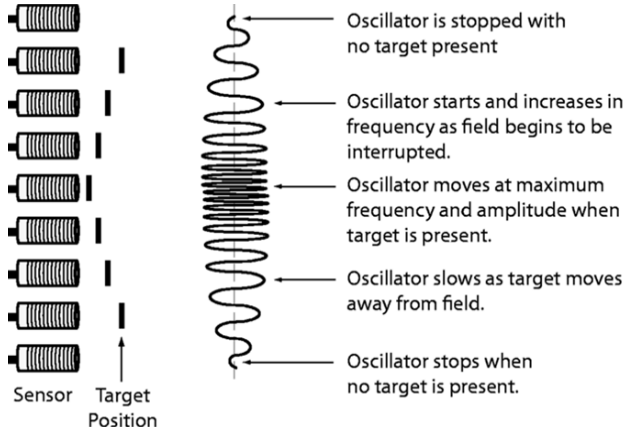


Fig. 1: Capacitive proximity operation; Source: Rockwell Automation (2014)

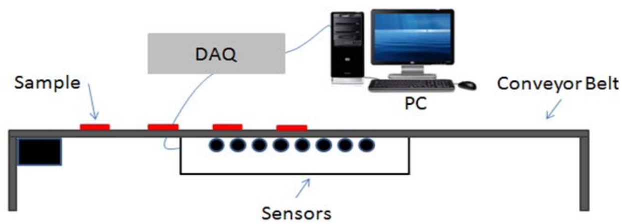


Fig. 2: Diagrammatic illustration of capacitive proximity sensor system

Fig. 3: Proximity sensors

Rockwell Automation (2014), capacitive proximity generates an electrostatic field and reacts to the changes in capacitance caused by the target approaching the electrostatic field. Furthermore, Namco (2013) mentioned that the strength of capacitance is differentiating based on the distance and the properties of materials.

In this research, an intelligent sorting system was applied which included the material handling system, formed by the conveyor, capacitive proximity sensor and a computer with the LABVIEW software as illustrated in Fig. 2. The conveyor was designed with the belt at 360 cm long and 50 cm wide. This conveyor ran at a speed that can be adjusted.

Next, for a capacitive proximity sensor, this sensor was formed by 16 proximity sensors in a box made by an acrylic. The sensors used were RIKO KC3030-KP2 (Fig. 3), which had a sensing range of about 2 to 30 mm with an operating voltage at DC12-24V. This capacitance sensor was ideal for this research because the sensor was able to detect the target and ignore the material of conveyor belt because the acrylic and belt had a low value of permittivity or dielectric constant. The sensors were covered by acrylic and placed under the belt of the conveyor. The sensors were able to detect the targets because the acrylic and the belt used had low values of capacitance than plastic (2.5 to 3 of dielectric constant value). The sensors can detect the targets and ignore the value of the acrylic and belt.

Table 1: Value of dielectric constants

Materials	Dielectric value (ε)
Papers	3.85
Plastics	3.00

In Fig. 4, the sensors were placed with 4x4 and two rows of them were set at the lower value of permittivity as the plastic, while another two rows were set at a higher value which was paper. The estimated value of dielectric constants of paper and plastic according to the Navy Electricity and Electronics Training Series (NEETS) (http://www.maritime.org/doc/neets) is given in Table 1.

The sample used in this research was papers and plastics. Papers and plastics have different values of permittivity which are presented in Table 2. We chose

Table 2: The percentage of plastic and paper in density

		Density: 0.455g/cm^3		Density: 0.28g/cm^3	
Sample	Code	Case1 Papers/plastics %	Case 2 Plastics/papers %	Case 3 Papers/plastics %	Case 4 Plastics/papers %
Sample 1	S1	10/90	90/10	10/90	90/10
Sample 2	S2	30/70	70/30	30/70	70/30
Sample 3	S3	50/50	50/50	50/50	50/50
Sample 4	S4	70/30	30/70	70/30	30/70
Sample 5	S5	90/10	10/70	90/10	10/70
Sample 6	S6	100/0	0/100	100/0	0/100

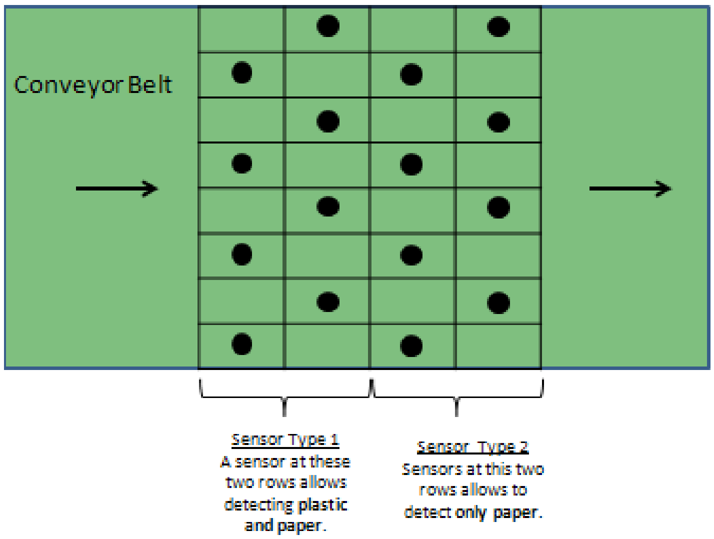


Fig. 4: View of capacitive proximity sensor position

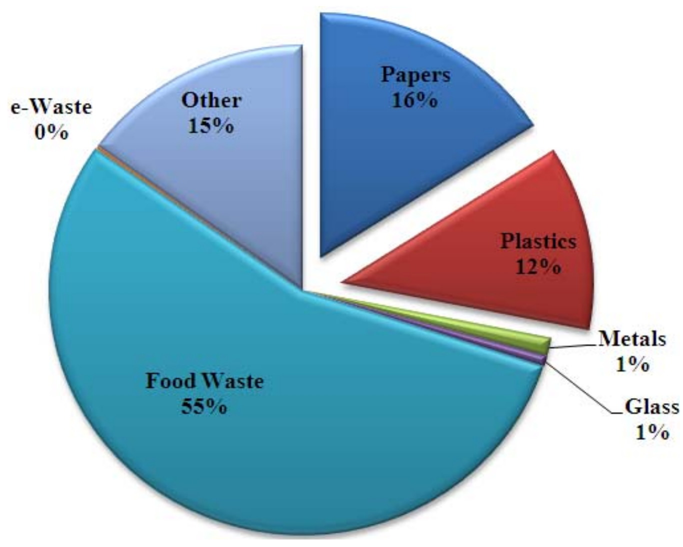


Fig. 5: Waste composition studies in UKM in 2011; Source: Tiew *et al*. (2011)

these materials as the sample because in the sorting of solid waste system, paper and plastic are the materials that are easily and mainly found in the waste stream. In Tiew *et al*. (2011) provided an in-depth analysis of the composition of solid waste in the Universiti Kebangsaan Malaysia (UKM) campus, visible in Fig. 5. The finding of their study showed that the recyclable materials generated largely were papers 15.9% and plastics 12.2%. These kinds of materials needed to be separated correctly as they can be recycled.

In this research, the samples were divided into four cases which were paper and plastic with two different

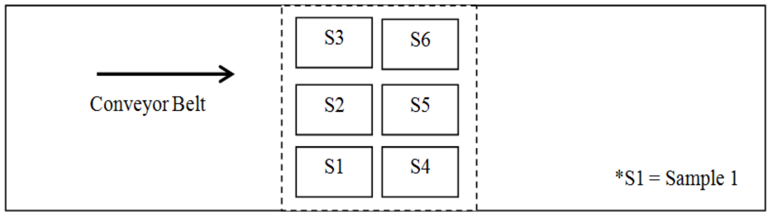


Fig. 6: The top view of samples on the capacitive proximity sensors system

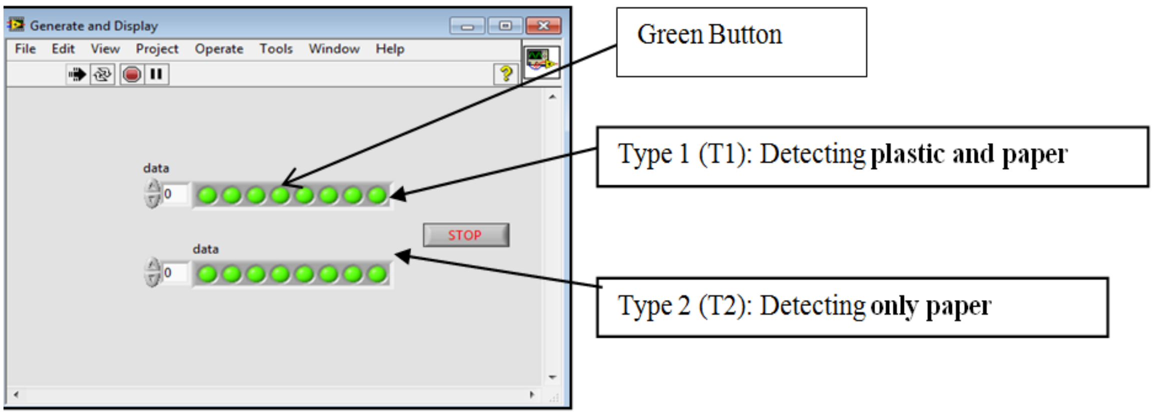


Fig. 7: Result from LABVIEW software shows the display of capacitive sensor

densities as presented in Table 2. In Table 2, case 1 consisted of 6 samples which were the combination of paper and plastic from 10%, 30%, 50%, 70%, 90% to 100%. This meant that for sample 1, 10% were made up of paper and 90% of plastic. Sample 2 consisted of 30% paper and 70% plastic and so on. The first and second cases were the group of paper and plastic (15.5cmx 10.5cmx2cm) with the density of 0.455g/cm^3. Meanwhile, the third and fourth cases were the group of paper and plastic (12×8.5c×2 cm) with the density of 0.28 g/cm^3.

LABVIEW software was installed to the computer to read the results from the sensor. Data Acquisition System (DAS) was used to connect the sensor with the computer. Figure 6 illustrated the top view of samples on the conveyor belt with an attachment of the capacitive sensor. The samples were located at the top of the conveyor and will go through the sensor with the lower speed so the capacitive sensors have enough time to detect and display results at the LABVIEW software.

RESULTS AND DISCUSSION

The identification of plastics and papers based on the dielectric value was studied by using the capacitance proximity sensor. The detection of each sensor was seen clearly and directly to the computer by using the LabVIEW software. The results from LabVIEW software showed the displays of capacitive sensor as presented in Fig. 7. As shown in the figure, the first level will detect plastics and paper and the second layer will detect only paper.

In this study, four experiments had been conducted and were labeled as four cases which were:

Case 1: In Case 1, an experiment was conducted on a paper the size of 15.5× 10.5×2 cm with the density of 0.455 g/cm^3. Table 3 shows that after the samples for case 1 were placed as mentioned in Fig. 6, they will undergo the sensors. First, samples 4, 5 and 6 will pass through the type 1 sensor and the result was all samples were detected by the sensors as shown by LabVIEW. Then, samples 1, 2 and 3 passed through the type 1 sensor and at the same time, samples 4, 5 and 6 passed through the type 2 sensor. As the samples were detected, the green button on the LabVIEW sensor will turn “off” or otherwise, it will stay “on”. The findings in Table 3 show samples 1, 2 and 3 were detected by type 1 sensor while only sample 4 was detected by the type 2 sensor. Samples 5 and 6 were not detected. After that, samples 1, 2 and 3 will pass through the type 2 sensors and the result showed that all samples were detected.

Case 2: Table 4 presents an experiment which was carried out on the plastics and papers with the density of 0.455g/cm^3 and was named as Case 2. The results showed that S1, S2 and S3 were detected by the type 1 sensor and this was because the type 1 sensor can detect plastic and paper. Meanwhile, S4and S5 were detected by the type 2 sensor which detected only paper. This

Table 3: The results of case 1 (Paper with 0.455g/cm^3 density)

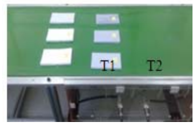
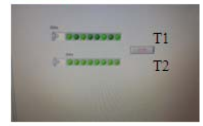
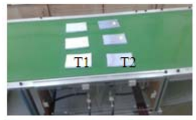
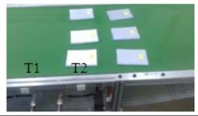
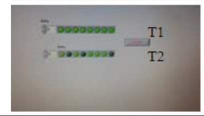
Position sample	Sample image	LabVIEW image
Type 1 : S4, S5, S6 Type 2 : None		
Type 1: S1, S2, S3 Type 2: S4, S5, S6		
Type 1: None Type 2: S1, S2, S3		

Table 4: The results of case 2 (Paper with 0.455g/cm^3 density)

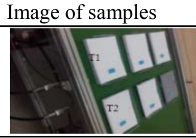
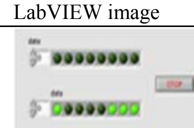
Position of samples	Image of samples	LabVIEW image
Type 1 : S1, S2, S3 Type 2 : S4, S5, S6		

Table 5: The results of case 3 (Paper with 0.28g /cm^3 density)

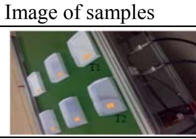
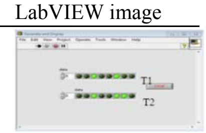
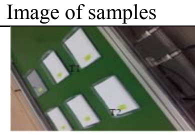
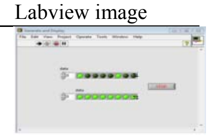
Position of samples	Image of samples	LabVIEW image
Type 1 : S1, S2, S3 Type 2 : S4, S5 and S6		

Table 6: The results of case 4 (Plastic with 0.28g /cm^3 density)

Position of samples	Image of samples	Labview image
Type 1 : S1, S2, S3 Type 2 : S4, S5 and S6		

condition occurred as there was a lot of percentage of paper in this sample and the permittivity value of papers was higher than plastic, making the sensor able to detect it. However, surprisingly, S6 with a content of 100% paper was not detected where theoretically, it should be spotted by the type 2 sensor. Later, after the calibration and adjustment of the sensor, S6 was able to be detected by the type 2 sensor.

Case 3: In Case 3, the samples were different and smaller than Cases 1 and 2. An experiment was conducted on a paper with the size 12×8.5×2cm and with the density of 0.28 g/cm^3. Table 5 above shows the results obtained from case 3.The results for this case showed that S1, S2 and S3 of paper were detected by the type 1 sensor. It was apparent from Table 5 that not all sensors from type 1 sensor can detect the samples. This was because the size of the samples were smaller and not in the range of the sensor's detection. S4, S5 and S6 also showed the same results where all these three samples were detected by the type 2 sensor when they were placed exactly at the sensor but when the sample sizes were smaller and away from the sensor, it cannot recognize the sample. This finding revealed that sample size did have an effect in detecting samples from the capacitive proximity sensor.

Case 4: Lastly, an experiment was conducted on the plastic (12×8.5×2 cm) with the density of 0.28 g/cm^3 as shown in Table 6. For the last case, the results showed that the type 1 sensor detected the S1, S2 and S3 of plastic. However, the type 2 sensor did not detect the S4, S5 and S6 of plastic. This happened because the type 2 sensor can only detect paper. Even though there were other 30 and 10% of paper, because of the lower value of permittivity, the samples' sizes and the distances between target and the sensor made the munable to be detected by sensors.

Table 7 and 8 showed the comparison based on density for Case 1 with Case 3 and Case 2 with Case 4. Based on the findings, there was not much concern regarding the paper. This was because papers have a high value of permittivity. Capacitive sensor senses the change of state based on the evaluation of the stimulus from an electrical field. This sensor detects non-metallic materials by measuring the change in capacitance. It depends on the dielectric constant of material, the mass, size and the distance from active

Table 7: Comparisons based on density for Case 1 and Case 3

		Case 1. Paper with density of 0.455g/cm^3		CASE 3. Paper with density of 0.28g/cm^3	
No	Paper/plastic Description	Type 1: Detects plastic and paper	Type 2: detects paper	Type 1: Detects plastic and paper	Type 2: detects paper
1	Sample 6 (100/0 %)	Detect	Detect	Detect	Detect
2	Sample 5 (90/10 %)	Detect	Detect	Detect	Detect
3	Sample 4 (70/30 %)	Detect	Detect	Detect	Detect
4	Sample 3 (50/50 %)	Detect	Detect	Detect	Detect
5	Sample 2 (30/70 %)	Detect	Detect	Detect	Detect
6	Sample 1 (10/90 %)	Detect	Detect	Detect	Does not detect

Table 8: Comparison based on density for Case 2 and Case 4

		CASE 2 Plastic with density of 0.455g/cm^3		CASE 4 Plastic with density of 0.28g/cm^3	
No	Plastic/paper Description	Type 1: Detect plastic and paper	Type 2: detect paper	Type 1: Detect plastic and paper	Type 2: detect paper
7	Sample 6 (100/0 %)	Detect	Does not detect	Detect	Does not detect
8	Sample 5 (90/10 %)	Detect	Does not detect	Detect	Does not detect
9	Sample 4 (70/30 %)	Detect	Detect	Detect	Does not detect
10	Sample 3 (50/50 %)	Detect	Detect	Detect	Detect
11	Sample 2 (30/70 %)	Detect	Detect	Detect	Detect
12	Sample 1 (10/90 %)	Detect	Detect	Detect	Detect

surface. It is easier to detect material with a high dielectric constant rather than a material with a low value.

The sensor was able to detect the existence of paper up until the least at 10% and this was influenced by the size and density of the sample. An example can be seen at sample 6 in Case 3. The sample of lower density that had only 10% of paper in the combination was not detected by the type 2 sensor, since the strength of the capacitance was differentiated based on the distance and the properties of the materials. As the density of sample is decreased, the permittivity value of the paper also decreased. In addition, the capacitance varies inversely with gap distance and directly with dielectric medium as well as the surface area of the target.

For the experiment with the plastic, there are some factors that made the sample to not be detected by the sensor. For samples 5 and 6 in Case 2, the sensor was not able to detect the plastic because of low permittivity values as the sensor only detected paper. The type 2 sensor only detected paper including the combination of paper and plastic where at least there was10% of paper in it. However, for samples 4, 5 and 6 in Case 4, the sensors did not detect the samples because of low permittivity in paper, since the sample was smaller and the dielectric constant was lower which made the capacitance value to be decreased.

CONCLUSION

As a conclusion, this capacitance proximity sensor is a reliable and suitable system that can be used to identify recycling materials which are paper and plastic. Besides using it to detect the level of liquid in the container, this sensor can be used to detect non-metal materials. This proximity sensor is able to identify paper and plastic automatically without involving manual separation and is really suitable for sorting solid waste system. This sensors are able to detect plastic as plastic has a low permittivity value. Besides that, these sensors are also able to detect paper with the combination of paper and plastic with at least 10% of paper included. However, there are limitations when the density of the sample, the target size and the distance between the sensor and the target that may influence the results of their capability to detect.

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