Wire-Mesh 16 × 16 Capacitance Sensor for Analysis of Capacitance Distribution on Cylindrical Pipe

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***Abstract*—The wire-mesh sensor is an intrusive sensor device that uses for generating 2-dimensional (2D) images of fluid flow. Sensors made of 2 layers copper wires, transmitter, and receiver, that perpendicular each other. The wire-mesh sensor will directly to measure the value of inductance or capacitance at the crossing wire. There are 208 data measurements in 16 × 16 cylindrical wire-mesh sensors. All data measurement then processed by Python software to obtain a 2D image of the capacitance distribution. Experiment results show the inhomogeneous distribution of capacitance that occurs in the wire-mesh sensor. Three types of liquids, distilled water, tap water and salt solution, showed circular pattern of capacitance distribution, with the highest capacitance value being in the central area of the image, while at edge area has a lower capacitance value than the central area.**

***Keywords*—Capacitance, Distribution, Python Software, Wire-Mesh, Cylinder, 2-Dimentional Image.**

I. Introduction

In some applications such as health sciences, industry, or in research frequently use various types of fluid that is not mixed in the liquid flow. To study the physical phenomena in this liquid flow, it is required variable measurements such as the velocity of each fluid or phase, concentration, and spatial distribution, among others [1]. Wire-Mesh Sensors (WMS) commonly used to obtain the distribution of the phase fraction and visualize behavior of fluid within a pipe [2]. In 1998, Prasser et al. introduce WMS based on conductivity measurements allowing the investigation of multiphase flows with a high spatial and time resolution [3]. Multiphase in a flow is described as a mixture of two or more physically distinct components, the combination of these mixtures can be a combination of one or more of the gaseous, liquid, or solid components [4]. It is a hybrid solution in between intrusive local flow parameter measurement and tomographic imaging [5]. Simple wire-mesh sensors have been introduced by Reinecke et al. [6], which uses a pair-wise conductivity measurement method of three layers of wire-mesh and image reconstruction tomography using iterative inverse algorithms. However, the wire-mesh type of point-wise sensor proposed by Prasser et al. being the first to be able to implement two-dimensional images of gas and liquid flow without artifact constraints in image processing. A wire-mesh based on capacitance measurement was developed by Silva et al. in 2007, this sensor basically measures the different permittivity of non-conducting fluids for example gas-oil two phase flow [7].

The wire-mesh sensor is generally made of a conductor (copper) wire consisting of two layers, the first layer is used as the transmitter while the second layer as the receiver [8]. The wire-mesh system read data at each cross point between transmitter and receiver wires. When the first layer acting as a transmitter is subjected to an electrical signal, the signal will not fall on the receiver layer due to the spacing between the layers, but when this signal arrives at the second layer acting as the receiver it is assumed to be a cross- Has been traversed by a conductor material (water) [2].

In this study, a tomography system device applies the principle of a wire-mesh sensor has been built to analyze the distribution of the dispersion of capacitance occurring within a cylindrical pipe. This wire-mesh sensor system is built from two horizontal layers of wires allowing, by local capacitance measurements, to detect the presence of a capacitance fluid between them.

However, with the combination of simple circuit and low price component the wire-mesh tomography system becomes an alternative device that can be applied in mapping a distribution of liquid capacitance in a cylindrical pipe.

II. Experimental

A. Materials

In this study used a PVC pipe with a diameter of 13 cm as a vessel of wire-mesh sensor, also used copper wire with a diameter of 1 mm as an electrode for the transmitters layer and receiver layer. Electronic components used in this system are Op-amp AD844 as transmitter signal amplifier and the current to voltage converter component, the CD4067 multiplexer are used as a switching gate in the transmitter and receiver system, then ATxmega128 microcontroller used as the ADC and as the switching control device of the multiplexer, USB to serial converter device FT232 to transmit digital data from microcontroller to computer, and also used signal generator AD9850 that capable to generate frequency equal to 1 MHz, opensource software phyton 2.7 used to generate 2D image of

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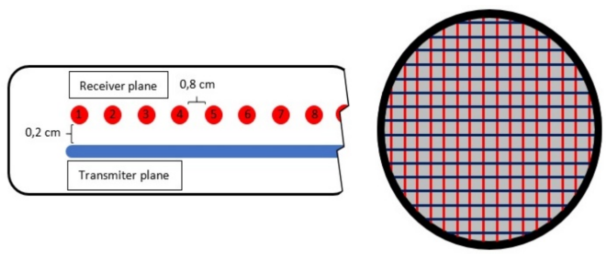
ditributuon. For the material to be analysed there are used tap water, distilled water, and salt water with molarity 0.1, 0.5, and 1 mol.

B. Design of Wire-Mesh Sensor

The wire-mesh sensor is made of copper wire which is divided into two layers: transmitter and receiver layer. Each layer is composed of 16 pieces of wire are parallel, while the wire in different layer are perpendicular to each other with 90^o angle. The distance between wires in one layer is 0.8 cm while the distance between 2 layers is 0.2 cm. The image resolution of the wire-mesh is obtained from the number of cross points between the electrode wires [2], so using 16 × 16 wire configuration, 256 points of resolution are obtained.



(a) (b)

Figure 1. Wire-mesh sensor illustration (a) side view, (b) top view.

Illustration of the sensor can be seen in Figure 1, the picture illustrates the side and top view of the sensor. Figure 1 (a) shows the side view of the sensor with the value of the interconnecting distance between the wires in one layer and the inter-wire distance value between the two layers. While in figure 1. (b) is the top view of the sensor, which is limited by a container in the form of a cylindrical pipe (Figure 2).

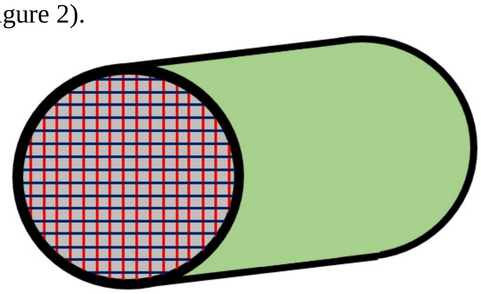


Figure 2. Wire-mesh sensor in a cylindrical pipe

C. Electronic System Wire-Mesh Sensor

The wire-mesh sensor adopts the measurement technique introduced by Prasser et al. This technique investigated the fraction of multiphase flow phase with high spatial and temporal resolution defined by the number of cross-section wires (transmitter and receiver layer) which related to the diameter of the cylinder [2].

Design of the wire-mesh sensor system can be seen in figure 3. Components requirement for manufacture of wire-mesh sensors such as, signal generator that used for generate the required signal for the transmitters layer, multiplexer as a signal flow switch, I-V converter as signal conditioner from receiver layer, and computer to convert data into 2-dimensional image.

The signal generator made by using AD9850, this device has excess can produce sinusoidal wave and square wave with frequency can be set up from 1 to 40 MHz. To chose desired frequency in AD9850, it can be adjust via digitally using a microcontroller, this is one of the advantages of AD9850, which is it can become variable signal generator in order to analyze wire-mesh sensor system according different frequency in transmitter layer. The signal used in this system wire-mesh sensor is a sinusoidal wave with single frequency 1 MHz, the selection of these frequencies corresponds to the results of a multiplexer experiment that has accuracy at frequencies below 1 MHz. This sinusiodal signal then transmitted to every 16 transmitter wires one by one.

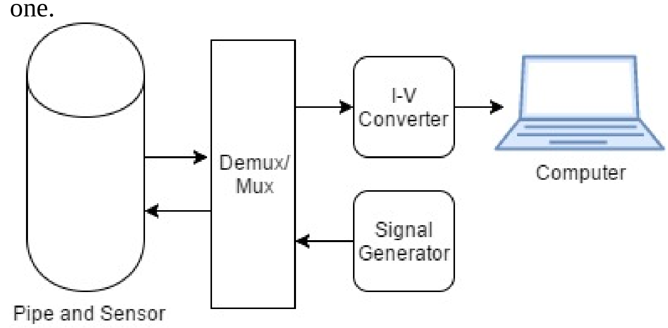


Figure 3. Diagram hardware of wire-mesh sensor.

In order to transmit signals one by one to all 16 wires, a demultiplexer device is required. An electronic switch caled multiplexer demultiplexer (mux/demux) is applied in this automatization switch system. Device CD4067 used because has feature that it can be applied as mux or demux in a time. The demultiplexer feature is used for the transmitter system, while the multiplexer feature is used for the receiver system. By using CD4067, transmission and receiver systems can be done automatically with electronic controls. The I/O (input/output) pin of this device is connected to each transmitter and receiver electrode wire, so by drive the control pin on CD4067, wire-mesh sensor can be used to measure each measurement point.

The signal that received on the transmitter wire is still in a current signal, whereas in a digital system the signal must be read as the voltage signal, so to change it can use the current converter circuit that can convert curent into voltage signal. In accordance to circuit introduced by Silva, et. al [7], a simple circuit consisting of an op-amp coupled with a capacitor and a resistor as feedback can convert a current into a voltage whose value is proportional each other. Fig. 4 is a schematic of a current-converting circuit into a voltage or I-V converter.

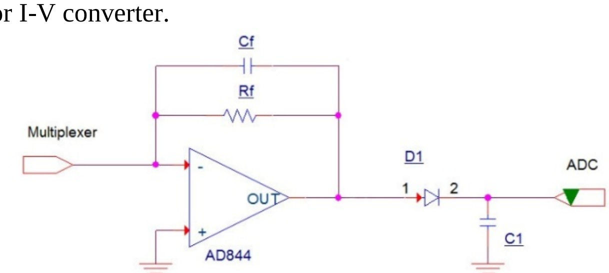


Figure 4. I-V converter circuit

By using equation (1), we can get the capacitance value that occur in cross-section wire-mesh sensor [7].

$$V_o = -V_i \frac{C_w}{C_f} \quad (1)$$

The output voltage (V_o) is is the output voltage of op-amp which will be read by ADC, the input voltage (V_i) is the voltage coming from the receiver wire. Capacitor wire (C_w) is representing capacitance of the wire-mesh sensor whose value varies according to the flowing substance between the two wire receivers and the transmitter.

One of the advantages of using AD844 is this op-amp works well as the active element in an operational current-to-voltage converter. This device analyzes includes the stray capacitance of the current source, which may be a high speed DAC [9]. This op-amp is also used to amplify the voltage of the signal generator because it can handle signal amplification with high frequency range (megaherzt).

D. Image Processing

To get 2-dimensional image from data, software python is applied. The advantages of this software is basicaly open source programing language, so it can be used for free, beside that the features are similar to matlab wich is very easy to understand and easy to use.

Because the output signal from the I-V converter is still an analog signal, it needs to be converted into digital form using ADC contained in microcontroller. This is needed because the computer that will process the data into 2-dimensional image can not read analog signal and only able to read signal in digital form. Delivery of digital data from the microcontroller to the computer in real time, in other words, every data read on each point of measurement of wire-mesh sensor is then sent directly to the computer. Until when all the measurement point data has been sent, then the program that has been made through phyton will immediately reconstruct the image from the data obtained. Data transfer on the wire-mesh sensor system occurs in real time, each measurement at the wire-mesh transmitter-receiver cross point, it will be send directly to the microcontroller ADC, after that microcontroller directly sent the data measurement to the computer and processed by the python program.

The data received by the computer is still in a voltage value, to get the capacitance value from the wire-meh sensor it is necessary to change the data using equation (1). This equation is inserted into the code script in the python 2-dimensional image program, so it is not just a program to create images but python software also performs mathematical calculations to get measured capacitance values in wire-mesh sensors.

III. RESULTS AND DISCUSSION

A. Demultiplexer

To know the limits of electronic devices, it is necessary to do experiments to find out. The tested device is multiplexer CD4067, this experiment is to determine maximum ability of multiplexer can handle highest frequency input or output. Multiplexer (MUX) itself is a device which has combination path data element that selects one of several inputs as output by using a select line [10].This experiment is very important because if the multiplexer is not able to transmit the desired frequency it will happen a change in the result of reading the value of capacitance. So if that happens, the measured capacitance value will be different from the actual capacitance value. Experiments were performed by varying the value of frequencies, ranging from 200 kHz to 5 MHz.

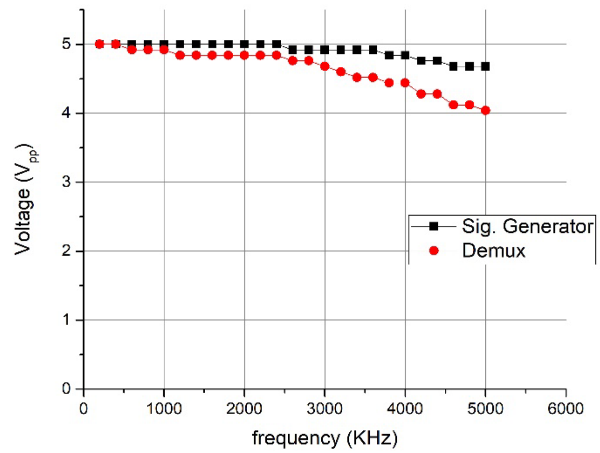


Figure 5. Multiplexer stability experiments on frequency variation

Figure 5 is the image of the multiplexer experiment results, the horizontal axis is the frequency whereas the vertical axis is the resulting voltage (Vpp). Line with the box pattern is the voltage of the generator signal and the line with the circle pattern is the voltage of the multiplexer. On the chart seen at a frequency of 600 kHz the voltage of the multiplexer has begun to decrease and constant at a voltage of up to 1 MHz frequency, but slowly drops again when the frequency raised. Until at 5 MHz the voltage drops to 4 Volts, this voltage drop affects the accuracy of real the capacitance readout by wire-mesh sensor, the measurement error will be very large if frequencies above 5 MHz is applied in the system. It was concluded that the use of the CD4067 type multiplexer is less suitable for use as a high frequency switching device, but if the built system requires high frequencies it can use relays,with consequences affecting the sensor readout speed.

B. Cylindrical Pipe and Wire-Mesh

The vessels to be used is PVC type pipe, not only the price is cheap and widely available but also it is quite rigid and strong when applied to a liquid flow. For design cylindrical pipe of wire-mesh sensor system, PVC pipe cut along 40 cm with a diameter of 14 cm, transmitter and receivers copper wires woven into a net form, but in every layer does not touch each other between them.

Device used in this experiments according to figure 6, the image is a cylindrical pipe in which there is woven wire-mesh sensor. To use it simply by connecting the connectors of each layer to the sensor's electronic device, then the liquid medium is poured into the pipe until the wires is submerged. Then automatically the screen on the computer will display 2-dimensional image of the measured capacitance distribution. Images are presented in real time, if there are some direct fluid change inside pipe e.g., change in slope level, fluid type and water level then the image will quickly change, furthermore the resulting image can be stored in computer memory.

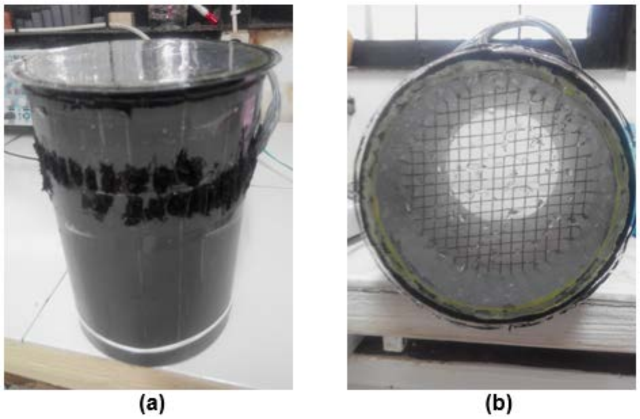


Figure 6. Image of the sensor used in the experiment (a) Pipe and (b) wire-mesh sensor

C. Reconstruction 2-Dimensional Image

In this research there are 4 types of fluid applied in wire-mesh sensor such as free air, distilled water, tap water, and 1 mol of salt solution. This variation aims to determine the ability of the sensor to read fluid changes from non-conductive (air) to the most conductive fluid (salt solution), and of course determines the capacitance distribution of each fluid.

Figure 7.a is the result image of the wire-mesh sensor with air media filling the cylinder pipe. A picture with white circle and black edges is the approximation of a cylindrical pipe shape, the shape of this circle is not perfect, it has a square edge shape, this is because each square represents the cross point of the receiver and transmitter wires, moreover if all the squares are combined it will become a 2-dimensional image of the cylindrical pipe. The color bar on the right side picture is the image legend, showing the value of the capacitance that changed into the color form, each color having its own value, for the color in the bottom position (white) it's means has low capacitance while the top position (blue) means highest value.

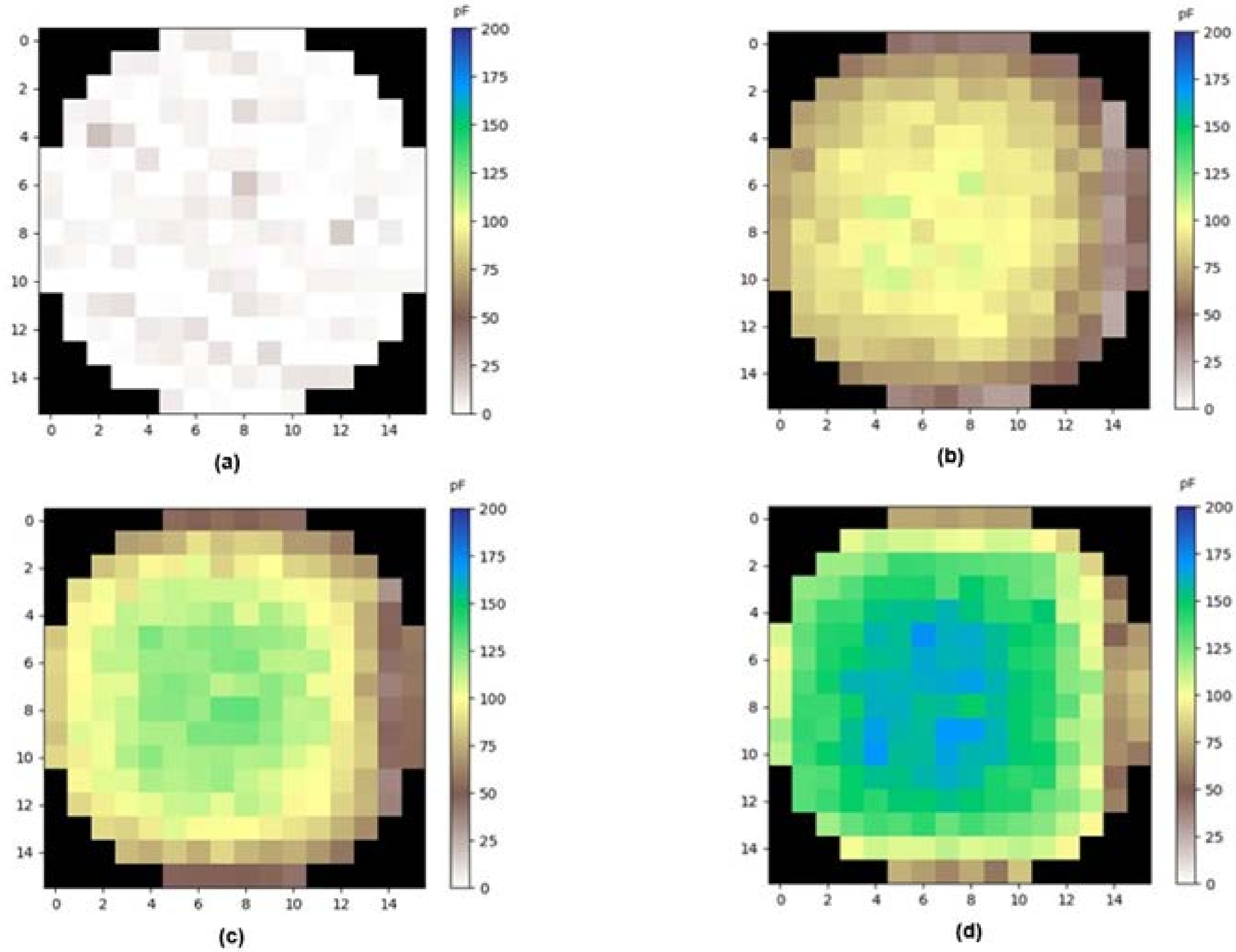


Figure 7. Images generated by wire mesh sensors using (a) free air, (b) distilled water, (c) tap water, (d) salt solution 1 mol

Filling cylinder pipe using free air causes the resulting image become mostly white (Fig 7.a) or in other word air has zero capacitance. In this case, its mean not absolutely zero, but there are measurement limits. Wire-mesh sensor system can not measure at a certain range, the system has a weakness in measuring capacitance on gas phase, especially free air, because the capacitance of air is too small for system to be measured. Therefore, the system will automatically send zero data to the computer that causes the resulting 2-dimensional image being white. Not all measuring points are zero, at some point indicate the sensor still capable to measure the capacitance value of the air, even though its looks vague with color pattern is light brown, this color still can identified with capacitance value at range 0 to 15 pF.

When using distilled water as media, the color pattern on the resulting image is increasingly visible, its very contrast if compared with results images using free air. The results image (Figure 7.b) has 3 main colors i.e., brown, yellow and green. The composition of the three colors is dominated by the yellow color in middle of the image, with brown color in edge of the image, while the green color looks vague in the center of image with total pixel image less than ten pixels. The quantity of the measured capacitance value at the sensor is around 100 pF in the center area and 50 pF of the edge, this is corresponding to the scale bar next to the image. Compared capacitance value between distilled water and free air (average capacitance equal to zero), the difference capacitance value between both materials is large enough, even though distilled water has no mineral content but as a dielectric material it is strong enough to increase the electric field between the transmitter and receiver wires. Its shows that the capacitance of distilled water is greater than free air. This difference corresponds to the permittivity value of each substance material, permittivity value of air is 1 whereas in distilled water is 80, hence the difference is big enough to produce very contrast color difference.

Increased capacitance occurs when using tap water. Figure 7.c is an image produced by the system using tap water media. In this picture the number of color patterns are equal with distilled water, there are 3 main colors i.e., the brown color that occur in the edge of the image, the yellow color located in the middle area of the image, and the green color in the center of the image. Whereas, the distinguishes attribute compared from the previous image are the area of green color are widened, this color pattern is almost half of the yellow pattern in the middle area of the image, this indicates that the value of capacitance on the sensor is increasing due to pouring tap water on cylinder pipe. In addition, the yellow color looks brighter with a capacitance value of about 150 pF and the brown color began to fade with capacitance value about 45 pF. Referring to the color scale next to the image, the measured capacitance value on the green scale is about 150 pF.

A new pattern is created when the salt solution is applied in the pipe. Figure 7.d is the image created by system using a salt solution with molarity level 1 mol. There are 4 color patterns filling the image including brown, yellow, green and blue, without any white color that fills the image. With more conductive the fluid has been applied, affect raise the capacitance value are obtained, this is indicated by the appearance of a new color just like blue. In accordance with the color scale, the blue color is above of all colors that ever appeared before (white, brown, yellow, green), the highest capacitance of the blue color measured about 165 pF, but the dominant color is green. The distribution pattern of the capacitance in the salt solution remains the same as the previous image pattern, the highest conductivity is at the center of image, shown in blue, while the green pattern dominates the entire color in the middle of the image. The yellow and brown colors now begin to fade and spread over the edges of the image, even more the brown color begins to be completely replaced with yellow. If some liquid with higher conductance value than the salt solution is applied, it is clearly predictable that the brown color will disappear, due to the increasement value of the capacitance occur in all points of measurement.

With the ability to change color in image reconstruction due to the different capacitance values, which are caused by variation fluid conductance, the utilization of the wire-mesh sensor can be developed. With these properties, wire-mesh sensor now capable being a device that can be used as type fluid predictor device from analyze conductivity value of the fluid inside the cylindrical pipe.

From four images that has been made, the identical pattern of capacitance distribution on cylindrical pipe, except on free air, it tends to be higher in the central area, this may be caused by electric field formed between the transmitter and receiver wires. This electric field is also created around the point to be measured, which causing increasement capacitance value of the point to be measured. Therefore, measuring located in the middle of cylindical pipe becomes very sensitive due to the influence of the surrounding electric field, whereas measurement in the edge area is less sensitive because only affected by the electric field just in one side.

When compared with the experiments results by some other researchers, for example Silva et al [7] and Prasser et al [3], distribution patterns that has been obtained did not match with the experiment result from other researcher. This is because the other researchers using calibration and binarization of the image they have obtained. So the color pattern of a single fluid will always be uniform and will change only when there are 2 or more liquids that fill their device.

IV. CONCLUSION

A study to know the capacity distribution pattern in cylindrical pipe has been successfully done. This study develops a device with capability producing 2-dimensional images of the distribution capacitance that occur inside the pipe. The design of the device refers to a sensor system device called wire-mesh sensor. A capacitance wire-mesh sensor is one kind of wire-mesh sensor system type, its capable to sensing the difference capacitance value in several fluid types. The principle of this device is analyze the electric field that occur between two wires (transmitter and receiver), where between them there is a dielectric material which can increase or decrease the capacitance value. This research using 16 × 16 wires, which can produce 208 measurement data and image with 208-pixel resolution.

There are 4 pieces of image has been obtained, each image shows the capacitance distribution pattern of 4 different liquid types, namely free air, distilled water, tap water, and salt solution. In free air image, there is no distribution pattern, because the measured capacitance is very small. Whereas in 3 other fluid types, they are having same identical patterns, but the color attributes that appear in the image are different, in all images shows that the highest capacitance value is in the center of the image with a circular pattern, while at the side of the edge shows the color pattern with a lower capacitance value than at center. The highest capacitance was obtained by a salt solution, with a value of 165 pF, illustrated by a light blue color pattern, and for the lowest capacitance obtained free air with an average value of 0 pF, with white color pattern.

Another function of the wire-mesh sensor that has been made, that is it can be used as a device with ability to predict the of substance type, especially fluid, based on the capacitance value of the substance. Of course we must have capacitance database values from various materials which will be predicted.

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