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Material characterization and imaging using rectangular spiral interdigital capacitive sensor array

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Abstract : **This paper presents a cost effective solution for proximity detection and imaging of material under test using an interdigital capacitance sensor array. The key element of the system is an image scanner which consists of a scan head. The scan head incorporates a parallel in plane capacitance sensor array having rectangular spiral shape which can be used as a proximity sensor and the measured capacitance values are used for gray scale image creation. The presence of a material under test changes the resultant electric field distribution. This property is used to detect the presence of an object. Scanner can be used to analyze real-world object to collect data is then used for image creation. The use of interdigital sensor array adds many features to the system. The resolution of the system was improved by the rectangular spiral shape and increased number of digits.**

Keywords — Capacitance sensor, Capacitance to digital converter, Grey scale image, Interdigital sensor, Non destructive testing

I. INTRODUCTION

Non Destructive Testing (NDT) is a group of techniques which allows materials to be tested without affecting their properties. Capacitance evaluation method of NDT provides a cost effective solution for the characterization of materials. This method can be effectively used for conductive, non-conductive as well as magnetic materials. Capacitance sensors are widely used because of their following features: fast response, flexibility in electrode design, non-intrusive and no radiation. Capacitive sensing technique can be used to evaluate pressure, humidity, detection of proximity etc. In such systems physical, chemical or mechanical properties of material under test is measured in terms of change in capacitance. The obtained analog capacitance values are then converted to digital values with the help of an electronic circuitry[1].

A proximity sensor converts information on the movement or presence of an object into electrical form. They found large application in daily life. Proximity sensors are used in automobiles to detect the presence of nearby vehicles or objects and also in parking assist functions. In mobile phones proximity sensors are used to detect whether the user's face is close to the screen during a phone call, prompting the screen to turn off to prevent false touches on the screen. [9]

In conventional capacitance sensors driving and sensing electrodes are placed opposite to each other in close proximity. When the driving and sensing electrodes are gradually open up, the electric field expands to a wider area and when the electrodes are open up to a coplanar plane the fringe field become predominant. This type sensors are called coplanar sensor and has the advantage of single side access of the material under test.[2] –[7]

Our aim was to develop a cost effective solution for proximity detection and imaging of the material under test. The setup consists of a CNC machine for scanning purpose, an interdigital capacitance sensor array, and the controller mechanisms. This set up provides the facility for both proximity detection and imaging of the material under test[9].

II. METHODOLOGY

The proposed system consist of a parallel in plane capacitance sensor array, a capacitance to digital converter circuitry, mechanism for movement of scan head, and also a controller for control and coordinate all the functions.

A. Principle of operation

Scanning an electrode pair across a surface and measuring the resultant change in stored charge for a given voltage and creates a map of changes in electrical properties within the sample allows to evaluate the properties of that material. The co-planar probe, which contains two electrodes, generates an electric field distribution within the test material when an AC voltage is applied between the positive and negative electrodes. The presence of the sample under test will affect the resultant electric field pattern [4]. In addition, any change in properties within the sample, such as the presence of a defect within the volume

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covered by the electric field distribution. The electrode arrangement is shown in figure 1.[1]

Geometry of the sensor electrodes includes the separation of electrodes, spacing and shape, are the parameters which determine the sensor performance [1]. Different electrode shape can be used, such as a square, rectangular, round, ring shape etc. In this work we are developing a sensor rectangular spiral in shape on a double sided PCB. 14 sensors were placed vertically. This is then connected to the 14 channels of CDC.

The AD7142 uses a method of sensing capacitance known as the shunt method. Using this method, an excitation source is connected to a transmitter generating an electric field to a receiver. The field lines measured at the receiver are translated into the digital domain by a Σ-Δ converter. When a finger, or other grounded object, interferes with the electric field, some of the field lines are shunted to ground and do not reach the receiver . Therefore, the total capacitance measured at the receiver decreases when an object comes close to the induced field. The excitation source and Σ-Δ ADC are implemented on the AD7142, and the transmitter and receiver are constructed on a PCB that makes up the external sensor.

When a sensor is approached, the total capacitance associated with that sensor, measured by the AD7142, changes. When the capacitance changes to such an extent that a set threshold is exceeded, the AD7142 registers this as a sensor touch. Preprogrammed threshold levels are used to determine if a change in capacitance is due to a sensor element being activated. If the capacitance exceeds one of the threshold limits, the AD7142 registers this as true sensor activation.

The principle of capacitive sensing is based on the interaction between an MUT and the interrogating electric field. An electric field generated from sensor electrodes penetrates through an MUT, and causes electric displacement within the MUT to counter the applied field. This displacement field changes the charge stored between the sensor electrodes, and thus alters inter electrode capacitance, which in turn can be used to infer the properties of the MUT, such as permittivity, conductivity and their distributions. An electrical stimulus is applied to a driving electrode while a measurement is taken from a sensing electrode. When Material under test (MUT) approaches the proximity region, the dielectric constant of the setup changes and the capacitance changes. The capacitance is directly proportional to the amount of dielectric constant. As the dielectric constant between the capacitive plates of a capacitor rises, the capacitance will also increase accordingly.

The obtained capacitance values are then converted to corresponding digital values using a capacitance to digital converter circuitry. The proposed method uses AD7142 as the capacitance to digital converter. The AD7142 uses a method of sensing capacitance known as the shunt method. Using this method, an excitation source is connected to a transmitter generating an electric field to a receiver. The field lines measured at the receiver electrode end is translated into the digital domain by a Σ-Δ converter. When a finger, or other grounded object, interferes with the electric field, some of the field lines are shunted to ground and do not reach the receiver. Therefore, the total capacitance measured at the receiver decreases when an object comes close to the induced field. This arrangement is shown in figure 1.

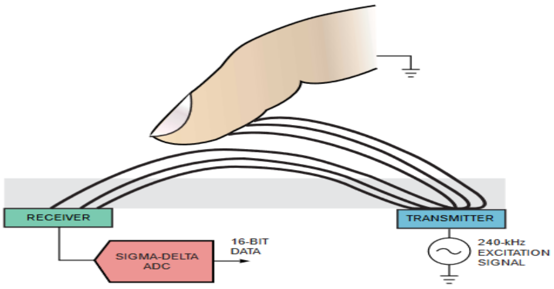

Fig 1: Principle of operation of capacitance sensor

For each sensor, the five steps listed below shows how to configure AD7142 for capacitance touch applications.

1. Set up the input connections.
2. Offset the bulk or stray capacitance.
3. Get the high and low clamp values.
4. Get the high and low offset values.
5. Set the sensitivity.

The response of the capacitance sensor depends on three factors:

- The size and type of the sensor element
- The size of the object touching the sensor
- The thickness and type of the covering material

The flow chart of the proposed methodology is shown in figure 3. The scan head moves Z axis up to a distance where a reduction in CDC code occurs which means that the proximity of material is detected. At this time the proximity flag on AD7142 will indicate the presence of material. The Z axis motion then stops and move towards X axis by scanning the material. The scan head acquire values every 0.5 inches and these values are stored on a matrix. After scanning the entire material, these stored CDC codes are converted to pixels and then corresponding grey scale image is created.

B. Sensor Development

Geometry of the sensor electrodes includes the separation of electrodes, spacing and shape, are the parameters which determine the sensor performance [1]. Different electrode shape can be used, such as a square, rectangular, round, ring

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shape etc. In this work we are developing a sensor rectangular spiral in shape on a double sided PCB. 14 sensors were placed vertically. This is then connected to the 14 channels of CDC.

The two electrodes were designed such that the spacing between them is 25 mills and width of each electrode is 25 mills. Total size of one sensor element is 500*500 mills. Electrodes are made of conductive materials such as Copper. When the material to be tested approaches the proximity region, due to the variation in dielectric constant the resultant capacitance value changes. This variation shows that the capacitance is proportional to the amount of dielectric constant. Dielectric constant of each and every material is different therefore the capacitance value also shows variations and this variation can be used for material characterization. The developed sensor PCB is as shown in figure 4.

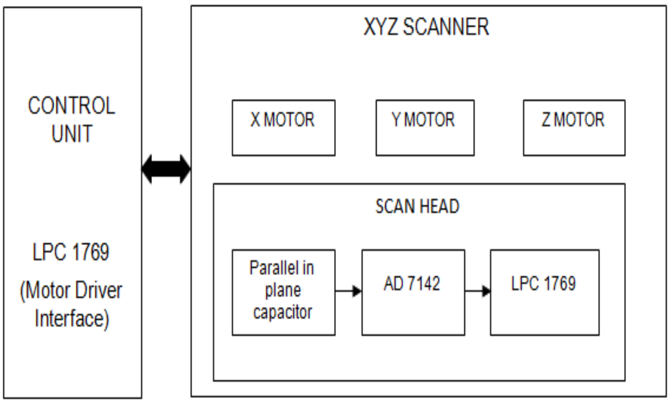

Fig 2: Block diagram of the proposed system

C. Experimental setup

Figure 5 shows the complete experimental setup for the proposed system. There are three Stepper motors which are used for X, Y and Z axis movement of the scanner and this arrangement help to scan the entire material under test. Control signals for the accurate motor movement was given by LPC 1769 ARM controller and the same controller helps to acquire CDC code corresponding to the material under test from the CDC. Scan head comprises of an interdigital capacitive sensor array having rectangular spiral shape and specific dimensions mentioned in section *B*. The 14 channels of the sensor array was connected to CDC device. AD7142 capacitance to digital converter consist of 14 channels and we can reduce the number of channels as per the requirement. The unused capacitance inputs must be connected to bias. I2C interface was used between controller and AD7142 to acquire the CDC code from AD7142. Proper functioning of CDC was controlled by three banks of registers named bank 1, 2 and 3. Bank 1 consists of power control registers, Bank 2 consist of stage configuration registers and bank 3 consist of result registers.

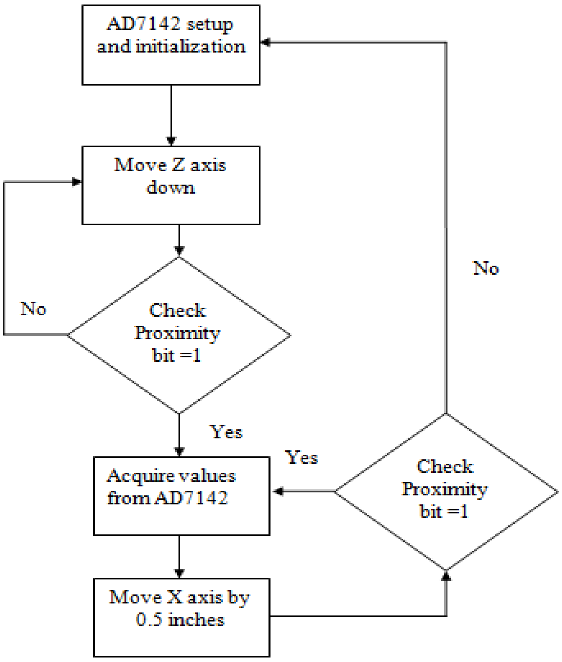

Fig 3: Flow chart of the proposed methodology

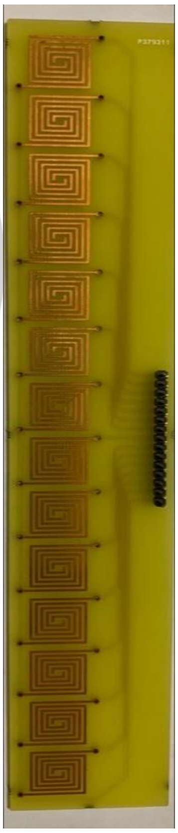

Fig 4: Designed interdigital capacitance sensor

III. RESULTS AND DISCUSSION

Different materials are tested in order to show the variation in CDC code. The materials used are human finger, glass, wood and steel. The proposed system shows different amount of variation for each object. These variations are due to difference in dielectric constants of materials under test.

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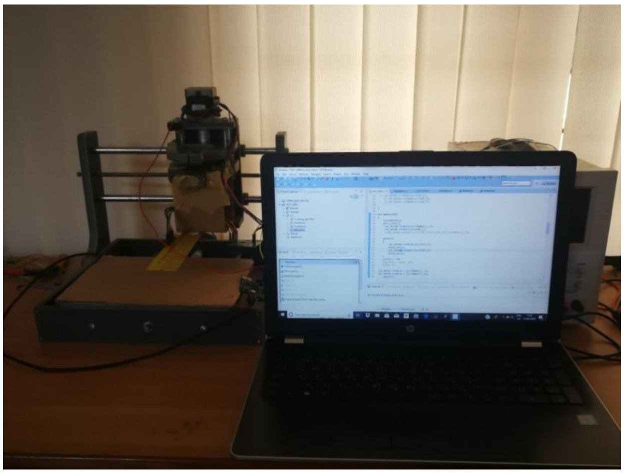

Fig 5: Experimental setup

A. Proximity range analysis

The proximity range of different objects is tabulated below.

Table 1: Proximity detection range of various materials

Material	Proximity distance
Finger	5 cm
Wood	2 .5 cm
Steel	2. cm
Glass	1.5 cm

From the table it is clear that different objects possess different proximity range because of the variation in their material properties. Finger was detected at largest distance because of increased dielectric constant and glass was detected at the least distance.

B. Sensitivity analysis

When there is no material under test, the CDC code of all the 0 to 9 channels will be around 34000 i.e. the capacitance values are around 1.75pF (figure 6 and table 2). The grapgh is plotted with capacitance value in pF on Y axis and distance in cm on X axis.

A steel material is placed on channels 6, 7, 8 and 9. Then the capacitance values on these channels shows a decrease to around 1.64pF whereas capacitance of other channels remains the same (figure 7 and table 3).

Table 2: Capacitance output without MUT

Distance= 5.5 cm	
Channel	Capacitance value
Ch_ 0	1.8
Ch_ 1	1.72
Ch_ 2	1.79
Ch_ 3	1.72
Ch_ 4	1.72
Ch_ 5	1.8
Ch_ 6	1.75
Ch_ 7	1.72
Ch_ 8	1.72
Ch_ 9	1.79

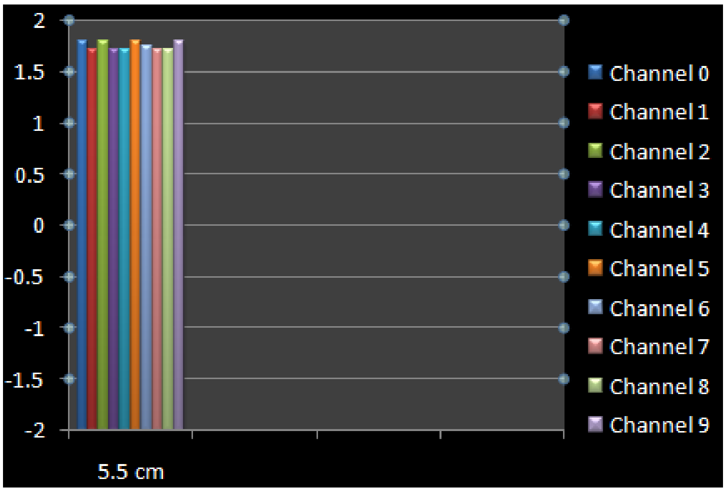

Fig 6: Capacitance (pF) v/s Distance (cm) without MUT

Table 3: Capacitance output with Steel

Channel	D= 2 cm	D= 1 cm	D= 0.5 cm
Ch_0	1.81193	1.81133	1.812341
Ch_1	1.72593	1.72699	1.726538
Ch_2	1.79320	1.79366	1.793055
Ch_3	1.72024	1.71969	1.719942
Ch_4	1.72955	1.73001	1.729056
Ch_5	1.80851	1.80796	1.808565
Ch_6	1.70790	1.66792	1.647331
Ch_7	1.70992	1.68620	1.661229
Ch_8	1.69587	1.66289	1.64718
Ch_9	1.76299	1.75695	1.718381

Glass material is placed on all channels and hence all the 10 channels show a decrease in output CDC code. As the distance between sensor PCB and material decreases glass shows a little variation when comparing to other materials tested.

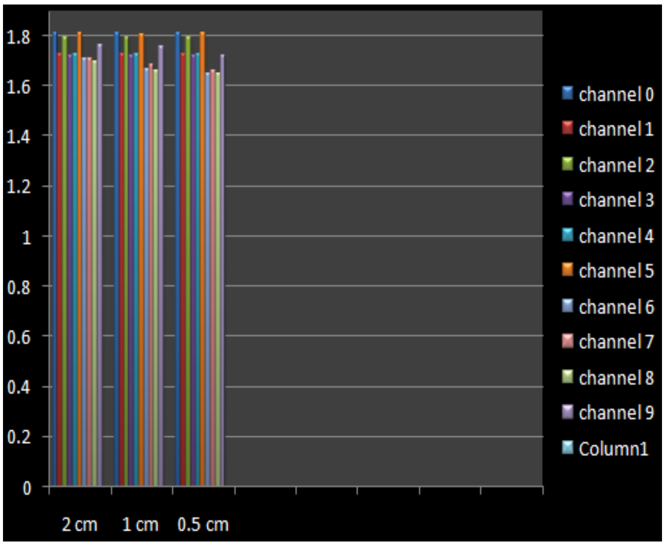

Fig 7: Capacitance (pF) v/s Distance (cm) with Steel

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Table 4: Capacitance output with Glass

Channel	D= 1.5 cm	D= 0.75 cm	D= 0.4 cm
Ch_0	1.704432	1.6814713	1.676536
Ch_1	1.726991	1.6933044	1.686959
Ch_2	1.73635	1.7073029	1.691693
Ch_3	1.70695	1.699045	1.6927
Ch_4	1.665761	1.64859	1.644612
Ch_5	1.766721	1.766721	1.762491
Ch_6	1.755139	1.729459	1.703778
Ch_7	1.701462	1.694513	1.68268
Ch_8	1.684744	1.679105	1.674371
Ch_9	1.676335	1.641994	1.631369

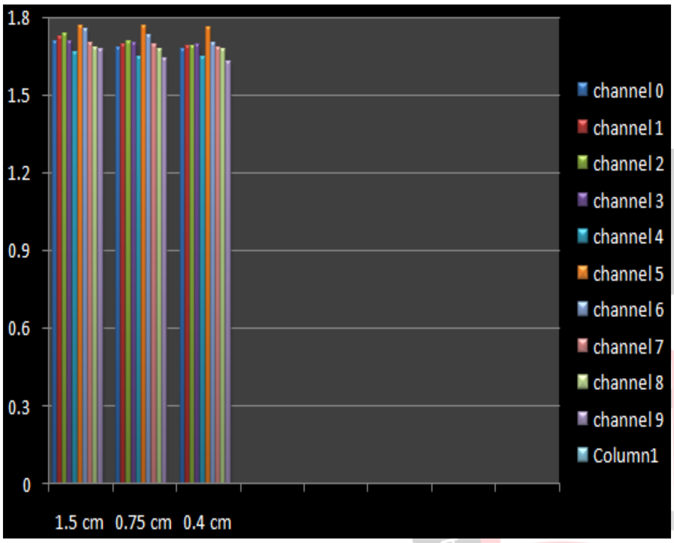

Fig 8: Capacitance (pF) v/s Distance (cm) with Glass

Wood is placed on all the channels and hence all the channels show a corresponding decrease in CDC code.

Table 5: Capacitance output with Wood

Channel	D=2.5cm	D= 2 cm	D= 1.5 cm	D= 0.5 cm
Ch_0	1.80866	1.78590	1.768835	1.761282
Ch_1	1.71289	1.70413	1.682730	1.661883
Ch_ 2	1.76259	1.76077	1.733084	1.710374
Ch_3	1.70327	1.68983	1.669034	1.659215
Ch_4	1.65921	1.69033	1.666063	1.654028
Ch_5	1.77039	1.75795	1.740587	1.714302
Ch_6	1.72276	1.70433	1.691139	1.651863
Ch_ 7	1.70392	1.68464	1.667976	1.658963
Ch_8	1.68519	1.66717	1.654079	1.624219
Ch_9	1.75513	1.73011	1.710475	1.642447

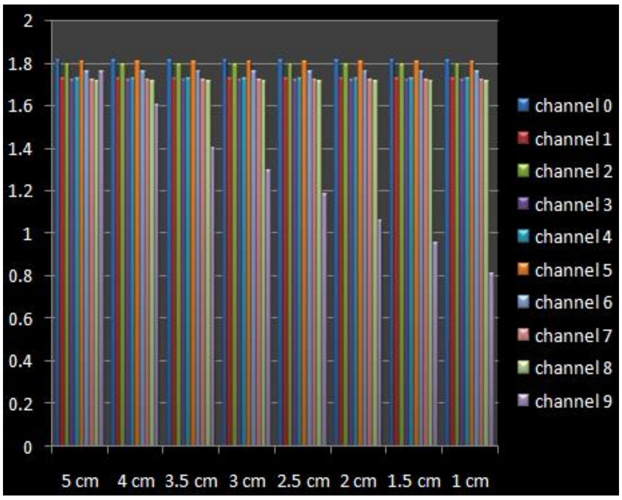

Fig 9: Capacitance (pF) v/s Distance (cm) with Human Wood

Human finger is placed at channel 9 only. Channel 9 shows a decrease in CDC code and all the other channels remain the same output code.

Table 6: Capacitance output with Human finger

Channel	D= 5 cm	D= 3.5 cm	D= 3 cm	D=2 cm	D=1.5 cm	D=3 cm
Ch_0	1.8116	1.8118	1.8113	1.81163	1.8111	1.811
Ch_1	1.7269	1.7264	1.725	1.7267	1.727	1.7284
Ch_2	1.7931	1.793	1.7935	1.7931	1.792	1.7935
Ch_3	1.7202	1.7207	1.720	1.720	1.720	1.720
Ch_4	1.7295	1.7297	1.7292	1.729	1.7301	1.7302
Ch_5	1.8085	1.808	1.808	1.8087	1.808	1.8086
Ch_6	1.7593	1.759	1.759	1.7593	1.759	1.759
Ch_7	1.7218	1.7220	1.7209	1.721	1.7214	1.721
Ch_8	1.7165	1.7164	1.716	1.716	1.715	1.716
Ch_9	1.7616	1.400	1.2941	1.060	0.954	0.812

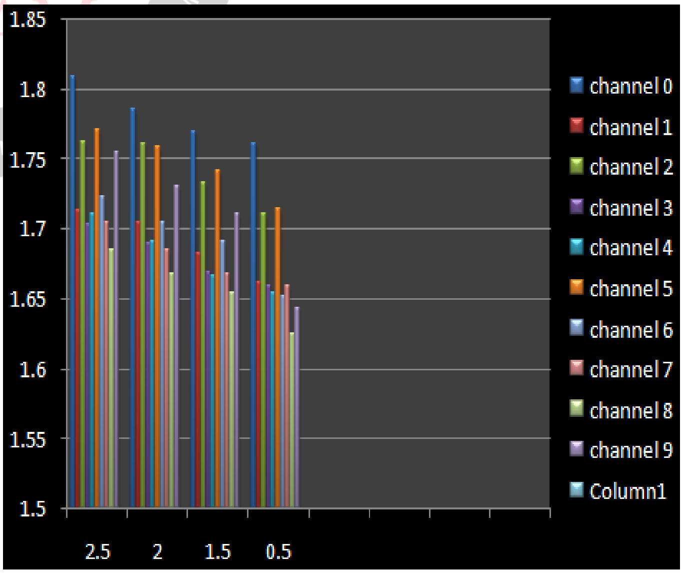

Fig 10: Capacitance (pF) v/s Distance (cm) with Human finger

C. Grey scale imaging

The XYZ scanner acquires data and it is send to the PC where the grayscale imaging application is running. First of all, Z axis motor is moved to detect the proximity of material under test it then stops and starts along X axis. Ten

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readings are taken in 0.5 inch and 10 such movements are made for a complete scan and hence grayscale image creation is made.

After covering a total distance of 12.7 cm (i.e. 0.5 inch x 10) along X axis, the system completes scanning. During scanning scan head moves along X axis and a total of 100 pixels is generated for creating grayscale image. By running mat lab program, it start processing the serial data that it received. This data is in between 0 and 255. A total of 100 values are receiving and corresponding pixel is filled with its grayscale. Corresponding pixel values are accordingly read into a matrix and further matrix to grayscale conversion is made. Thus the grayscale is created for each material under test.

Various readings are taken and their images are created. First of all image is created of a surface which is not having any flaw. So this is the normal grayscale background.

Table 7: Pixel values of figure 11

SCAN1	SCAN2	SCAN3	SCAN4	SCAN5	SCAN6	SCAN7	SCAN8	SCAN9	SCAN10
PIXELPOSITION-PIXEL VALUE									
0-159	0-159	0-159	0-159	0-159	0-159	0-159	0-159	0-159	0-159
1-163	1-163	1-163	1-163	1-163	1-163	1-163	1-163	1-163	1-163
2-160	2-160	2-160	2-160	2-160	2-160	2-160	2-160	2-160	2-160
3-158	3-158	3-158	3-158	3-158	3-158	3-158	3-158	3-158	3-158
4-157	4-157	4-157	4-157	4-157	4-157	4-157	4-157	4-157	4-157
5-166	5-166	5-166	5-166	5-166	5-166	5-166	5-166	5-166	5-166
6-166	6-166	6-166	6-166	6-166	6-166	6-166	6-166	6-166	6-166
7-168	7-168	7-168	7-168	7-168	7-168	7-168	7-168	7-168	7-168
8-169	8-169	8-169	8-169	8-169	8-169	8-169	8-169	8-169	8-169
9-157	9-157	9-157	9-157	9-157	9-157	9-157	9-157	9-157	9-157

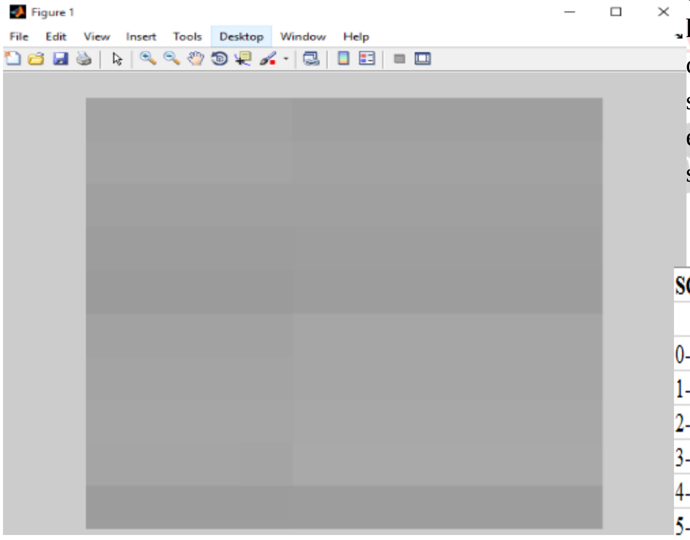

Fig 11: Grayscale image of the surface without having any flaw

Table 8: pixel values of figure 12

SCAN1	SCAN2	SCAN3	SCAN4	SCAN5	SCAN6	SCAN7	SCAN8	SCAN9	SCAN10
PIXELPOSITION-PIXEL VALUE									
0-165	0-165	0-165	0-165	0-165	0-162	0-161	0-163	0-160	0-160
1-165	1-165	1-165	1-165	1-165	1-163	1-162	1-163	1-162	1-161
2-160	2-161	2-161	2-161	2-161	2-159	2-159	2-159	2-158	2-158
3-157	3-158	3-158	3-158	3-158	3-156	3-155	3-156	3-155	3-155
4-156	4-156	4-156	4-156	4-156	4-153	4-152	4-156	4-152	4-152
5-163	5-163	5-163	5-163	5-163	5-156	5-149	5-255	5-149	5-156
6-163	6-163	6-163	6-163	6-163	6-156	6-146	6-214	6-148	6-153
7-165	7-165	7-165	7-165	7-165	7-160	7-149	7-255	7-188	7-156
8-164	8-164	8-164	8-164	8-164	8-160	8-160	8-166	8-160	8-159
9-154	9-154	9-154	9-154	9-154	9-151	9-152	9-158	9-154	9-153

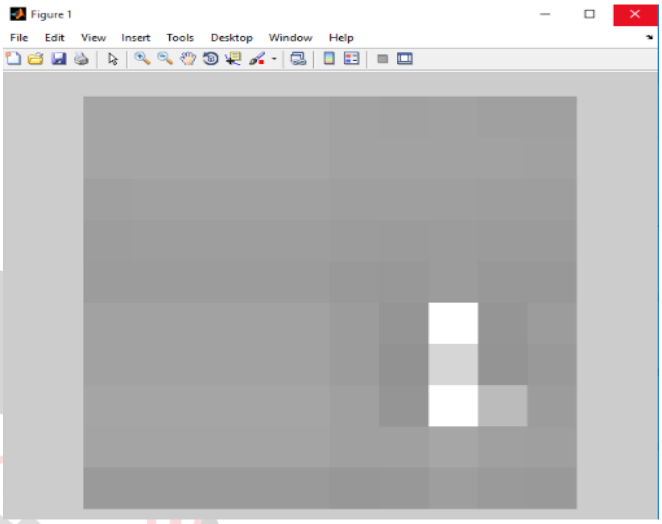

Fig 12: Grayscale image showing different grayscale values

Figure 11,12 and 13 shows different gray scale values created using mat lab. Defect or any other flaws can be easily detected using this technique. As different object having different dielectric constant the capacitance value changes with every object. Hence the CDC value also shows variation which can be detected. One of such example is shown in figure 13 where the color difference shows the hand near to the sensor.

Table 9: pixel values of figure 13

SCAN1	SCAN2	SCAN3	SCAN4	SCAN5	SCAN6	SCAN7	SCAN8	SCAN9	SCAN10
PIXELPOSITION-PIXEL VALUE									
0-159	0-159	0-154	0-158	0-164	0-159	0-159	0-159	0-159	0-159
1-163	1-163	1-161	1-160	1-162	1-161	1-163	1-163	1-163	1-163
2-160	2-160	2-158	2-156	2-158	2-157	2-160	2-160	2-160	2-160
3-158	3-158	3-156	3-136	3-138	3-161	3-158	3-158	3-158	3-158
4-157	4-157	4-155	4-154	4-154	4-154	4-157	4-157	4-157	4-157
5-166	5-166	5-165	5-164	5-165	5-165	5-166	5-166	5-166	5-166
6-166	6-166	6-165	6-165	6-165	6-165	6-166	6-166	6-166	6-166
7-168	7-167	7-167	7-167	7-167	7-167	7-168	7-168	7-168	7-168
8-169	8-169	8-169	8-169	8-169	8-169	8-169	8-169	8-169	8-169
9-156	9-156	9-156	9-156	9-156	9-156	9-156	9-156	9-156	9-156

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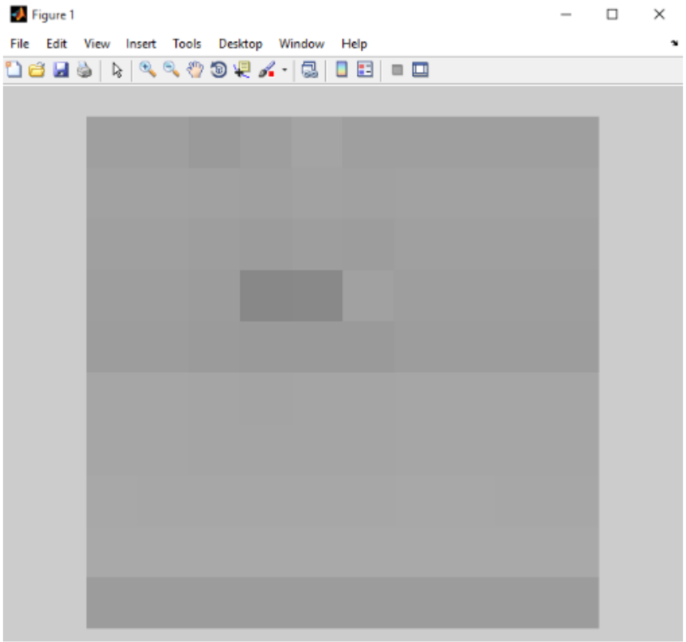

Fig 13: Grayscale image when hand placed near to sensor

IV. CONCLUSION

Successfully developed the proposed cost effective system for non destructive testing of materials. The developed system was capable of detecting the proximity of different objects at different distances based on material properties and creating corresponding grayscale images. All the proposed objectives are achieved using interdigital capacitance sensor and a high resolution capacitance to digital converter AD7142. In the case of proximity detection the proximity range varies with material type and characteristics. Among the tested materials human finger shows highest sensitivity and Glass material shows least sensitivity. Imaging of the material under test can be done using the variation in capacitance values. Any flaws in the material under test can be detected by using the grayscale image of the material. The proposed system has found interesting applications on the field of non destructive testing as the imaging does not change the physical properties of the material under test. According to the previous work [9], the proposed system possesses improved resolution because of the use of AD7142 and the sensor geometry.

REFERENCES

[1] Ravinder Sharma, Swetha Goyal, Rajesh Khanna ”Non-destructive evaluation of composite materials using a capacitive sensing technique” *MIT international journal of electronics and communication*, 2011, 1,(2) ,pp. 73-77

[2] Alexander v. Mamishev, member, IEEE, Kishore sundara-rajan, student member, ieee, fumin yang, student member, IEEE, Yanqing du, member, IEEE, and markus zahn, fellow, IEEE, “Interdigital sensors and transducers”

[3] Mamishev, B. C. Lesieutre, and M. Zahn, “Optimization of multi-wavelength interdigital dielectrometry instrumentation and algorithms,”

IEEE Trans. Dielect. Elect. Insulation, pp. 408–420, June1998.

[4] Mamishev, B. A. Berdnikov, J. P. Rivenc, B. C. Lesieutre, and M. Zahn, “Surface contact effects in interdigital dielectrometry,” in *Proc. 10th Int. Symp. High Voltage Engineering*, vol. 6, 1997, pp. 357–360.

[5] N. Goldfine, M. E. Van Steenberg, and A. Washabaugh, “Inductive and capacitive sensor arrays for *in situ* composition sensors,” in *Proc. IEEE Aerospace Conf.*, vol. 1, 2001, pp. 299–309.

[6] K.Varadan,V.V.Varadan, and X. Q. Bao, “Integration of interdigital transducers, MEMS and antennas for smart structures,” in *Proc. Smart Electronics and MEMS Conf.*, 1996, pp. 95–106.

[7] K. Toda, “Characteristics of interdigital transducers for mechanical sensing and nondestructive testing,” *Sens. Actuators A, Phys.*, vol. A44, no. 3, pp. 241–247, Sept. 1994.

[8] Yunzhi Huang, Zheng Zhan, and Nicola Bowler “Optimization of the coplanar interdigital capacitive sensor” , *AIP Advances* 4, 027119 (2014)

[9] Aswathy Prabhakaran,M. Tech student MACE, Athira M V, Mtech student MACE, Jiss Paul, Associate Professor, MACE, Kerala, India, “System Development of proximity detection and imaging using capacitance sensor”, *IJREAM* , *ISSN : 2454-9150* Vol-04, Issue-03, June 2018

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