Position Detection on Two-Dimensional Signal Transmission Sheet by Magnetic Field Pattern Sensing

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This paper proposes a method for a ubiquitous sensor to detect the position and direction on the Two-Dimensional Signal Transmission sheet (2DST sheet), and conducts several basic experiments. First, we propose the algorithm to code the position information on the 2DST sheet, and prove that the room-sized 2DST sheet is covered by using this algorithm. Next, we perform simulations of the electromagnetic field modulation by the coding pattern, and confirm the vertical direction magnetic field is useful to detect the coding pattern because it is especially strong along the edge of the conductor pattern. Finally, we design a coil detector which sense this vertical-direction magnetic field and conducted the experiments. The results show that our method is useful for position detection on the 2DST sheet.

Keywords: Two-Dimensional Communication, sensor network, ubiquitous computing

1. INTRODUCTION

Our group has proposed a new communication technology named “Two-Dimensional Communication” for high density sensor network used in living rooms, offices, and factories, and also used in cars, air planes, and robots as an alternative communication technology to WiFi, CAN, and so on [1]. Sensor nodes are placed on a sheet comprised of an insulator layer and conductor layers, which is named Two-Dimensional Signal Transmission sheet (2DST sheet, Fig.1). The sensor nodes can communicate with each other using microwave propagating in the 2DST sheet. The microwave propagating in the 2DST sheet is also used to supply electricity to each sensor node. The sensor nodes can communicate and receive electricity without electrical contacts wherever they are placed on the 2DST sheet.

One general problem in sensor networks is to identify the positions of the distributed sensors. It is cumbersome to specify the positions of large numbers of sensor nodes in installing them in the facility. Even for relatively small numbers of sensors, if they are placed at arbitrary positions or their positions are time-varying, some positioning mechanism is required to relate each sensor to its position.

In this paper, we propose a method for detecting the positions and directions of sensor nodes arbitrarily placed on the 2DST sheet. The position detection of the sensor nodes is useful not only for acquiring location specific information, but also for efficiently supplying electricity to targeted sensor nodes. In addition, by detecting the position of various devices, like displays, PDAs, cell phones, laptops, etc. on a 2DST sheet, it is possible to provide location specific function or information to the devices (e.g. DataTile[5], Microsoft Surface [2]).

There are several possible methods to detect the position of the sensor nodes placed on a two dimensional surface. For example, Pin&Play system [3] utilizes images captured with an external camera. Microsoft Surface also uses a camera placed at the backside of the display to detect the position and directions of 2D barcode-like tags. The problem in practical use of the vision-based system like Pin&Play system is that an external camera should be placed for one surface. Also it can be a drawback that it usually suffers from occlusion problem. DataTile uses RFID tags and identifies the positions of Tiles by RFID readers distributed on the surface. Although we can follow this method for positioning on 2DST sheet, it makes the structure of the 2DST sheet complex.

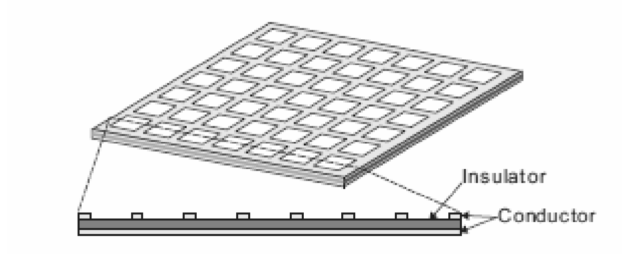

Figure 1. The structure of Two-Dimensional Signal Transmission sheet (2DST sheet) described in [1]. Two conductive layers sandwich the insulator layer. The top layer of conductor has mesh structure.

We employ the method which utilizes the electromagnetic field in close proximity to the 2DST sheet, which is produced by the propagation of microwave. This method requires only a small modification to the existing 2DST system. In addition, the method does not suffer from occlusion problems. Therefore thin obstacles like a piece of paper can be placed between the 2DST sheet and the position detection sensor.

In Section3, the method for encoding the position on the 2DST sheet is described. In Section 4, the results of the electromagnetic simulation are described. In Section 5, based on the analyses in Section 4, we propose a sensor device to measure the patterns of the electromagnetic field on the 2DST sheet. We fabricated the prototypes and conducted several fundamental experiments to confirm the feasibility of the proposed method.

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2. POSITIONING SYSTEM OVERVIEW

The basic idea of the proposed method is inspired by a pen-positioning system by Anoto [6]. Anoto's pen identifies its position on special paper by optically reading the fine patterns printed on the paper. The printed pattern at each location is unique so that the pen can identify the location. In our system, we use electromagnetic pattern produced by the mesh layer of 2DST sheet. Over the mesh layer shown in Figure 1, evanescent waves localized around the surface are generated when electromagnetic waves propagate through a 2DST sheet. A sensor node located near the surface can sense the evanescent wave pattern, while we can freely change the mesh pattern under the constraint that the macroscopic sheet inductance is kept constant [1]. Therefore if we assign a unique mesh pattern to each location, a sensor node can identify the location by reading the electromagnetic field on the 2DST sheet.

In the design of our coding system, we set the following goal of specifications,

1) Unique identification on 2DST sheet larger than 10 m square
2) Millimeter precision of position sensing
3) The size of the detector is smaller than 10 cm square

We show a method to realize the specifications in the following section.

3. POSITION ENCODING

In this paper, we code 1 bit information in one grid of mesh using square patches on the four corners of the grid. We call a grid with patches a "patched grid," and a grid with no patches a "plain grid" as shown in Figure 2.

First, we suppose primitive codes composed of 2×2 grids as shown in Figure 3 (a). We call the 2×2 mesh-grid "primitive." Next, 3×3 primitives form one "Unit" as shown in Figure 3 (b). One Unit represents the X-Y coordinates at the position of the Unit.

In order to identify the area of Unit and their orientation, we use only 11 primitives in the $2^4 = 16$ possible primitives. The primitive without patched grids is used for indicating Boundary zone. Since the primitives inside a Unit always have one or two patched grids, we can easily identify the Boundary zone on the 2DST sheet. The upper right primitive of a Unit is assigned for the start-code, which is the special code for determining the direction of the Unit. And in the other primitives, the patterns corresponding to numbers of 0 – 9 are used for coding X-Y coordinates. The primitive with four patched grids is not used in this design.

We calculated how large area this algorithm could cover. If we assume 7 mm pitch mesh as used in [1], the area of one primitive is $4\times(7\times10^{-3})^2$ [m^2]. One Unit contains 9 primitives and occupies the area of 16 primitives, counting the Boundary zone. The number of primitives that code position information in one Unit is 8. Hence, the area covered with this algorithm is $10^8\times4\times(7\times10^{-3})\times16 = 313600$ [m^2]. This means that devices on a 2DST sheet can identify their position in 560 meters square. This is large enough for our purpose of position identification on a room size 2DST sheet. Additionally, one Unit is in size of 4.2 cm square, which is smaller than the goal specifications mentioned above. If we identify the Unit, we can determine the direction and sub-mesh position from the observed 2D pattern of the electromagnetic field.

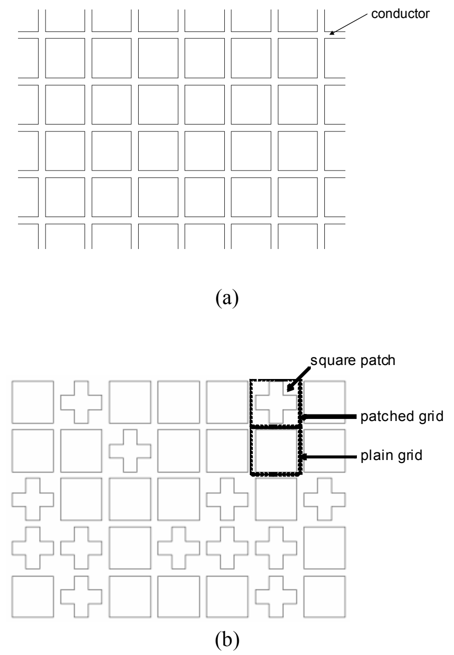


Figure 2. (a) is the normal mesh pattern for 2DST sheet. (b) is the example of position coding mesh pattern. The patched grid has four square patches on the corners, and we express 1 bit information by whether the grid has the patches or not.

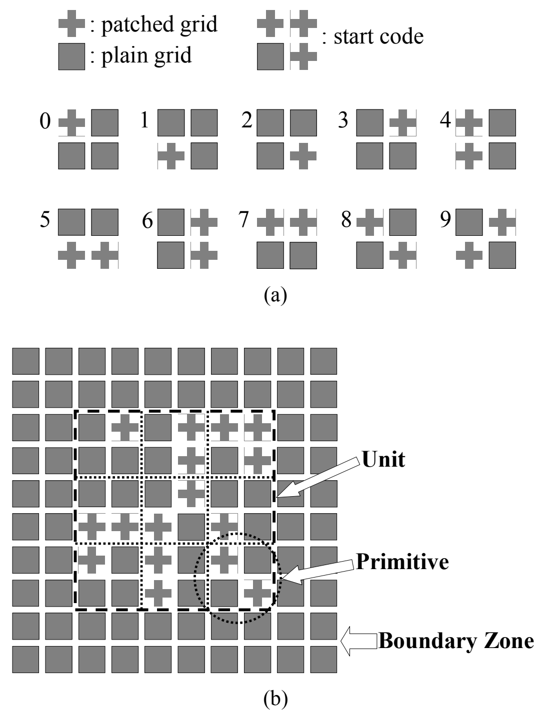
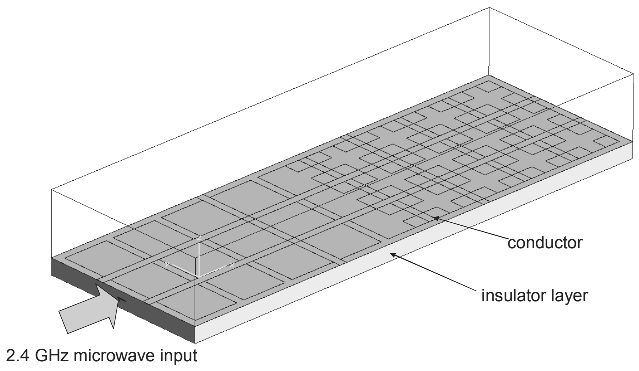
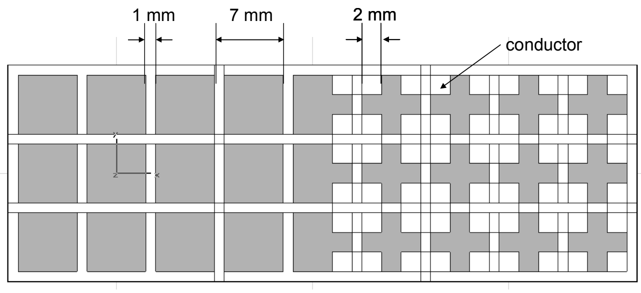


Figure 3. Position coding on a 2DST sheet. Two kinds of grids (plain or patched) provide 1bit information to a grid. The start code is defined in (a). The X-Y coordinate value is coded in a Unit using 8 primitives. A Unit is framed by Boundary zone for separating neighbor Units.



(a)



(b)

Figure 4. The simulation model of a 2DST sheet for analyses of the electromagnetic fields on the surface of the sheet. (a): the overall view of the model, and (b): the top view of the model.

4. PHYSICAL DETECTION

The next problem to be examined is what physical parameters should be measured to identify the codes. In this paper, we selected vertical magnetic field component B_z as the measurand. The reason of the selection is that simulation results told that B_z pattern showed the code pattern most clearly among all electric and magnetic components. In this section, we only show the simulation results of B_z pattern obtained by a software MW-STUDIO (AET Japan Inc.). The 2DST sheet was modeled as follows. The insulator layer is with the relative permittivity ε_r = 4.9 and the thick ness of 2.0 mm. We use perfect conductive boundary condition in bottom of the insulator layer for the bottom conductor layer. The top conductor layer has the 7 mm pitch mesh structure with 1 mm width conductor. There are 2 mm square conductor patches at the corners of some grids. The model is shown in Figure 4. We input 2.4 GHz electromagnetic wave to the side face of this 2DST sheet model, and we assumed no reflection occurs at the sheet edge.

Figure 5 shows the simulation result of the vertical-direction magnetic fields immediately above the mesh conductor layer. In this result, the vertical direction magnetic fields are especially strong along the edges of mesh and patches. The grid pattern is clearly visualized by the B_z pattern.

Next, we confirmed the change of the propagation property as a result of adding the patches to normal mesh structure. We made three models of 2DST sheets. The first model has the normal mesh structure whose grids are all plain as shown in Figure 6 (a). A half of the second model has patched grids, and all grids of the third model have patches, as shown in (b) and (c), respectively. We used the same conditions in the above simulation. We analyzed the S-parameter when the electromagnetic wave is inputted to the side of these 2DST sheet models.

The results are shown in Figure 7. The S-parameters corresponding to each 2DST sheet model are plotted. Some differences among them are found, which reveals that the sheet inductance of the 2DST sheet is changed by the patches. Although the difference is not critical to the signal transmission, it induces reflection at the boundary of the pattern. Therefore, the dimension of the patch should be optimized in a future work so that no reflection at the boundary occurs.

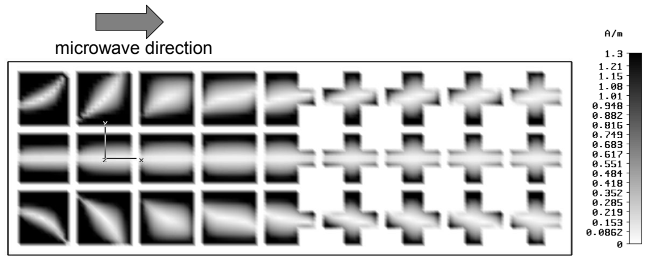
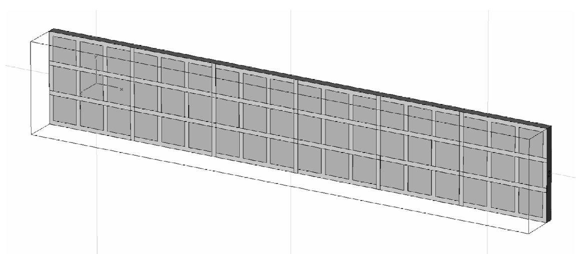
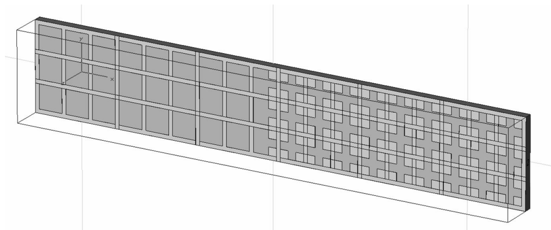


Figure 5. The result of simulation of the model shown in Figure 4. The time average of the vertical magnetic fields immediately above the mesh conductor layer. It is shown that the magnetic fields are strong along the edges of mesh and patches.



(a)



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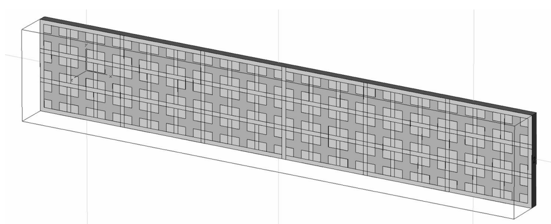
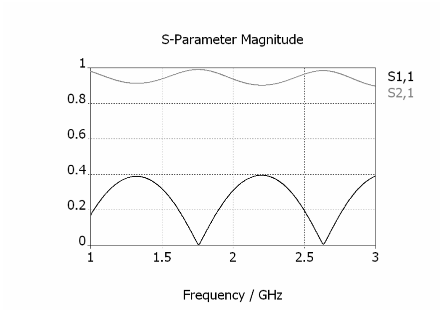


(c)

Figure 6. The models of simulation analyses for propagation property analysis. (a): the model with normal mesh structure, (b): a half of the grids are with patches, and (c): the model with all patched grids. In the simulation analyses, microwave is inputted to left side face of the plates, and Port 1 is the left side face and Port 2 is the right side face of the plates.



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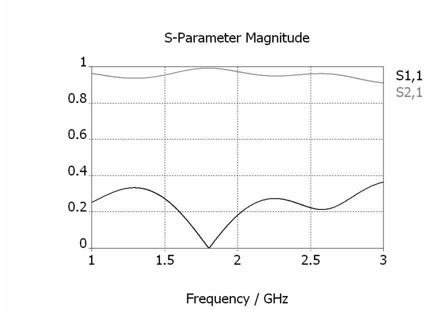

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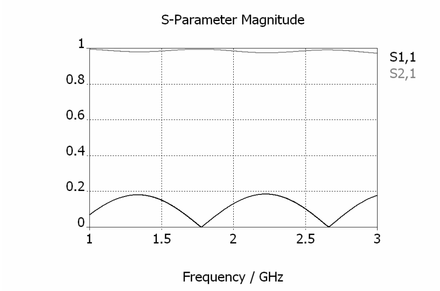
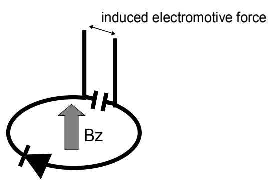


(c)

Figure 7. The results of the simulation analyses in Figure 6. The S-parameter graphs corresponding to the models in Figure 6 are shown. Some differences are found among them, though the differences are not critical to the signal transmission.



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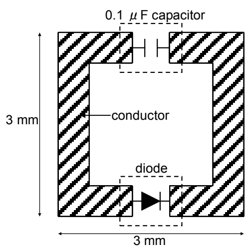

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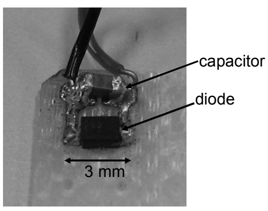


(c)

Figure 8. (a): the architecture of the proposed sensor coil that senses the vertical-direction magnetic field. (b): the pattern diagram of the sensor coil. (c): the fabricated prototype of single coil unit.

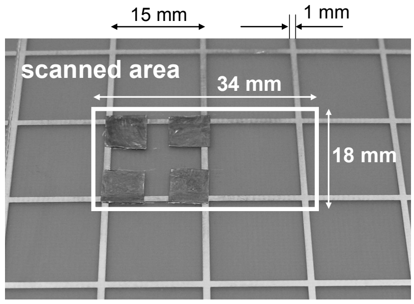


Figure 9. The area we scanned with the single coil unit shown in Figure 8 (b). In the basic experiment, we used 14 mm pitch mesh 2DST sheet, with meshes of 1 mm width. We added square conductor patches to a grid, and scanned the area around the patches with 2 mm intervals.

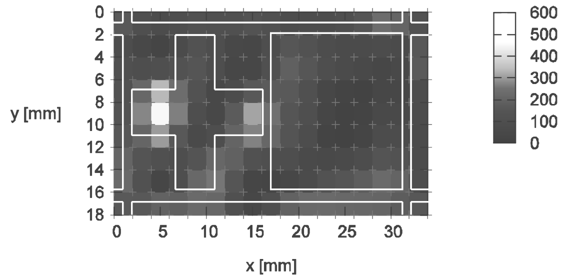


Figure 10. The result of the experiment shown in Figure 9. From this graph, we find the output voltage is smaller in the square patches and at the center of the plain grid.

5. EXPERIMENTS

Based on the results of Section 4, we fabricated a prototype of the position detector. It is a small coil that senses the vertical magnetic field. When it is put on the 2DST sheet, the vertical magnetic field induce the electromotive force. The time-varying electromotive force is rectified through a diode and a capacitor, so that it is measured as DC voltage. The architecture and prototype is shown in Figure 8.

We use a 15 mm pitch mesh 2DST sheet for the basic experiment. The experiment was conducted as follows. As shown in Figure 9, we scanned two grids, one grid with patches and the other without patches, using the coil with 2 mm intervals. The result is shown in Figure 10. From this result, the difference between the patched grid (left side) and the plain grid (right side) is confirmed.

Next, we tried a 7 mm pitch 2DST sheet which was used in the system of [1] (Figure 11). We used the same coil and scanned a patched grid and a plain grid respectively with 1 mm intervals. The result is shown in Figure 12. Although the difference of two grids is clearly observed, we could not recognize the patch pattern with appropriate symmetry. This result shows that the size of the sensor coil should be smaller, for 7 mm pitch mesh.

Finally, we fabricated a 4×4 coil array as the first prototype which reads larger area at once. This array is shown in Figure 13. Using this coil array, we conducted an experiment to detect the mesh pattern (Figure 14(a)). The result is shown in Figure 14(b). The result shows that the array can read the mesh lines clearly.

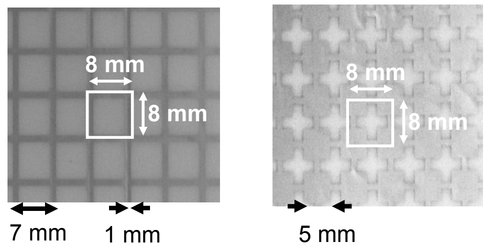
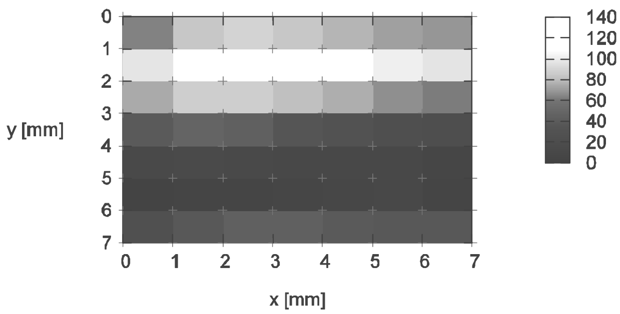
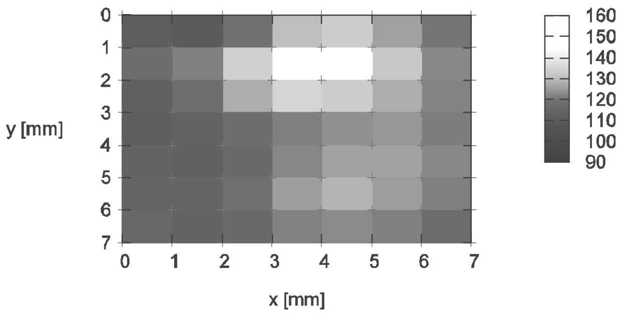


Figure 11. The pictures of 7 mm pitch mesh 2DST sheet (the left side). We added the 2 mm square patches to the plain grids (the right side). We scanned the area shown in these white boxes with the single coil unit shown in Figure 8 (b) with 1mm intervals.



(a)



(b)

Figure 12. The results of the scanning experiment in condition of Figure 11. (a) is the result of scanning a plain grid (the left side picture in Figure 11), and (b) is the result of scanning a patched grid (the right side picture in Figure 11).

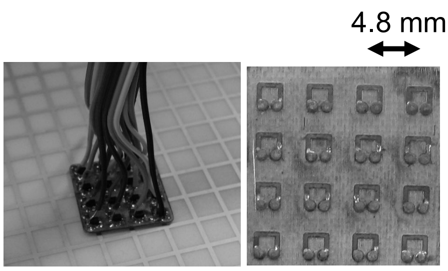
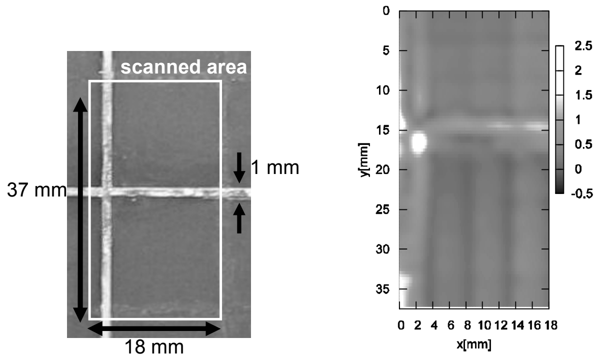


Figure 13. The overall view of the implemented 4×4 coil array (the left side), and the bottom view of the coil array (the right side).



(a) (b)

Figure 14. (a) shows the area of scanning with the coil array in Figure 13. We put the coil array in the white box and measured shifting the array with 1.2 mm intervals, and we got 256×512 output data. (b) shows this result. The output is high at the conductor edges.

6. CONCLUSION

This paper proposed a method to detect the position and direction on the 2DST sheet, and conducted several basic experiments. First, we proposed the algorithm to code the position information on the 2DST sheet, and proved that the room-sized 2DST sheet is covered by using this algorithm. Next, we performed simulations of the electromagnetic field modulation by the coding pattern, and confirmed the vertical direction magnetic field is useful to detect the coding pattern because it is especially strong along the edge of the conductor pattern. Finally, we designed a coil detector which sensed this vertical-direction magnetic field and conducted the experiments. The results show that our method is useful for position detection on the 2DST sheet.

In the next step, we will develop a smaller coil and implement a high density coil array, which does not require scanning of the sensor on the 2DST sheet.

Acknowledgements

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