Semi-Solid State Printer

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***Abstract*—Printer is one of the important output devices, which is used widely. The existing ones are bulky and relatively slow thus requires more printing time (ppm), which is due to the moving mechanical parts and mechanical constrains. In this new idea, the array of piezoelectric actuators, in the form of layer is used to provide impact on a paper containing carbonic paper in between. This impact results in the deposition of loosely bound ink, of carbon paper, to deposit on the blank sheet. In this approach, the printing time can be minimized to a few milliseconds, because of the quick response time of the actuator. The thickness of the semi-solid state printer can be as low as few millimeters! The length and width can be customized as per the size of paper. In brief, it can be proved as extremely thin, incredibly fast and silent printer.**

***Index Terms*— actuator, array, crystal, carbonic paper, piezoelectric.**

I. Introduction

The key element of this machine (printer) is the piezoelectric crystal, which acts as actuator. Actuator is the one, which converts one form of energy to another. The name "Semi-Solid State" speaks that the machine does not contain any moving part as incase of traditional printers, but still shows very small uniaxial displacement, for the process of printing.

II. Piezoelectric Crystal

These crystals are kind of transducers, which basically converts electrical energy into mechanical stress and vice versa.

A. Working

In certain crystals like quartz, when strain is applied, the charges which are present inside it, moves apart, that is the positive ones moves slightly to one of the side, while the negative goes to the opposite side. This separation of charges creates electric field inside the crystal. Proper conductor is connected to convert the electric field into voltage or current which is a result of flow of negative charges (electrons) through the conductor.

The opposite is also true, that is when voltage is applied on the two parallel faces of the crystal, the crystal experiences expansion (say), while if the polarity of applied voltage is reversed, the crystal experiences contraction. This phenomenon is explained in Fig. 1.

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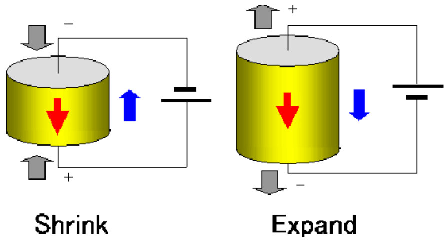

Figure 1. Working of piezoelectric crystal

B. Types

Focusing on this application, there are two kinds of piezoelectric transducers available:

1) Direct piezoelectric actuator.

These actuators are meant for relatively less stroke and a layer thinner than 100 micrometer can be constructed. The advantage in this type is that, it can be operated below 150 Volts, which is very much less than the usual operating voltage. (Usually a voltage of order kilo-volts is needed). Stroke up to 100 micrometer can be obtained using this kind of actuator.

2) Amplified piezoelectric actuator.

These are the one, which are mainly used for relatively larger stroke, which goes up to a few millimeters. These are quiet bulky and may not be suitable for this application. The voltage requirement is also relatively high and also the current requirement are high, which overall increases the power consumption of the unit. These are usually used for heavy-duty works, as it can provide an enormous force, and also a better protection against its own deformation.

C. Materials

TABLE I. Different Types of Materials

Materials	Piezoelectric Constant $x10^{-12}m/V$
Quartz	2.3
Barium titanate	100-149
Lead niobate	80-85
Lead zirconate titanate	250-365

Courtesy: http://www.azom.com.

The common materials are Quarts, Barium titanate, Lead nibolate etc. so these materials have some piezoelectric constant shown in the above table I.

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III. Array

The piezoelectric actuators are arranged in a fashion similar to row and column. All the elements or actuators will have a unique number, which is simply its position in the row and column in which it falls. This helps in providing the interface and communicating with the piezoelectric actuators.

The number of actuators per unit is area will account for the overall resolution of the item that is going to be printed. Greater the number of actuators per unit area, higher is the resolution, and also, higher will be the cost.

Arrays are of many types, some of them are one dimensional (or 1D) array, two dimensional, three-dimensional arrays and so on, which is categorized on the basis of the position of regularly, arranged actuators.

Focusing on this requirement, a *two dimensional* array is needed. A 2D array consists of two variables to identify an element, in usual practice it is taken as “i” and “j” which represents rows and column. From figure 2 this arrangement can be explained clearly.

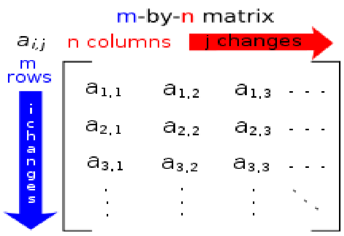


Figure 2. Matrix spatial arrangement

IV. Positioning of Elements

Each actuator is provided a unique value of i and j, which is represented as (i, j) depending on its position in the matrix. Each element is connected to a transistor or any power device like field effective transistor (FET), MOSFET or any suitable power device. These devices are connected or interfaced to a microcontroller unit (MCU). So as per the program the signal is provided to the power device and then the piezoelectric crystal is actuated.

The microcontroller operates usually at low voltage level voltage and current, so this cannot be directly used to drive the piezoelectric actuators. For the same, a suitable power device is required. These power devices are used as a switching device for the actuators. Each and every piezoelectric actuator requires this solid state switching device. This device accepts a small value of current as a triggering signal from the microcontroller that is usually less than 100 milliamps.

All the piezoelectric actuators are connected to a unique actuator, which are interfaced to the microcontroller by means of USART or any other suitable method. The output of microcontroller can be selected through the program and so as the output of the actuator. In short, the actuators can now be interfaced through a program. A kind of matrix grid is produced by means of standard codes, so that the actual program on the computer can have command over all the piezoelectric actuators, indirectly.

V. Software Integration

The element, which needs to be created, is first produced in the computer. As per the program written for the operating system, each and every element of the array can be accessed. The program loads the file that needs to be printed and the program (or software), will transmit the commands to selected actuators, while the rest of them gets retracted back. Due to this, a relatively a greater stroke length can be obtained. A continuous data transmission can be done using different ways. USART (Universal Synchronous Asynchronous Receiver/Transmitter) being one among the common interfacing techniques. This utilizes a continuous data transmission from one microcontroller to another in the form of characters at some baud rate. 9600-baud rate is generally preferred, as it is neither too slow for the transmission of character nor too fast wherein there is a possibility of data loss. The start and stop bits encloses the meaningful data streaming in a given period of time.

VI. Unicolor Printing Process

As the printing command is given to the printer, the software decodes the information in a fashion that suits to its own microcontroller. Then as per the content, to be printed, the piezoelectric crystals are actuated. This actuation results in mainly a uniaxial dimension change along the length of all the actuators. Some may extend to full extent, some may retract fully and some may partially actuate. This array is kept over the blank (or wherever printing is needed) having a carbonic paper sandwiched in between them. The output, from this, may be predicted very well, that is, the portions where extension takes place goes dark, which is due to the fact that the loosely bounded ink of carbonic paper sticks to the paper under the action of pressure provided by the actuators.

VII. Color Printing

Color printings can also e done using this technique, but a different kind of carbonic paper is needed. This carbonic paper should contain the three primary colors (Red, Green and Blue) and small enough to be considered as a single entity. If not, our eyes can distinguish the dots or the variations in the color, which is undesirable. Increasing the number of actuators in a given area can solve this issue. Ideally the number of actuators for color printing is three times of the same in unicolor print technology, and hence the power devices also gets multiplied, which overall results in complexity of things. This can be overcome by selecting suitable material and proper technique for the piezoelectric crystal deposition.

VIII. The Process

Consider an alphabet “I” for the purpose of printing. For simplicity let us consider a 7*5 matrix:

A. Matrix A

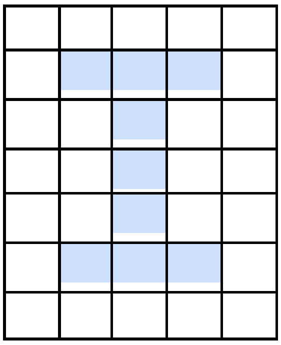


Figure 3. Matrix with 5 by 6 resolution

B. Matrix B

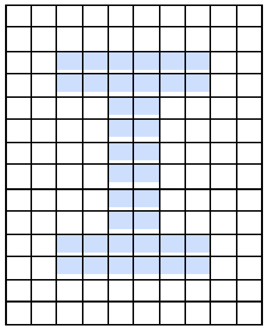


Figure 4. Matrix with, higher, 10 by 12 resolution

The white portions are the piezoelectric crystals or actuators, and these can be arranged in a repeating fashion, with much higher resolution. Higher the resolution higher will be the clarity.

To print the letter "I" the elements of the matrix to be addressed are:

A(2,2), A(2,3), A(2,4); A(3,3); A(4,3); A(5,3); A(6,2), A(6,3), A(6,4).

The nine elements are quoted in the format:

A(i,j)

wherein,

A: the matrix name

i: the absolute row number (position)

j: the absolute column number (position)

1signal provided by the on board microcontroller. For the rest of the elements the reverse signals are supplied to so that the higher absolute difference of extension can be obtained, which is again a plus point. So the same process is carried out in a large scale. This extension of elements imparts force on the carbonic paper, which in turn forced the relatively loose bonded ink of the carbonic paper to stick on the desired paper.

Next we move on to some higher resolution, and let it be a matrix of 14*10. If the resolution of same matrix is increased further, a relatively higher resolution is achieved, at the cost of high processing demand and space. For this example consider the figure 4, which is again a matrix of order 14*10 and named as matrix B. so to produce the same alphabet "I", the elements which needs to be actuated are:

B(3,3), B(3,4), B(3,5), B(3,6), B(3,7), B(3,8); B(4,3), B(4,4), B(4,5), B(4,6), B(4,7), B(4,8), B(5,5), B(5,6); B(6,5), B(6,6), B(7,5), B(7,6); B(8,5), B(8,6); B(9,5), B(9,6), B(10,5), B(10,6); B(11,3), B(11,4), B(11,5), B(11,6), B(11,7), B(11,8); B(12,3), B(12,4), B(12,5), B(12,6), B(12,7), B(12,8).

By actuating the above thirty-six elements the same letter can be obtained, as shown in figure 4

IX. Relative Arrangement

The relative arrangement of the elementary components, like piezoelectric actuators array, carbonic paper and the paper are shown in the fig. 5.

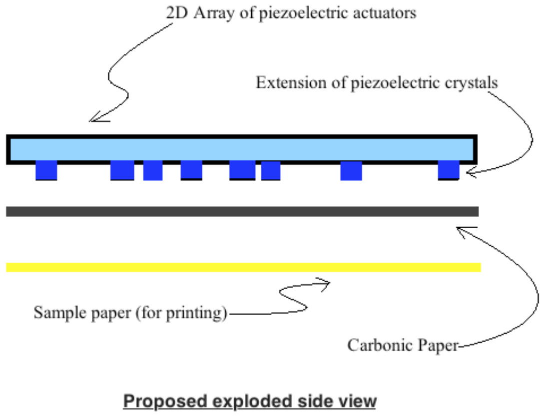


Figure 5. Exploded view

There is a two dimensional array of direct piezoelectric crystal running all over the carbonic paper and covering it. The sample paper is at the bottom with a carbonic paper sandwiched in between. The loosely bond ink is facing the paper on which the matter is to be printed. The above figure shows the exploded (lateral) view of the proposed setup. The overall thickness of complete setup can be approximated in the order of millimeters.

The extension, provided by the direct piezoelectric actuator is close to 100 micrometers is good enough to provide strain marks on the paper, provided a good quality carbonic paper is used.

X. Power Supply

The actuators are the only element, which requires high voltage, so that a stronger electric field can be applied for the proper extension and contraction of the integral element or actuator.

A power supply, which is able to provide a constant 150 to 200 Volts, is suitable for this purpose. For this voltage range there are many options:

Cascade voltage *multiplier*

- This process accepts AC as an input and delivers AC as an output (basically AC-AC converter). The supplied AC voltage is passed through several repeating fashions of series of diode and capacitors and as a result it experiences voltage lag due to capacitors which gets cumulatively added to the unidirectional voltage provided by the diodes. As a result, at each and every ladder (or series) the voltage gets multiplied to certain factor (Fig. 6), which depends on the design parameters. For this purpose the output must be converted to DC, using *bridge rectifier* or any other suitable method.

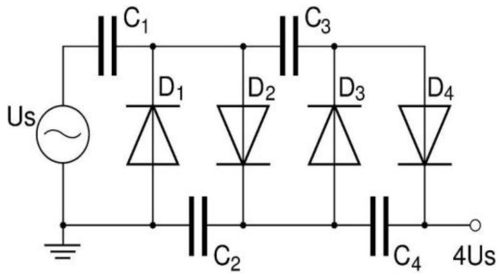
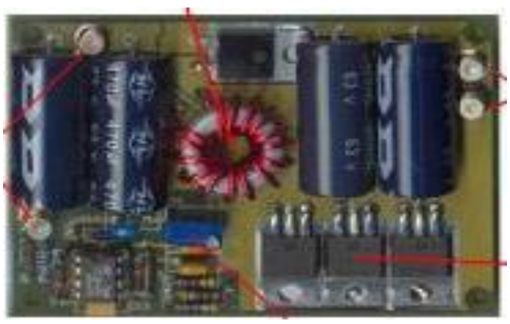


Figure 6. Block diagram of cascade voltage multiplier circuit

- Here we can see that, the input alternating voltage of some magnitude is increased by a factor of four. The only drawback in this process is that the output voltage may not be expected as a constant one. The output voltage is a direct function of input one; it means the change in input will be directly reflected in the output by some factor, which is not desirable, as it will affect the magnitude of extension of the piezoelectric actuators, hence the printing may not be up to the standard.
- *DC-to-DC converters* can be considered a good option. The input of 5 volts is converted to 150 to 200 volts as per requirement or it can be adjusted in real time depending on the requirement of the system and can be controlled electronically. These converters contains a small microcontrollers in it, which is the brain of this controller and responsible for providing an constant voltage and current output.
- It contains some of the discreet components like MOSFETs, inductor, capacitor, diodes, resistors, microcontrollers and so on, shown in Fig. 7.



Courtesy: http://www.coolcircuit.com

Figure 7. Components of circuit

One more advantage of this is that it can be powered with existing systems, as 5 volts supply is very common and easy to connect, in fact most of the data transfer takes place at 5 volt level, so to avoid any level conversion devices it's better to stick to 5 volts only, for obtaining voltages of order of hundred.

XI. Block Diagram

The overall process is shown in the form of block diagram in figure 8.

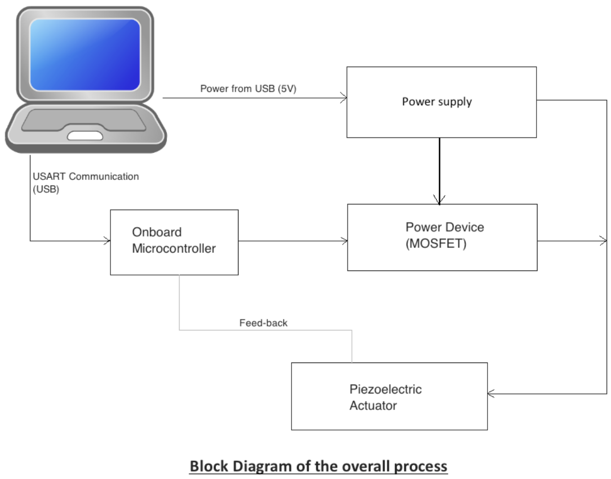


Figure 8. Overall process

The whole process is explained in figure 8, in the form of block diagram. USB is being the power source for the Power supply, which is essentially DC-DC converter and converts 5 volts to a constant voltage somewhere in between 100 to 150 volts. This output is supplied to the power device, which may be MOSFET, and are responsible for providing the proper power to the direct piezoelectric actuators. The on-board microcontroller (uC) is connected to the USB and USART communication takes place between the uC and the processor present in the computer. This basically allows the computer to have control over each element in a proper fashion using the software.

XII. Conclusions

Operation of this printer is very simple and can be considered as a "*stamp*". It may be very useful when instant printing is required. Due to almost no moving parts a longer life can be expected. Mass manufacturing may decrease its overall cost. Color printing can also be done after some modifications. When it comes for the resolution or clarity the existing laser printer cannot be compared with these simple ones, but its future cannot be expected.

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