Innovation in Micro Actuators and Big Data Technology Transform Visually Impaired Daily Life Activities and Improve Their Access to Information Technology Resources

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***Abstract*—** It is indeed very alarming when we learn that every five seconds one person in the world goes blind. 285 million people are visually impaired worldwide. 39 million are blind and 246 have low vision, 90% of the world's visually impaired live in developing countries. This blind and visually impaired community Tactile and Braille is the most efficient possible way to read, write and interact with latest information technology resources. There are many outstanding efforts have been done on previous decades to improve this community quality of life. This paper presents the current state of the art of the current micro actuators technology and its latest development for visually impaired information technology access application. It is also presents innovative tactile graphical display using electro rheological fluid micro actuators for the visually impaired people information technology (IT) access application. The display consists of 124x4 dots. Each dot is a micro electro rheological fluid actuator. The micro-actuator is designed based on linear vertical movement principles. An advanced software tools and embedded system based on voltage matrix manipulation are developed, to provide the graphical display near real time control. The actuator design and development process and software control tools is presented in this paper. Prototype size 124x4 dots, on a matrix form, of 2.54mm pitch, was manufactured. The experimental tests carried out into the prototype showed a close agreement with the standard criteria of Tactile Braille applications. The stroke and dynamic time response test showed the practicability of the developed graphical tactile display, for visually impaired IT access applications.

***Keywords*—**Electro rheological fluid actuator, micro actuator, tactile graphical display, visually impaired IT applications, visually impaired display.

I. Introduction

ELECTRONIC refreshable graphical tactile display is one of the most operational tactile interfaces approaches, for the visually impaired and blind access to information technology (IT) resources. Tactile displays show the information by simulating the sense touch. They are used as reading and IT interactive tools for visually impaired and blind people. The most common patterns available commercially are in one row form and called a text display. **Figure 1** shows an example of the one row form electronic tactile display.

Figure 1 One row form electronic refreshable graphical tactile display for the visually impaired and blind access to information technology resources [1-5]

In most cases the display is placed under a conventional computer keyboard or laptop keyboard or integrated as part of the keyboard and enables the end user to read the contents of the computer screen by touch in Braille. Each cell has eight dots made of metal or nylon, which are electronically controlled to move up and down, to display a Braille version of characters, numbers, punctuation that appear on the personal computer screen [1-5]. Braille displays designed for use with desktop PCs are around 70 to 80 cells in length. The conventional Commercial actuators used in these applications were electro-mechanical actuator in a form of very tiny solenoid or piezo-ceramic bending element actuator [2]. The electro-mechanical actuator using very tiny solenoid has been used to latch a pin, up or down. One of the major problem faced these kind of actuators were prone to stick, due to dust and dirt. **Figure 2** shows an example of the principle of piezoelectric

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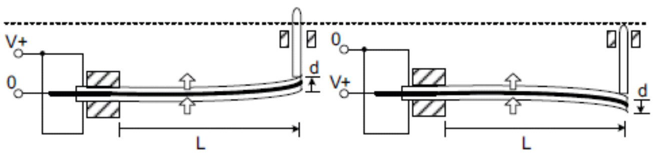
actuators, clamping mechanism and assembled module consisting of 8 actuators.

The piezoelectric actuator concept is based on using a little piece of ceramic substrate that's shaped to the right dimensions, applying 200 volts and precise operating frequency on it, the dimension of the piezo actuator element changes [2-3]. The main issues with those actuators technology is that they are expensive since the price of a Braille cell of eight dots, is about 35 Euros and the cost of a Braille display of one line of text around 10,000 Euros.



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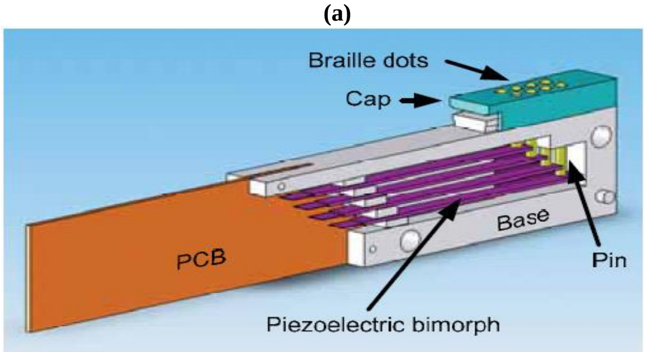
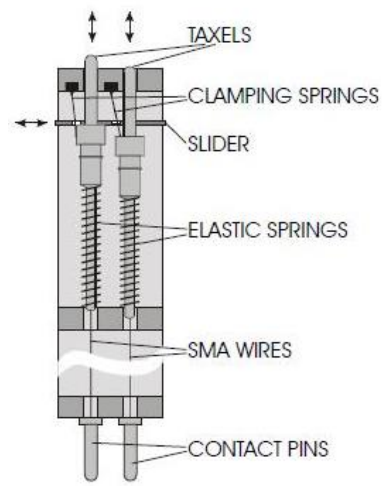


(b)

Figure 2 Micro-piezo actuator (a) working principle of piezoelectric actuators and clamping mechanism (b) assembled module consisting of 8 actuators [2-3]

One of the proposed universal approaches to reduce the cost is a force display that has a pointer device, such as a computer mouse and a small tactile display on it. The VirtTouch mouse is based on the idea of, a finger or few fingers are rest on the display and the content is refreshed as the mouse is moved along, to interpret virtual tactile image. The cost of this type of display is around 5,000 Euros. However the information these devices can transmit, to the skin is limited. This is because much information is collected by dynamic mechanoreceptors in the skin while fingers explore a surface, because of the slip or tangential forces. The cost barriers show that none of these micro actuators technology is economically good enough, to be implemented in high resolution and large scale displacement tactile graphics displays that are explored with the finger. Therefore, there is still a great attention in new micro actuators technology which could allow a more inventive functioning in terms of operability, manufacturing process, integration, performance and cost [6-9]. There are a wide variety of prospective and most of the activities were focused on electrical simulation, which is an old idea but it has not got the desired results yet [3-5]. Here are some examples: Shape memory alloy (SMA) actuators, these are actuators made of wires and its length changes to around 5% when heated by a current of a level of 2A. **Figure 3** shows the structure, principle of SMA actuators and clamping Mechanism, (b) assembled module of 16 actuators in one row. Most problems to be solved for such technology are small stroke, high power consumption, slow response and need of small mechanical structures.



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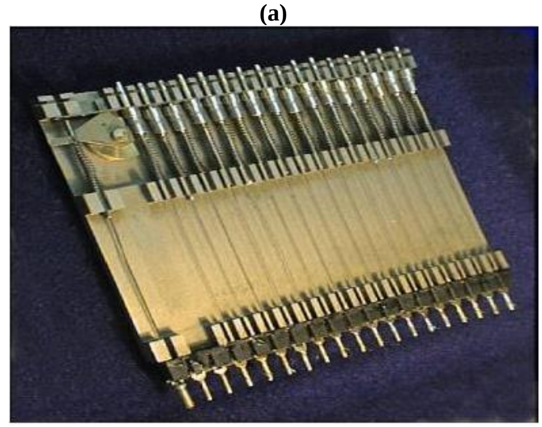


(b)

Figure 3 SMA actuators (a) structure and clamping Mechanism, (b) assembled module of 16 actuators in one row [4-6]

Pneumatic actuators, these are actuators electro-statically actuated. These are bulky ones, unless they use micro actuators, to control the flow, such as, actuators in Micro-Electro-Mechanical Systems (MEMS) technologies [2-6]. Pneumatic micro actuators that are based on Electro- Rheological (ER) fluid technology have great attention since the response of the ER fluid is fast, almost in msec, but the resolution and stroke are poor [6-8, 10-14]. The main phenomenon of the ER fluid is focused on the physics nature of the fluid and its natural sensation to change from one phase to another when an electric field is applied. The density of such fluid changes as the electric field increase. The ER fluid is comprises of a colloidal dispersion consisting of insulative base oil and a slightly conductive dielectric solid particulate, in the size of 10 to 50microns. A commonly accepted explanation of the ER fluid effect is that in the presence of an electric field, the particles became polarised and attract each other accordingly. It is the electrostatic forces between particles that hold the structure together in a solid state. These forces are obviously dependent on the strength of the electric field applied [3, 11, 14]. Fricke J., 1996 has developed a display based on these fluids and has showed the possibility of improving the performance.

There are also more innovative research and development that could be integrated and be part of future similar products that can serve this community and help to recover human disability challenge. For instant: Takahiko Nakamura and Satoshi Suzuki, 2014 has developed an automatic method to develop an indoor mapping system using the SLAM technique. The outcomes of this research introduce a novel automation system to maintain good childcare service and support kindergarten staffs using objective monitoring system. Muh-Don Hsiao, Chuen-Horng Lin and Jr-Wei Chen, 2014 has developed automatic fiducial mark (FM) detection and search methods for LED wafer mark image which can improve the manually marked FM. The work illustrates the application of image processing in LED wafer technology. In the proposed detection, the upper reference FM is detected automatically, while the lower reference fiducial mark (RFM) is determined by using an image enhancement technique. As for the automated search FMs of LED wafer images, four steps, namely, rough search, FM matching, fine search and trimming for sub-pixel images were considered. The experimental work performed has proven that the proposed automatic detection of the RFM can effectively detect the upper FM and strengthen the unobvious lower FM in the LED wafer image with smaller error and better effect than that of the manually marked FM. Bashar Enjarini and Axel Gräser, 2014 has developed a new algorithm for segmentation of planar regions from depth images. The development of a new segmentation algorithm was motivated by the results of other state-of-the-art algorithms which are optimized to segment depth images acquired by the laser scanners or structure light cameras and which however, have delivered low accuracy results when applied on depth images computed from stereo cameras. The proposed planar segmentation algorithm is based on a novel feature to be called Gradient of Depth feature. The experimental results confirm the robustness of the proposed algorithm in segmentation of the planar regions of planar and non-planar (i.e. cylindrical or curved) objects in different types of images and in different scenarios. Such pioneering development could be integrated to this community products and the necessary code could be develop to help in navigation and object detection.

The tactile display developed in this research is presenting a real breakthrough in IT access application and overcome most of the aforementioned technical barriers, at lower cost. The development process of the display has passed through a number of stages. The first stage focused on an investigation into the micro actuator technology state of the art that allowed identifying the possible right technology, to overcome the current technical and cost issues. This is also enabled to map out the display design specifications and architecture. The second stage focused on display design and interactive interface system. This considered tactile displays standard criteria, the safety aspect, miniaturisation, the amplitude of the vertical movement, the vertical holding force , dynamic time response and refreshment rate. This has also considered system sustainability, durability, and endurance and production process. The final stage focused on material selection, prototyping and test and validation of the manufactured prototype.

II. PROPOSED MICRO-ACTUATOR STRUCTURE

There are several key approaches that can be used to form the convexity of a surface, to meet the standard criteria of Braille display IT access applications. These can be classified into two main principles, which are linear movement and rotational movement. The proposed micro actuator structure is based on the linear movement principles. **Figure 4** shows the schematic of the new micro actuator. It is made of three main plates, the top, middle and bottom plate. The top plate was designed to accommodate the plastic pins and to allow vertical movements of 0.7mm in any position (vertical, horizontal or upside down). This is the standard movement needed for IT Tactile application. The middle plate is to accommodate the ER-fluid and the conduction pins. The thickness of the middle plate was determined considering the ER fluid characteristics and the vertical holding force needed. The plates were machined using CNC machine, in a matrix form, each-hole in the matric of a size of 1.5mm diameter. The inner of each hole has been coated with Nickel film of 10µm thickness using electroless process. The bottom plate was designed as a reservoir for the ER fluid and has been machined in a matrix of holes of size 1.00 mm. These holes are to hold the conduction pins. The centre conduction pins has been made of phosphor-bronze and of a dimension of 1.02mm diameter. This gives a distance of 250µm in the centre plate, to be filled with ER-fluid. This was calculated to allow the use of 250volts drive and to satisfy the standard of domestic invention.

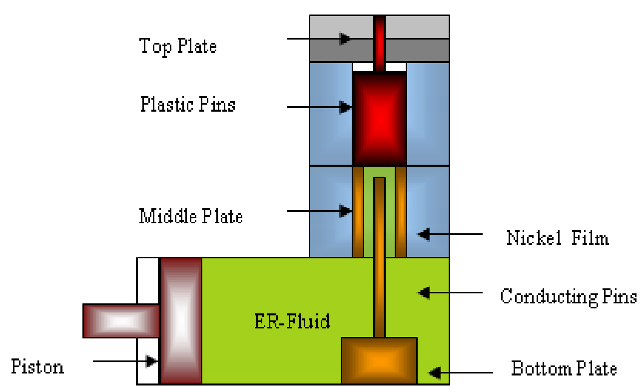


Figure 4 Structure of the new micro actuator using ER fluid technology and linear movement principles

The micro actuator structure is used to design an array of 124x4, of electrically controllable micro actuators. The shape of the actuator has been designed on a cylindrical structure, to make sure that a uniform electric field has been created inside the actuator since non-uniform electric field can affect the steady flow of the fluid. The region occupied by fluid which lies between the vertical conducting pins and the coated surface is known as the high-field region. The fluid within the micro actuators is driven by a master piston. The conducting pins are co-axial cylindrical electrodes, to ensure that the electric field strength is distributed calculably with radial and axial symmetry in this region. Consequently if the horizontal conductors are grounded and the centre conductors are brought to high voltage, the small gap size ensures that the electric field strength is high in this region and this region only.

III. WORKING PRINCIPLES OF MICRO ACTUATOR

The principle of operation of the ER micro actuator is mainly based on the ER-fluid phenomena. When the system is at static start and or at the begging of a cycle, all pins are down. When the piston is pressurised the fluid underneath the pins, all the pins will be pushed upward to their mechanical limit. Application of an electric field across the high-field area will “solidify” the fluid between the conductors and isolate the pins from the pressure developed in the main reservoir. Conversely if the piston depressurised, the free pins will be pushed down to their initial state. This means that at the end of each cycle, when the voltage is released and the electric field on the high voltage area is vanished, all the pins will be pushed down to the begging cycle by atmospheric pressure. The proposed design allows operation using only double of the actuator number of a display of size NxN matrix. N is the number of rows and / or columns in the display matrix. This is made it possible by the perpendicular orientation of the two sets of conductors, i.e. horizontal and vertical ones. Two methods can be applied, time multiplexing and voltage multiplexing. Voltage multiplexing is currently preferred and has been adapted as suggested by Fricke J., 1996.

IV. PROTOTYPING, EXPERIMENTS, TEST AND VALIDATION

A prototype of size 3x3 micro actuators, in a matrix form was fabricated. Perspex material has been used in manufacturing the first prototype and has been successfully machined using CNC machine. Perspex is a transparent thermoplastic material which would allow the observation of revolutionize of the fluid characteristics with the existence of the electric field. Several tests have been carried to the first developed 3x3 prototype and this showed few teething issues. The first test was air pressure test, this aimed to ensure the legitimacy of the vertical movement principles used on the actuators design. The second one was fluid test and this was aiming to test the ER fluid practicality. These tests showed that after a number of testing cycles, ER fluid particles were contaminated underneath the plastic pins. There was also some oil leakage from the gap, between the top and bottom plates surfaces. An O-ring of rubber has been used between the middle and the bottom plate to stop the oil leakage. Rubber sheeting elastic material was used as a membrane and this was selected to provide three functions for the micro actuator system [13-14, 18-23]. These functions are: to insulate the ER fluid from the other parts of the system. The second one is to deform easily with a minimum amount of pressure and recover its original structure without any fatal destruction into the material micro structure. The last function is to seal the main parts together and stop any fluid leaking. Due to the nature of the ER-fluid it was necessary to identifying chemical and physical compatibility of the rubber material [13-14, 18-23]. Therefore an investigation into the influences of the ER-fluid on the material micro structure and lifetime has been carried out. Two types of ER-fluid (LID3354S fluid and Solid Resinol 415/TRX10) and several types of commercial materials have been used on this investigation. It was found that the LATEX and EPDM rubber are the most suitable material since there was no chemical reaction or change in the material properties. The EPDM rubber sheeting was found to be the most suitable material. The Chemical and Physical Properties of EPDM rubber sheeting used were: Tensile stress (TB): 12.8MPa, Elongation at break (EB): 150%, Hardness, shore (HS) = Shore A 78, Volume Resistively: 10Ωcm, Resistively: Oil resistance material, Applications: General purpose, Colour: Black colour, Working temperature: 40 0C app, Physical dimensions available are: 0.050x360 x 360 mm, 0.1x360 x 360 mm.

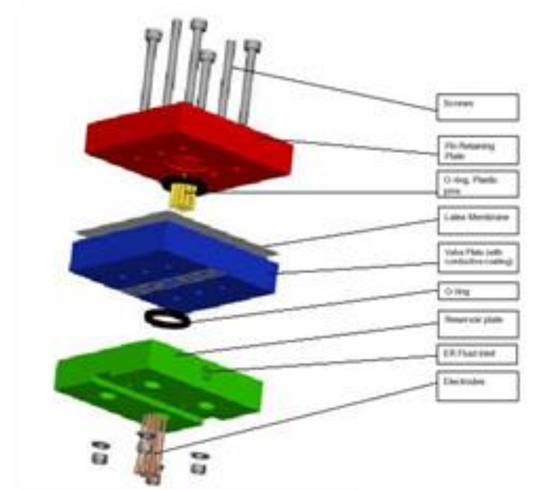


Figure 5 Schematic of the 3x3 matrix of the proposed micro actuator using ER fluid technology and linear movement principles

Figure 5 shows an exploded assembly of the 3x3 prototype. The necessary test rig has been built. This was composed of a hydraulic drive, DC ER fluid electronic drive, frequency generator and power MOSFET switching unit. Voltage multiplexing has been used during the test process. This arrangement allows updating the 3x3 matrix prototype one row at a time, i.e. conductors 1 – 3 can be at either 0 or 350V. Individual actuators on row 1 will be controllable by the column drive circuitry. It is then possible to build up a complete tactile graphical display using this methodology and would be able to display a complete “image” on the array row by row. Series of theoretical and experimental analysis to define the performance of the developed micro actuators to be implemented in high resolution tactile graphical display has been conducted. The main standard criteria of Braille were considered as a first priority. A consideration of expected behaviour of the micro actuators due to the manufacturing tolerances was then conducted followed by a consideration of current consumption against the position of the conducting pins in the core of the micro actuators.

A. Standard Criteria of Braille

The vertical holding force for each micro actuator was measured and it was found that each one was able to carry a vertical holding force equal to 200mN. The practical test showed that the actuators were able to provide 0.7 mm at a pumping pressure of 2.5Pascal. This was measured at the end of the pumping tube and with an EPDM rubber with a thickness of 50µm.

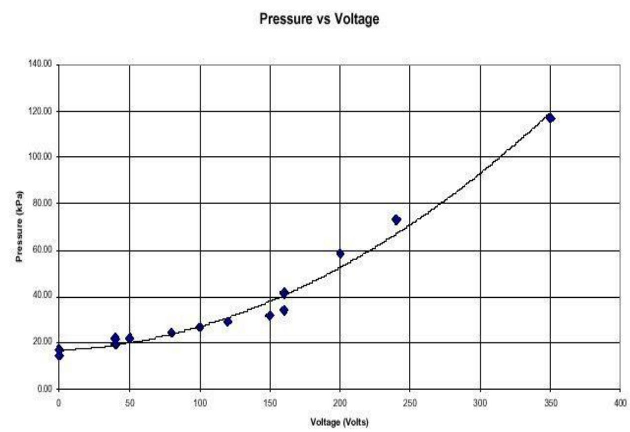
B. Current and Power Consumption

Current and power consumption tests showed that the developed prototype operates at an acceptable voltage on the range of (±250 to ±350 V). This voltage is low enough that the protection of the user can be achieved without great difficulty, and low cost devices may be used for electronic drive circuitry (<±400V). Current consumption at room temperature has been measured at 1.5µA per actuator, giving rise to approximately 3Watt power consumption from the actuators in normal operation. Considering the current and power consumption for the display system, it was found that the system will be running on the room temperature and this is typically on the recommended range to obtain high performance of EPDM material chosen for this application.

C. Expected Variation of Actuators

For such micro-actuator technology, studying the manufacturing tolerances consequence on the system performance is an essential issue. The manufacturing tolerance in the current system can change the position of the conducting electrode in the centre core of the actuator which has been chosen to be in a cylindrical shape. 1.00mm holes is used for 1.02mm diameter electrode pins (electrode pin tolerance □ 0.01mm) to ensure a proper interface fit that compensate any CNC drilling tolerance (CNC Tolerance is of 5µm). This is achieved by employing a smaller diameter holes than the pins accurate positioning of the electrode. Variation of the actuators behaviour is therefore only affected by misalignment or slightly bending of the pins. **Figure 6 (a)** shows the expected behaviour of the micro actuators due to the manufacturing tolerances. Experimental tests were conducted to determine the maximum tolerance allowed, at different voltage, for these circumstances.

Expected variations in the actuators behaviour were both focused on power consumption and vertical holding force. The test was carried out using a single 1.00 mm diameter conducting pin inside a 1.5mm cylindrical hole. The conducting pin could be moved from its centre position to simulate misalignment. The system was then fitted with a micrometer to accurately measure any offsets from the centre pin location. To hold out the desired finger print of 150mN, the required pressure equals approximately 11kpa. This is the pressure required for comfortable reading of the pins for the tactile graphical display application. The force required to depress the pins in order to register feedback should be more than 150mN, but less than 350mN force. Figure 6 (b) shows the current consumption against the position of the conducting pins. It is clearly observable that the current consumption remains fairly constant independent of the position. This means that perfect alignment is not crucial as long as the gap between the conducting pins and the cylindrical tube is at least bigger than the size of the particles of ER-fluid which is in the range of 10 to 100µm.



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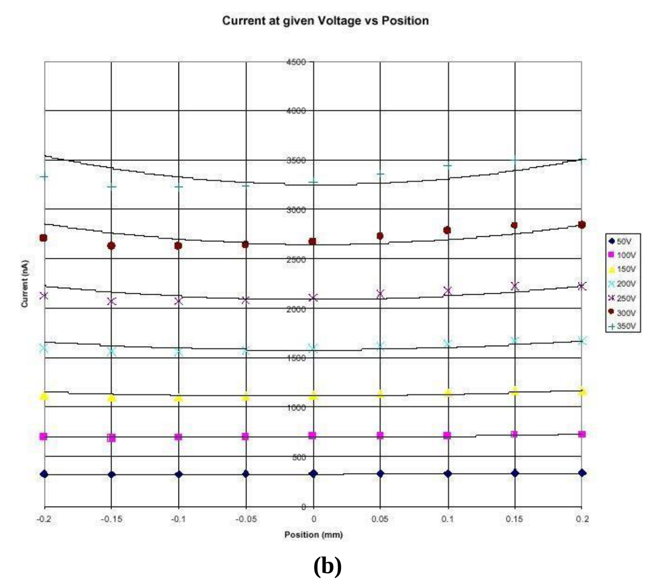

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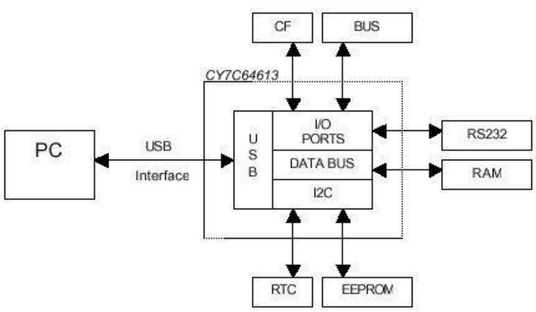
Figure 6 (a) Expected behaviour of the micro actuators due to the manufacturing tolerances & (b) Current consumption against the position of the conducting pins in the core of the micro actuators

A prototype size 128x4 dots have been manufactured of ABS material and this is shown in **Figure 7**. ABS material has been selected for three main reasons. The first reason was the material is easy to be machined using CNC machine, easy to be milled, its machining tools are available commercially and it provides an excellent rigidity. The 128x4 dots prototype was equipped with a dedicated control unit. The controller unit consists of a micro controller µC, a hydraulic drive and 270 volt DC power supply card for the operation of the ER fluid actuators. The µC with the serial interface, 64Byte RAM, and 128KByte flash ROM are mounted on a single board. The power supply card and the other electronics are plugged onto this host module. **Figure 8** shows an overview of electronic interface & Protocol layout and data flow block diagram of the developed 128x4 dots tactile display.

Figure 7 The developed 128x4 interactive interface graphical tactile display prototype using ABS and ER fluid technology



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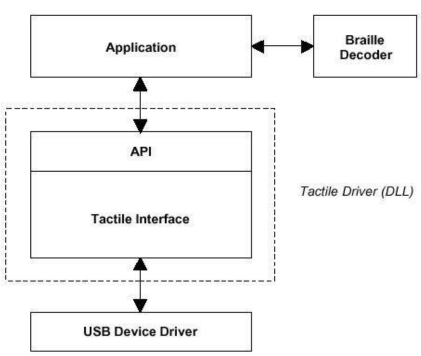

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Figure 8 Overview of electronic & Protocol layout and data flow block diagram of the developed 128x4 dots tactile display using ER Fluid technology

The control unit receives the image data via a USB serial interface from an external computer. The image is stored in the RAM of the host module. The control unit continuously reads the data and calculates the pattern to be displayed on the tactile matrix correspondent to the actual image data provided. The software consists of two independent parts running on the µC software and the external computer respectively

The µC software is executed in a time loop of Hz. In this loop the µC read out the data of the image to be displayed and activate the correspondent dots in the tactile matrix. In the next step, it receives new images from the computer and saves them in the local RAM. The code is written in C which allows low level access to hardware. The software running in the external computer has the task to generate images to be displayed on the tactile matrix display. Tools have been developed to send parts from the graphics files (*.jpg or *.bmp or html format) to the tactile display. It is also possible to draw directly in the display using a mouse of external computer. For the graphical interface the QT library is used, which allows to run the program under different operating system (such as Windows or Linux).

V. CONCLUSIONS

The current state of the art of the micro actuators technology and its latest development for visually impaired information technology access application has been presented in this paper. The development of an innovative tactile graphical display using electro rheological fluid micro actuators for the visually impaired people information technology (IT) access application has been also covered. A new tactile graphical display consists of 512 dots. The dots are a matrix of ER micro actuator. An advanced software tools and embedded system based on voltage and matrix manipulation has been developed to provide the display near real time control. Prototype size 124x4 on a matrix form, with a separation distance of 2.54mm, was designed and fabricated. Tests carried out into the developed prototype showed that each micro actuator was able to provide a vertical movement of 0.7mm and a vertical holding force of 100 to 200mN. These satisfy the necessary requirement of Braille IT access applications. The experimental results of the stroke and dynamic response showed the practicability of the developed graphical tactile display, for visually impaired information technology access applications.

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