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New Approach to 2*D* Braille Device Design

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Introduction

The problem to develop a novel interactive display that will facilitate access for visually impaired people to the modern Information Technology world is quite topical today. There are several approaches to solve this problem, let us mention here EC Project ITACTI (Smart Interactive Tactile Interface Effecting Graphical Display for the Visually Impaired, IST-2001-32240, 2001 – 2006), in which Kaunas University of Technology was partner, responsible for the development of 2*D* screen, allowing many thousands of moving actuators (dots) to be addressed and moved individually. This tactile graphical display made it possible to further integrate the visually impaired population into the Information Society, improving their access to many resources, including internet pages, by offering a more natural and effective display, consisting of an array of at least 128 x 64 individual actuators displaying either 10 x 40 characters of Braille (2x5 pins per character), 12 x 40 (2x4 pins per character) or tactile graphics (www.smarttec.co.uk).

The display was based on the application of smart materials valve design, in which a ERF valve presents a hole in a multi-layer board, filled with ERF and controlled by the applied voltage, the polarity of which is changing according to every layer [1-7].

Another interesting approach is *laterotactile* stimulation, a new type of tactile feedback studied and developed by Prof. Hayward's team at McGill University's Haptics Laboratory [8,9]. It is based on lateral skin deformation, or laterotactile stimulation and exploits a tactile stimulation mode by which a traveling wave of lateral skin deformation can induce the sensation of a moving feature under the fingertip.

The specific features of the method presented in this paper are several: (*a*) the possibility to differentiate colors or contrast by relating each color or lucidity to frequency of stimulation in extremely wide frequency range (from 0 to approx. 150 Hz); (*b*) when using touch sensitive screen it is possible to exploit the advantages of GPS, Geographic information systems and 2*D* graphical information; (*c*) reading text is not limited to using specific areas of screen as in classical Braille screens [2, 3]; (*d*) very important feature of the method is low cost of the device.

Generating tangential tactile stimulation

Blind operator can comprehend that visual information (colour, contour, shadow) is varied when he feels the variation of the tangential force which acts on his finger. This force can be created by one or three (in case of reading the text) miniature electromagnets, which the blind pushes on the magnetic plate by his finger and can be varied by varying the electromagnet excitation current.

The structural schematic of the device is presented in Fig. 1. In this figure MP is the touch sensitive plate, covered by thin ferromagnetic layer, on which with the help of processor P the visual information is represented, EM – miniature electromagnet, PM – the unit of electromagnet position measurement, EC – the unit of electromagnet excitation current control.

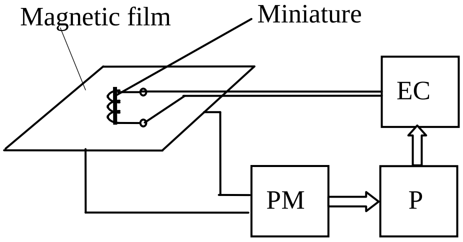

Fig. 1. The structural schematic of the visual information representation

The blind operator moves the miniature electromagnet EM with his finger, and electromagnet glissades on the plane MP. The measurement unit of the position PM fixes the coordinates x_M, y_M of electromagnet EM and transmits its position into processor P. Processor forms the control signal $u_p = u_p(x_M, y_M)$ of the miniature electromagnet excitation current magnitude, which relates to the intensity of visual information in this point (height of relief, darkness of shadow, intensity or change of colour) and transmits it to the unit of electromagnet excitation current control EC.

The output current of EC I_e flows in the electromagnet EM, which creates proportional to current I_e magnetic flux density B_M. The moving on the ferromagnetic plate electromagnet is acted by force $F(x_M, y_M)$, depending on the magnetic flux density B_M in this point. The blind feels the change of the force which acts to his finger. The voltage supplied to miniature electromagnet is in the form of short pulses with the frequency related to color or intensity of the scanned area. Initial experiments indicate that blind operator can feel the frequencies up to 150 Hz, differentiating between frequencies in steps, equal to 10-15 Hz. Therefore he feels the change of visual information in the point occupied by the electromagnet. Together with the audio information such method of the information representation can give the adequate information about some object for the blind.

The forces acting on the miniature electromagnet

The cross section of miniature shown in Fig. 2.

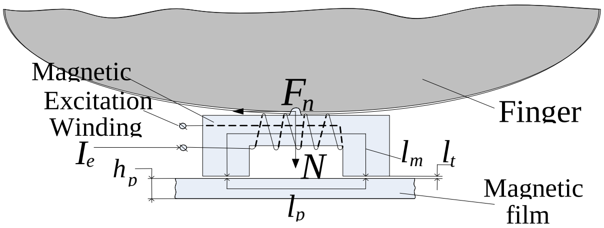

Fig. 2. Magnetic circuit and the forces acting to the electromagnet

The magnetic circuit is composed of electromagnet magnetic core with the mean length of magnetic line equal to l_m, of the part of miniature in which the magnetic lines with the mean length of magnetic lines equal to l_p are distributed and of the gap between the ferromagnetic film and the bottom of the electromagnet magnetic core. The height of this gap is equal to l_t. The current I_e flowing in the excitation windings EW creates the electromagnet magnetic flux.

The force $\boldsymbol{F}_t$ of the finger PR acts to electromagnet in the direction parallel to the surface of the plate MP. It can be expressed:

$$\boldsymbol{F}_t = f\boldsymbol{N}, \tag{1}$$

where $\boldsymbol{N}$ is the normal force, acting to the electromagnet in the direction perpendicular to the surface of the plate MP, f is the friction coefficient.

The normal force has three components: the weight force $\boldsymbol{P}$, the electromagnet attraction force $\boldsymbol{T}$ and the normal component $\boldsymbol{F}_n$ of the finger force:

$$\boldsymbol{N} = \boldsymbol{P} + \boldsymbol{T} + \boldsymbol{F_n}\,. \tag{2}$$

We suppose that finger acts only parallel to the ferromagnetic plate surface and $\boldsymbol{F}_n$=0. The weight force P is proportional to the electromagnet mass m_e:

$$P = m_e g, \tag{3}$$

where $g \approx 9{,}8$ m/s^2 is the free fall acceleration.

Evaluation of the electromagnet's attraction force *T*

We evaluate the electromagnet force, writing the elementary variation $\mathrm{d}W_m$ of the magnetic field energy density W_m which arises because the elementary variation $\mathrm{d}V_t$ of the volume of the gap between the electromagnet bottom and the ferromagnetic plate surface:

$$\mathrm{d}W_m = \frac{B_t H_t}{2}\mathrm{d}V_t, \tag{4}$$

where B_t and H_t are, correspondingly, the values of the magnetic flux density and magnetic field strength in the gap. Let the magnetic field lines be perpendicular to the ferromagnetic plate. In this case $B_t = B_{ty}$, $H_t = H_{ty}$.

The total area of the both electromagnet branches bottom is S. Let the height of the gap in the both branches be the same and equal to l_t. The elementary variation of gap volume is $\mathrm{d}V_t = S\mathrm{d}l_t$. Therefore

$$\mathrm{d}W_m = \frac{B_{ty} H_{ty}}{2} S\mathrm{d}l_t. \tag{5}$$

Vice versa the variation $\mathrm{d}W_m$ can be expressed evaluating the value of force T as follows:

$$\mathrm{d}W_m = T\mathrm{d}l_t. \tag{6}$$

We obtain of (5) and (6):

$$T = \frac{dW_m}{dl_t} = \frac{B_{ty} H_{ty}}{2} S. \tag{7}$$

The structure of volume V_t can be different. On the electromagnet bottom can be formed special nonmagnetic gap by polish or other nonmagnetic material. If the special nonmagnetic gap is not formed, it is composed of the uneven parts of the electromagnet bottom, in which partially are intervened the air gaps. The height l_t of the volume V_t depends on the quality of the electromagnet bottom surface processing and can be very little. We suppose, that the relative permeability of the gap μ_{rt} has the value being in the interval $1 \le \mu_{rt} < \mu_{rm}$, where μ_{rm} is relative permeability of the electromagnet core. The magnetic field strength can be expressed this way:

$$H_{ty} = {}^{B_{ty}}\!\big/_{\mu_{rt}\mu_0}, \tag{8}$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m.

The expression (8) we can substitute into (7):

$$T = ({}^{S}\!\big/_{2\mu_{rt}\mu_0})B_{ty}^2. \tag{9}$$

Therefore, the dependence of electromagnet attraction force T on the magnetic flux density B_{ty} is parabolic.

Analysis of the magnetic circuit

Magnetic circuit is composed of three parts connected in series: the electromagnet core (magnetic resistance R_{mm}), ferromagnetic plate (magnetic resistance R_{mp}), gap with magnetic resistance R_{mp} and the magneto motive force source $F_m=NI_e$, where N is number of the excitation windings turns. The equivalent electric schema of this circuit is presented in the Fig. 3.

We suppose that magnetic flux Φ is distributed uniformly in this circuit the dependence magnetic flux density B_{ty} on the magnetic field strength H_{ty} is linear, therefore, the relative permeabilities of the core μ_{rm}, of the ferromagnetic plate μ_{rp} and of the gap μ_{rt} are constant.

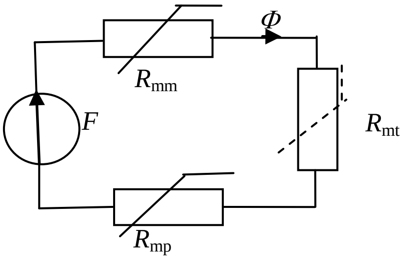

Fig. 3. Equivalent electric schema of the electromagnet

We can write by Kirchhoff law:

$$\frac{\Phi l_m}{\mu_{rm}\mu_0 S_m}+\frac{\Phi l_p}{\mu_{rp}\mu_0 S_p}+\frac{\Phi l_t}{\mu_{rt}\mu_0 S_t}=NI_e. \qquad (10)$$

The height l_t of gap is very little and we can write: $S_t \approx S_m = S$. In this case magnetic flux Φ can be expressed:

$$\Phi=\frac{NI_e\mu_0 S}{[l_m/\mu_{rm}+(l_p/\mu_{rp})(S/S_p)+l_t/\mu_{rt}]}. \qquad (11)$$

In the gap magnetic flux density B_{ty} is equal to

$$B_{ty}=\frac{\Phi}{S}=\frac{NI_e\mu_0}{a+l_t/\mu_{rt}}, \qquad (12)$$

where $a=l_m/\mu_{rm}+(l_p/\mu_{rp})(S/S_p)=\text{const}$.

Substituting (12) into (9) we obtain the expression of the electromagnet attraction force value:

$$T=\frac{N^2\mu_{rt}\mu_0 S}{2(a\mu_{rt}+l_t)^2}I_e^2. \qquad (13)$$

The dependence T on I_e is parabolic. To obtain the linear dependence the force $T=T(u)$ on the control action u we can using the converter $I_e=I_e(\sqrt{h})$.

The strategy of the gap formation

If the height l_t of the gap between the electromagnet bottom and ferromagnetic plate is not formed specially, it is very complicate to ensure the stability of the force T. It depends on quality of the electromagnet core bottom surface processing, on the ferromagnetic plate surface baldness, on the cleanness of the both surfaces, on the position of the finger on the electromagnet and other. When it is not a necessity to transform the small variation of the visual information and it is sufficient to fix the sharp changes, the gap cannot be formed specially.

The special formation of the gap height l_t allows the visual information to transform more accurately. The gap can be completed by the magnetic material with not big value of the permeability μ_{rt}. When the gap height is formed exactly, the force T can be expressed this way:

$$T=\frac{(K_m N)^2\mu_{rt}\mu_0 S}{2l_t{}^2}I_e{}^2, \qquad (14)$$

where factor K_m depends on the magnetic circuit design:

$$K_m=\frac{1}{1+(l_m/l_t)(\mu_{rt}/\mu_{rm})+(l_p/l_t)(\mu_{rt}/\mu_{rp})(S/S_p)}. \qquad (15)$$

The value of K_m diminishes importantly with l_t increase but the stability of the T is significantly better than in the case when the gap is not formed.

Modeling of the magnetic circuit

Modeling was performed the real influence l_t on the T to clear. The modeled design is showed in Fig. 4. The program package COSMOSM was used. The 3D magnetic problem was solved. Because the design symmetry the ¼ part of the magnetic circuit limited by planes xOy, yOz and xOz was modeled. The design was divided into 4 areas: core M with relative permeability μ_{rm}, ferromagnetic plate P, with relative permeability μ_{rp}, gap TR with relative permeability μ_{rt} and nonmagnetic medium with relative permeability $\mu_{ra}=1$.

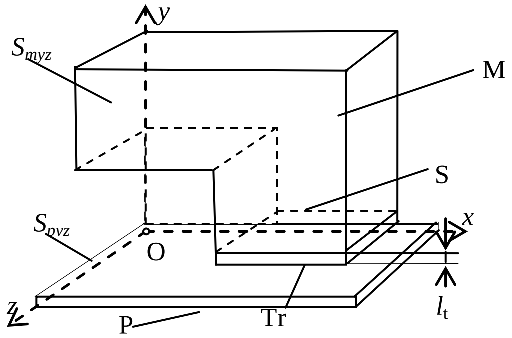

Fig. 4. The modeled design

For magnetic flux creation the magnetic potentials difference was set. The some magnetic potential U_{m0} was assigned to the plane S_{myz}, and the magnetic potential $U_m=0$ to the plane S_{pyz}(see Fig. 4). The dependence of the vertical component of the magnetic flux density mean value B_{tv} in the gap TR on the gap height l_t and the permeabilities of different areas was investigated.

In the Fig. 5 the dependences B_{tv} on the l_t when the gap height l_t was varied between 0 and 0,1h, where h is the electromagnet height are presented for $\mu_{rm}=\mu_{rp}=1000$ and for $\mu_{rm}=1000$, o $\mu_{rp}=100$. We can see that agreeably with prediction the fastest variation of B_{tv} is for small gaps. If μ_{rp}

is diminished to 100 the variation speed decreases but the B_{tv} values decrease, too.

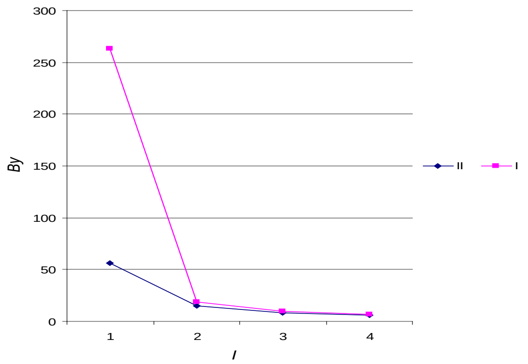

Fig. 5. The dependence of the magnetic flux density B_y on the gap height l_t: I – μ_{rm}=μ_{rp}=1000, II – μ_{rm}=1000, μ_{rp}=100

The modeling results prove the conclusion that for accurate transform of visual information the nonmagnetic gap between the electromagnetic bottom and ferromagnetic plate must be formed. The optimal gap height is (0,02-0,04) of the electromagnet height.

Conclusion

When the blind is moving the miniature electromagnet by his finger on ferromagnetic surface, he can translate the visual information's (height, colour, shadow) variation in some point of the surface by the force which acts to the electromagnet in this point. This force can be varied varying the electromagnet excitation force; blind operator can feel the frequencies up to 150 Hz, differentiating between frequencies in steps, equal to 10-15 Hz and related to color or intensity of the graphical element.

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When blind operator is moving the electromagnet by his finger on ferromagnetic surface, he can "read" the visual information's (height, colour, shadow) variation in some point of the surface by the force, which acts on the electromagnet in this point. The force can be varied by varying the electromagnet excitation current, depending on the point coordinates. The dependence of the force on the excitation current, magnetic circuit parameters and magnetic properties is obtained. For the accurate formation of the relief height, the bottom of the electromagnet must be separated at ferromagnetic surface by a small nonmagnetic gap. The modeling results are presented. Ill. 5, bibl. 9 (in English; abstracts in English, Russian and Lithuanian).

Р. Бансевичюс, В. Гудаускис, А. Жвиронас, Ю. А. Вирбалис. Новый подход к созданию плоского экрана Брайля для передачи графической информации слепому // Электроника и электротехника. – Каунас: Технология, 2010. – № 4(100). – С. 3–6.

Слепой, двигая пальцем электромагнит по феромагнитной поверхности, может ощущать изменения визуальной информации (высоты, цвета, теней) по изменению силы, действующей на электромагнит в этой точке. Эта силу можно менять, меняя ток возбуждения электромагнита. Получена зависимость силы, действующей на электромагнит от тока возбуждения, параметров магнитной цепи и ее магнитных свойств. Информация о текущей высоте рельефа будет достаточно точной, если нижняя часть электромагнита будет отделена от феромагнитной поверхности небольшим немагнитным промежутком. В этом случае сила, ощущаемая пальцем слепого, будет мало зависеть от чистоты поверхностей нижней части электромагнита и от положения пальца слепого на электромагните. Представлены результаты моделирования. Ил. 5, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

R. Bansevičius, M. Gudauskis, A. Žvironas, J. A. Virbalis. Naujo tipo 2D Brailio ekrano grafinei informacijai nuskaityti kūrimas ir tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 4(100). – P. 3–6.

Neregys, stumdamas pirštu elektromagnetą feromagnetine plokšte, pagal jėgos, veikiančios elektromagnetą tam tikrame taške, pokyčius gali jausti vizualinės informacijos (aukščio, spalvų, šešėlių) pokyčius. Tą jėgą galima keisti keičiant elektromagneto žadinimo srovę. Gauta šios jėgos priklausomybė nuo žadinimo srovės, magnetinės grandinės parametrų ir magnetinių savybių. Norint pakankamai tiksliai suformuoti reljefo aukštį, reikia elektromagneto apačią nuo feromagnetinės plokštės atskirti nedideliu nemagnetiniu tarpeliu. Šiuo atveju neregio piršto juntama jėga daug mažiau priklausys nuo elektromagneto apačios ir pagrindo paviršių švarumo ir neregio piršto padėties. Pateikti modeliavimo rezultatai. Il. 5, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).