

3D PRINTING TECHNOLOGY IN TACTILE MAPS COMPILING

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Abstract

The paper presents a joint research activity of specialists on digital maps and specialists-education of the blind. The authors seek to evaluate and develop aspects of interpretation and perception of geospace by modern tactile maps based on 3D printing. There are three newly introduced types of tactile maps (all coloured). Map of type A is a tactile map printed by 3D printing technology (Contex 3D printers) as traditional relief tactile map with 5 mm thick background using both positive and negative relief with labelling by Braille letters. Map of type B is an inverse form of tactile map printed by 3D printing technology which will be used for casting type A tactile maps. Finally map of type C is a sound tactile map derived from map of type A posed onto box with digital voice records of geoinformation (attributes, navigations etc.) activated by touch on maps surface. The paper also describes present situation in tactile maps production and steps in recent testing the new type maps. The paper treats a number of particular research topics such as analysis of the present Czech and foreign tactile maps, user demand analysis, testing 3D printer capabilities, producing new type tactile maps, testing new type tactile maps by blind users etc.

INTRODUCTION

Present modern information-based society offers many possibilities for visualisation of geospace using the latest information technologies. Geospace (geographic space) is defined as a part of landscape environment determined by places of human activities influence on

the nature. Geospace (determined by that way) is perceived by human being through its senses or vicariously by geoinformation (geographic information, spatially located information). Correct geospace perception is precondition for both practical life at any place on the Earth and for cognitive process of natural and social phenomena (objects and processes). Integration of blind people into ordinary life in geospace is very difficult process. The research topics related to geospace presentation by blind people are dealt with in Anglo-Saxon countries from 80s of the 20th century. The first tactile maps served for practicing of spatial orientation and movement and they used lineal representation of everyday pathways for various users (i.e. way from home to office, shipping etc.) by form of pressed plastic plate made at special vacuum printers. These types of tactile maps are used more as technical aids rather than geospace representations. The only approximation of real geospace was so called 3D maps – plastic embossment maps primarily designed seeing people and intermediating the blind perception of earth surface complexity. However they cannot provide him geographical information (occurrence point, linear and aerial phenomena – i.e. hospital, railways, protected areas etc.). During 1990s quality and technology of printers was improved and it impacted tactile maps production. This development forced International cartographic association ICA to establish Commission on maps and graphics for blind people, which commits itself to improved technology of tactile maps and access to the blind to geoinformation. ICA puts into program of its conferences (from 1993) sessions and exhibitions related to tactile maps. ICA also publishes newsletter TacNEWS.

Many teachers of blind people have only two possibilities for teaching geospace perception – pressed plates and plastic relief maps (thermo-vacuum plates, thermoactive foam materials, individual handy-made maps). The teachers help themselves by various modifications of plastic maps – i.e. emphasizing linear symbols by fabric or plastic belts or by labels with Braille letters. According to data of Tyfloservis o.p.s. (department of Association of the blind in the Czech Republic) training of spatial orientation and movement in courses is 22 %, special graphics 2 %, Braille learning 8 % and using technical aids 8 %. Tactile maps would be more practical and effective in all trainings and contribute to better client adaptation. Tactile maps availability and their high costs are the greatest barriers in many countries for their better development, distribution and using.

THE AIMS OF THE RESEARCH

The main aim of the author's research is to assess and to develop all aspects of interpretation and perception of geospace by spatial information on modern type tactile maps based on 3D printing from the view of current state of cartographical production technology. The research consists of particular topics as assessment of world methodologies and standards for tactile maps production, user's requirements analysis on present tactile maps and analysis of 3D printing technology for tactile maps production in GIS. The main part of research includes designing and completing geodatabase tactile maps production, compiling of tactile maps symbology within GIS and printing new three types of tactile maps by 3D printing technology. The research will conclude by testing printed tactile maps by end users (the blind).

Tactile maps of modern type means three map modifications (all coloured):

- Type A: tactile map printed by 3D printing technology (Contex 3D printers) as traditional relief tactile map with 5 mm thick base using both positive and negative relief with labelling by Braille,
- Type B: inverse form of tactile map printed by 3D printing technology which will be used for casting type A tactile maps,
- Type C: sound tactile map (of type A) posed onto a box with digital voice geoinformation activated by touch on maps surface.

CURRENT TECHNOLOGIES IN TACTILE MAPS MAKING

Each regular ICA international cartographic conference tactile maps are displayed at honoured place. During last 12 years there is no significant progress in tactile maps production. There are only two visible trends – improving tactile map colouring due to new materials and larger map format due to the latest printing devices. However comparison of tactile map interpretation methods (used symbology, colours etc.) was not published yet. It is because of difficulty of collecting of maximal number of tactile maps (from all countries) at one place. Generally, in all countries most activities are concentrated among cartographer rather than educators. Within this particular aim, the applicants will make detailed analysis from three views – cartographic (how tactile map expresses geospace), pedagogical (how geospace is read) and geoinformatics (how GIS assists managing geoinformation and 3D printing).

Modern cartographic methods offer many possibilities how to explain map contains. But in the world of visually impaired people the cartographers apply special methodology and technology for expressing of space. Tactile cartography uses several technologies of making graphic information tactile. The basic principle of a tactile map (also known as a raised or embossed map) is to present an extremely simple version of a visual image. Representation of raised or embossed graphic for haptic sense is generally named tactile graphic. Tactile graphics are images that use raised surfaces so that a visually impaired person can feel them. They are used to convey non-textual information such as maps, paintings, graphs and diagrams. Tactile graphics can be seen as a subset of accessible images. Images can be made accessible to the visually impaired in various ways, such as verbal description, sound, or haptic (tactual) feedback. The most being used technologies for tactual graphics are:

- “Craft” – Its principles are based on various manual model making using materials which are glued together to form a tactile graphic, usually a one-off. They can be very durable depending on the materials used. The technology is used for pre-school education, recognition of materials and colours, basic shapes and similar simple tasks. Despite they are originally made for user needs, no reproductions are made – every example is original. The craft technology is very time consuming and requires testing and training.
- Embossed graphics – The technique of Embossed graphics is based on Braille graphics. A printer punches dots into paper and those dots can be placed in such a way as to form graphics. They are suitable to mass-produce – paper is cheap, no height variation (on

most embossers), limited shapes and fills. However, tactile maps from embossed graphic are not very durable, not easily visible (no colours).

Swell (microcapsule) paper graphics – The principle of the technology is in using a special type of paper with microcapsules of alcohol embedded in the paper which burst when exposed to heat and make the surface of the paper swell up. Microcapsules of alcohol embedded in the paper burst when exposed to heat and make the surface of the paper swell up. Putting black ink on the paper before a heat process enables control over the raised areas. The technology needs special fuser and paper but is easy to update or edit and reproduce in bulk. Tactile maps can be drawn, photocopied, or printed with inkjet printers. It is easy to add non-raised print labels, easily visible when raised. Cartographers can create lines, shapes and fills. Black areas may smudge easily. However, only limited number of useful fills and textures are available and there is difficult to add Braille without transcription software or good Braille font.

Thermoform graphics – The technology is a collage master covered with plastic, heated and vacuumed over the original to create a copy. Thermoform diagrams are created from a process where a sheet of plastic is heated and vacuumed on top of a model or master. The master can be made up from almost anything, although certain substances can be more durable than others. It makes good height and texture variations and is easy to produce multiple copies from one master and to add Braille text. Thermoform graphics technology requires intensive skill to make collage, craft materials and expensive machine (but each copy is cheap to make) with slow reproduction speed. Different paper weights allow for high definition images.

3D print – Technology of 3D printing is based on creating 3D object by layering and connecting successive cross sections of material. Layers of a fine powder (plaster, corn starch, or resins) are selectively bonded by "printing" an adhesive from the inkjet print head in the shape of each cross-section as determined by a 3D file. Tactile maps are full colour objects, easy to update or edit and reproduce in bulk. Machine and print are relatively expensive but there are no limitations of shapes curves. There is only limitation of printing area. The 3D print technology is revolutionary approach for expressing geospace by material way. The Contex 3D printers (by Danish company Contex) make 3D print of object from computer 3D model (processed within GIS). The software cuts 3D file onto hundreds very thin layers (0.089-0.203 mm). First, rotating cylinder makes thin layer of powder and printing head puts liquid glue in horizontal profile of final model. This procedure repeats. Up to today 3D print was extremely money and time consuming (printing velocity 2-4 layers per minute). Today, 3D printing takes only hours with 3D Contex printer.

CONCEPTUAL AND METHODOLOGICAL APPROACHES

The particular task of design, development and usability of maps for persons with visual impairment is based on the actual needs of these persons. The general principles of development of maps for persons with visual impairment are crucial when preparing such maps. The principles are: the overall slipperiness of the material surface, the factors concerning the health risks of the material used, the suitability of the material for touching, the possibility to wash the material which is connected with hygiene conditions of its usage

and the necessity to carry out a survey of usefulness and purposefulness of the map which is actually being prepared. The map should be as concise as possible and it should depict only necessities, but it should at the same time give the person overall information about the place. During the research the authors will cooperate with the organisation Tyflocentrum Olomouc and the actual users of the tactile maps to determine the most suitable and acceptable technical parameters (such as descriptions, colours, abbreviations, sign keys etc.) from those stated in various publications and resources. However, the complete research concerning maps and plans for persons with visual impairment that are already being used was not carried out in the Czech Republic yet. As a consequence we have to prepare the databases of more complete maps and plans first and only after that we will select the most suitable technical parameters which we will consult with specialists (teachers and advisers) before final decisions.

After preliminary analysis of used tactile map printing technologies the authors can comment that new 3D printing technology based on layering and gluing gips powder makes possible new capabilities in 3D object modelling. Tactile maps are only one of possible ways of applying that technology. Used 3D printing was by maximal format 254×356×203 mm and thickness of one layer 0.089-0.203 mm. However progress in improving technical parameters of other printing technologies is so rapid that at the end of research activities the parameters of 3D printing will be twice stronger. Nevertheless current parameters are sufficient for required criteria of tactile models (it means maximal width 55 cm, length for bimanual perception 105 cm, for monomanual 75-80 cm). ESRI products are selected as the fundamental software environment for the research implementation. All basic relief expression parameters of tactile models will be, especially relief point radius 1.2 mm, point height 0.75 mm, spacing in base 1.2 mm, spacing in top 2.4 mm, parabolic shape of relief line (height:width ~ 3:2), distance lines and points etc. The authors set methodology for tactile map computer model building (from easily available data sets) and conversion approach into output (3D printer) device language.

Within research, 3D printing (at Contex printer) tactile map of type A has been produced. Because printed model consists of 50 % of pores it was easy to apply infiltrants arranging selected properties. Contex Company provides many preparations which can make the model either hard, flexible, smooth, waterproof etc. This is used when looking for the best printing procedures. The printed maps were used for testing by end blind users (see below). The printing procedure respected all rules for tactile model constructing, i.e. surface roughness, health wholesomeness, touch amenity, washing and other hygienic requirements. Particular manuals for the first tactile map type is compiling now. The first point of view is the one of blind and purblind pupils of elementary and secondary schools in the Czech Republic - those whose impairment is inborn (congenital visual impairment). The second one is the one of adult users of maps – the clients of organisations typhlo-centres and typhlo-services from the whole Czech Republic. These users will be divided into two groups of blind adults – first, adults with congenital blindness (they try to improve their abilities and skills) and second, persons who became blind during their life (they have to develop necessary abilities and learn how to use them). The testing by adult users of

both groups (congenital and acquired blindness) will be carried out in cooperation with organisation Tyflocentrum Olomouc, which successfully cooperates with the department of special education on a long time basis and which has already agreed on the cooperation. Tyflocentrum Olomouc as well as the research applicants supposes that, thanks to the outcomes of testing of individual groups, they will be able to identify plans and maps suitable for each degree of visual loss, proper colour contrast and marks and abbreviations appropriate for tactile as well as visual perception.

TESTING OF TACTILE MAPS OF TYPE A

Modern tactile maps are stipulated mainly for blind persons and persons with severe visual debility. They should help pupils and students and primary and secondary schools, as well as adults, as part of spatial orientation and independent movement training. The authors have therefore, for the purpose of testing, contacted educational organizations for pupils and students, and at the same time institutions, which provide services to adults – i.e. typhlo-service and typhlo-centre (organizations for adults with visual impairment, dealing with 2. degree physiotherapy). The following institutions, out of those researchers have contacted, promised to cooperate:

- 3 primary schools for pupils with visual impairment,
- 2 secondary schools (Grammar school and Secondary Vocational school),
- 2 typhlo-centres.

When selecting a sample stipulated for testing, the authors tried to accept the variations in approaches to persons with various degrees of impairment in various age categories. From the perspective of blind persons, it is mainly the tactile experience which is important and which can be further used in their practical lives. On the other hand for persons with severe visual debility, focus on tactile as well as coloured and contrasting design of samples, legends and thus created tactile maps, is desirable.

In relation to individual age groups, it is always essential to take into consideration the experiences that the respondents have gained, and it was always important to take it into account within the testing perimeters. The expected variations between children and students of primary and secondary schools with clear visual deficiencies, and persons with a combined impairment (out of which one is a visual impairment) were often confirmed within the scope of testing, and this factor will have to be considered in the subsequent phase of further maps creation and follow-up testing.

The tests were carried out at selected institutions, at the end of 2008. Our cooperation with these establishments was excellent to the point that our expectations were exceeded, and the test participants expressed great interest not only in the presented samples, but also in further development and the possibility of a future offer of modern type tactile maps. Not only the educational and counselling approached institutions, but also institutions, whose scope of activities does not involve care and services for persons with visual impairment, expressed interest in maps that the authors presented and proposed in certain alternatives.

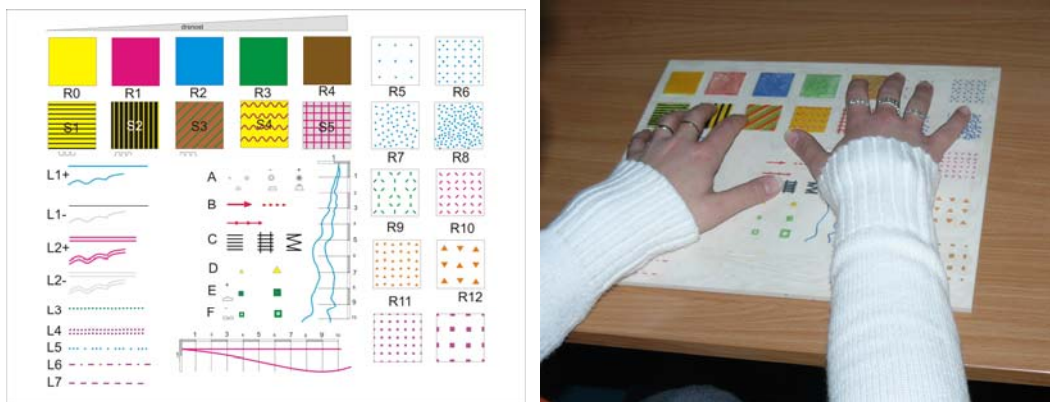


Figure 1. Testing board for tactile map of type A producing (left) and its testing by the blind (right). Explanations: R0-R4 roughness/harshness; R5-R12 testing types of patterns; L1-L7 testing lines with positive and negative embossing; A – point marker – circular with positive and negative embossing; B – direction marker, arrows; C – impediment marker – stairs, rails, zebra crossing; D – F point markers – triangle, square – with positive and negative embossing; no marking – testing measures for recognition of double or single embossed line – curved lines (blue) and straight lines (red).

In the above stated organizations, 80 % of blind persons and 20 % of persons with a severe visual debility from the selected number of respondents participated in the proposed testing, where a predominant group (75 %) of respondents were recruited from pupils and students of primary and secondary schools. The prevalence of tested individuals within school establishments was, according to our opinion, impacted by:

- 1) unsubstantiated prejudice of adults, concerning utilisation of such modern tactile maps in practical life,
- 2) awareness of school principles about the benefits of such modern type tactile maps within the teaching process.

For the purpose of testing, the authors have divided the sample card into several areas:

- line Aa, focused on roughness of material for persons with visual impairment on the level of blindness,
- line Ab, focused on distinguishing colour intensity of samples and comparing colour spectrum of similar shade samples for persons with severe visual debility,
- line Ba, differentiating in a structure of crosshatching in individual samples (blind persons),
- line Bb, differentiating of a colour contrast in crosshatched samples (persons with visual debility),
- column Ca and Da, focused on different structures of individual sectors with a different type of structural image, e.g. small and large triangles, intensity of dots, circles, etc. (blind persons),
- column Cb and Db, together with Ab, different intensity of shades in used colours (persons with visual debility),

- column E, which was focused on perception and differentiating of variations in embossed lines – simple, double, dot-and-dash, dotted, dashed and negative embossed lines,
- centre of the sample card F is focused on differentiating fine nuances between the embossed appearance of individual fine segments, e.g. arrows, traces/tracks, points (blind persons), this part was modified for persons with visual debility into appearance, which is visually distinguishable.

The following, and often surprising, findings result from the acquired data and conducted analysis:

- Aa – structure of this line of samples does not require changing (to the most segment 2 and 3 could be better differentiated),
- Ab, Cb and Db – there is a need for slight increase in colour intensity of some samples (especially brown, ochre and orange), on the contrary blue, green and pink colours were completely satisfactory,
- Ba and Bb – the contrasts perceived through touch as well as vision are completely satisfactory,
- Ca and Da – some samples must be changed or their distinctiveness significantly increased,
- E – the negative embossment is not palpable, it must be more defined; double lines are distinguishable from simple lines; occasional difficulties when differentiating variations between dot-and-dash and dashed line,
- F – the legend of traces/tracks was satisfactory for all respondents, as well as a simple arrow, on the other hand a legend formed by very fine points was unsatisfactory – it was often confused.

Conclusions were drawn on the basis of the above stated test results, pursuant to which the current samples are being amended, and they will form the base for further material processing of modern type tactile maps within the project.

PRELIMINARY RESULTS AND THEIR PRACTICAL UTILISATION

The research outputs are new knowledge on theory of production and conceptual approaches of tactile maps and compiling methodology for tactile map symbology and creating font set of tactile symbols for selected GIS software. Guidelines for new type tactile maps design are completing including catalogue of geovisualization methods for tactile maps. The authors are currently applying examples of new type tactile maps to test possibility of sense of touch development in order to improve understanding spatial relationships, spatial orientation and movement of the blind based on higher awareness about space. The results are useful by all institutions (not only related to the blind) within public administration for decision making in the whole society and by all organisations dealing with spatial information.

The importance of the research for practice can be seen in using above mentioned results. In general research level the research brings methodological solution for geospace

visualization at modern type tactile maps, methodology for the best interpretation method choosing of tactile map geodatabase and guidelines for their correct implementation. The methodology involves also specifics of automated production of three modern type tactile maps within GIS software (the most popular in the Czech Republic). The applicants assume that final tactile map examples and final book with all achieved results will be efficient tool for schools for blind children and many organisations which need to integrate the blind into various activities (employers, shopping centres, transport companies, subjects of emergency management etc.).

Further important research result will be reviewing and assessment of present-day Czech and foreign trends in using tools for geospace perception by the blind and users's requirements analysis on present tactile maps (type A, B, C) that will provide methodological background for many further research of similar specialisation.

Exploitation of the new type tactile maps will be very large – including using within school education, applying by officers of regional centres for the blinds, local governments and development agencies. Produced tactile maps in three new types will serve for development of geospace perception and orientation of the blind – both children and adults. The maps will assist to remove fear of space and recognising unknown places.

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References

- AMICK, N., CORCORAN, J. (et al.) (1997): *Guidelines for design of tactile graphics* [on-line]. New York, American Printing House for the Blind [<http://www.aph.org/edresearch/guides.htm>]
- BENTZEN, B. (1973): *Sites, Perception and the Non-visual Experience*. In Kidwell, CLARKE, C.R. (1993): *Introduction to Thermoforming 3: Vacuum Forming*. Ammanford, Dyfed, C.R. Clarke & Co. Ltd. [<http://www.crclarke.co.uk/>]
- CLARKE, C.R. (undated): *Vacuum Forming and Braille Reproduction*. Ammanford, Dyfed, C.R. Clarke & Co. Ltd. [<http://www.crclarke.co.uk/>]
- ČERVENKA, P. (1999): *Mapy a orientační plány pro zrakově postižené: metody tvorby a způsoby využití*. Praha: Aula.
- EDMAN, P.K. (1992): *Tactile Graphics*. New York: American Foundation for the Blind.
- GARDINER, E.A.H. (2001): *The Role of Tactile Maps in Environmental Education and Recreation in Areas of Managed Countryside*. University of Manchester, PhD. Thesis (unpublished).
- GIBSON, J.J. (1968): *The Senses Considered as Perceptual Systems*. London, George Allen and Unwin Ltd.
- GILBERT C.P. (1988): *Touchdown Sheepville*. Royal Blind Society of New South Wales.
- GILL, J.M. (1973): *Design, Production, and Evaluation of Tactual Maps for the Blind*. University of Warwick, PhD. Thesis (unpublished).
- GREENSPAN, J.D., BOLANOWSKI, S.J. (1996): *The psychophysics of tactile perception and its peripheral physiological basis*. San Diego, Academic Press. pp 25-104.

- Halton Borough Council (1997): *Halton Revealed: Aerial Photographic Survey of Halton*, surveyed in May 1997 at 25cm resolution. Halton, Halton Borough Council.
- HINTON, R. (1988): *New Ways with Diagrams*. London, RNIB.
- HIRN, H. (2005): *Tactile maps for preschool children: the curriculum*. Proceedings of XXII International Cartographic Conference A Coruña 2005 proceedings, CD
- JAMES, G.A., ARMSTRONG, J.D. (1976): *Handbook for Mobility Maps*. Mobility Monograph No.2, Nottingham, Blind Mobility Research Unit, Department of Psychology, University of Nottingham.
- JEHOEL, S., DINAR, S., MCCALLUM, D., ROWELL, J., UNGAR, S. (2005): *A scientific approach to tactile map desing: minimum elevation of tactile map symbols*. Proceedings of XXII International Cartographic Conference A Coruña 2005 proceedings, CD
- JESENSKÝ, J. (1970): *Poznávací význam tyflografiky*. Praha: SPN, 1970.
- KRUEGER, L.E. (1982): *Historical perspective*. In Schiff, W., Foulke, E. (eds.): *Tactual Perception: a Sourcebook*. Cambridge, Cambridge University Press, pp 1-54.
- LAMOTTE, R.H., WHITEHOUSE, J. (1986): *Tactile detection of a dot on a smooth surface: peripheral neural events*. *Journal of Neurophysiology*, 56 (4), pp 1109-1128.
- LAW, B. (1993): *A Guide to RNIB's Raised Diagram Copying Service*. London, RNIB.
- LEDERMAN, S.J. (1974): *Tactile roughness of grooved surfaces: the touching process and effects of macro- and micro-surface structure*. *Perception and Psychophysics*, 16 (2), pp 385-395.
- LOBBEN, A. K. (2005): *Identifying the needs of tactile map makers*. Proceedings of XXII International Cartographic Conference A Coruña 2005 proceedings, CD
- NOLAN, C.Y., MORRIS, J.E. (1971): *Improvement of Tactual Symbols for Blind Children*. Final Report, Washington, DC, Department of Health, Education and Welfare.
- PERKINS, C., GARDINER, A. (1997): *"What I really, really want": how visually impaired people can improve tactile map design in ICC 97*. Proceedings of 18th ICA/ACI International Cartographic Conference: Stockholm, Sweden, 23-27 June 1997, Ottoson, L (Ed.). Stockholm: Swedish Cartographic Society. 4, pp 1159-1166.
- ROWELL, J., UNGAR, S. (2005): *Feeling our way: Tactile map user requirements – a survey*. Proceedings of XXII International Cartographic Conference A Coruña 2005 proceedings, CD
- SCHIFF, W (1982): *A user's view of tangible graphics: The Louisville Workshop*. In: Schiff, W., Foulke, E. (eds.): *Tactual Perception: a Sourcebook*. Cambridge, Cambridge University Press, pp 430-453.
- SIEKIERSKA, E., LABELLE, R. (2001): *Tactile mapping project at Canadian Federal Mapping Agency - Mapping Services Branch*. Proceedings of the 20th International Cartographic Conference, ICC 2001 Beijing China, August 6-10, 2001. Mapping the 21st Century, Scientific and Technical Program Committee LOC for ICC 2001 Beijing China (Eds.). Beijing: Chinese Society of Geodesy Photogrammetry and Cartography. 5, pp 2932-2942.
- THEISSEN, N. (2000): *Computer-aided Tactual Graphics (Getting Started...)*. Enfield, Royal Blind Society.
- TSUJI, B., LINDGAARD, G., PARUSH, A. (2005): *Landmarks for navigators who are visually impaired*. Proceedings of XXII International Cartographic Conference A Coruña 2005 proceedings, CD
- UNGAR, S., JEHOEL, S., MCCALLUM, D., ROWELL, J. (2005): *„Tactualization“ of spatial information: towards a perceptual-cognitive approach to tactile map design*. Proceedings of XXII International Cartographic Conference A Coruña 2005 proceedings, CD
- WIEDEL, J.W., GROVES, P.A. (1969): *Tactual Mapping: Design, Reproduction, Reading and Interpretation*. Washington, DC, Department of Health, Education and Welfare