Signalization System for Visually Impaired People

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ABSTRACT

One of the most important problems faced by blind and partially sighted people when they travel is the inability to cross the street safely. The existing sound signalling systems are not provided with the facility enabling the impaired person to recognize the right direction when crossing the street. Hence, a new solution using the digital sound synthesis of the signal based on the space localization phenomena is presented and discussed.

SOMMAIRE

Un de problèmes le plus importants des aveugles est de traverser la rue en toute sécurité. On constate, que les systèmes de signalisation sonores qui existent présentement n'aident pas les aveugles à traverser dans la bonne direction. C'est pourquoi les nouvelles solutions basées sur le phénomène de localisation spatiale utilisant la synthèse numérique d'un signal sont presentées et vont être l'objet des disscusions.

1. INTRODUCTION

Since mobility is an important key to the impaired man's personal independence, thus maximal efforts should be made in order to improve technological aids for the visually disabled people. Modern technology has proven to be very helpful in this field of interests.

Electronic orientation systems designed to overcome these problems are quite advanced conceptually and technologically, today. That domain comprises clear path indicators warning of the presence of obstacles, orientation systems informing about bus stops, street names or numbers and zebra crossing signalling systems. Hence, many sound signalling systems were developed and mounted at street crossings all over the world. Unfortunately, almost each one of the systems is different and produces signals not like the other ones. Thus, it is impossible for the blind people to recognize signals and understand them, and consequently to remain safe when travelling abroad their own quarters. Moreover, all these systems supply the audible information only about the current traffic phase, it is red or green, not helping the visually disabled to choose and to maintain the proper direction when crossing the street. Moreover, in the case of complex street crossings, and in windy weather, the blind cannot be sure at which direction the green light was actually switched on. Hence, the idea stems from the need to develop a system really guiding the visually impaired along the zebra crossing. The elaborated and tested prototype of such a system using the space localization hearing abilities will be presented and discussed below.

2. ACOUSTIC SIGNALLING SYSTEMS FOR PEDESTRIANS

Available bibliographical references show that probably there is no general system solution of the zebra crossing aural signalization system standardized for the area of a whole country or at least of a noticeable region. Contrarily, there exist a great number of unique solutions having nevertheless some common features as follows:

1. Sound source: one or two loudspeakers placed at both sides of the crossing and mounted onto the traffic light signalization posts. The alternative solution is based on the vibrators mounted on the light posts at the height of the human arm;
2. Acoustic signals: repeated sound impulses or tone signals. The repetition period or character of those signals changes depending on the traffic light phase. Some systems do not generate any signal during the red light for the pedestrians;
3. Acoustical signalling may be provided with the automatic level control to regulate the signal volume depending on the current traffic noise level.

For many years the Swedish firm LM Ericsson has been producing sound signalling devices ticking with the speed of 75 cycles per minute during the red traffic phase and of 750 cycles per minute during the green light for the pedestrians.

Another Swedish firm GEWA developed a signalization facility "VIAFON". That device produces short signals repeated with the frequency of 0.4 to 1 Hz. The aim of these signals is to guide the blind to the start button mounted on the post close to the zebra crossing. That button is used to start the main acoustic signalization system of the crossing. Hence, the spitefulness of the continuously repeated loud signals disturbing the local inhabitants may be diminished.

Some systems installed in Denmark produce short noise impulses repeated 25 times per minute (red light) and 100 times per minute (green light). The duration of the "stop" signal is equal to 400 ms and of the "go" signal is equal to 200 ms. The noise is narrow-band with the changeable middle frequency being equal to 733 Hz, 880 Hz, 1056 Hz or 1267 Hz [1]. Setting various frequency characteristics allows the blind to discern the zebra crossing he or she is looking for. However, the use of noise as a warning signal is not generally recommended, because such a signal is rather difficult to be localized [6].

The English city information system "ELSIE" [2] and its French equivalent "SYN-PHONIE" [3] are based on digital synthesis of speech. Though, these systems revealed their advantages supplying information at the bus stops [4], however speech signal is easily-masked by the traffic noise and therefore must be amplified to a high level causing serious disturbances to the people living or working in the neighbourhood.

Some sound signalization systems mounted in U.S. cities use bird voices to announce traffic light phases. The call of the cuckoo signalizes the green light and the bird chirping means the red phase. Similar signals are less disturbing, however it is unfortunate that the problem of the proper interpretation of the signal meaning by the blind cannot be solved definitively by the use of bird voices or even the signals might be confused with real bird singing.

More than ten years ago (in 1984) in Basel, Switzerland, an experiment was organized by the "Vereinigung Schweizerischer Strassenfachleute" (Union of the Swiss Roadmen) in order to compare various acoustic signalization systems [3]. The results have proven that:

1. The visual signals given by the blind before entering the crossing by them are generally not respected by drivers,
2. The acoustic and vibration facilities come without any standards or regulations,
3. Acoustic systems may be supplemented by the vibration facilities to help the people impaired both visually and aurally,
4. The emission may be continued also during the red phase for the pedestrians.

As is seen from the above directions, the need of guiding the blind along the crossing was marked up only due to the vibration facilities. However, in the opinion of the authors, the problem of guiding the blind along the traverse path is important also for the purely acoustic signalization systems. The proposed concept and the tested new technical solution will be discussed in the further part of this paper.

3. LOCALIZATION OF THE RIGHT DIRECTION

The knowledge on the so-called spatial hearing is highly developed and an imposing number of books and articles were published on that topic [5]. Though many observations and theories are quoted there, concerning directional properties of the hearing sense, they dealt mainly with the abilities of listeners placed in anechoic rooms, mostly with their heads fixed. Little was done, however, to investigate the localization abilities in real conditions, it is within the bounded space, where reflected sound influences the localization precision, where sound signals are richly complex, and moreover, where the listener uses his augmented aural abilities as most visually impaired people do. Consequently, observations regarding the spatial properties of hearing in real environment should be employed when designing the above said sound system [6][7]. However, most free-field studies of spatial hearing in noise have considered the detection and the recognition of signals while skipping the problem of sound localization. This matter is discussed more thoroughly in some recent publications [8]. Moreover, specialized research on blind people's aural acuity and sound localization ability presented in the literature should be considered [9].

3.1 Sound source directivity

Noisy street environment conditions tend to mask the sound signal unless it is of a sufficiently high level. As it was proven in recent investigations [8] the ability to determine the direction of the signal decrease nearly monotonically in each dimension as the signal-to-noise ratio was lowered. On the other hand, the level of the signal should be as low as possible in order not to disturb pedestrians, drivers, and especially people living nearby. To ease a compromise, many sound sources of high directivity should be used at the crossing area, thus decreasing the source-listener distance and augmenting the ratio of signal to masking noise. This requirement leads to the selection of small horn loudspeakers as sound sources, having highly directional characteristics, yet without significant side-lobes. In comparison to omnidirectional loudspeakers employed in some experimental systems, the horn loudspeakers allow to create a distinct sound path, recognizable aurally and pointing to the nearest signal source.

3.2 Sound signal shape

The sound signal employed in the designed system should satisfy many requirements. It should be composed of many harmonics within the range of the highest sensitivity of the hearing sense, keeping however the tonal character of the spectrum, to avoid, as far as possible, a potential masking by the surrounding noise. The harmonics should be tuned to just scale in order to strengthen the difference tones corroborating the sound impression with discrete low frequency components resistant to masking, within the so called timbre-spectrum [10]. The melody of the signal should be selected in such a way, that its melody-line would be easily remembered and encouraging to traverse the crossing. The signal melody should be composed of several notes separately, to create many attack transients enhancing the subject capability to detect the source direction. A broader research on appropriate melodies has been executed [11]. The melody must be as short, as it is demanded by its repetition rate, while its pitch and tempo must be adjustable according to system requirements. It is obvious, that the level of the signal transmitted by particular loudspeakers ought to be easily adjustable to achieve optimal listening conditions within the crossing area.

A particular problem is created by the possibility of an application of the automatic signal level control, depending on actual noise level. Such solutions work in some experimental installations [3]. They ease to reach a desired signal-to-noise ratio, however, they create serious difficulties in the aural assessment of the source distance and direction. Fast changes in signal level can distort its characteristic features providing discrimination cues for the signal recognition, as well as for the distance and direction assessment. Aural assessment of the source distance and direction is significantly less precise when the signal reaching the listener's ears is composed of several components coming from more than one source sounding together. Therefore the subsequent loudspeakers situated within the crossing area should emit their signal successively, thus creating repeated signal waves wandering along the traverse path. It means that the greater the number of loudspeakers positioned along the traverse path, the better are the conditions for distance and direction assessments. In simple crossing with short traverse paths only two sources for every path may be applied. However, in such conditions finding the proper direction relatively easy is for a blind person. On the contrary, long, broad, and complex crossings with an irregular path direction, being the most difficult to be crossed by impaired people, are at the same time appropriate for installing there several loudspeakers on every traverse path.

The above stated requirements for the signal distribution, emission and control may be fulfilled economically only thanks to the digital microprocessor control applied to the system.

3.3. Sound sources placement

At least two loudspeakers are to be placed at the start- and end-point of every traverse path. They should be placed above the pedestrian heads level, directed slightly downwards, their main radiation axis turned to the path line. When the same path is used for both directions of traversing, two sets of speakers are to be installed each of them in the opposite sense. Unfortunately, the topology of existing street crossings does not allow acousticians to place sound sources optionally. Practically, their positions and mounting heights are determined by the localization and construction of light signalization posts (see Fig. 4). Mostly, only sidewards and downwards tilts of loudspeakers may be selected optionally, allowing one to optimize the system efficiency.

4. NEW SYSTEM CONCEPT

In order to ensure proper promotion of the proposed system, it is important to consider its economical aspect. Correspondingly, the cost of the system installation should be carefully examined. As the basic idea of the proposed solution assumes guiding the blind along the zebra, thus a certain number of sound sources should be used to produce spatially moving signals. Fig. 1 shows an example of a street crossing provided with the installation enabling to emit the direction-oriented acoustic signals. As is seen from the figure, in order to allow for that feature, it is necessary to mount directional sound sources on the posts at the street borders. Moreover, a pair of that type of sources (horn loudspeakers) oriented opposite should be mounted on the posts either at the safety island or in another case at each middle-street sidewalk border. The cost of the signalling system would be greatly influenced by the necessity to connect each loudspeaker to the common control system. As it induces the necessity to place wires under the pavement, so the cost will be particularly high in the case of mounting the signaling devices at the hitherto existing crossings. Hence, another solution was proposed by the authors. The idea will be presented below.

4.1 Synchronization of sound sources

Using individual microcontrollers for each sound source it is possible to construct separate modules acting as elements of a chain system, though these modules are not connected with each other with the use of any additional wire or a wireless link. The idea is based on the use of existing traffic light connections linking all "strategy" spots on the area of the street crossing. The set of individual signalling modules may use common start signal appearing at the moment of switching on of the green light at the defined direction of the zebra crossing. Starting from this moment, all mentioned modules are activated by the appearance of the current supply, since they are powered from the traffic light electric installation. At the same time one of the modules closest to the sidewalks on both sides of the street emits a short sound motif (e.g. motif A as in Fig. 2a). In the meantime, the microcontrollers of the remaining modules wait counting the passing time. As the module microcontrollers use quartz clocks, thus a synchronization among them is easy to achieve. Namely, after ending the first module emission, the next one starts to produce the same sound motif (motif B and subsequently motif D as in Fig. 2a) etc. That process is repeated in such a way, that some kind of "melody wave" is created moving away and subsequently returning back.

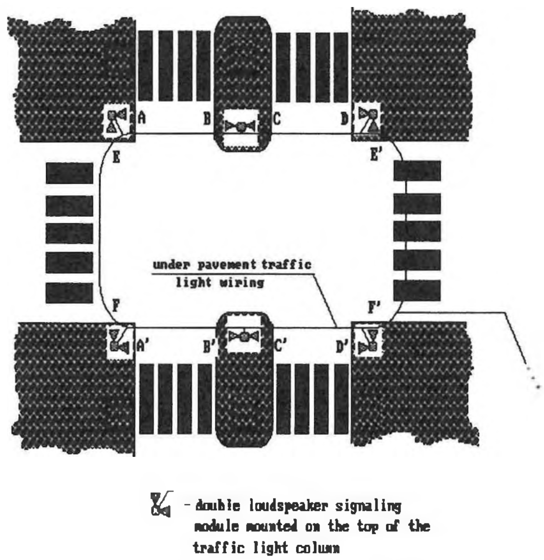


Fig. 1 Example street crossing provided with the "moving source" acoustic signaling system.

Fig. 2 Musical scores illustrating process of generating the "moving source" (a) and the "steady source" signals (crossing points denoted as in fig. 1).

As the green phase approaches its end, the green light starts to blink. That phase can be recognized by the modules microcontrollers and the speed of the moving wave may be increased (individual notes will be played back 2 times faster than normally). That provides a signal informing the blind pedestrian about the ending of the green phase.

4.2 Sound synthesis and control of the signalling module

The signal may be easily produced in the digital circuitry with the use of the sampling method. As the sound of the signalling trumpet emitted at a reasonably low level proved to be very useful in the initial experiments due to its great immunity to masking by the traffic noise, even without the use of an automatic level control, thus the sampled steady-state waveform of that sound was applied as the basis for the signal sampling synthesis.
The play back of up to 10.000 samples for each note allows to generate a signal providing synthetic trumpet within the musical scale of a single octave (523,2 Hz - 987,8 Hz). The characteristics of the signal and noise are presented in Fig. 3.

In the elaborated prototype of the signalling system a single chip microcontroller was used. Since it is recommended to construct each module as being uniform, so a set of DIP-switches was used to select the module position in the system (initial time delay), the number of the modules in the whole system (repetition period), the kind of melody (different for each crossing direction) and the speed of signal playing back (depending on the street width and crossing configuration). Some additional functions of the microcontroller enable to regulate the temperature inside the module (important for winter conditions) and to produce an alarm signal in the case of opening the module by an unauthorized person. The photo of the signalling module mounted to the traffic lamp set is shown in Fig. 4.

a)

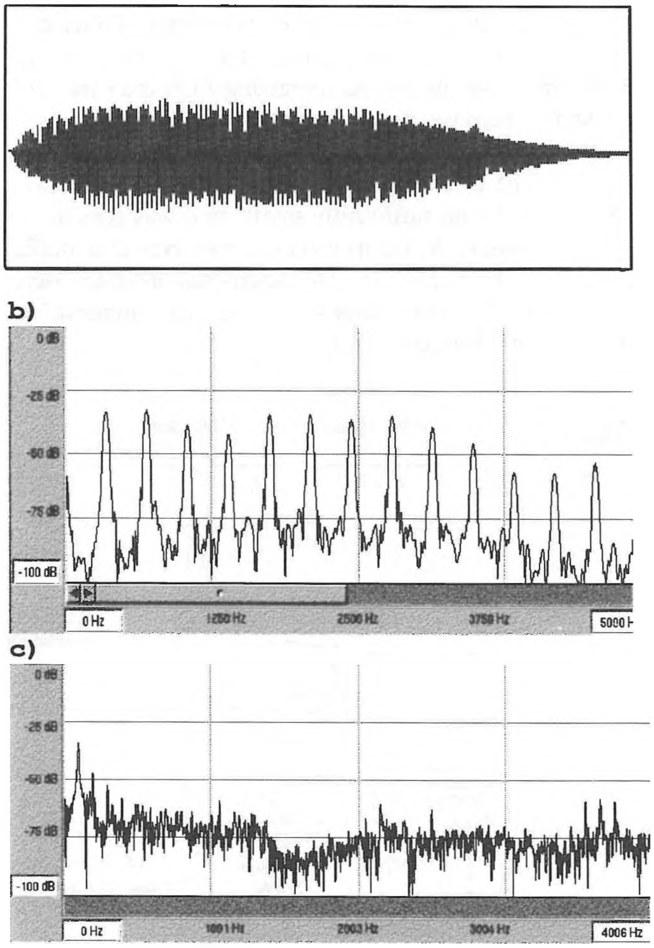


Fig. 3 Time-domain shape of the signal (a); spectral analysis of the signal (b) and spectral analysis of a traffic noise pattern (c).

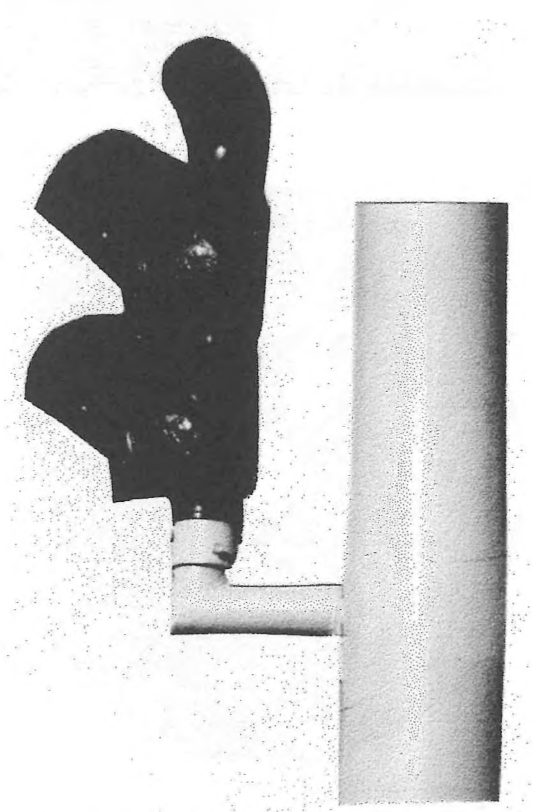
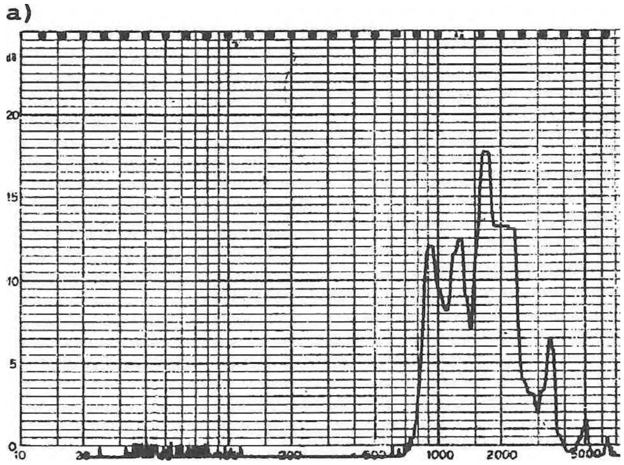


Fig. 4 The traffic light set with the acoustic signallizer.

4.3 Loudspeakers

The main feature of the loudspeaker applied in the discussed system is its directivity. That characteristics mainly influences the ability of the blind to recognize the right direction. The frequency characteristics of the loudspeaker is of less importance, provided the signal spectrum components in the band 500 Hz - 5 kHz may be transmitted without excessive attenuation. Characteristics of the loudspeaker used in the elaborated experimental system are presented in Fig. 5.

a)



b)

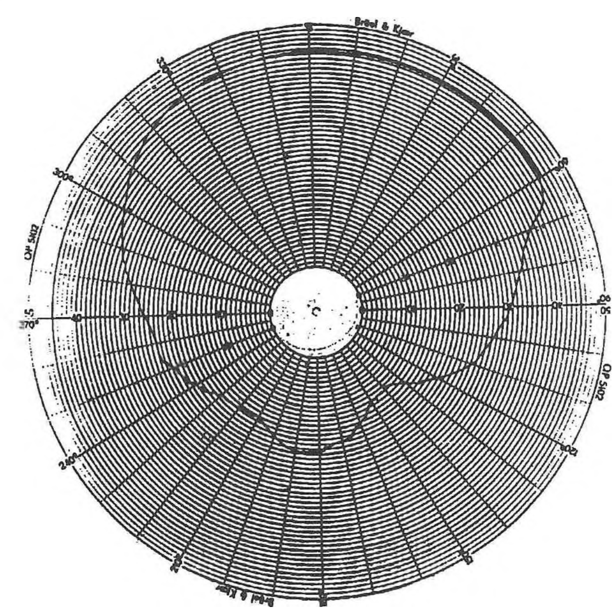


Fig. 5 Acoustic characteristics of the signalling module: (a) pressure response versus frequency; (b) directivity.

4.4 Electronic circuitry

Thanks to the microprocessor technology, the sound module electronics can be maintained simple, compact and cheap. Practically, the cost of the production of the single electronic board can be maintain less than the cost of a single horn loudspeaker. The total cost is comparable to the cost of installation of traditional electro-mechanical signalling devices produced some years ago.

The simplified block diagram of the elaborated prototype device is presented in Fig. 6. As is seen from figure, the electronic part of the sound module consists of a few blocks mostly based on popular and cheap integrated circuits. The synchronization of modules is easy to achieve, because all of them are resetted at the beginning of each green light phase. In such conditions the accuracy of counting time by the microprocessor employing quartz clock is out of questions (stability of a typical quartz crystal is at a rate of 10^{-5}). There was no necessary to install the reconstruction filter after the D/A converter, because the loudspeaker plays this role as a mechanical filter of frequency response as in Fig. 5a.

The electronic board and the horn loudspeaker (power 5 VA) are sufficiently small, so it was possible to place the whole device in a typical case-box of a traffic signalling lamp (Fig. 4). The additional modules were built-up on the top of lamp sets remaining "invisible" to the majority of street walkers.

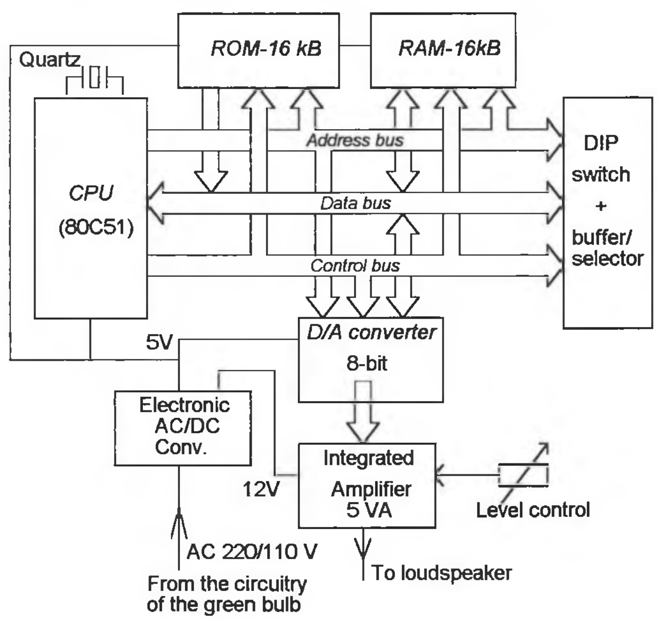


Fig. 6 Block diagram of the electronic circuitry of the signalization module.

5. RESULTS

The elaborated prototype of the system was installed at a busy street crossing in the town Gdansk, Poland (lay-out scheme presented in Fig. 1). System features were assessed by blind people crossing the street and by observers. The behaviour of blind men crossing the street was observed when system was switched off and when using the "moving source" program (as in Fig. 2a) and the "steady source" program (Fig. 2b). Each subject crossed the street 9 times (3 times for each situation). In the conducted experiments 3 blind men and 1 partially sighted woman were engaged. Tested people crossed the street individually. The break between consecutive attempts of individual subjects was determined also by the cycle of light change and was approximately equal to 15 minutes. All subjects were accustomed to the street crossing lay-out, because they use it everyday when approaching the special factory employing impaired people. The time spent to cross the street of width of 21 meters (from place A to place D shown in Fig. 1) was used as a measure of the effectiveness of the signalization facility. All tests were performed in the presence of traffic noise at the average level of 70-76 dB_A (measured at the safety island). The level of sound produced by each loudspeaker was equal 80 dB_A (measured from the distance of 1m from the source). Results are gathered in Tab. 1.

Tab. 1 Comparison of efficiency of crossing the street

subject / average time of 3 attempts [s]	without signals	steady source	moving source
man 1	42	39	32
man 2	51	39	35
man 3	39	37	26
woman	36	32	28
average time	**42**	**37**	**30**

As is seen from Tab. 1, when taking advantage of the "moving source" localization facility it was possible for the visually impaired to get to the other side of the street more safely and faster (averaged time was shorter at about 30%). In the case when the sound source was not moving, performance of the tested system was worse, however the directional characteristics and the increased number of installed loudspeakers caused that the street was crossed more efficiently in all cases. The averaging of results obscured some effects resulting from the change of noise sources (cars waiting at the zebra) and the customization of subjects to the repeated procedures. However, differences caused by these factors not exceeded 7% in repetitions of tests for all subjects.

6. CONCLUSIONS

The economical factor related to installation of signalization systems caused that many of previously formulated recommendations (e.g. the use of vibration facilities) were never implemented practically. Consequently, some new proposals of improvements in auditory zebra crossing signalization systems were formulated, implemented and tested by the authors. The economical benefit of this system results mainly from the fact that the cost of installing additional wires is eliminated, because it is not requiring connection between speakers.

As it was proven by described tests and by everyday observation of the street crossing at which the system is installed, visually impaired people can benefit from such a facility. Consequently, authors would greatly appreciate further promotion of their idea of the improved signalling facility or other relevant ideas in order to make such solutions more commonly used by the impaired people.

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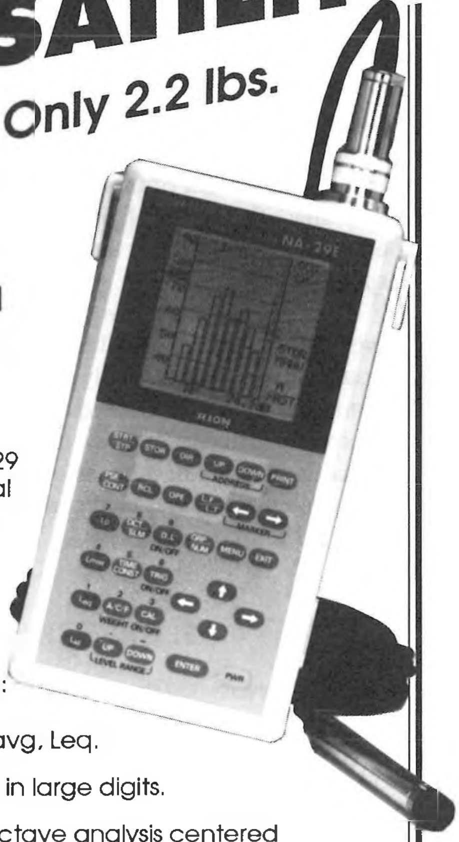

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