Assistive Technologies For The Blind: A Digital Ecosystem Perspective

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ABSTRACT

Assistive technology devices for the blind are portable electronic devices that are either hand-held or worn by the visually impaired user, to warn of obstacles ahead. These devices form a small part of a much wider support infrastructure of people and systems that cluster about a particular disability. Various disabilities, in turn, form part of a greater ecosystem of clusters. These clusters may form about a nucleus of various specific disabilities, such as vision impairment, speech or hearing loss, each focusing on its own particular disability category. Clusters are comprised of teams of therapists, carers, trainers, as well as device manufacturers, who design and produce computer-based systems such as mobility aids. There is, however, little evidence of any real crossover collaboration or communication between different disability support clusters.

Categories and Subject Descriptors

K.4.2 [Social Issues]: Assistive Technologies For Persons With Disabilities.

General Terms

Human Factors.

Keywords

Obstacle warning displays, assistive technology, sound interface displays, laser, disabled, infrared, long cane, portable electronic device, sensory channels, visually impaired, ultrasonic pulse-echo, ambient sound cues.

1. INTRODUCTION

There are approximately ten competing mobility aids and orientation mapping devices for the blind on the market at present, some with significant drawbacks. Many assistive technology devices use ultrasonic pulse-echo techniques to gauge subject to object distance. Some use infrared light transceivers or laser technology to locate and warn of obstacles. These devices exhibit a number of problems, the most significant of which are related to the interface display that conveys navigation/obstacle warning information to the user.

Other sensory channels should not be compromised by the device. This is exactly what can happen when, for example, audio signals are used in obstacle warning on/off displays or more significantly in orientation solutions, where continuous streams of synthetically generated stereo sound mask the natural ambient sound cues used by the blind. Despite the challenges, the commendable feature all these assistive device developers have in common is; they are striving to help a section of the population with a severe disability.

Devices can be heavy and cumbersome, which is very problematic in a device intended for extended periods of use. Many of these devices are highly visible, advertising the user's disability. The devices may compromise one or more senses in the process of conveying information, a critical disadvantage for visually impaired users. Many current aids use vibrating buttons or pads in the display to warn of upcoming obstacles, a method which is only capable of conveying limited information regarding direction and proximity to the nearest object. Some of the more sophisticated devices use an audio interface in order to deliver more complex information, but this compromises the user's hearing, a critical impairment for a blind user.

Many currently available orientation devices suffer from lack of accuracy. They often have a limited means of 'mapping' the terrain ahead, and more importantly, they are typically incapable of transmitting/transferring that information usefully to the user. Although many mobility aids can warn of obstacles up to six metres ahead and crudely convey the distance of said objects to the client, they cannot convey what would normally be regarded as *field of view* information to the user without compromising other critical sensory channels.

Although complex GPS systems have had some success in addressing this limitation, they seldom warn of obstacles immediately ahead, are often unsuited for indoor use, may be extremely bulky to wear, typically, are prohibitively expensive and they too often severely compromise the natural function of the auditory sense. They cannot be regarded as stand-alone systems.

If the client is presented with limited orientation feedback, not only is quality of life impaired, but also mobility may be reduced

to an isolated step-by-step cane assisted progression, typically punctuated by non specific on/off warning signals from a mobility aid. Relatively few visually impaired people accept the devices that are currently available. This is not surprising as the performance of these devices, for the reasons discussed above, cannot always justify the price tag. Clients will accept the standard Long Cane for its simplicity and predictability and the fact that it is approximately a fiftieth of the cost of a sophisticated electronic aid.

2. A COTTAGE INDUSTRY

Current products have largely not gained significant traction in the market. Some of this is due to an inadequate feature set, sometimes combined with a high retail price. The companies responsible for the competing products tend to be small. There is no one player with a significant market advantage against the others. A successful design example is Sound Foresight, a spin-out company from Leeds University which sells the Ultracane (See Fig. 1).

The UltraCane is essentially an advanced, ultrasonic device integrated into a cane [1]. It feeds information about upcoming obstacles through to a series of vibrating buttons on the handle, conveying distance and rudimentary height information. It has two ranges, three metres and five/six metres, and its sensors detect from 1 inch off the floor to 'just above your head'. Since its launch in 2004, Sound Foresight has sold UltraCanes into 15+ countries. It has been featured on television programmes and in newspapers and magazines around the world, and won numerous awards.
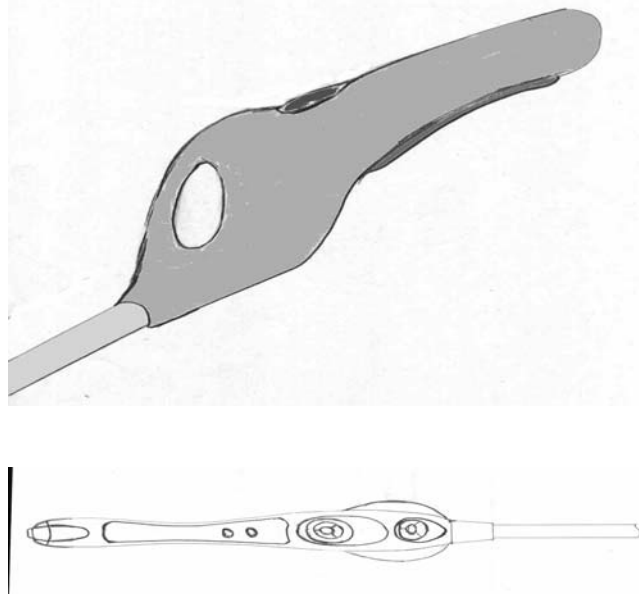
Figure 1. The Ultracane. Here, the ultrasonic transceiver circuit and user display are appropriately and unobtrusively molded into the handle of a functional cane. The output signals are displayed on a vibrating tactile interface.

The K Bat-Sonar takes complex echoes as return signals from ultrasonic waves, initially generated by the device, then translates them into audible tone rich sounds. These synthetic sounds are amplified and sent to earphones worn by the user. When the system is attached to a long cane, it can be used in the usual way by scanning repeatedly from one side to the other. However, the range of the cane is extended beyond the usual short stick length to the range of the transceiver unit clipped on near the handle and which, in fact, becomes the replacement handle for the combined assembly.

The system is described as a spatial sensor using echolocation bio-acoustic technology. The handbook describes this as 'sonocular perception'. However, it also refers to the substantial learning commitment required for this conversion to an alternative perception. 'Learning the many subtle nuances of spatial perception is a continuous self-oriented process and extends over a long period of time'.

The statement, 'K' Sonar acts as a vision substitute', needs to be examined carefully. There is also a clear suggestion that 'two are better than one' and that the device be used in conjunction with a Longcane [2]. If it were in fact a true substitute for vision, surely there would be no need for attaching it to a cane and relying on the cane as a primary close range assistive device? It is true that the BAT website [2] does admit limitations of both cane and device; 'This combination removes most of the limitations of either aid by itself.' If we accept this, then must the Longcane also be regarded as a vision substitute?

The Miniguide (See Fig 2) uses ultrasonic echo-location to detect objects [3]. The aid vibrates to indicate the distance to objects - the faster the vibration rate the nearer the object. There is also an earphone socket which can be used to provide sound feedback. A single push button is used to switch the aid on or off and also change settings. The aid can accommodate ranges of between 0.5m and 8m, depending on the chosen mode. The Miniguide has a transmitter/ receiver pair that should be held one above the other while in operation. Thus, users must pay attention to ensure they are holding their devices vertically. This, we believe, inhibits 'unconscious' operation.
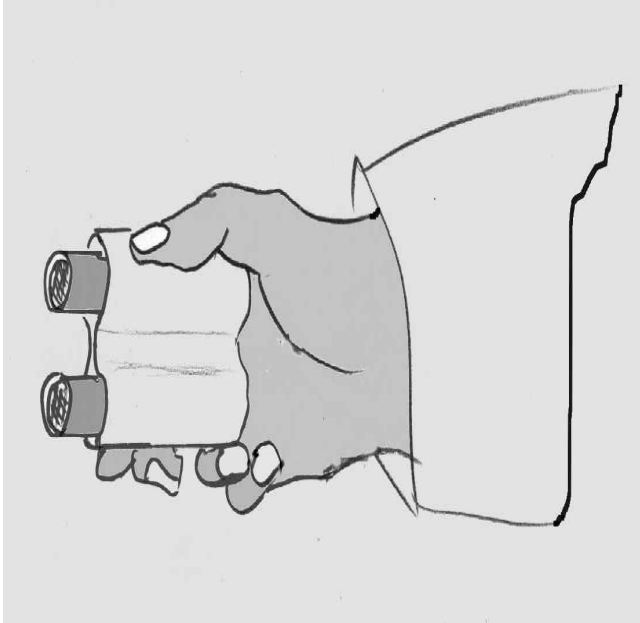
Figure 2. The Miniguide is a small handheld device that uses ultrasonic pulses to echo locate obstacles in its path. It has the advantage of a low current requirement. However, when used indoors, most ultrasonic devices pick up unwanted ambient echoes from adjacent walls, ceilings and surfaces which may corrupt the result.

3. USER PERCEPTION OF AIDS

There are a number of reviews such as those listed in Currently Available Electronic Travel Aids for the Blind [4]. None of these can be regarded as more than a rough guide. Clear evidence of why current aids are rejected can be found in relevant conference and journal papers such as [5, 6, 7]. Blasch for example, states that few are regularly used. Davies in 2006 refers to *only limited continued use of the device* [6].

The downfall of many of current devices is that they prioritise the obstacle immediately in front of the user and do not provide additional information to the user. ETA rejection has existed since the report from National Research Council [8]. This report refers to auditory interfaces that compromise the natural feedback derived from tapping a long cane. These auditory displays are still the most common user interface in more sophisticated orientation devices.

The Teletact 2, in order to overcome some of the problems associated with both laser telemeter and infra-red forward scanning technologies, combines both in one system [9]. An earlier version made use of the laser only, the reflected beam of which can result in a confused signal from plate glass, such as in a door or front to a building. There was also a problem with lasers not picking up dark objects, such as black cars or other vehicles. Grass at the side of a path could also be confusing to a laser-based system.

In case of both proximeter and laser telemetric detection, the system transmits telemeter information. When it senses the proximeter signal only, it sends a "window warning" signal to the user, in order to warn them that they may be approaching a window. The proximeter works within a range of 3 meters, and gives a window pane / black car detection up to two meters. See Figure 3.
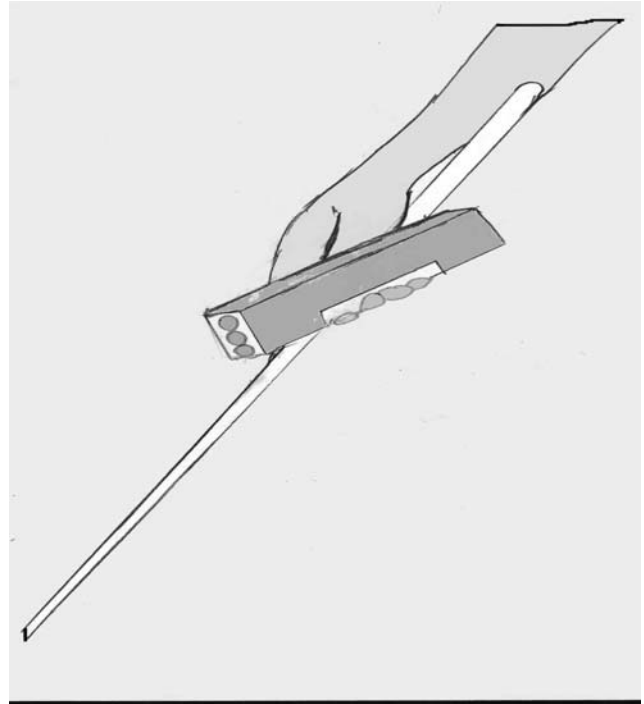

Figure 3. The Teletact 2 uses both infra-red and laser technologies for judging the range of objects in the path of the user.

It uses vibrating devices located under the user's fingers. Experiments were conducted with two, four and eight vibrating devices, and the four-device solution turned out to be the most successful. The principle of this method is simple. Each finger (except the thumb) is in contact with one and only one vibrating pad. Each vibrating pad corresponds to a distance interval. If an obstacle is detected within one of the four distance intervals, then the corresponding vibrating device is activated.

Although the Teletact 2 overcomes some of the problems associated with the previous model, it is essentially a go/no go device. The design is unique in that it makes use of both an infra-red proximeter and laser telemeter. Infra-red systems usually work well indoors, but can be adversely affected by interference from the outdoor environment, such as sunlight.

The Sonic Pathfinder is a head mounted device. This system evolved from work of The Blind Mobility Research Unit at Nottingham University. It is designed for out of doors use in conjunction with a Longcane, a dog or residual vision [10].

The system is a head-mounted pulse-echo sonar system incorporating five transducers and a microcomputer. The main decision algorithm reacts to the nearest object and is center weighted, displaying earphone tones on a pitch-to-distance rationale. Many sonar-based systems do not function well inside walled areas due to false echoes confusing valid return data.

4. A GLOBAL VIEW
In the developed countries the number of blind people was estimated to be 3.5 million in 1990 and 3.8 million in 2002, an increase of 8.5 %.

Australia
About 480,000 of Australia's 20 million residents are visually impaired, and over 50,000 of these people are legally blind. Projections indicate that by 2024, over 800,000 Australians will suffer from visual impairment, and approximately 90,000 will be blind [11].

America
The total number of Americans with blindness in 1995 was approximately 1.3 million, and that number grew to 1.5 million in 2000. Incorporating the high death rates for older age groups, the expected net growth in the prevalence of low vision and blindness is approximately 36,000 cases per year until 2025. However, the annual incidence, the number of new cases added each year, will grow from the current 256,000 to 500,000 in 2020 [12].

Globally
The World Health Organization estimated that in 2002 there were 161 million (about 2.6% of the world population) visually impaired people in the world, of whom 124 million (about 2%) had low vision and 37 million (about 0.6%) were blind [13].

In developing countries, excluding China and India, 18.8 million people were blind in 1990 compared to 19.4 million in 2002, an increase of 3%. In China and India the estimated numbers of blind people in 1990 were 6.7 and 8.9 million, respectively; in 2002 there were an estimated 6.9 million blind people in China and 6.7 million in India. These figures indicate an increase of 3% in the number of blind people in China and a decrease of 25% in India.

The following is a quote from Margrain [14]:
"The number of people with impaired sight that cannot be improved with the use of spectacles or other treatments is growing. Demographic data suggests that the numbers of people with impaired vision are likely to increase at least until 2021 because the main causes of low vision are age related. Medical intervention is unlikely to reduce significantly the numbers of people with impaired vision in the foreseeable future because there is currently no treatment for the primary cause of visual impairment, age related macular degeneration. Given that it will not be possible to cure visual impairment the emphasis must be on providing an effective rehabilitative *low vision service*."

Client statistics from the Canadian National Institute for the Blind (CNIB) show an increase in those in need of services from their organization; and these numbers are considered to be conservative because data collection is a result of self-report and collected from individuals who participate in their services.

Vision impairment is responsible for 18 percent of hip fractures by older Americans at a cost of treatment of $2.2 billion each year. If we could prevent just 20 percent of such hip fractures, it is estimated that US$441 million would be saved annually [15]. This is just one example of the considerable healthcare costs caused by vision impairment.

5. HUMAN-MACHINE INTERFACES
Existing devices can be broken down into two categories. First the simpler type that warn of an obstacle in the forward vicinity of the user, but convey little or no detail with respect to position or object identification. They may use buzzers, simple warning vibration or synthetic tones as the user interface. They do not usually warn of drop-offs, such as potholes, in any truly reliable way.

The second category may have enhanced range and precision, as in the case of some laser based types, but often with a far too simplistic binary information go/no go user interface, or, alternatively, use complex sonar sweeping techniques that convert ultrasonic reflected signals into a synthetic but *inhuman* audio signal that is presented to the user. Such devices require substantial learning and compromise the natural sound cues that are absolutely essential for a blind person.

Many of the competing products have poor and inappropriate human-machine interfaces. A recent paper in the Proceedings of the 2005 IEEE Engineering in Medicine and Biology Conference reinforces these views [16]. Velazquez et al confirm that although many ETAs have been proposed to improve mobility and safety navigation independence for the visually impaired, *none of these devices is widely used and user acceptance is low.* Four shortcomings are identified in all ETAs.

They obtain a 3D world perception via complex and time-consuming operations: environment scanning using sonar-wave or laser beam requires the user to actively scan the environment, to memorize the gathered information, to analyze it and to take a decision: constant activity and conscious effort that requires intense concentration ,reduces walking speed and quickly fatigues the user.

They provide an acoustic feedback that interferes with the blind persons ability to pick up environmental cues. Another problem is degradation and overloading of the hearing sense. Most of these critical interfaces are designed by electronics engineers who have little knowledge of human perception. Many of these devices had their origins as robotics projects.

They are invasive. They are intrusive and disturb the environment with their scanning and feedback technologies.

They are still burdensome and conspicuous to be portable devices, which are essential needs for people with visual impairments.

Hakkinen's IEEE conference paper [17] refers directly in the title to 'Postural Stability and Sickness Symptoms After Head Mounted Display Use.' The findings show clearly these common displays produce adverse affects on the user.

6. AUDITORY USER INTERFACES

Scanned objects normally produce multiple echoes, translated by the receiver into unique invariant 'tone-complex' sounds, which users listen to and learn to recognize. The human brain is very good (it is claimed) at learning and remembering certain sound-signature sequences in a similar way that it learns a musical tune. The sound signatures vary according to how far away the device is from the object, thus indicating distance. The user listens to these sounds through miniature earphones and can detect the differences between sound sequences thus identifying the different objects. This allows limited mapping and orientation for the user at a price.

Any auditory user interface has the potential to interfere with the users' hearing of natural ambient sound cues. This is a critical factor for a blind user. If used in a safe environment by a truly driven person prepared to learn over time, sound signatures representing a visual scene could significantly enhance quality of life. However, the 'real world' is not safe, and there are serious safety concerns about restricting the hearing of a blind user in an uncontrolled environment.

Beyond the safety aspect, blind users have learned to depend on their hearing, and any product which continuously interferes with it may lead to a compromised alternative human sensory input. Supporting evidence for this claim can be universally found from very different disciplines. Some of these have already been referenced in the preceding sections. More specific reference can be found from Johnson and Higgins who refer to visual –auditory substitution taxing a sensory modality that is already extensively used for communication and localization [18].

Recent studies indicate that a 20 minute usage of acoustic feedback devices causes serious human information registration, reduces the capacity to perform usual tasks and affects the individual posture and equilibrium [17].

Such interfaces may fail because of their complex, confusing and restrictive masking audio feedback, particularly to the frail user. They are often not suitable for a typical elderly blind user who is likely to have multiple disabilities. A Study by Ross and Blasch [19] clearly indicated that blind people preferred a tapping tactile interface to sound feedback.

7. DIGITAL ECOSYSTEM MODELS

Issues of complexity with respect to individual requirements must be seen within the context of a wider ecology of the particular user, with that person clearly at the centre, contributing to a team solution. An established and highly successful ecological approach to designing individualized education programs for the disabled student has been refined over twenty years into a highly recommended model and is now regarded as 'best practice' [20].

This ecological approach has not as yet permeated all areas of disability support. However, the power of the digital ecosystem framework is now accepted within many other disciplines, particularly with respect to small enterprise collaboration [21].
Within small business, the advent of the web has allowed sales penetration over vast distances. Accompanying these advances have come new modes of marketing and partnership possibilities that would have been impossible only a few years ago. With this connectivity has come a fertile and dynamic business theatre that cannot be avoided if small enterprises are to survive. This interaction has led to collaborative workflow models [22].

The logic behind collaborative workflows is to produce a sequence of activities that not only produce a meaningful result, but also to facilitate small groups working together to achieve common goals. The actual physical distance and associated limitations between these entities then becomes less important as web based tools are used to link enterprises and their common aspirations [23]. The entities themselves may be small companies competing against large predator corporations, or widely dispersed cottage industries (such as those associated with assistive devices) with a common interest [24].

Beyond the standard empowerment the digital ecosystem model has provided, are more specific areas that are pertinent to such groups operating in harmony. One of the most important of these is trust evaluation [25]. Other typical support areas are logistics and privacy [26, 27]. These would act as foundations for the model that is proposed.

Digital Ecosystems For Cohesive Assistive Clusters (DECAC) is a proposed collaborative cluster-based ecosystem model, neither limited by distance between clusters nor the particular disability types associated with each of the clusters. Individual clusters may include a range of specialist personnel associated with the support of a client requirement. The output of such an environment would not only be the efficient research and development of appropriate assistive devices, but also result in more streamlining for the teams in their everyday support of an individual, be that speech therapy for dysarthria patients or training in the use of a long cane or mobility aid for the visually impaired.

The author has developed a prototype device, which it is hoped, will be the first step in addressing some of the listed problems. This working prototype has a unique tactile interface design which, even in its basic form, has distinct user advantages over many other systems, including those devices with tactile interfaces. As with some of the sonar systems listed above in the paper, this first prototype is best suited to outdoor use. Future models are not limited to sonar technology, however.

The design criteria has and will in the future, concentrate on intuitive interfaces that do not compromise certain other all-important sensory channels. These interfaces, now under development, will be configurable for users who are both deaf and blind.

There will also be an emphasis on ease of learning and use. It is unacceptable to expect someone, who may have multiple disabilities, to undertake a long and complex learning program in how to use a new device.

The author won Curtin's **New Inventor Competition for 2007**. This evaluation was based on a novel mobility aid design resulting in a fully functional prototype.

The Innovation in the design is summarised as follows:

❑ A portable mobility aid incorporating warning *obstacle ahead* information with advanced mapping capabilities as a **stand-alone** device. It does not rely on GPS or other external signals such as required by radio tags.

❑ The system is also **stand-alone** in another sense, as it can if required, replace a standard long cane or guide dog or third person assistance. It is therefore a hands-free device.

❑ Dependent on user requirements, the system can also be configured to be an **augmentative** assistive device to be used with a standard cane or dog.

❑ A unique tactile display is used to convey system output data (field of view features) to the user.

❑ The proposed design is unique in that it offers **environmentally contextual drop-off and step up warning** in a hands-free design. Of all the competition, only the Laser Cane offers drop-off warning, but it is **not hand-free.**

At this stage, no further technical specification can be given due to IP novelty protection. It is hoped that in future papers, we will be able to concentrate more freely on the technical aspects of the design. However, Figure 4 illustrates the first working prototype. This uses ultrasound for range-finding and is mounted on a cane for test purposes. Initial tests have proved the system to be at least as effective as many of the alternative commercial systems just discussed.
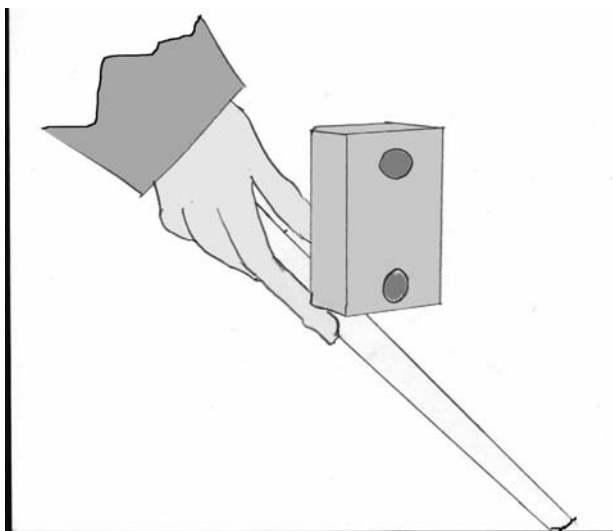

Figure 4. The initial prototype fixed to a cane

The digital ecosystem paradigm offers opportunities for both knowledge sharing within a wider ecology as well as user cognition-centred adaptability and flexibility for all assistive technologies. The design of specifically targeted Digital Ecosystem guidelines will fill a basic requirement for society in general and all disabled people in particular.

The author will use the above prototype device development in order to help model a digital ecosystem framework, progressing the step-by-step stages in line with these ecosystem framework criteria.

The existing successful first prototype design will form the basis for a range of advanced products for the visually impaired, that will first need to be systematically tested on a sample during trials after miniaturised test prototypes are built. This operation will run parallel to the research into the formulation of a coherent set of guidelines for the DECAC model.

8. THE DECAC PATH

With each client representing a nucleus at the centre of his or her support cluster, an individual's local ecological environment has been acknowledged (as discussed and cited in previous sections) as a worthwhile starting point, offering a framework from which specialist support action may be fleshed out.

Each support cluster would have a number of clients within its particular category of disability. Cluster membership would not be determined by distance or physical boundaries. The aim would be to maximize use of the digital ecosystem paradigm in order to break existing physical boundaries.

By applying a DECAC strategy, current digital technologies such as mobile, the internet and video conferencing can be coordinated and optimized to deliver the best outcome for all members of this ecosystem.

Open-ended but novel design solutions would be encouraged from both hardware and software developers. The sharing and exchange of common modular solutions at both a functional and user interface level would be part of the ecosystem membership requirement. The protection of intellectual property (IP) would remain an individual company's prime commercial consideration.

The difference would be in the focus and modular consideration of appropriate novel and relevant ideas, when first considering I.P. matters. This will not always be relevant to designs, but when it is, it should in fact enhance the potential for profit and sales within the DECAC community itself, as well as in a wider context (external to the ecosystem).

Those academic cluster members who currently work within a limited research environment with a very small interest group would have the opportunity to share their research and ongoing projects on a wider stage within the digital ecosystem. Cross-disciplinary interaction would be nurtured by DECAC.

9. OUTLINE OF DECAC STRUCTURE

A cluster of people with a vast range of interdisciplinary skills would focus on a user group of people all with a common disability. There would be many separate clusters, meeting the challenges of specific needs of different disability groups. As now, it may be assumed that special education specialists, therapists, medics, academics, engineers and particularly hardware and software experts would form part of each cluster, the main difference being a recognition of the greater ecosystem in which each cluster coexists and operates.

Users at the center of each cluster, the nucleus, would determine the nature of the environment. Clusters would communicate with each other for a common good and the ecosystem itself would be able to benefit from its size in terms of external links and its critical mass. See Figure 5.
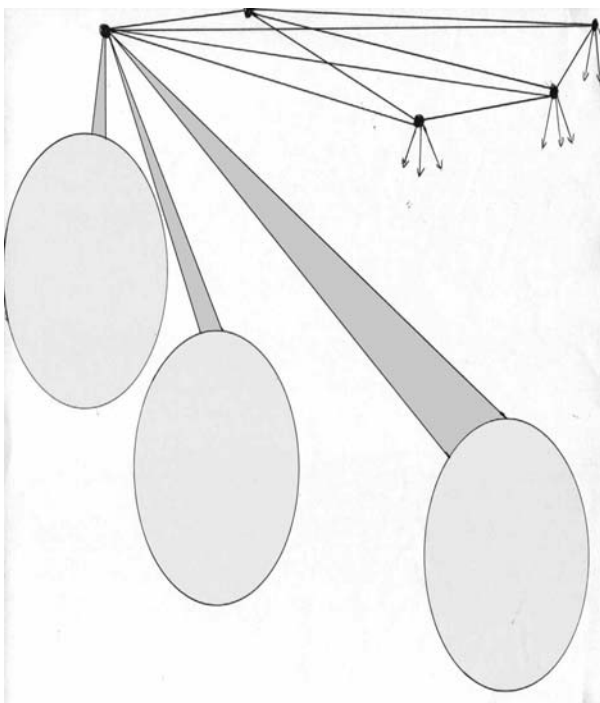

Figure 5. DECAC structure showing clusters

A starting point for such a structure may take into account the problem as defined by Liu et al when referring to *building the right systems* and the need for better tools and environments in their paper on component-based medical and assistive devices and systems [28]. They put forward a ten-year roadmap, which fits well as a start to implementing the DECAC paradigm. Clusters need to be client centered, taking into account breakthrough research such as that of Bach-Y-Rita into sensory substitution [29] and Merzenich into brain plasticity [30].

A global advantage and DECAC's greater mass would benefit the ecology on many levels. There would be lower manufacturing costs than is now associated with small-run dedicated systems production. This advantage would result from greater demand for

DECAC modular units across clusters and existing boundaries. Relatively large production runs catering for a global DECAC module demand would drive production costs down.

10. CONCLUSION

As most devices are produced by small, unlisted companies, there is little in the way of publicly available, reliable sales figures, and as such the addressable market is not well defined. However, interviews conducted with industry experts, in addition to the small size of the companies themselves, suggest that these competing devices have so far failed to achieve any significant market presence, and in many cases, have inherent user interface design issues.

User cognition requirements can easily be overshadowed by a drive to implement the latest technology. In this respect, the aim should be to retain as far as possible, those learned schemas that the user is comfortable with, but at the same time extend the possibilities of range and resolution by cautiously using the latest technology; but doing that in an appropriate manner.

Taking the users background experience into account should be one of the major considerations of a good design; a characteristic that is sometimes neglected in current cottage industry products.

The author's prototype programme and parallel DECAC framework development will, hopefully, be a step in the right direction. Further prototype solutions will follow. It is hoped that the description of this novel design and DECAC development work may be covered in detail in papers in the near future.

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