MEMORANDUM
RM-5672-RC
AUGUST 1988

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THE VISUALLY HANDICAPPED

S. M. Genensky, P. Baran, H. L. Moshin and H. Steingold
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This Rand study is presented as a competent treatment of the subject, worthy of publication. The Rand Corporation vouches for the quality of the research, without necessarily endorsing the opinions and conclusions of the authors.

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PREFACE AND SUMMARY

This Memorandum describes an inexpensive (< $1000.) experimental closed circuit TV system that can help the visually handicapped to read, write, and perform other precise manual operations requiring visual feedback. It is of potential value to any partially-sighted person who has difficulty reading and writing even with the aid of eyeglasses, but who could carry on these operations if he had the use of a visual aid that increased magnification, brightness or contrast, or some combination of these factors.

The prototype system uses inexpensive off-the-shelf units, and it permits the user to sit naturally and comfortably while reading or writing. A modification of the system could be of value to visually handicapped people in schools, at work, and at home.
ACKNOWLEDGMENTS

The authors wish to thank Mr. D. P. Cooper of the Bell and Howell Corporation, who designed a biaxial gimbal for the closed circuit TV system discussed here. A uniaxial modification of Mr. Cooper's gimbal is currently in use as the camera yoke in the present system.

The authors also wish to thank their colleagues, Messrs. R. W. Clewett, F. L. Champagne, J. T. Cothes, and G. W. Dietrich for their help in building parts for and maintaining the system.
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A CLOSED CIRCUIT TV SYSTEM FOR THE VISUALLY HANDICAPPED

1. INTRODUCTION

At various periods during the past two years we have experimented with the prototype of a device which could help the visually handicapped with their reading and writing. The term "visually handicapped" refers to persons with poor vision who are unable to read or write or who have difficulty reading and writing even with the aid of eyeglasses, but who could be helped by a visual aid which increases image magnification, light intensity or brightness, or some combination of these factors.

We originally considered purely optical devices to accomplish this goal, but all the optical instruments that we considered were either too expensive, cumbersome, complicated or delicate. The major problem with using passive optical systems is that they are all "light losers," that is, they are subject to light losses due to reflection from optical surfaces and due to absorption, diffusion and scattering within optical media.

The germ of the idea for the system we have been experimenting on came from Mr. David S. Grey, a mathematician and consultant in optical design, who suggested that we use a closed circuit TV system. He pointed out that a closed circuit TV system can be a light amplifier, and also that cheap, compact TV components are readily available.

A recent reference to the use of closed circuit TV for assisting visually handicapped people with their reading has come to our attention. It describes the use of a hand-held TV camera to accomplish the task.* Our early experience

with a camera mounted in a biaxial gimbal and guided manually by a long rod indicated that such a guidance system would not be satisfactory because it is uncomfortable to manipulate the rod over long periods of time. We believe that a system using a hand-held TV camera would prove to be even more uncomfortable to operate than the rod-controlled device just described.* We have restricted our TV camera to rotation about a fixed but arbitrary horizontal axis and are using an electrically operated servomechanism to move the camera.

*In correspondence with Dr. Genensky, dated March 26, 1968, Dr. Weed pointed out that he and his colleagues have modified their reading device since the publication of the paper cited on p. 1. Now "the camera is held stationary above the desk and the printed page is moved beneath the lens by means of a mechanical stage."
2. THE PROTOTYPE SYSTEM*

The prototype system consists primarily of (a) a TV monitor resting on a shelf, which may be moved toward or away from the user and which may be raised or lowered slightly to suit his convenience, (b) a TV camera that may be rotated about a fixed but arbitrary horizontal axis by means of an electrically operated servomechanism and (c) a working surface used to support reading and writing materials. (See Fig. 1.) A small portion of those materials may be seen on the TV screen at any particular time. (See Fig. 2.) The user rotates a knob connected to a synchro transmitter, which in turn causes a synchro receiver to move the TV camera across a line of the reading or writing material. Line advancement is achieved by sliding the material toward the back of the working surface.

Although some mention of the system's cost is necessary, the figures given here are not complete. They do not include for example, the cost equivalent of the time spent at and away from RAND by the authors and their colleagues, David S. Grey and Dexter P. Cooper, in discussions concerning the design, operation and evaluation of the system. We have spent less than $750 on hardware, including $100 for replacement of a vidicon that showed signs of wear. Less than $3000 was spent on technician labor, and most of this cost is nonrecurring. It is doubtful that an exact duplication of the prototype system will be built. However, before a cost estimate of a commercial system can be made, that system will have to be designed. Such a system will no doubt include some and perhaps all of the improvements discussed in Section 4.

*The terms "the prototype system" and "the system" are used interchangeably to refer to the closed circuit TV system discussed throughout the remainder of this Memorandum and described in more detail in Appendixes A and B.
Fig. 1—General view of prototype system in operation
\begin{align*}
\alpha!\beta! &= \int_0^\infty \int_0^1 u^\alpha (1 - u)^\beta v^{\alpha+\beta+1} \\
&= \left( \int_0^\infty u^{\alpha+\beta+1} e^{-x} \, du \right) \left[ \int_0^1 v^{-\beta+1} \, dv \right] \\
&= (\alpha + \beta + 1)! \int_0^1 u^\alpha (1 - u)^\beta \\
\text{Note: } A(\alpha, \beta) \text{ has the stated }
\end{align*}

Fig. 2—Typical view of reading matter on TV monitor
3. EXPERIENCE WITH THE PROTOTYPE SYSTEM

The prototype system is installed in the office of one of the authors (Dr. Samuel M. Genensky) and is used daily to assist him with his reading and writing.* He has been able to adjust to the system quite readily. For example, he was able to master in a matter of minutes the rather complex maneuver of writing on ruled paper clearly and along a straight line, while at the same time observing on the TV screen only a portion of the writing paper, a part of his right hand, and the writing end of his pencil or pen. His integration with the system has been so complete that when he is writing with a pencil, makes a mistake and erases the mistake, he occasionally finds himself blowing on the TV screen in an attempt to remove the erasures from the writing paper.

The system allows him to read type magnified about 3 times while seated in a natural position with his right eye about 2 inches from the monitor screen, and it eliminates the necessity of his either holding printed material close to his face, or bending over it so as to bring his right eye within a couple of inches of the printed page—actions which, though effective, frequently are very uncomfortable. Using no magnification the system also permits him to write while

*Dr. Genensky has corneal scars on both eyes, the result of an infection of unknown origin which occurred in 1927 shortly after his birth. Partial iridectomies were performed on both of his eyes in November 1927. He lost all vision in his left eye, probably from glaucoma either prior to or shortly after the operation. He has vision in his right eye, sees through a "cat's eye"-shaped opening in the iris of that eye, and measured at 20 feet, his visual acuity is approximately 8/500. However, he is able to resolve the 15 line on a Reduced Snellen Chart unaided if the printed material is brought to within about an inch and a half of his right eye. The opening through which he sees does not respond to dilatation medication so no direct observation of the posterior chamber of the eye is possible short of surgical procedures. He has no measurable color insensitivity, has good light-gathering power and a large, though less than normal, right-eye visual field.
sitting comfortably erect with his right eye about an inch from the monitor screen and with pen or pencil and writing tablet at desk level. Before the prototype system was developed, he wrote by bringing his eyes to within a couple of inches of the writing paper which rested on either an inclined board, a stack of books or a desk top—maneuvers which again, though effective, were often very tiring.

The system has also been tested by four other visually handicapped persons:

(a) a woman of about thirty-five who lost all of the vision in her right eye and the macular vision in her left eye as a result of uveitis. This woman was able to manipulate the system with ease, and with it she was able to read printed material that she could not otherwise resolve except with the aid of a strong magnifying glass. The material was magnified about 3 times, and her left eye was about 4 inches from the monitor screen.

(b) a man of about seventy who has macular degeneration in both eyes. His uncorrected visual acuity is 8/300 in the right eye and 20/200 in the left eye. Vision in his left eye can be corrected to 20/100 using a Feinbloom 2.2 magnifier with a reading attachment. This gentleman, who enjoys playing the cello, can no longer read music while playing his instrument. Using the system, he was able to read a portion of a musical score that had been magnified approximately 2.8 times from a viewing distance of approximately three feet from the screen of the TV monitor.

(c) a man in his late fifties who has partial optic atrophy in both eyes, and who can count fingers at one foot. Using the system, this gentleman was able to read newspaper type magnified 12 times from a viewing distance of about an inch from the screen of the TV monitor. He reports that he is unable to read such type with any other visual aid he has tried.
(d) a man in his early seventies who has macular degeneration in both eyes, and whose uncorrected visual acuity is 20/200 in the right eye and 20/100 in the left eye. Using the system, this man was able to read printed Hebrew magnified 8 times from a viewing distance of about 18 inches from the screen of the TV monitor. Unlike the people described in (a), (b) and (c), he showed little enthusiasm for the system. In part this may have been due to a language barrier, which made communication slow and difficult.
4. DESIGN RECOMMENDATIONS AND THE PROBLEM OF X-RADIATION

The prototype system was built as an experimental device and even though it has undergone many modifications and will undoubtedly undergo further changes, what is important is that it works, and it is fully operational (when it is not undergoing some type of alteration). The following modifications are being made or are being considered. We believe that they would improve the system's flexibility, ease of operation and overall quality.

Relocate the dimmer switch, which controls the lighting system, and the switch that controls the vertical motion of the TV camera to a more convenient position for the user. (Currently, the user must reach over to the far right-hand corner of the working surface to operate these controls.)

Install a TV-monitor support that permits the user not only to move the monitor horizontally toward or away from his face, but also allows him greater flexibility in moving it vertically. (The prototype system permits only minor adjustments in the height of the monitor above the working surface, and this precludes the possibility of persons of widely varying heights seated in chairs of varying heights from operating the system comfortably.)

Replace the current lighting system by one which produces less heat in the vicinity of the working surface. Since only a small portion of the working surface is seen by the TV camera at any particular time, it may be possible to sufficiently illuminate the area viewed, for example, by fitting a reflector and a ring shaped lighting unit on the TV camera or its lens adapter.

Attach a left margin guide to the working surface. At the magnification at which the prototype system is used (which, measured on the face of the monitor is approximately 1x to 17.6x) if writing or reading materials are not placed directly perpendicular to the camera, blurring may occur at
the extremities of the viewed line due to limited depth of field. For letter or legal size writing material and most books, a stationary, properly placed margin guide would make this problem easily avoidable. If a margin guide were installed that could be rotated and translated, it could be of value in conjunction with a wider variety of writing and reading materials.

Install a damping device to eliminate or drastically reduce the camera vibration induced by the operation of the servomechanism. This vibration can cause image degradation and can also damage the camera and its delicate vidicon.

Modify the automatic light control circuits of the TV camera and the contrast control circuits of the TV monitor to increase the useful contrast. At present the light intensity at the face of the monitor is greater than desired at the sought-after contrast levels. This gives rise to glare, which in turn causes some unnecessary fatigue. Other glare-reducing techniques could be used, including placing a filter over the face of the TV monitor.

Replace the hand-operated controls that govern the motion and focusing of the TV camera by foot-operated controls. This would greatly increase the usefulness of the current system by allowing the user to have both hands free for such things as writing or turning the pages of a book.

Develop and install a zoom lens that (a) is compatible with the TV camera used in this or a similar system, (b) can focus to, say, within a few inches of the working surface, (c) has a useful magnification range, and (d) can be adjusted remotely. The device we are currently using to vary image magnification, although working, is rather make-shift and awkward, and we believe it should be replaced by more sophisticated equipment—though this could prove to be an expensive innovation.
X-Radiation

Whenever one is in proximity to high voltage one may be exposed to harmful X-rays. The criterion used to determine whether a TV receiver is safe with respect to X-ray emission is that at normal distances from the TV screen and over long periods of time (~ 1000 hr/yr), the whole-body X-radiation dose is increased by no more than 5 per cent over the natural background dosage one receives from cosmic rays.* The X-ray emission from the TV monitor used in the prototype system is expected to be much less than the maximum allowed by this criterion, because the monitor uses an accelerating voltage of 8KV. This voltage is low compared to that used in larger TV receivers. On the other hand since users of the prototype system tend to bring their eyes within a few inches of the monitor screen, they may be receiving an X-ray dosage which is of the order of one hundred times greater than that which an observer would receive if he viewed the screen at a normal viewing distance.** Even so, the X-ray emission of the monitor is very probably still so low that this is not a problem. Nevertheless, we intend to investigate this question further.

Should the X-radiation in close proximity to the monitor screen turn out to be higher than is acceptable, it could be reduced to a safe level by simply placing a small thickness of glass over the present monitor screen.


**"Electro-optical Characteristics of Television Systems," RCA Reviews, March 1948, pp. 5-37. O. H. Schade defines normal viewing distance as any TV screen-to-viewer distance which is greater than 4 and less than 7 times the vertical height of the screen being viewed.
5. POTENTIAL USERS

Precise data on the number of people in the United States who fall within our definition of "visually handicapped" are unavailable; however, the number probably is greater than two hundred thousand and less than two million.* We believe that some improved versions of the prototype system would be of great value to many of these people.

Such a system could be used, for example, to help students read and write at their desks, in a library, in their homes, etc. Variations of the system could also help students (a) to see, very likely for the first time, material which their teacher or one of their classmates writes upon a blackboard, or (b) to watch a demonstration or experiment which would otherwise be only partially visible to at most two or three of them at a time.

Other variations of the system could be used to assist visually handicapped men and women with their work in the office, in the factory and in the home. They could, for example, permit such people (a) to type, and at the same time, to see what they are typing, (b) to write and read while seated in a natural position at a desk, table or bench, and (c) to assemble or manipulate parts they might not otherwise be able to handle because either they could not see them, or even if they could, the parts would have to be brought dangerously close to the eyes for proper examination.

The prototype system or a modification of it, would be of great value to many elderly people who, for one reason or another, are no longer able to read newspapers, magazines, or books with the aid of a magnifying glass. Books with oversized type are currently available for use by such people (as well as other visually handicapped persons), but unfortunately these books are expensive, limited in number and, out of necessity, use a large but standard type size. A closed circuit TV system with a wide range of magnification could transform instantaneously the writing or printing on any piece of paper into a wide range of oversized writing or lettering.
Appendix A

DETAILS OF CONSTRUCTION

For ease of description throughout this and the following appendix, each part of the prototype system is consistently designated by a numeral in parentheses. (See Figs. 3-5.)

The system consists of a Concord, Model MTC-12, television camera (1), equipped with an extension tube that serves as a variable-length lens adapter (2), which accommodates a Schneider-Kreuznach Symmar f5.6 100 mm lens (3). The camera is mounted in a yoke (4) that may be rotated by means of a gear train (5) and synchro receiver (6). The yoke (4), gear train (5), and synchro receiver (6) are supported by an aluminum housing (7), which rides on two vertical aluminum members (8) of rectangular cross-section rigidly bolted through a wooden backing (9) to the wall. The camera (1) is raised or lowered by a motor (10) rigidly attached to a horizontal platform (11), which in turn is fastened to the upper ends of the vertical aluminum members (8). The user raises or lowers the camera (1) by a switch (12) that activates the motor (10). The camera (1) is rotated in a selected vertical plane by turning a knob (13) attached to a synchro transmitter (14), which is electrically connected to the synchro receiver (6). The knob (13) and synchro transmitter (14) may be placed at any convenient position on the horizontal wooden working surface (15). The vertical plane of rotation of the camera (1) may be changed by loosening the knob (16), turning the camera (1) through the desired angle and then retightening the knob (16). A Sony, TV5-305UW, television monitor (17) is mounted on an extendable wooden shelf (18), which is attached to the wall through the wooden backing (9) by means of a hinge (19) and two turnbuckle adjustable rods (20). The extendable wooden shelf (18) permits the user to position the TV
Fig. 3—General view of the prototype system
Fig. 4—Detail of camera assembly
Fig. 5—Side view of the prototype system
KEY TO FIGURES 3-5

(1) TV camera
(2) Variable-length lens adapter
(3) Lens
(4) Yoke
(5) Gear train
(6) Synchro receiver
(7) Aluminum housing
(8) Aluminum members
(9) Wooden backing
(10) Motor (raises and lowers camera)
(11) Horizontal platform
(12) Switch (controls camera height)
(13) Knob (activates synchro transmitter)
(14) Synchro transmitter
(15) Wooden working surface
(16) Knob (used in changing plane of camera rotation)
(17) TV monitor
(18) Wooden extendable shelf
(19) Hinge
(20) Turnbuckle adjustable rods
(21) Spotlights
(22) 20-inch rods
(23) Flanges
(24) Dimmer control circuit and switch
(25) Common or main power switch
monitor (17) as close to his eyes as he finds comfortable. A small adjustment in the height of the TV monitor (17) can be effected by rotating the turnbuckles on each rod (20). Illumination of the working surface (15) is provided by four 130-watt spotlights (21) that are clamped to, but may be rotated about or moved along, two 20-inch rods (22), which are attached to flanges (23) that in turn are attached to the wall through the wooden backing (9). The intensity of the illumination provided by the spotlights (21) is controlled by a dimmer control circuit and switch (24). As it is currently wired, all electrical power for the system, with the exception of the spotlights (21), is controlled by a common switch (25).
Appendix B

OPERATION

The system is quite simple to operate. The user turns on the main power switch (25) and the dimmer switch (24), and then adjusts the intensity of the illumination on the working surface (15) by rotating the dimmer switch (24). He then adjusts the height of the shelf (18) supporting the TV monitor (17) by rotating the turnbuckles on the rods (20). If the system is used by only one user, this is generally a one-time adjustment.

The user slides the shelf (18) toward or away from himself in order to achieve a satisfactory eye to receiver distance. Writing or reading material is placed on the working surface (15) directly below the camera (1). Image clarity and the desired magnification are achieved by rotating the lower portion of the lens adapter (2) and by adjusting the height of the camera (1) using the switch (12). Image brightness and contrast are controlled by adjusting the appropriately marked knobs on the TV monitor (17). Using the knob (13) the user guides the camera (1) across the line he is reading or along the line upon which he is writing. Line advancement is accomplished by sliding the reading or writing material along and toward the rear of the working surface (15). Most people prefer to write with the writing paper inclined to the near edge of the desk or table. As this angle of inclination may vary from user to user, it may be necessary to adjust the plane in which the camera (1) rotates under the action of the synchro receiver (6). This is accomplished by loosening the knob (16), rotating the camera (1) through the desired angle and then retightening the knob (16).

If the illumination distribution on the working surface (15) needs to be altered, this can be accomplished by doing one or more of the following: rotating each of the
spotlights (21) about the rods (22), shifting the position of the spotlights (21) along the rods (22), or altering the number of spotlights (21) per rod (22).