MAN-COMPUTER GRAPHICS: CURRENT AND NEW HARDWARE IMPLEMENTATIONS

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VOLUME I
INTRODUCTION AND APPENDICES

A THESIS SUBMITTED TO THE UNIVERSITY OF ADELAIDE
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PREFACE

Several years ago, Ivan Sutherland, originator of the "Sketchpad" program, a milestone in Graphical Communication and Man-computer Interaction, listed "ten unsolved problems" confronting workers in the field of Computer-Graphics, of which

"...the first and biggest unsolved problem...is to build a low-cost display device suitable for on-line graphical use" (1).

Among the requirements of such an on-line graphics unit, he stated, are:

- geometrical fidelity and display precision
- short or "instant" response to any user modification
- direct user-input capability via a "pen" or "stylus"

including "pointing ability", by which certain features of the graphic display may be indicated to the computer for further consideration, by using the "stylus" or "pen".

The project, of which this thesis is the result, originally had as its topic a novel approach to Computer-aided-circuit-design, specifically the possibility of
using graphical methods for solving circuits with linear and non-linear elements. Immediately the problem mentioned by Sutherland arose. Without a "display device" with the aforementioned features, the project would at most have been a paper and pencil exercise. The real dilemma was economics. Existing commercial units with some of the above features had a starting price of around $20,000 - $30,000. It is not surprising then that the topic of the project was changed, namely to develop a low-cost Interactive Graphic Unit with (hopefully) all of the above features. To use existing approaches and techniques would have been merely to duplicate existing efforts and to duplicate (if not increase) existing costs. A wholly new and radical approach had to be taken.

The philosophy of the approach was to use existing components and devices and interconnect them (electrically and optically), into a new system, rather than to attempt to develop a new system from fundamentals (again economics would preclude the latter approach).

The proposed Interactive Graphics console is called "VIDIOGRAPHIC" (Video Integrated Display and Input Optical Graphic Interactive Console), the keywords being "Video" and "Optical", as TV techniques along with optical techniques are used to implement Input, Display, and Display Refresh Storage.

The major portion of this study was, quite naturally, performing feasibility studies of the proposed system; and since new concepts using existing devices were used, fundamental work in widely varying areas was done. System requirements had to be verified for satisfactory perform-
ance. Consequently a completely finished usable Graphics System was out of the question for a project such as a Ph.D. Thesis.

What resulted was very encouraging and rewarding. That a low cost Graphics System, based on a wholly new principle is feasible, is clearly evident. What is more evident is that more work needs to be done to implement this feasibility study into a useful system, or even a commercial system. This work must be left to others.

The apparent great length of the thesis is unavoidable. Since the concepts on which VIDOGRAPHIC is based are on principles which by themselves may not be wholly new, but which when integrated to form the system, are new, a full description of these principles and their interrelation with each other, was necessary; often, since some principles or existing systems were used for which they were not originally designed for, some trivial and some not so obvious explanations and calculations had to be done to demonstrate the feasibility of that feature in "VIDOGRAPHIC". Thus rather than concentrate in some detail on some aspect of a hypothetical Interactive Graphics Console, the Graphics Console itself had to be examined in detail to show its feasibility. Consequently paper calculations, at the expense of experimental realization, form the main body of the thesis.

The experimental work supporting it are those parts of the feasibility study which could not be proved or "demonstrated" on paper, namely the very important requirement of being able to precisely measure the distortion of the Display and Graphics Input Subsystems of "VIDOGRAPHIC". Other experimental work describes certain
very linear hybrid circuits required for the implementation of "VIDIOGRAPHIC".

The results presented here, both on paper and with hardware, indicate that a truly economic (< $2000) Interactive Graphics Console is feasible.

The other major portion of this thesis is a short review of the development and capabilities of Man-Computer-Graphics (MCG), by which is meant the solution of diverse problems jointly by a user and a computer, with the mutual communication and interaction during the problem-solving phase being in some graphical form. An overview of the technology of implementing MCG is also given, by describing the requirements and implementation of the Interactive Graphics Console (IGC), which is the link between the user and the central processor where the problem is being solved.

The aim of these two chapters is to indicate where the thesis work fits into the state-of-the-art of MCG and why the realization of an economic IGC is necessary. The requirements and current technology of the IGC is given to indicate requirements for the IGC proposed here, and to avoid duplicating any previous work.

**PLAN OF THESIS**

The Thesis is divided into four parts:

(i) Part 1 (Chapters 1-2) introduces the field of Man-Computer Graphics (MCG) and indicates the main problem areas in this field.

(ii) Part 2 (Chapters 3-10), forming the main body of the Thesis, describes in detail the theory and
feasibility of the proposed Interactive Graphics Console "VIDIOGRAPHIC".

(iii) Part 3 (Chapter 11) describes some of the experimental work and circuits required to implement "VIDIOGRAPHIC".

(iv) A set of Appendices, in which expressions and concepts used in the above chapters are derived and explained, conclude the Thesis.

Specifically the contents of the chapters are as follows:

Chapter 1 introduces the topic of Man-Computer Graphics, indicates the area of applications and the main problem areas. Appendix 1 tabularly indicates the wide range of applications of Man-Computer Graphics.

Chapter 2 describes the unit by which a user interacts with the computer during Man-Computer Graphics operation; this is the "Interactive Graphics Console" (IGC). Its requirements and performance parameters are listed and compared with existing implementations (Appendices 3-5). Main Computer - IGC interaction, as well as the software required for IGC, are briefly touched upon.

Chapter 3 introduces the proposed IGC, "VIDIOGRAPHIC", based on the novel idea of display refresh storage and user-input of graphics being implemented by optical means. The operation of "VIDIOGRAPHIC", its development, the subsystems required and the requirements for its feasibility are given. Briefly the system consists of a Display Subsystem (a CRT), an Graphics Input Subsystem
(a Vidicon and Light-Emitting Pen), a Storage Refresh Subsystem (the interconnected CRT-Vidicon), and a Schmidt Optical System (from existing domestic TV-Projection receivers) to implement graphics input and display refresh storage.

Chapter 4 examines the first of the major requirements for VIDOGRAPHIC, which is that adequate luminous flux be generated within the system (at the CRT screen) to be visible by the user on a viewing screen, and to be incident on the Vidicon faceplate to generate adequate output signal for maintenance of display refresh.

Chapter 5 examines the readout process from the Vidicon, as it is usually considered that Vidicons give uneven and poor quality output signals.

Chapter 6 examines the required optical system (the Schmidt Optical System from TV-Projection receivers), which enables simultaneous CRT screen viewing, and the imaging of this onto the Vidicon faceplate, and also enables user-input of graphics with a light-emitting pen. The source for the pen is obtained from the CRT screen itself.

Chapter 7 examines the second main requirement for "VIDOGRAPHIC", which is the ensuring of a steady display (otherwise the display would move out of the user's view within seconds, leaving a blank viewing area). This requires display points being relocated or "position corrected" each refresh cycle. The correction information to perform this location"position-correction"is obtained from Moire Patterns measurements, and then is encoded graphically in certain areas of the CRT scanned area. This graphic information is thus available each display-scan interval.
Chapter 8 describes the graphic correction decoding circuits and the correction-implementation circuits required to result in a linear (better than 0.25%) CRT and Vidicon.

Chapter 9 examines the primary causes of CRT and Vidicon display distortion, namely pincushion and barrel distortion, derives expressions for these and the means of correcting them. The circuits in Chapter 8 corrected "remanent distortion", i.e. distortion after pincushion or barrel distortion have been minimized or eliminated.

Chapter 10 concludes the feasibility study of VIDOGRAPHIC with a general overview of the system, advantages and disadvantages and the expected cost of the system. A comparison is made between the expected performance parameters of VIDOGRAPHIC with those required of an ideal IGC as enumerated in Chapter 2.

Chapter 11 gives the results of experimental work done towards realizing "VIDOGRAPHIC" and the various circuits of high linearity required to implement the scanning and the distortion correction circuits.

Much of the above work is original.

The concept of "VIDOGRAPHIC" is new, as is obviously the means of implementing it, specifically the methods of display distortion measurements (Moire patterns), the encoding of this distortion graphically as distortion correction information, and the associated means of implementing the correction.

The derivation of expressions for pincushion and barrel distortion, and defocussing in both the CRT
and the Vidicon have not been seen anywhere (other than in the most approximate forms), although possibly they have been derived elsewhere, as, for example, "anti-pin-cushioning" circuits are currently available commercially.

The light emitting pen and its CRT illuminating source is new in concept.

Expressions for the photocurrent buildup and decay time constants in the Vidicon have been derived and are original.

Phosphor buildup effects requiring derivation cannot be found in the literature and are thus considered original.

The Vidicon beam discharge effects of Chapter 5, have been extended in parts, on existing work; that whole chapter (Chapter 5) forms a comprehensive resume of all possible Vidicon signal output defects.

Finally, Chapter 2, though not original in content, at least performs the function of a fairly comprehensive review of existing hardware implementation of requirements and techniques associated with Man-Computer Graphics, as a comprehensive review such as this is lacking in the literature.

A note about notation. Since the thesis ranges over a wide range of topics, consequently many quantities, units etc. are mentioned in short separate sections; the definitions and notation for these is kept within the relevant section, as it is felt that a lengthy table of notation at the beginning of the thesis is not warranted under these conditions.
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## REFERENCES

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SUMMARY

"Man-Computer Graphics" may be defined as the solution of problems by a computer where, during some stage of data input, processing or output of results, data is manipulated or presented in graphic form; in addition, the user interacts with the computer on-line during one or more stages of data input, processing, or data output. The Man-Computer Interface enabling this is an "Interactive Graphics Console" or IGC.

One of the major current problems in Man-Computer Graphics is the absence of an economical and highly interactive IGC. By "economical" is meant low capital outlay for the IGC and low CPU tie-up time during use; and by "highly interactive" is meant the ability by the user to input graphic data easily, as say with a "pen" or "stylus", with very short response time, and the ability to interact with displayed graphics information.

A wholly new means of implementing such an IGC is described and its feasibility explored.

The name of the proposed system, "VIDIOGRAPHIC", (for Video Integrated Display and Input Optical GRAPHic Interactive Console) indicates the means used to implement this. TV techniques and commercially available equipment are used; optical methods are used to achieve user-graphics input, user-display interaction, and display refresh storage.

Basically the system consists of a TV Vidicon
camera looking back at its own output displayed on a CRT. Under certain conditions of CRT and Vidicons linearity and CRT luminance, a CRT display is self-maintaining. Graphics input and user-display interaction is achieved with a simple light-emitting "pen."

Calculations and feasibility studies indicate the practical feasibility of "VIDIOGRAPHIC." Means of implementing the proposed system and new circuit designs to achieve this are given.

A general overview of the Man-Computer Graphics field along with comprehensive hardware review of existing techniques are also given; in the poorly documented Man-Computer Graphics field these in themselves form a useful function. In this case they are also useful in comparing how "VIDIOGRAPHIC" meets the requirements of an economical and highly interactive IGC.