Charge-Coupled Analog Computer Elements
and Their Application to Smart Image Sensors

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ABSTRACT

CHARGE-COUPLED ANALOG COMPUTER ELEMENTS
AND THEIR APPLICATION TO SMART IMAGE SENSORS

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Real-time machine vision in mobile robots requires pre-processing of images at speeds well in excess of one billion operations per second, depending on the resolution of the image plane. To obtain such high speed in a compact, light-weight, and low-power computing system, alternatives to the standard serial digital processor are currently being explored. The spatially parallel architecture, in which the inter-processor communication structure reflects the topology of the focal plane mosaic of elemental sensors, is organized in a way natural for image pre-processing. The most logical place for the processor array is the imaging focal plane. Such positioning avoids the serial encoding and transmission of the inherently parallel input data, but the available real-estate places a premium on processor simplicity and innovation.

In this dissertation, an analog processor based on the manipulation of discrete charge packets in a semiconductor is advocated. Such a processor shows promise for high density focal plane computing (more than 4000 processors/cm²). The work focuses on the basic building blocks of the charge-coupled computer, a charge packet differencer/replicator and a charge packet magnitude comparator. The former is implemented in a novel circuit in an inherently linear and compact way through the use of three-dimensional charge coupling. The prototype
circuit was fabricated and measured at Yale, and was shown to operate properly in a manner consistent with its analysis.

Also investigated in the course of this research was the bistable metal/tunnel-oxide/semiconductor (MTOS) junction. The application of this device as a charge packet magnitude comparator was explored by utilizing its hot electron impact ionization internal positive feedback mechanism. It was found that the physical computation time of this device is somewhat longer than was desired in the charge-coupled computer, though it actually performs well as a charge-packet threshold detector.

The control circuitry integrated with the MTOS junction provided a unique opportunity to investigate the internal charging and discharging currents of the thin oxide capacitor. Using a novel charge packet injection technique, the dynamic response of the junction was studied and a measure of the oxide hole transport current and hot tunneling electron induced impact ionization current was made as a function of oxide voltage. The MTOS junction can also be controlled in a steady state manner by utilizing a diode-controlled MOS inversion layer to pin the MTOS junction surface potential. A new voltage-controlled N-type negative resistance was discovered in the course of making basic device measurements. The mechanism of this negative resistance in the charge-coupled MTOS-PN junctions is explained.

The dissertation spans a spectrum from machine vision, through solid-state circuit design to semiconductor device physics. Parochial progress, such as the fabrication of sub-micron interelectrode gaps, suppression of dark current, and the fabrication of a 33 Å gate oxide enhancement mode MOSFET is also reported.
Machines and intelligence are mutually exclusive concepts, at least philosophically. Yet, no one can deny that a machine can be made to appear to be intelligent. Witness the rise of elaborate computer programs which appear to convert a bank of switches into a thinking machine. Indeed, as human technology grows, the definition of human intelligence becomes more elusive. Perhaps there is no such thing as human intelligence in the sense that it is presently and emotionally defined.

It is in this context that 'smart' sensors are pursued. Such sensors can be viewed in terms of an incremental step toward machine intelligence, or as a solution to a practical problem. (Maybe human 'smartness' is also a solution to some Darwinian practical problem.) The norm for approaching the smart sensor problem, which can be considered as reducing the entropy of sensed information, is to adapt a bank of switches for the specific information processing task. Unfortunately, few researchers consider the issue of whether the digital approach is truly optimal for the job. Machine vision is a good example of this.

At the risk of alienating the entire computer science community in one stroke, the following observation is put forth. The problem of entropy reduction of information can be mathematically expressed. It is rarely formulated in Boolean algebra. Yet, the engineering problem of implementing the formulation seems to be routinely solved in a digital
state space. The reasons are historically clear (reduction of total computational error) but philosophically puzzling. Computer scientists take this Boolean algebra based machine, and operate it with a human-esque communication language. It would seem more reasonable to first formulate the problem in a more natural mathematics (e.g. predicate calculus) and second, perform the engineering implementation in a way which more closely resembles the abstract information manipulation.

The thesis presented here pales in comparison to the aspirations of the above paragraph. Perhaps some small step to smart robot vision sensing has been achieved, but the thesis is really a discussion of solid-state circuitry design, fabrication, and measurement. To a lesser extent, it is also a study of solid-state physical phenomena. It has been an interesting investigation and has served well as an educational experience.

The investigation succeeded in converting ideas to practice (the essence of engineering) because of the support of many people. Some support was realized indirectly, such as that provided by Becky Friedkin, my patient wife. Some support was realized directly, such as the proficient and expedient typing of Arlene Vasso, and the graphic arts expertise of Sal Datillo. I would like to thank all those who have enabled me to sit here and write a preface to a Ph.D. dissertation. In particular, I would like to acknowledge:

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Without the assistance of the individuals and institutions listed above, it is a certainty that this dissertation would not exist. To those above and those which I have erroneously omitted, I would also like to extend my sincere gratitude.

Finally, I would like to dedicate this dissertation to the person who pulls a dusty copy off a library shelf, or who views a yellowed microfiche, and wonders why someone might spend five years of their life to work on a trivial problem such as robot vision. After all, even children understand the basics of robotics...
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<td>5.4-2</td>
<td>Linearity distortion.</td>
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