A VESTIBULO-OCULAR REFLEX DATA ACQUISITION SYSTEM

by

NEIL JOSEPH KELLY

A thesis submitted to the

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ABSTRACT

The Vestibulo-Ocular Reflex (VOR) generates eye movements in response to head motion to keep an image fixed on the retina as the head moves. Researchers at the University of Manitoba required a system that could produce head movement and monitor the resulting eye position to continue investigation of VOR behavior.

This dissertation describes the design and construction of this system, the VOR Data Acquisition System (VORDAS).

The VORDAS consists of a computer controlled, motor driven, rotating chair and Electro-Oculogram (EOG) data collection system. The EOG is a recording of eye position made by sensing the corneal-retinal potential of the eye.

The VORDAS is capable of generating arbitrary chair velocities and recording one channel of EOG data. The chair has a top speed of 300 degrees/sec, and top acceleration of 300 degrees/sec/sec, for frequencies of dc to 0.5 Hz.

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I would like to acknowledge and thank EG&G Torque Systems for permission to reprint sections of their S-1201 Serial Input Module manual in this dissertation.

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To my wife and children,

who have endured and sacrificed much for this work.

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GLOSSARY

General abbreviations used in this glossary are:

abbr	abbreviate(d); abbreviation
SI	International System of Units
wrt	with respect to

Acronyms and abbreviations used in this dissertation are:

aliasing the effect of creating non-existent frequencies caused by sampling a waveform at a rate lower than the Nyquist rate.

acceleration profile the angular acceleration wrt time of the subject over the duration of the run.

bit abbr of **b**inary dig**it**; a single binary digit, ie a "1" or a "0".

byte a binary number made up of 8 bits.

CW abbr of clockwise.

CCW abbr of counterclockwise.

D/A acronym of **D**igital to **A**nalog.

DAC acronym of **D**igital to **A**nalog **C**onverter.

EDAC acronym of **E**OG **D**ata **A**cquisition **C**ontroller.

EOG acronym of **E**lectro-**O**culo**g**ram; **E**lectro-**O**culo**g**raphy. Recording of eye position made by sensing the corneal-retinal potential of the eye.

EPROM acronym of **E**rasable **P**rogrammable **R**ead-**O**nly **M**emory. A computer memory device that can be programmed with electric pulses, retains its information without power, and can be erased by exposure to ultraviolet light.

FIFO acronym of **F**irst-**I**n-**F**irst-**O**ut. A FIFO is a memory device used to store data similar to a stack. When read, the FIFO outputs the first datum it received.

Hz abbr of cycles per second.

k abbr of SI kilo-. Represents 10^3.

K abbr in computer terminology to represent 2^{10}, or 1024 decimal.

latch a device that maintains an output signal after the input signal has changed or disappeared.

m abbr of SI milli-. Represents 10^{-3}.

M abbr in computer terminology to represent 2^{20}, or 1048576 decimal.

MIT acronym of **M**assachusetts **I**nstitute of **T**echnology.

PIA acronym of **P**eripheral **I**nterface **A**dapter. An 8 bit programmable interface device manufactured by Motorola Semiconductors. An 8 bit interface to a microprocessor's data bus, the PIA's input output characteristics are determined by the way it is programmed.

PLA acronym of **P**hase **L**ock **A**dvance. A term used by EG&G Torque Systems to identify the input of their S-1201 position controller that accepts digital pulses that each cause the motor being controlled to advance one position unit.

PPI acronym of **P**arallel **P**eripheral **I**nterface. An 8 bit programmable interface device manufactured by Intel. See PIA above.

PWM acronym of **P**ulse **W**idth **M**odulation.

quadrature a term meaning 90 degrees out of phase.

real time a computer term used to indicate that a computer must complete its task within a specified period of time. An example is a computer being supplied with data once every second. If the computer is busy when the data is supplied to it, the data is lost.

RAM acronym of **R**andom **A**ccess **M**emory. General use memory of a computer. It can be programmed and erased electrically, but loses the information stored in it when power is turned off.

researcher the person operating the VORDAS.

RPM acronym of **R**evolutions **P**er **M**inute.

run or **examination run** the period of time when the chair is in motion.

servo controller a device used to control the velocity of a servo motor. It is also referred to as servo amplifier or servo drive.

servo motor an electric motor designed to generate high accelerations.

subject the person being examined.

tachogenerator a linear device that generates an output voltage proportional to its angular velocity.

μ abbr of SI micro-. Represents 10^{-6}.

velocity profile the angular velocity of the subject wrt time over the duration of the run (spelled with lower case letters).

Velocity Profile the disk file storing the data to control the VORDAS during the run (spelled with capital letters).

VOR acronym of **V**estibulo-**O**cular **R**eflex. The VOR changes eye position in response to head motion to keep an image fixed on the retina.

VORDAS acronym of **VOR** **D**ata **A**cquisition **S**ystem, the subject of this thesis and dissertation.

Chapter 1

INTRODUCTION

1.1 Objective

The objective of this thesis was to design and build a system to record a human subject's eye position in the horizontal plane as the subject's head experiences angular acceleration about the vertical axis. The system was to consist of a computer controlled, motor driven, rotating examination chair and an Electro-Oculogram (EOG) data acquisition system. The EOG is a recording of eye position made by sensing the corneal-retinal potential of the eye [1].

1.2 Background

Doctors Ireland, Jell, Onyshko, and Shwedyk of the University of Manitoba are conducting ongoing research to develop a more accurate mathematical model of the human Vestibulo-Ocular Reflex (VOR) system. The goals of the research are to advance the knowledge of the function of the human VOR and, ultimately, to develop a clinical tool for non-invasive diagnosis of VOR system dysfunction.

The Vestibulo-Ocular reflex, literally meaning the Ear-Eye reflex, is generated by the VOR system which consists of the semi-circular canals of the inner ear, neural pathways in the brain, and the eye muscles. The function of the VOR is to keep an image fixed at the center of the retina as the head moves [2]. It is the VOR that makes it possible for objects to be seen unblurred when driving over a bumpy road.

The dual pathway model of the VOR reported by Arbez [3] was developed at the University of Manitoba largely using parameters from existing literature. For the most part the parameters in the existing literature were based on data from animal experiments. They were modified to reflect the results of rotational tests done using a clinical chair at the Health Sciences Center in Winnipeg, Manitoba, but the limited capabilities of that examination chair prevented further research.

More accurate determination of the model parameters requires human EOG data obtained in response to a wider range and greater variety of inputs than were possible with the clinical chair available to the the University [4]. Therefore, to continue the research it was necessary to design and build the VOR Data Acquisition System (VORDAS).

This thesis set out to achieve the VORDAS specifications listed in Table 1. The original specifications for maximum acceleration and velocity, stated in the Manitoba Health Research Council proposal [4], were 200 degrees/sec^2 and 255 degrees/sec respectively. The target values of these two parameters were increased to 300 degrees/sec^2 and 300 degrees/sec respectively to maximize the range of input stimuli the VORDAS could produce.

1.3 Outline Of Dissertation

This dissertation describes the design and construction of the VOR Data Acquisition System defined by the specifications in Table 1. A detailed description of the theory, design and equipment of the VORDAS required so much space it could not all be included in this dissertation. Therefore, this dissertation is an overview of the work done and the results achieved.

The detailed technical information of the VORDAS, including circuit diagrams, device specifications, flowcharts, and software listings, are contained in two University of Manitoba Department of Electrical Engineering reports. These reports are the VORDAS Hardware Manual, Report Number 88-1 and the VORDAS Software Manual, Report Number 88-2. These manuals are listed in the bibliography for those readers interested in further detail.

TABLE 1

Specifications of the
Vestibulo-Ocular Reflex Data Acquisition System

Rotation:

Acceleration	-Maximum acceleration of 300 deg/sec^2 and a resolution of 1 deg/sec^2. -Arbitrary acceleration profiles. -Sinusoidal profiles of 0.01 to 0.5 Hz. -Triangular profiles of 0.01 to 0.5 Hz. -Random disturbance with frequencies of 0.01 Hz to 0.50 Hz.
Velocity	-Maximum velocity of 300 deg/sec with a resolution of 1 deg/sec.

Trim:

Pitch	-Fixed velocity of 10 deg/sec from upright to supine.
Vertical	-Fixed velocity of 3 in/sec over a 20 inch range.
Head tilt	-Fixed velocity of 10 deg/sec over a 50 degree range.

Safety features:

-Hardware acceleration limit at 400 deg/sec^2.
-Hardware velocity limit at 330 deg/sec.
-Software limits on velocity and acceleration.
-Pressure mats for proximity detection.
-Operator/subject "panic" buttons.
-Hardware interlocking of chair motion.

Data acquisition:

-Able to digitize and store EOG data from the test run on floppy disk.

The body of this dissertation describes the work done during this thesis in the following order:

1) An overview of the VORDAS.
2) A discussion of the VORDAS hardware and its considerations.
3) A discussion of the VORDAS software and its considerations.
4) A discussion of the theory of the rotation control system. This discussion focuses on the key parameters and considerations that effect the operation and selection of the system. The discussion was not included in the description of the VORDAS hardware because it is somewhat involved and would constitute a confusing digression that would make it difficult for the reader to follow the interconnections of the system hardware.
5) The results of this study.
6) Recommendations.

The reader should be aware that the material in this dissertation was arranged so that its presentation would be easy to follow and understand and does not necessarily reflect actual chronological progression of the work done.

A discussion of the EOG and of dipole generation has been included in appendix D for completeness.

Chapter 2

VORDAS SYSTEM OVERVIEW

A block diagram of the VORDAS is shown in Figure 1. It consists of a motor driven examination chair, a Velocity Control computer, EOG conditioning electronics, a Data Acquisition computer, a Main computer, and Emergency-stop (E-Stop) electronics.

The Examination Chair:

1) Is rotated by a dc servo motor through a right angle worm-gear transmission.
2) Has three ac motors that provide the trim functions of elevation, pitch, and head tilt.
3) Uses slip rings to get EOG data, control signals, and power to and from the chair.

The Velocity Control Computer:

1) Controls chair motion and EOG data collection during the run.
2) Monitors system status and sends status information to the Main computer.

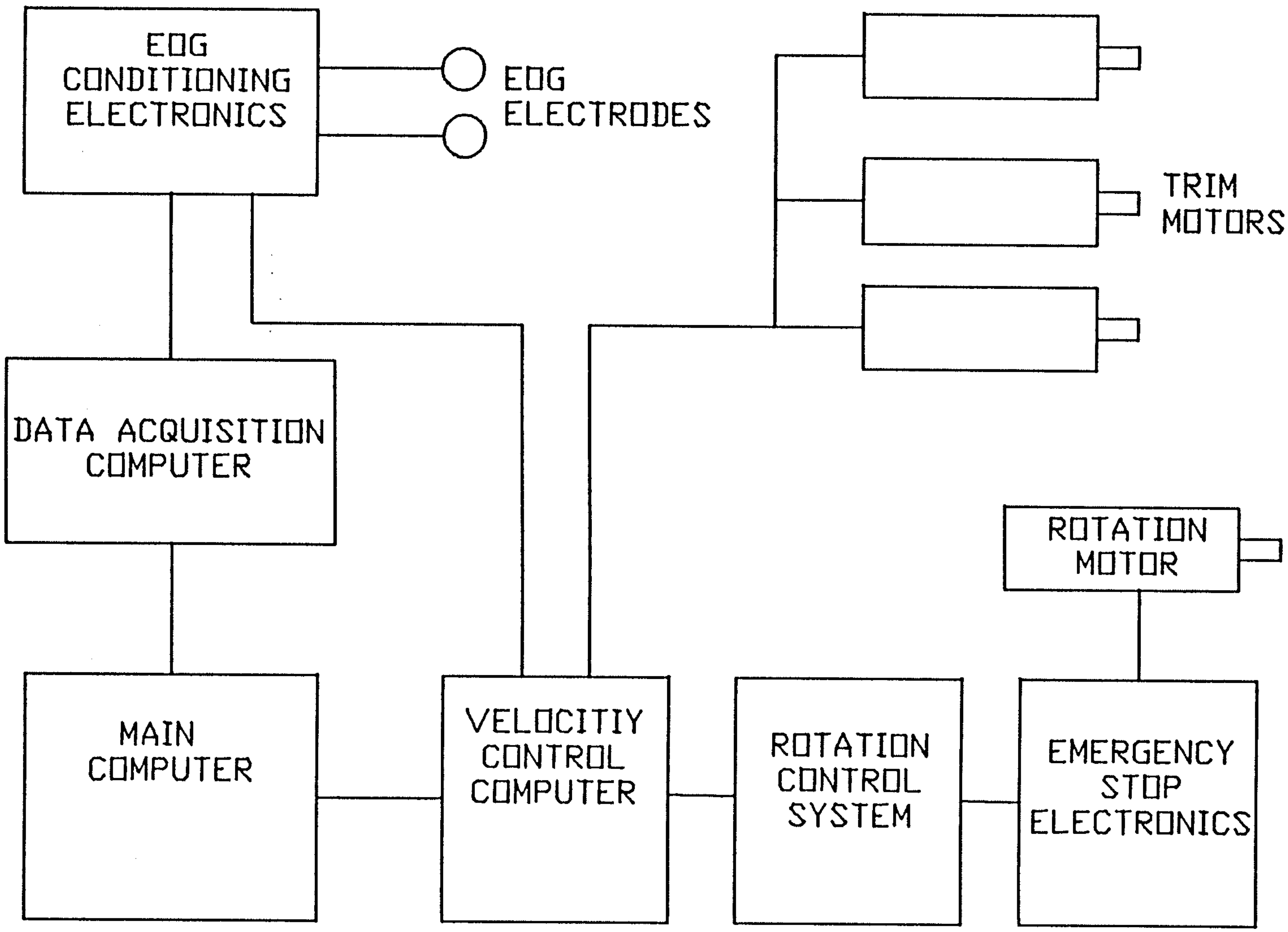

FIGURE 1: BLOCK DIAGRAM OF THE VORDAS.

The EOG Conditioning Electronics:

1) Amplify and filter the EOG signal.
2) Sample the analog EOG signal and convert it into a binary number for transmission to the Main computer.

The Data Acquisition Computer:

1) Controls wall mounted Light Emitting Diodes (LED's) to perform calibration samples of the subject's EOG.
2) Compacts and buffers EOG data.

The Main Computer:

1) Is used to create data files, called Velocity Profiles, from the mathematical description of the acceleration the researcher wants the subject to experience.
2) Allows the researcher to input commands.
3) Displays system status information to the researcher.
4) Sends the data needed to control the chair motion to the Velocity Control computer.
5) Stores the EOG data in a disk file for later use.

The E-Stop Electronics:

1) Detect emergency conditions.
2) Shut down the system in the event of an emergency.
3) Allow the system to be reset after an emergency.

Chapter 3

HARDWARE DESIGN

3.1 Chair/Frame

There were three main considerations in selecting a chair for the VORDAS. First, the chair had to have built-in motors capable of producing trim motions of elevation, pitch, and head tilt to the specifications in Table 1. Second, the chair had to weigh as little as possible to minimize the load inertia. Third the chair should have an open type of frame so that any changes or additions for subject safety, structural strength, and control would be easy to make.

Study of a similar system, designed and built at the Massachusetts Institute of Technology (MIT) and reported by Tole et al [5], led to the selection and use of an examination chair manufactured by Surgical Mechanical Research, Inc [6]. The SMR MAXI III weighs approximately 80 kg, and three constant speed ac motors provide the required trim functions. An AUTORETURN function activates the pitch and elevation motors to return the chair to an upright, unelevated position. Head tilt is not affected by the autoreturn function. Solid state relays, mounted on the base of the chair, allow computer control of the trim functions without audible mechanical relay noise.

Figure 2 shows the mounting arrangement of the chair. The chair is mounted so that, when the subject is sitting upright, the axis of rotation is approximately through the axis of the subject's spine where it intersects the skull. In this way the angular motion generated by the chair is the same as the motion generated by the subject turning his head from side to side. However, this mounting arrangement means that the subject experiences radial acceleration OUT of the chair rather than INTO the chair, a sensation that tends to be somewhat discomforting.

Restraints were added to insure that the subject would be both safe and able to relax comfortably during the run. The restraints consist of a lap belt, two shoulder belts. The lap and shoulder belts are three inches wide and fully adjustable for maximum comfort.

A subject panic button insures that a subject that feels uncomfortable can stop the run.

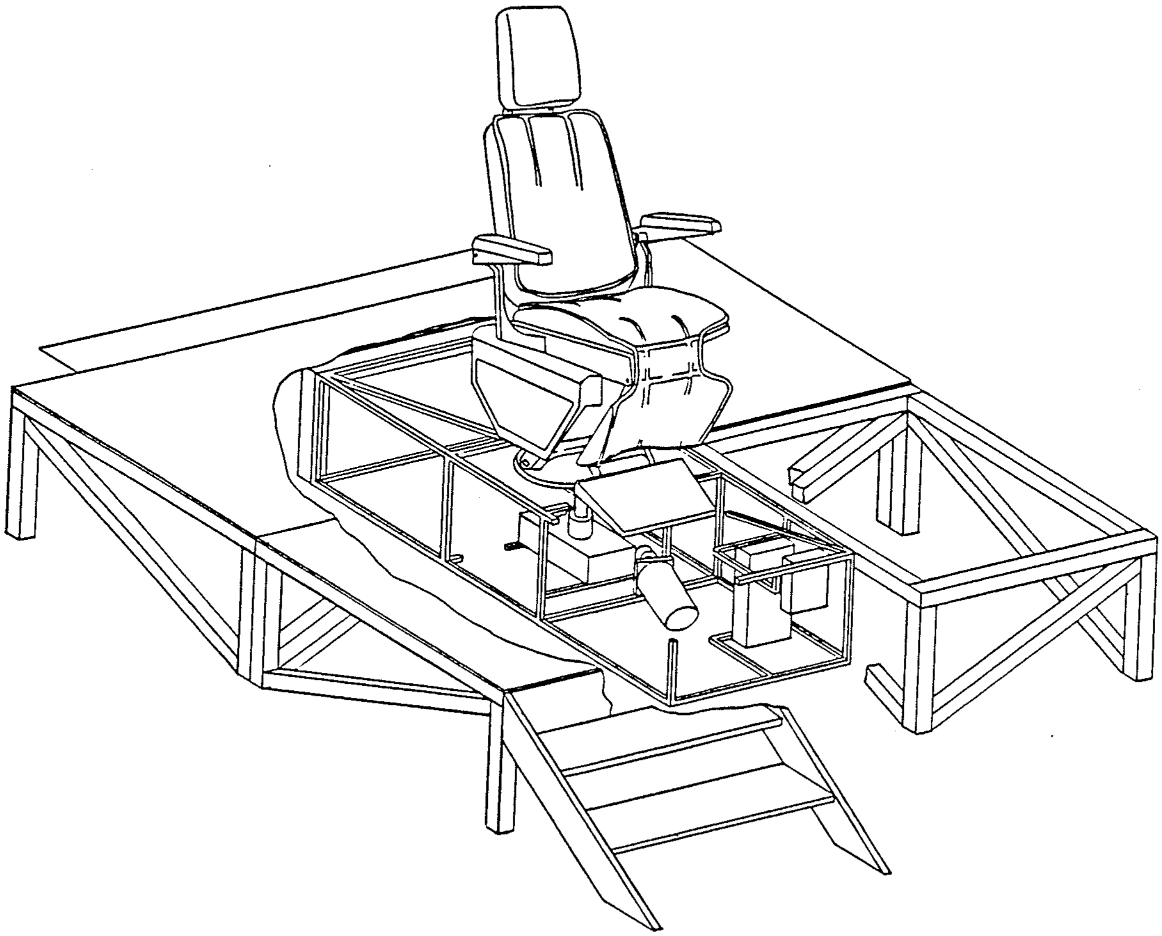

FIGURE 2: Chair mounting arrangement

The chair, and all of its drive components, are mounted on a movable frame in a sub-floor. The sub-floor was required to provide enough room under the chair for the drive components. Mounting the chair and drive components on a movable frame allows removal of the chair from the sub-floor for service. The frame has levelers at six points for support and leveling of the frame.

3.2 Drive Components

Chair rotation is provided by a dc servo motor through a torque limiting clutch and a transmission. Factors considered in selecting the components to drive the chair were:

1) All of the mechanical components must be smooth and quiet so that the subject would not have any external stimulus that could interfere with the normal VOR stimulus.
2) A right angle transmission should be used to minimize the overall height of the chair/drive combination.
3) The transmission should have little or no backlash because the feedback sensors are directly connected to the motor, not the chair.
4) The transmission should not have any belts in it that could stretch under acceleration.
5) There must be some way to stop the chair quickly, but in a controlled manner, in an emergency.
6) There must be some way of getting power, data, and control wiring to the chair.
7) There should be some device incorporated into the chair drive train to limit chair acceleration in the event of equipment failure.
8) The motor must be matched to the transmission to provide the torque required to accelerate the chair over the speeds of the dc motor.

A worm-gear transmission was selected for the VORDAS because:

1) Worm-gear transmissions can operate with zero backlash.
2) Worm-gear transmissions can be self-locking, that is, they cannot be driven from the gear side [7]. In practice even self-locking worm-gear transmissions can be driven from the gear side but doing so is very inefficient. This means that a self-locking worm-gear transmission will act as a brake if power is removed from the motor. Therefore, a quick, controlled stop can be effected in an emergency simply by disconnecting the power to the motor without the need to install any additional braking device.
3) Worm-gear transmissions are smooth and quiet.

The driven shaft of the transmission was bored to allow data and control cabling to be routed to the chair.

A low noise, multi-contact slip ring package mounted under the transmission was used to route data and control signals to the chair. Two power slip rings, mounted on the drive shaft above the transmission, provide 120 Vac power to the chair.

Slip rings are, at best, electrically noisy devices. At worst, dirt and contact surface imperfections can cause complete, momentary loss of the signal. Multi-contact slip rings help reduce and eliminate complete loss of signal, but noise is still present. For example, the signal slip ring package used in the VORDAS has a maximum noise level of 100 mV. This noise would become part of and corrupt analog signals transmitted through the slip rings. On the other hand digital signals will not be affected by the noise provided they have a high enough noise margin. One way to increase the noise margin of any digital signal is to increase its signal level. Therefore, to achieve maximum noise immunity, 12V digital signals are transmitted through the slip rings.

The motor is connected to the transmission through a mechanical torque limiting clutch to prevent high accelerations that could injure the subject. The clutch disconnects the motor from the transmission when the input torque is greater than the trip limit of the clutch. The trip limit is adjustable, and has been set to meet the specifications of Table 1. Note that the clutch does not cause the motor to shut down, and re-engages if and when the input torque drops below the trip limit of the clutch.

A dc servo motor was selected based on the chair inertia, the required maximum chair acceleration and the transmission gear ratio (14:1). The inertia of the chair and a 90 kg subject was reported by Tole et al [5] as 203.5 in-lb-sec^2. The maximum torque required to accelerate the chair