

# High-precision portable instrument to measure position angles of a video camera for bird flight research

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A battery-powered portable instrument for research on the aerodynamics of bird flight has been built to automatically measure and record the horizontal and vertical angles at which a video camera is pointed as an operator videotapes a soaring bird. Each angle was measured to a precision of about 20 arc seconds or better. Two complete systems were constructed, and a triangulation method was used so the same bird in flight could be videotaped by two cameras at different locations to establish the radius vectors from an origin to the bird. The angle information was generated by rotary transducers attached to the camera mounts, and the angle values along with timing data were stored in the semiconductor memory of a single-board computer. The equipment has been successfully tested in the field and promises to have a wider application where a portable instrument is required to measure angles to high precision.

## INTRODUCTION

The video camera mount and computerized recording system described here and shown in block diagram form in Fig. 1 were designed for a research project on the aerodynamics of bird flight, developed from work started by Caple *et al.*<sup>1</sup> References in the literature show several different techniques such as radar,<sup>2-4</sup> two phototheodolites coordinated by a radio link,<sup>5</sup> and a range-finder-theodolite combination<sup>6</sup> have been used in the past to determine the speed of birds in flight. For our research, it was required to have a portable instrument that could be set up in the field to collect and store the angle values at which a video camera was pointed as an operator videotaped a soaring bird. Two complete systems were built so that a triangulation method could be used to determine the time-varying radius vectors from an origin to the bird. For this method, it was necessary to know the horizontal and vertical angles of the camera axis and the times at which the angle values were recorded. The distance between the cameras and their relative vertical displacement were also required. The distance was determined with a Lietz<sup>7</sup> infrared electronic distance measuring meter, and the relative vertical displacement was determined by using the video camera mount as an electronic surveying transit.

The video images of a soaring bird, which were recorded using a portable VCR, and the angle values, which were recorded in the memory of a single-board computer, were later correlated from timing data. This timing data included digital values automatically placed on each frame of the videotape in one-hundredths of a second intervals by character generator clocks in the cameras and computer clock values stored in memory with the angle information. Both the video clocks and the computer clocks were set from hand-held crystal-controlled LCD chronograph/stopwatches (accuracy =  $\pm 0.5$  s/day) used as time standards. These standards were, in turn, checked each day against the National Bureau of Standards WWV radio timing signals. As a further check, at the start and end of a field session, the displays of the

chronograph standards were videotaped for a short time providing side-by-side comparisons of the standards with the video clocks. In addition, the computer clocks were compared each day with the standards.

Video images were required for two purposes: (1) the apparent angle of bank of the bird was taken from the images and used to find the true angle of bank, and (2) the correction to the measured pointing angle of the camera was taken from the images and applied to the data when the bird was not in the center of the picture. Image distances were calibrated by photographing a standard object at a measured distance from the camera to establish the angular displacement of a given length. The horizontal and vertical coordinates of the bird could then be converted to angular corrections to the recorded data and the radius vector of the bird established.

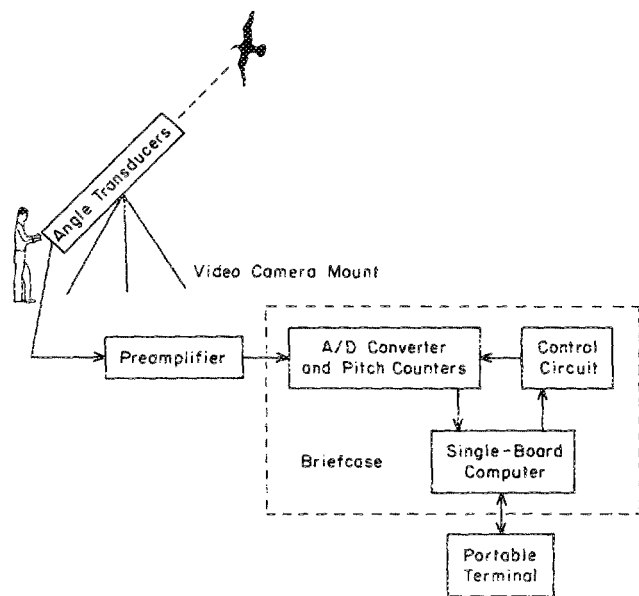


FIG. 1. Block diagram of video camera angle measuring and recording system.

The video camera mounts were constructed to be attached to a standard camera tripod stand and were designed with ball-bearing joints so the camera could be freely rotated in a horizontal and vertical plane. Two angle transducers were connected to the mount as shown in Fig. 2, and they generated electrical output signals in response to the motion of the camera. These transducers were rotary Inductosyns<sup>8</sup> manufactured by Farrand Controls<sup>9</sup> and were essentially air-coupled electrical transformers with stationary and rotating windings as described by Boyes.<sup>10</sup> The rotating winding was excited by an ac voltage, and the induced voltages in the stationary windings were used to determine the angles as described later. Since the induced voltages were only a few millivolts in amplitude, an Analog Devices<sup>11</sup> IPA1764 preamplifier was placed close to the transducers, providing amplification for the signals and electrical isolation and impedance matching. The amplified ac signals were converted to digital form for storage in the semiconductor memory of a single-board computer that also supplied time information and signals to the control circuit to maintain proper flow of the data. A portable terminal connected to the computer enabled an operator to monitor the process.

### I. ANGLE TRANSDUCERS

It was required that the transducers for the video camera mounts be able to measure angles to a high resolution, yet still be reliable in a dusty environment and also be portable, shock resistant, thermally stable, and cost effective. Several different types of angle transducers<sup>12</sup> such as Inductosyns,<sup>8</sup> resolvers,<sup>13</sup> optical encoders, potentiometers, contact encoders, and an absolute optical angle transducer<sup>14</sup> were considered for the mounts. The transducer that best met the stringent requirements placed on it, however, was the rotary

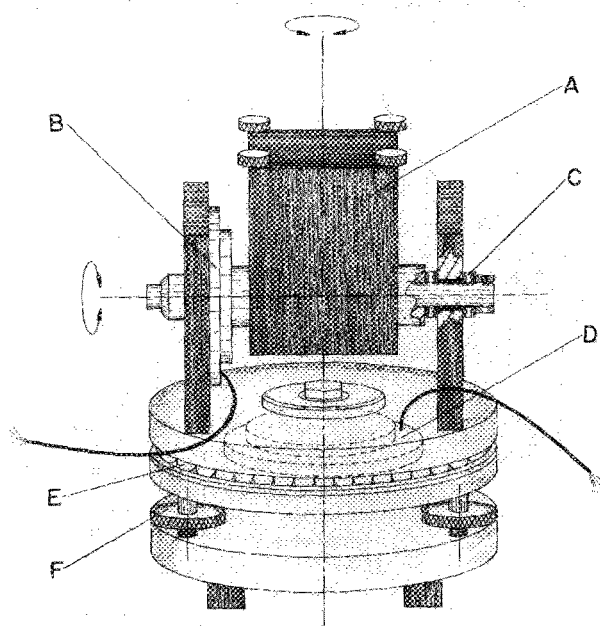


FIG. 2. Schematic drawing of video camera mount: A, video camera platform; B, vertical angle transducer; C, vertical bearing; D, horizontal angle transducer; E, horizontal ball-bearing joint; F, horizontal leveling screws.

Inductosyn.<sup>8</sup> The one we used consisted of two approximately 7.5-cm-diam machined metal disks attached facing each other on a common axis and separated by an air gap of about 0.127 mm. One disk was designed to rotate with respect to the other one. The electrical "windings" that formed the transformer between the rotating and stationary parts were actually precision serpentine printed circuit patterns repeated in an annular ring around the facing surfaces at the outer edges of each disk, but electrically insulated from the metal. The length of one complete cycle of the pattern is called the pitch  $P$ . The pitches were at  $2^\circ$  intervals for a total of 180 pitches around the rotor disk. An Analog Devices model OSC1754 sine-wave oscillator at a frequency of 10 kHz and a current of about 300 mA was used as the excitation power source for the movable winding. The fixed disk had two output windings. The second winding had the same pitch  $P$  and was located adjacent to the first but displaced  $P/4$  from it. These two windings produced induced voltages whose amplitudes were proportional to the sine and the cosine of the relative angle of displacement within the pitch. The sine and cosine outputs were required for the A/D converter the same as the outputs produced by the  $90^\circ$  phased windings of a resolver.<sup>13</sup>

### II. A/D CONVERTER

The A/D converter used was an Analog Devices model 1S20 type 12-bit resolver-to-digital tracking converter, a hybrid integrated circuit. In the converter a closed-loop system is formed from a phase-sensitive detector, an integrator, and a voltage-controlled oscillator. Input signals are compared to an internally generated digital value and a null difference is sought. Among the many advantages of this system is its ability to track angles at a rate up to 170 pitches per second for a 12-bit unit. The inherent ratiometric nature of the conversion process ensured that electrical noise on the input signal was relatively unimportant and that accuracy was not sensitive to voltage drops between the transducer and the converter. A new low-power monolithic version of this same type A/D converter and an explanation of the conversion process has recently been reported.<sup>15,16</sup> This newer version could be used to reduce the power requirements of a future improved system.

The converter divided each  $2^\circ$  pitch into a 12-bit reading (4095 parts), a precision of about 2 arc seconds. Considering the effect of the other components, however, it is estimated that overall precision is about 20 arc seconds. The 12-bit digital output from the converter was in tri-state logic form with a high- and low-byte enable input. This allowed the unit to be programmed to transfer the 12-bit angle value to the 8-bit computer inputs as the higher 8 bits and then the lower 4 bits over the same input lines. The converter also had a ripple clock output and direction signal, permitting the pitch count to be digitized and read into the computer memory by some additional circuitry.

### III. SINGLE-BOARD COMPUTER

The computer used for generating signals to the control circuit and for data storage was a Tattletale model II manufactured by Onset Computer Corporation.<sup>17</sup> It was a 7.4-

×12.7-cm battery-powered single-board computer with 256K of 8-bit RAM (random access memory). Of the available RAM, 16K was for program storage, 12K was split between variable storage and an area for user assembly language routines, and 4K was for stack and system variables. The remaining 224K was used for data storage. The computer had 14 digital lines which could be programmed as either input or output lines. Eight of these were used to input the pitch and angle values from the transducers and the other lines were used for control signals. In addition, the model II had a real-time clock and a serial RS-232C port. Programming for the computer was done with a real-time BASIC interpreter provided in ROM (read only memory). This had many of the features of standard BASIC, but without the severe speed penalty normally associated with the language.

A data-taking sequence was initiated by the computer issuing an inhibit signal latching the 8-bit horizontal and vertical pitches and the two associated 12-bit angle readings into electronic buffers. Then the internal clock was read and the value stored in memory. Next, control signals were sent to the buffers so that the 40 bits representing the pitches and angle readings could be read, 8 bits at a time, into memory. The inhibit signal was released and the sequence was repeated after waiting the programmed scanning time. Normally, readings were taken at the rate of four scans per second.

The general logic of the complete data logging program is shown by the flowchart in Fig. 3. The menu for the program was displayed on the portable terminal connected to the serial port of the computer. In addition to starting the data-logging process, provisions were made to initialize the clock and to reset the pitch counts at any camera setting. All of these functions were initiated by commands from the terminal. After the data-taking command was selected, the terminal could be disconnected if desired. It was normally kept in operation, however, so the data-collection process could be monitored. The terminal provided a way of checking to make sure the instrument was reading and storing angles correctly. The checking process used a software option in the computer program which allowed the time and angle data and memory location information to be displayed on the terminal every 5 s (every 20th data point). Thus, at this slow rate it was possible to visually inspect the data as it was actually being collected. As another check, the camera could be turned to a known angle and the displayed values compared with the known values. A very careful comparison of this type was made in the laboratory before taking the instrument in the field. Limited angle comparison measurements were done in the field as well.

Finally, when the 224K of computer memory was filled, the data values were downloaded to a disk through a portable disk drive connected to the terminal. The OFFLD command provided in the BASIC interpreter was used for the download procedure. This command invoked the X-Modem protocol<sup>18</sup> (error checking routine) to accurately transfer the data.

#### IV. AUXILIARY COMPONENTS

The circuit designed to interface the angle transducers to the single-board computer was constructed using low-

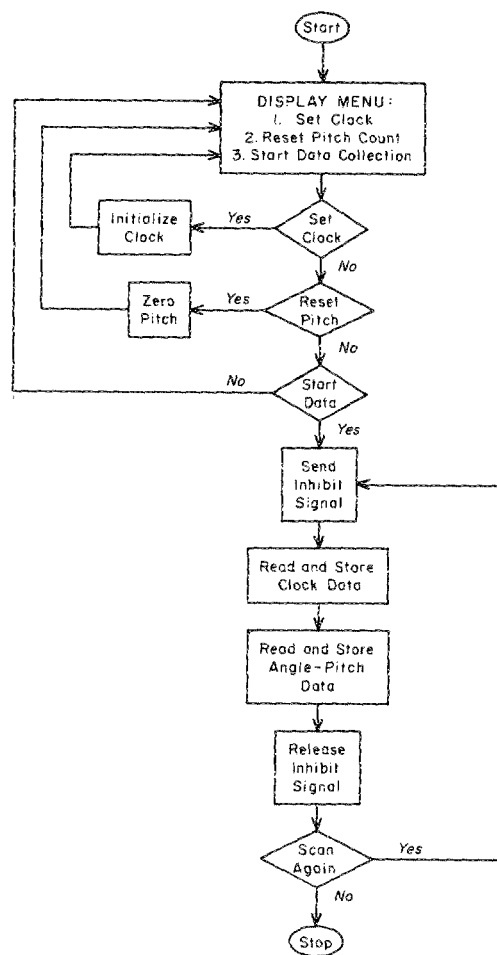


FIG. 3. Flowchart of program stored in single-board computer used to set clock, reset pitch counters, or start data collection.

power Schottky TTL (transistor-transistor logic) integrated circuits. The binary pitch counter and buffer latch shown in the schematic diagram of Fig. 4 were used to accumulate and temporarily store the pitch count data before it was transferred to the computer memory. The counter was built with 74LS169A synchronous 4-bit up-down binary counter chips and the latch with the 74LS373 octal D-type transparent tri-state latch chip. The horizontal and vertical transducers each required this type of interface with the ripple clock and direction outputs from the A/D converters being connected to the counters so they would count up or down according to the clockwise or counterclockwise rotations of the video camera in the horizontal or vertical planes. During the data collection process when the computer issued a low signal to the inhibit pin 11 of the 74LS373, the pitch count was latched and would not change value until after the count was read and a high signal was issued to the pin.

The circuit shown in the schematic diagram of Fig. 5, designed to send signals to transfer the 40-bit pitch and angle information from the buffers to the 8-bit lines of the computer and to reset the pitch counters, utilized the 74LS138 integrated circuit. Four output lines from the computer port were connected to this decoder with three lines being connected to the inputs of the device and the fourth being used

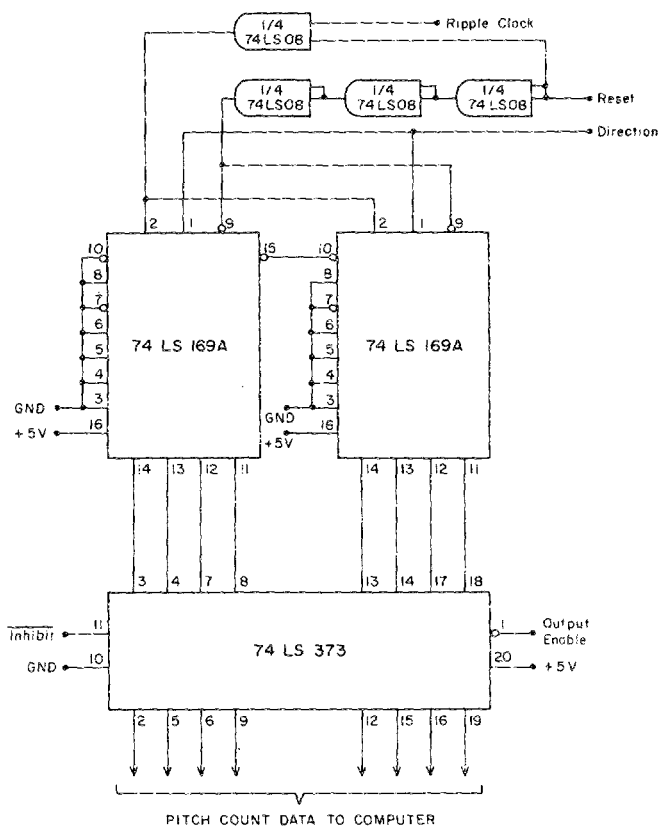


FIG. 4. Schematic diagram of pitch counter and latch circuit.

for an enable signal for the chip. The eight combinations of logic 1's and 0's of the three input lines produced a unique logic 0 on one of the eight output lines of the unit. Six of the lines were connected to the active-low enable pins of the angle and pitch latches, and the other two were connected to the reset pins on the vertical and horizontal pitch counters. Thus by sending voltages represented by binary numbers from 000 to 111 on the three output lines of the computer, it was possible to enable a latch or reset the counters under program control. Since the A/D converters already had tri-

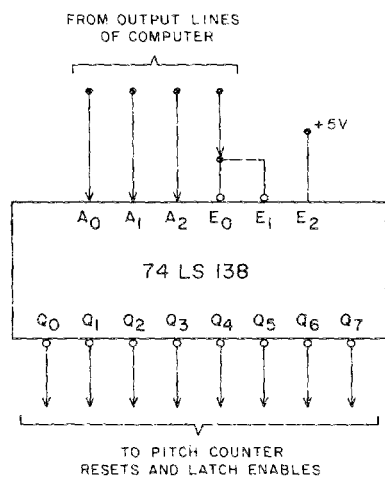


FIG. 5. Schematic diagram of decoding control circuit used to send signals to reset pitch counters and enable latches.

state latches so that the 12-bit angle values could be enabled as the most significant 8-bits and then the least significant 4-bits, additional circuitry was not needed for this part of the instrument.

The electronic components that comprised the transducer oscillator, the A/D converters, the control circuit, and the single-board computer were housed in a briefcase for portability. Suitable receptacles and cables with plugs were used to electrically connect the briefcase components to the other parts of the system. The electrical power for the complete instrument was supplied by one 12-V car battery; however, since some of the components required +5 V and some  $\pm 15$  V, two dc-to-dc converters<sup>19</sup> were used for the appropriate voltage conversion and regulation. A fully charged battery could power the system for several hours of continuous operation.

## V. FIELD EXPERIENCE

Field measurements with the video camera system at bird colonies in Arizona, Texas, Alaska, and New Zealand have shown the instrument is portable enough to be transported long distances and is reliable in harsh outdoor environments. For example, all equipment for the trip to New Zealand with the exception of the two car batteries which were purchased at the time of arrival there, was flown on the airline as regular luggage. Also, once we were in New Zealand, it was necessary to move the equipment every day from a storage location to the measurement site, a distance of several kilometers, and operate the system during hot and dusty summer days. Data were taken for approximately twenty days during a month without any major problems with the components. We experienced similar good reliability with the equipment at the other bird colonies in the United States.

It was found that the instrument operated within the original design specifications. The high precision in measuring angles and the reliability in the field indicated the instrument could have a potentially wider application as a recording electronic surveying transit. We utilized this feature in a minor way when we measured the relative difference in height between the two video cameras. Proposed improvements in the hardware and software of the system would make it more compact and easier to use in the future.

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<sup>8</sup>*Inductosyn: Precision Linear and Rotary Transducers*, Farrand Controls,

Inc., 99 Wall St., Valhalla, NY 10595; Inductosyn is a registered trademark of Farrand.

<sup>9</sup>Farrand Controls, Inc., 99 Wall St., Valhalla, NY 10595.

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<sup>17</sup>Onset Computer Corp., 199 Main St., N. Falmouth, MA 02556; Tattletale is a registered trademark of Onset.

<sup>18</sup>The X-Modem protocol software is in the public domain and is available from many computer bulletin board systems. It was originated by W. Christianson and is maintained by I. Hoff.

<sup>19</sup>International Power Sources, Inc., 10 Cochituate St., Natick, MA 01760.

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