INFRARED OPTICAL SENSOR FOR FAST MEASUREMENT OF DISTANCE AND INCLINATION

Jun Okamoto Jr., Lucas A. Moscato
Escola Politécnica da Universidade de São Paulo
Deptartamento de Engenharia Mecânica
Caixa Postal 8174
São Paulo - SP
05508 - Brazil

ABSTRACT

An infrared optical sensor is being developed for fast measurement of distance and inclination. The main purpose of this sensor is for robot control, to assist in the manipulation of unoriented objects.

A previous work with this type of sensor has shown good results for application of this sensor in robot control. The goal of this new development is to increase resolution and measurement rate, which should yield in better precision through statistical data processing.

It is shown in this paper a new hardware structure necessary to achieve this goal and the sensor characteristics obtained operating the sensor in laboratory environment.

Keywords: infrared optical sensor; distance measurement; inclination measurement; fast measurement rate; robot control.

1. INTRODUCTION

At the Laboratory of Automation and Systems of the Escola Politécnica da Universidade de São Paulo, is being developed an infrared optical sensor to measure distance in a short range and inclination in two axis. Fast measurement rate is one of the main goals of this development so that high speed robot movements are possible while analyzing an object to be manipulated.

Inclination measurement is an appropriate feature to solve some robotic problems, such as handling overlapping parts detected by a vision system. This problem arises because it is not possible to measure the depth of the scene with a non-stereo (or fixed) vision system. This sensor could help in this case, giving to the robot controller information about the object-sensor distance and object-sensor inclination. The robot controller, using this information, can orient and move the end-effector to grasp the object properly.

Fast measurement rate is a highly desirable characteristic which improves efficiency of data processing. In other words, during two consecutive samples of the robot controller, the sensor can measure several times at the same point and the acquired data can be processed to filter the measurement, reducing errors and deviations.

Applications of this sensor are mainly in robot control due to its class of accuracy, response time and size of sensor head. However, if accuracy is improved, applications could be extend to parts inspection, quality control, and other.

This paper describes an infrared optical sensor, for which was developed a dedicated hardware to improve the sensor resolution and measurement rate. It is explained here how fast measurement rate was achieved, how the sensor was implemented and the results obtained with this new method.

2. MEASUREMENT METHOD

A previous work with this type of sensor has shown good results for application in robot control (Okamoto, 1988). In that work a dual slope method was used to process the sensor signal and convert it to digital form. In this new development a dedicated hardware is used to improve significantly the measurement rate compared to the previous method. In this item this new measurement method is explained in detail.

Measurement with this sensor is done using triangulation of the light diffused in the object's surface.

Distance and inclination measurements are accomplished by the activation of different light sources.

a) Distance measurement

Figure 2-1 shows the basic arrangement for distance measurement. L_1 to L_4 are light sources and P is the light detector. The light sources must emmit light in all directions uniformely. The light detector "sees" only a point on the object's surface. The object's surface must diffuse light in all directions.

The activation at the same moment of the pairs L_1-L_4 or L_2-L_3 cancels the influence of the object inclination in the distance measurement.

The received light intensity at P from the pair L_1-L_4 is

$$I_A = I_1 + I_4 \tag{2.1}$$

where I_1 is the light intensity at P from L_1 and I_4 is the light intensity at P from L_4.

The Lambert cosine law (Sears, 1962) for L_1 and L_4 are, respectively

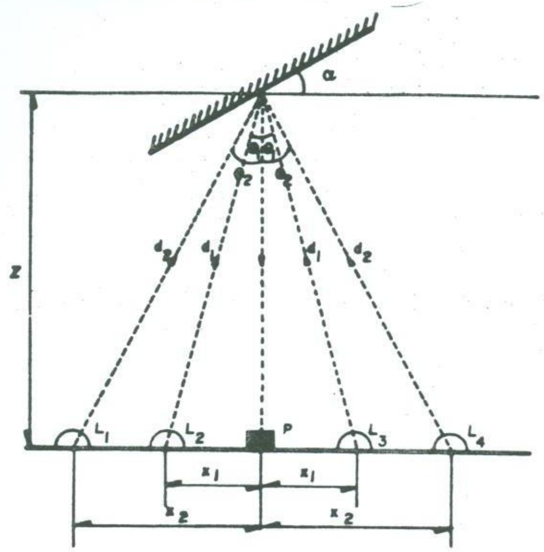

Figure 2-1. Distance measurement

$$I_1 = \frac{C.G_1}{d_2^2} \cdot \frac{\cos(\theta_2 + \alpha)}{\cos\alpha} \qquad (2.2)$$

$$I_4 = \frac{C.G_4}{d_2^2} \cdot \frac{\cos(\theta_2 - \alpha)}{\cos\alpha} \qquad (2.3)$$

where C is a constant related to the reflectivity coefficient of the object's surface and G_1 and G_4 are the light intensities of the light sources L_1 and L_4, respectively.

Considering that the light intensity of the light sources are equal, then

$$I_A = I_1 + I_4 =$$

$$= \frac{C.G}{d_2^2} \cdot \frac{\cos(\theta_2 - \alpha) + \cos(\theta_2 + \alpha)}{\cos\alpha} \qquad (2.4)$$

Expanding the cosines and reducing (2.4), result in

$$I_A = \frac{C.G}{d_2^2} \cdot \cos\theta_2 \qquad (2.5)$$

Analogously, the received light intensity at P from the pair L_2-L_3 is

$$I_B = I_2 + I_3 = \frac{C.G}{d_1^2} \cdot \cos\theta_1 \qquad (2.6)$$

The different paths for the light are determined by L_1-L_4 and L_2-L_3. Taking the ratio of the light intensity at P for those two different paths, using (2.5) and (2.6), we determine the distance z.

$$\frac{I_A}{I_B} = \frac{\cos\theta_2 \; d_1^2}{\cos\theta_1 \; d_2^2} \qquad (2.7)$$

By triangle relations, we have

$$\cos\theta_i = \frac{z}{(x_i^2 + z^2)^{1/2}} \qquad (2.8)$$

$$d_i^2 = x_i^2 + z^2 \qquad (2.9)$$

Substituting in (2.7), we obtain

$$\frac{I_A}{I_B} = \frac{(x_1^2 + z^2)^{3/2}}{(x_2^2 + z^2)^{3/2}} \qquad (2.10)$$

or

$$z = \left(\frac{(I_A/I_B)^{2/3} x_2^2 - x_1^2}{1 - (I_A/I_B)^{2/3}} \right)^{1/2} \qquad (2.11)$$

This result is independent of the object's surface reflectivity coefficient and inclination. The distances between light sources and light detector affect directly the measurement value.

b) Inclination Measurement

Figure 2-2 shows the arrangement for inclination measurement. L_5 and L_6 are light sources and P is the light detector. The same assumptions made for distance measurement apply for inclination measurement.

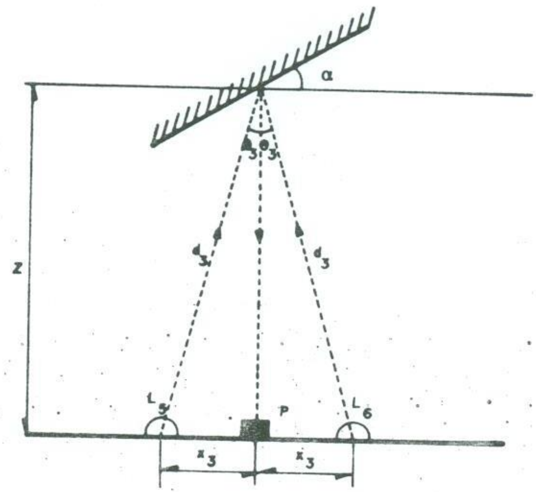

Figure 2-2. Inclination measurement

Inclination can be measured taking the ratio of the light intensity diffused by the object's surface from two different paths, corresponding to the activation of L_5 and L_6.

The light intensity at P from L_5 and L_6 are, respectively

$$I_C = \frac{C.G_5}{d_3^2} \cdot \cos(\theta_3 + \alpha) \qquad (2.12)$$

$$I_D = \frac{C.G_6}{d_3^2} \cdot \cos(\theta_3 - \alpha) \qquad (2.13)$$

where C is a constant related to the object's surface reflectivity coefficient, G_5 and G_6 are the light intensities of the light sources L_5 and L_6, respectively.

Considering that the light intensities of the sources are equal, the ratio of the two light intensities is

$$\frac{I_D}{I_C} = \frac{\cos(\theta_3 - \alpha)}{\cos(\theta_3 + \alpha)} \qquad (2.14)$$

Expanding the cosines, we have

$$\frac{I_D}{I_C} = \frac{\cos\theta_3 \cos\alpha + \sin\theta_3 \sin\alpha}{\cos\theta_3 \cos\alpha - \sin\theta_3 \sin\alpha} \qquad (2.15)$$

By triangle relations, we have

$$\cos\theta_i = \frac{z}{(x_3^2 + z^2)^{1/2}} \qquad (2.16)$$

$$\sin\theta_i = \frac{x_3}{(x_3^2 + z^2)^{1/2}} \qquad (2.17)$$

Substituting (2.16) and (2.17) in (2.15), results in

$$\frac{I_D}{I_C} = \frac{z + x_3 \tan\alpha}{z - x_3 \tan\alpha} \qquad (2.18)$$

or

$$\alpha = \frac{I_D/I_C - 1}{I_D/I_C + 1} \cdot \frac{z}{x_3} \qquad (2.19)$$

This result is independent of the object's surface reflectivity coefficient. The distance between the sensor head and object must be known to measure the inclination correctly.

3. IMPLEMENTATION

Using this sensor for robot control creates the need of a fast data processing unit that prepares the sensor data in time to be used by the robot controller. In order to fulfill this requirement a basic structure of the infrared optical sensor is proposed, shown in Figure 3-1. The function of each block is explained below.

a) Sensor Head

The sensor head is composed by infrared LEDs (Light Emitting Diodes), its drivers, a photo diode and its converter, receives

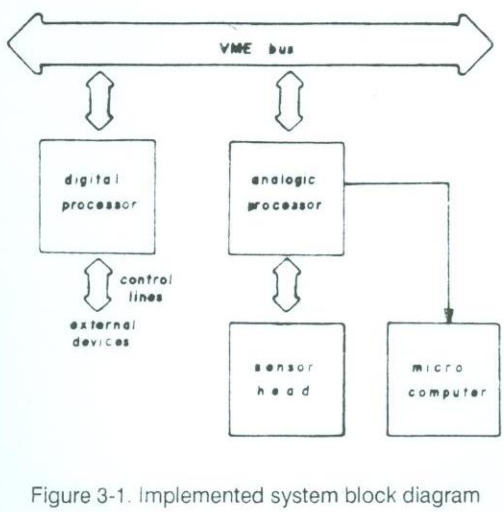

Figure 3-1. Implemented system block diagram

commands and sends signal from and to the analogic processor.

Figure 3-2 shows the prototype head and its dimensions. The prototype was mounted on a PCB, connected to the analogic processor by a 1.0 m flat cable.

The sensor head can be installed on the robot's hand, measuring distances and inclination, to control a appropriate grasping of objects.

b) Analogic Processor

The analogic processor (Figure 3-3) is a dedicated hardware to process the signal received from the sensor head, controlled by

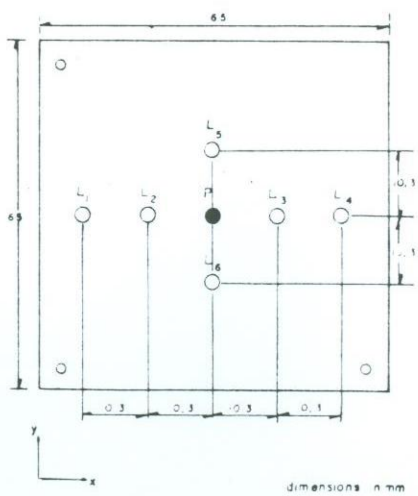

Figure 3-2. Sensor head

a digital logic. It also contains a logic to activate the sensor head LEDs in appropriate sequence depending on the parameter being measured. It includes a digital interface to a VME bus connected to the digital processor. This processor has separate registers for distance and inclination measurement.

The analogic processor contains an internal control register, externaly programmable, that controls the measurement mode. Programming this register one can chose which parameter is to be measured, that is, distance only, distance and angle in the X-axis, angle in the Y-axis only, etc. Any combination of the three parameters is possible, including no measurement.

To process the received signal a division of the received signal from two different paths is done by a hardware divider implemented with non-linear amplifiers. The internal control logic controls a sequence of operations in the following order:

The internal control register is read and the parameter to be measured is determined.

- Sample and hold the background light (sample and hold 1 in Figure 3-3), which is subtracted from the received signal until the end of the measurement.
- Sample (sample and hold 2 in Figure 3-3) the signal from the first path and hold this signal to be divided by the other signal later. The path is determined by the control logic that activates the appropriate LEDs or LED, or distance or inclination respectively.
- The LEDs for the other path are then activated and after few microseconds the result of the division is stable. A pulse for the A/D converter is generated by the control logic.
- After a few microseconds, the parameter (12-bits) is registered in one of the three 16-bit register available, one for each parameter. At this moment the data is ready to be read by the digital processor.

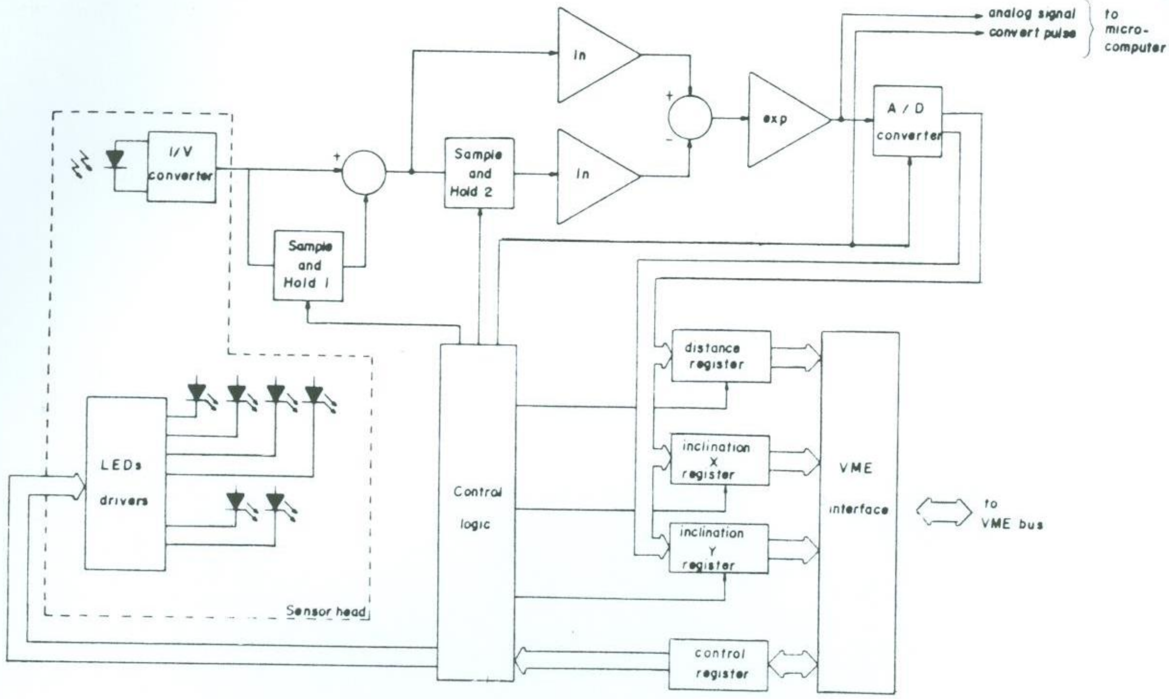

Figure 3-3. Analogic processor block diagram

- The control register is read again to determine the next parameter to be measured.

The analogic processor can be connected to an external microcomputer that can evaluate the data being measured, and the sensor performance. The connection to this microcomputer does not affect the measurement or disturbs the signal, so the analogic processor can be connected, at the same time, to the digital processor and be used for control.

c) Digital Processor

The digital processor is a microcomputer based on a 68000 microprocessor to process the distance and inclination information from the analogic processor. It is connected via VME bus to the analogic processor and can be connected to other VME compatible peripheral devices.

This processor can control external devices, such as servo motors, stepping motors. Here, the sensor information can be used to close a feedback loop, for instance.

At the time of the writting of this paper the digital processor is under test of the hardware and no software has been written for it, yet.

d) Microcomputer

Connected directly to the analogic processor, through an A/D converter, used to evaluate the sensor performance without disturbing the measurement process.

The A/D converter pluged-in the microcomputer is, in this case, a 10-bits A/D converter. The conversion is controlled by the same signal, from the analogic processor, that is used to trigger the analogic processor's A/D converter, so that the microcomputer can acquire data at the same rate as the measurement is done.

A program, written in Pascal, controls the acquisition and display of the sensor data. Using a graphic display, each measurement is displayed as a dot in a scaled screen. A numerical display shows the average and standard deviation for a programable number of data samples.

4. EXPERIMENTAL RESULTS

The sensor head was mounted on a special structure, for the evaluation of the sensor's characteristics (Photo 4-1). Using a caliper the sensor head can be positioned at a known distance from a rotating wall. This wall can rotate 45° to the left and to the right.

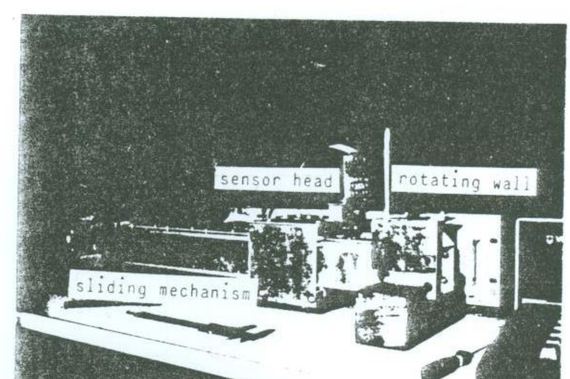

Photo 4-1. Testing bench

The distance measurement characteristic was evaluated changing the distance between the sensor head and the wall for different angles of rotation of the wall. Figure 4-1 shows this result.

The plotted data is the average for 1,000 samples, in this case the standard deviation around the average was less than 0.3%. The output scale was normalized for values between zero and one.

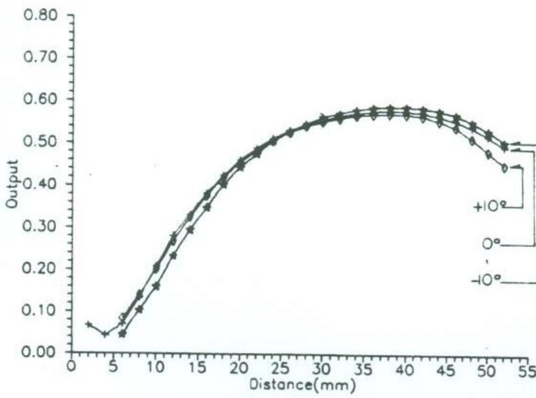

Figure 4-1. Distance measurement data

The inclination measurement characteristic was evaluated rotating the wall for different distances of the sensor head. Figure 4-2 shows the result for the x-axis and Figure 4-3 shows the result for y-axis. The plotted data is the average of 1,000 samples and the standard deviation for this case was less than 0.5%.

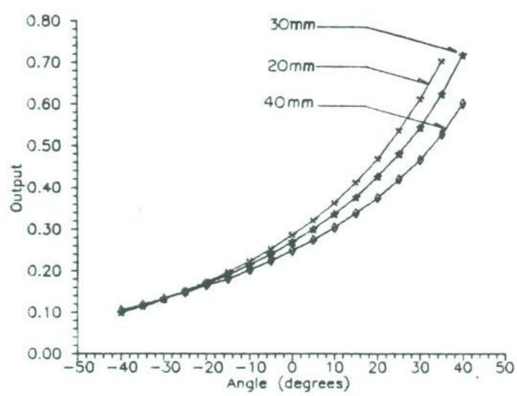

Figure 4-2. Inclination measurement, x-axis data

The total time interval for one measurement was 54 μs, compared to the measurement rate of the sensor introduced by Okamoto (1988), an improvement of more than 100 times was achieved.

The resolution obtained in the previous work (Okamoto, 1988) was restricted by an 8-bits counter, while in this new development a 12-bits A/D converter determines the resolution of the sensor.

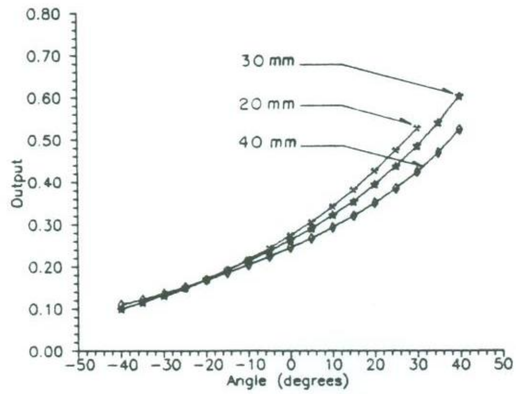

Figure 4-3. Inclination measurement, y-axis data

As in the sensor developed by Okamoto (1988), the precision is determined by the positioning precision of the optical elements in the sensor head, precision of the lenses of the optical elements, etc. So, the precision obtained for this sensor is around 1 mm for distance measurement and 2° for inclination measurement.

5. CONCLUSION

It was presented, in this paper, the development of an infrared optical sensor for fast measurement of distance and inclination. The results obtained show an improvement in the measurement rate and resolution compared to previous work.

Next goal of this developmet will concentrate in the improvement of the precision, through the improvement of the mechanical positioning of the optical elements. Furthermore, after the completion of the digital processor hardware, it is planned the connection to the analogic processor and the effective use of this sensor in control.

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7. REFERENCES

Okamoto, J. Jr. & Hasegawa, K. (1988); "Development of an Optical Multifunctional Proximity Sensor for Robot Control"; 3º CONAI; São Paulo - Brazil.

Sears, F. W. (1962); *Principles of Physics Series - Optics*; Addison Publishing Co., Inc.

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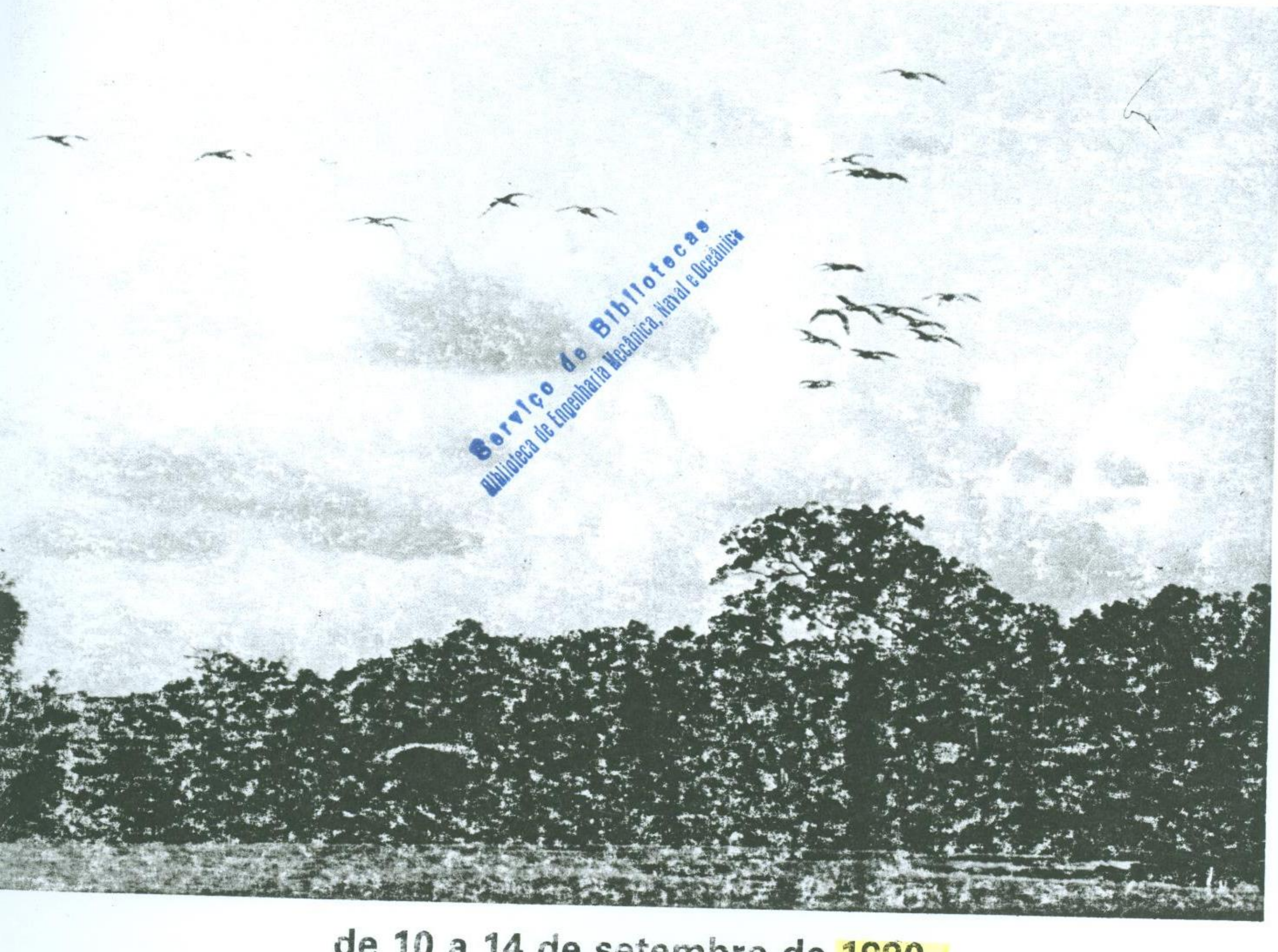

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