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A MOBILE ROBOT WITH SONIC SENSORS AND ITS UNDERSTANDING OF A SIMPLE WORLD

by

Yutaka Kanayama

Shin'ichi Yuta

Jun'ichi Iijima

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INSTITUTE
OF
INFORMATION SCIENCES AND ELECTRONICS

UNIVERSITY OF TSUKUBA

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Yutaka Kanayama
University of Tsukuba, Sakura, Ibaraki 305 Japan

Shin'ichi Yuta
University of Tsukuba, Sakura, Ibaraki 305 Japan

Jun'ichi Iijima
The University of Electrocommunications, Chofu, Tokyo 182 Japan

Abstract:

This paper discusses how a mobile robot with supersonic sensors can look at the world and distinguishes the difference between walls and other objects. This intelligent self-contained robot, named Yamabico 3.1 was developed under a project whose purpose was, in part to construct a robot which knows its position in the world. The robot has two microcomputer systems for the brain and the legs, and a communication system between the two. It has four supersonic eyes, a neck, and batteries. The leg system consists of two driving wheels with DC motors and ensures smooth movement.

Second, a method for the robot to recognize a simple world is described. A simple method is proposed for noise elimination. Then the robot's images of a simple world are described and a method by which the robot can recognize straight walls is proposed. Least squares fitting is used for the discrimination. This procedure gives the distance to the wall and the direction of the wall with respect to that of the robot's path. Finally, a robot control method for straight movement along a wall is proposed. The software for all of this is a part of the basic brain monitor of Yamabico 3.1.

0. Introduction

Mobility is an extremely important ability for intelligent robots, because they cannot perform their tasks fully without it. Many mobile robots which use TV cameras for understanding their environment have been reported [1][2][3][4]. Scene analysis is needed for an intelligent automaton to recognize objects and get three-dimensional information.

Supersonic sensing is another tool for understanding the world [5]. This paper describes the method, abilities and limitations of supersonic sensing by mobile robots. Small power consumption, good cost/performance ratios, light weight and ease of acquiring distance information are advantages of this method.

Yamabico 3.1 is a self-contained intelligent robot from the Yamabico family and has functions very similar to those of Yamabico 3 [6]. The name, roughly equivalent to "Echo", was chosen to highlight its sonic sensing method. Since the angular precision of sonic devices is limited, the images obtained are fuzzy. An algorithm for deriving reliable information from noisy data is presented later in this paper.

In this analysis, the environment of the robot is restricted to a hallway surrounded by planar walls. Worlds of this type are well adapted to being understood by a robot with four eyes. This is the first step foward describing the world by using simple eyes. Experiments with more complex worlds will be reported in subsequent papers.

Section 1 describes the hardware and software of the Yamabico 3.1 robot. In Section 2, some results of basic experiments with supersonic eyes are presented. These results are needed in designing the wall recognition algorithm presented in Section 3.

Section 4 is devoted to a method by which Yamabico can walk straight along a wall.

1. A mobile Robot Yamabico 3.1

Yamabico 3.1 was constructed to serve as a tool to develop the world-understanding concept used by mobile robots. (See Figure 1) One of the main purposes of this project is to construct a robot which is aware of its position in the world, with or without a map. The results reported in this paper are the first step towards that goal.

1.1 Hardware

The architecture of Yamabico 3.1 is shown in Figure 2. Its main features are as follows:

(1) It consists of a brain, two legs, a neck, four supersonic eyes, and batteries, carried in one body.

(2) It contains two microcomputer systems for the brain and the leg system, which are hand-shaked through a communication port. Each of the system consists of an MC6802 8-bit microprocessor, ROM, RAM and monitor.

(3) The entire body can be moved by two driving wheels and two swivel-castor wheels. The driving wheels are controlled by a microprocessor and DC motors to ensure smooth movement [7].

(4) The eye system is mounted on the neck, which can rotate around the central axis.

(5) The eye system consists of four transmitter-receiver pairs which are mounted so that adjacent eyes are separated 90° in azimuth. Each transmitter emits 40KHz waves horizontally and the corresponding receiver gets an echo if an object exists in its

direction. The time interval is proportional to the distance to the object. This eye can detect an object as far as 3m distant. The horns are now being rebuilt and the sensing ability will be improved.

(6) The energy supply is from NiCD batteries.

1.2 Software

Yamabico is a multiprocessor system and its software system is devided into two parts; the brain monitor and the leg monitor. The leg system is a slave of the brain system. The communication between the two is done by an interrupt procedure through the communication port and there is a leg command system (See Figure 3).

The most important brain monitor functions are:

(1) Supporting concurrent processes and interrupt handling.

(2) Supporting basic I/O functions including console ones, such as sonic eye operation.

(3) Sending commands to the leg system, such as a turn command.

(4) Supporting basic arithmetic functions.

(5) Execution of the user's programs.

The most important leg monitor functions are:

(1) Supporting concurrent processes and interrupt handling.

(2) Supporting the basic leg commands.

(3) Sending commands to the brain system.

(4) Supporting basic arithmetic functions.

2. Characteristics of the Sonic Sensors

In this section, basic experimental data of the sonic sensors of Yamabico 3.1 are presented. Assume the robot is moving straight to the right along a wall (See Figure 4). If Yamabico uses the left eye to measure the distance to the wall at fixed intervals, we obtain a sequence of points, P_0, P_1, ..., P_i. Assume that the path of the robot is straight, and take a coordinate system such that the x axis coincides with the path. Then the sequence is expressed as (x_0, y_0), ..., (x_i, y_i), where each x_j is obtained by using a leg command that tells the walking distance, and each y_j is obtained by using an eye function.

The following figures show how a simple would is seen by the robot with supersonic eyes. Figure 5 shows a result for an uneven wall. Each dot in the figure represents an object which caused an echo. Note that at the transient area TA, the observed values do not change abruptly. We notice some points which lie much closer to the robot than adjacent points do. We call them noise data, which are supposed to be caused by environmental sonic noise. All noise data are smaller than true data. In a usual laboratory environment, the probability of noise data occurrence is about 1%.

Figure 6 and 7 describe how the eye sees a plastic sylinder and a person standing in front of a straight wall. The broken vertical lines in the figures represent the absence of echoes at those points. In this case we stipulate that $y_j = 0$.

We are interested in the angular precision of sonic sensing. If the eye looks at a wall at an incidence angle of 45°, then the sonic receiver accepts no echoes at all. Figure 8 shows responses which are obtained by scanning the wall when the neck is rotating. The data tell us that the eye gets an echo when it looks at the wall at an incidence angle less than 20°.

When the robot is stationary and a person goes by between the robot and a wall, the eye perceives an image like that shown in Figure 9.

The preceding results say that measured values sometimes contain noise, that false values are always smaller than the true ones, and that under certain conditions the eye misses echoes. Let us propose a simple method of eliminating noise.

Assume that the robot is moving and coordinates (x_j, y_j) have been observed. Let (x, y) be the results of the next observation. In most cases, there is a parameter δ such that the difference $|y - y_j| \leq \delta$.[†] On the other hand, if $y < y_i - \delta$, then y might possibly be noise data. Also, if $y = 0$, (that is, no echo has come), there is a slight possibility that the eye will catch an echo in the second trial. In the latter two cases, new coordinates (x', y') are immediately observed and are taken as (x_{j+1}, y_{j+1}). That is,

$$(x_{j+1}, y_{j+1}) = \begin{cases} (x, y), & \text{if } y \geqq y_j - \delta \text{ and } y \neq 0, \\ (x', y'), & \text{otherwise.} \end{cases}$$

Then, this method makes not more than two measurements for one point. One reason the robot does not make many observations is that the robot is moving between sonic emissions.

Figure 10 shows the result of noise elimination in the same environment as that of Figure 5. This function is implemented in the basic eye subroutines of the brain monitor.

3. Recognizing Walls

It is necessary for a mobile robot to know the distance from itself to the nearest wall. It is, however, not appropriate to get only one value and accept it as a true distance, because random

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† Typically, $\delta = 4$cm.

noise may override a signal and because the eye may pick up a value in a transient area between two walls. The following line fitting procedure is employed after noise elimination. This is a sort of one-dimensional image processing.

We have to determine whether or not the mobile robot is facing a planar wall. For that purpose, we take the last $2N+1$ data $(x_{-N}, y_{-N}), \cdots, (x_N, y_N)$ and make a least squares fit to get the equation $y = ax + b$ with respect to the robot path. (See Figure 11). Assume that for all j with $-N \le j \le N$, $y_j \ne 0$. That is, at each $2N+1$ point, the eye accepts an echo.

The coefficients a and b and the sum of squares of residuals S are given by the following equations.

$$\begin{cases} (\sum_j x_j^2)a + (\sum_j x_j)b = \sum_j x_j y_j \\ (\sum_j x_j)a + (\sum_j 1)b = \sum_j y_j \\ S = \sum_j y_j^2 - a\sum_j x_j y_j - b\sum_j y_j \end{cases}$$

where all summation is taken from -N to N.

Let $x_{-N}, \cdots, x_N$ be normalized as $-N\Delta x, \cdots, N\Delta x$ respectively†. That is, the x coordinate is local and moved to the forward direction of the robot as a new current value (x, y) comes. Let K denote $\frac{1}{3}N(N+1)(2N+1)$. Then a, b and S are evaluated by the following:

$$\begin{cases} a = \frac{1}{K}\sum_j x_j y_j \\ b = \frac{1}{2N+1}\sum_j y_j \\ S = \sum_j y_j^2 - \frac{1}{K}(\sum_j x_j y_j)^2 - \frac{1}{2N+1}(\sum_j y_j)^2 \end{cases}$$

Therefore the only requirement is to compute $\sum y_j$, $\sum x_j y_j$ and $\sum y_j^2$ at each step. The program for this evaluation in real time is

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† Typically $N = 8$ and $\Delta x = 1\text{cm}$.

shown in Figure 12. In this program, the variables "sumy", "sumxy" and "sumyy" denote the above summations. z[1..m] is an array representing the sequence y_{-N} to y_N. The variable "sig", "dx" and "x0" represent the number of nonzero values in the array z, Δx and $n\Delta x$ respectively. The $2N+1$ data under consideration are recognized as on a straight wall if $sig = 2N+1$ and $S < S_m$, where S_m is a parameter of this method†.

This algorithm has been coded and executed for the situation shown in Figure 5. The result is presented in Figure 13, where the bold parts of the lines are the region that the robot recognized as a wall.

If there exists any difference in the distances between walls and the robot, then the robot recognizes the shape of walls. Thus, the robot can draw a map of a world which the robot had not known before.

4. Control of Straight-Line Movement

To walk straight is an important function for mobile robots. It is, however, impossible to do so through a long path without help of eyes, because of imbalances between the two motor systems and irregularities in the floor surface. Therefore it is necessary for the robot to utilize its eye during its walk.

A first-order prediction of the track of the robot is the basis for this method. Suppose that we have Yamabico walk along a long straight wall. Its four eyes and the algorithm described in Section 3 can be used for that purpose.

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† Typically $S_m = 100cm^2$.

LL' is a line on which the mobile robot is to walk, and is away from the wall by a distance c. (See Figure 14). When the robot is at P_1:

(1) By using the algorithm shown is Section 3, the robot gets the distance b and the slope a at P_1 and predicts its position P_2 which is beyond P_1 by a distance e. Let b_2 be a distance from the wall to the robot.

(2) If $c - t \leq b_2 \leq c + t$, then no special operation occurs. Otherwise the direction of the robot is changed by $\Delta\theta = \frac{b_2 - c}{e}$ such that new expected point P_2' is on LL'. This adjustment of direction can be done smmothly by one of the leg commands of Yamabico 3.1 [7].

(3) The above procedure (1) and (2) is repeated once in a distance r along the route. t, e and r are important parameters of this procedure. Their typical values are 5cm, 2m and 1m.

5. Concluding Remarks

The four-way eyes work very well in recognizing worlds where all walls are parallel or intersect at right angles. The cost-performance of supersonic eyes is good. Least square fitting is practical for recognizing walls in real time. The leg functions mentioned in this paper are necessary for a robot without any map of the world and also for a robot that has a map of the world.

Acknowledgement

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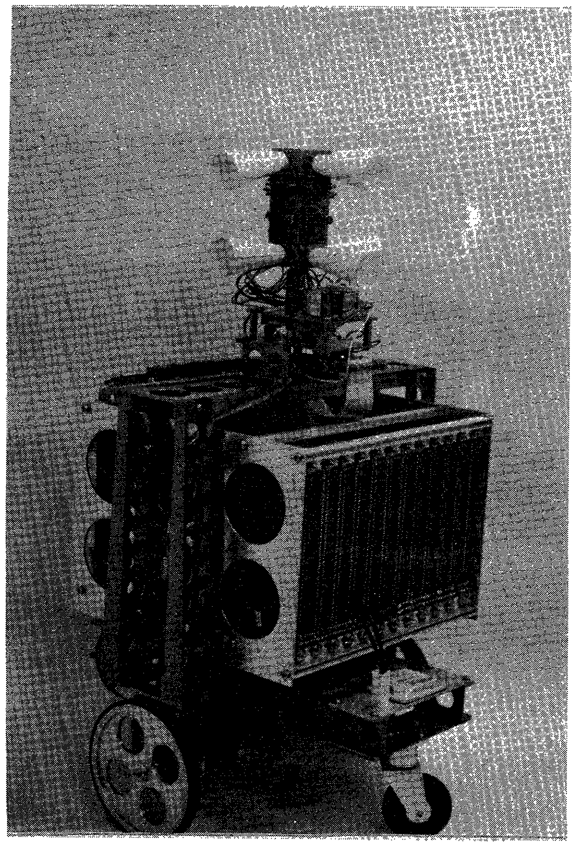


Figure 1 Yamabico 3.1

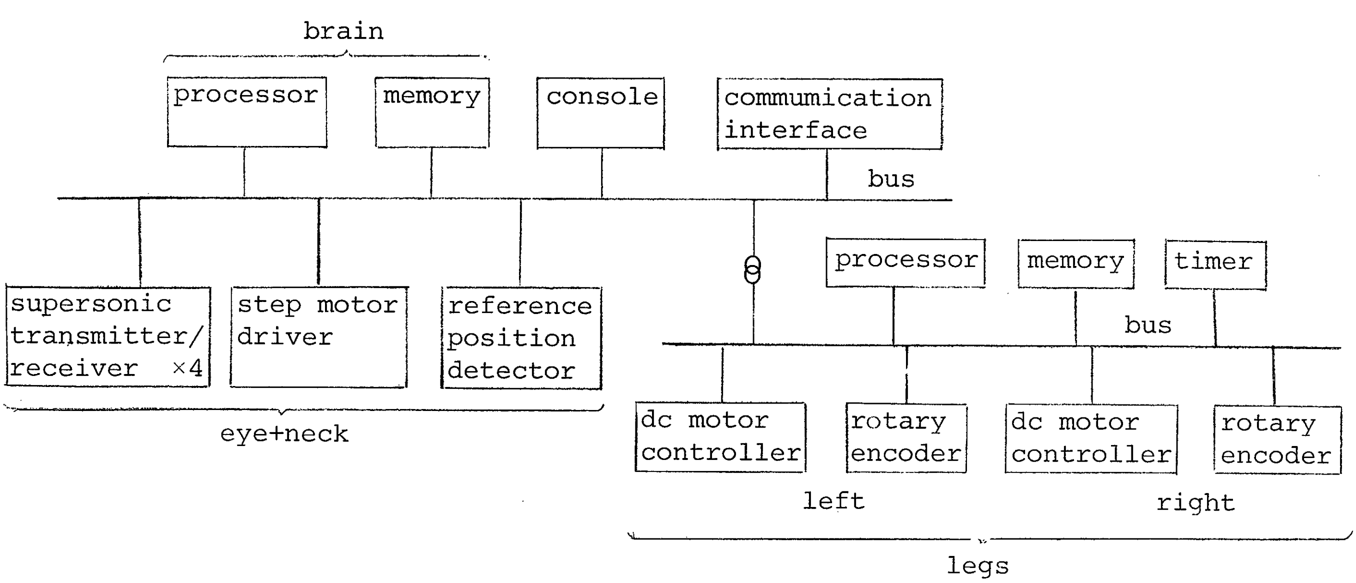


Figure 2 The architecture of Yamabico 3.1

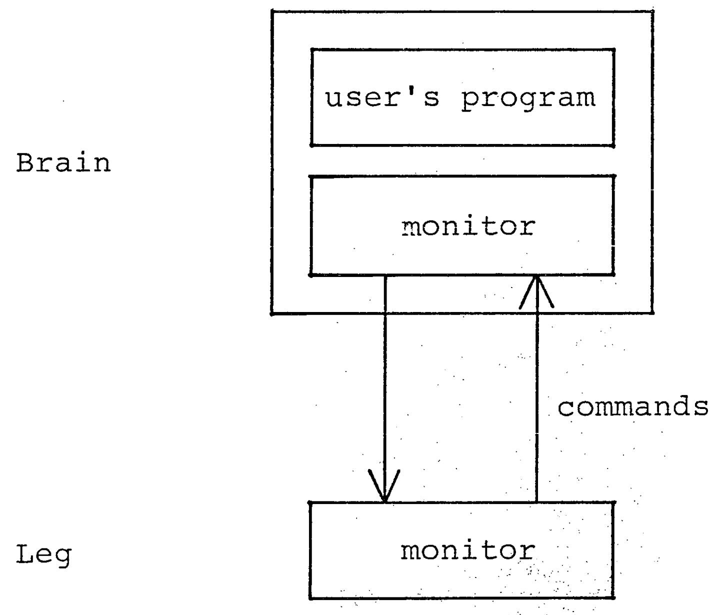


Figure 3 The brain and the leg system

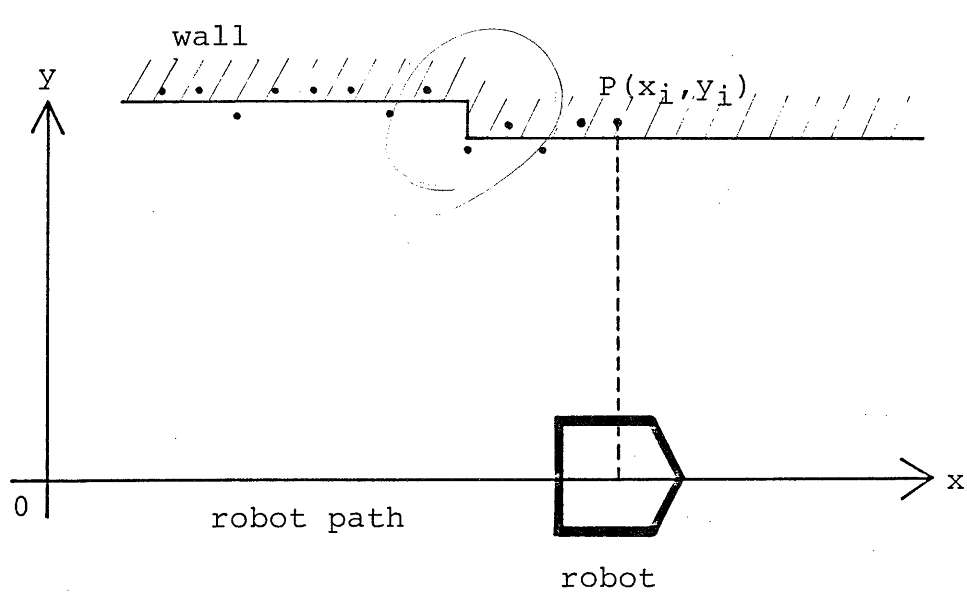


Figure 4 Walking along a wall

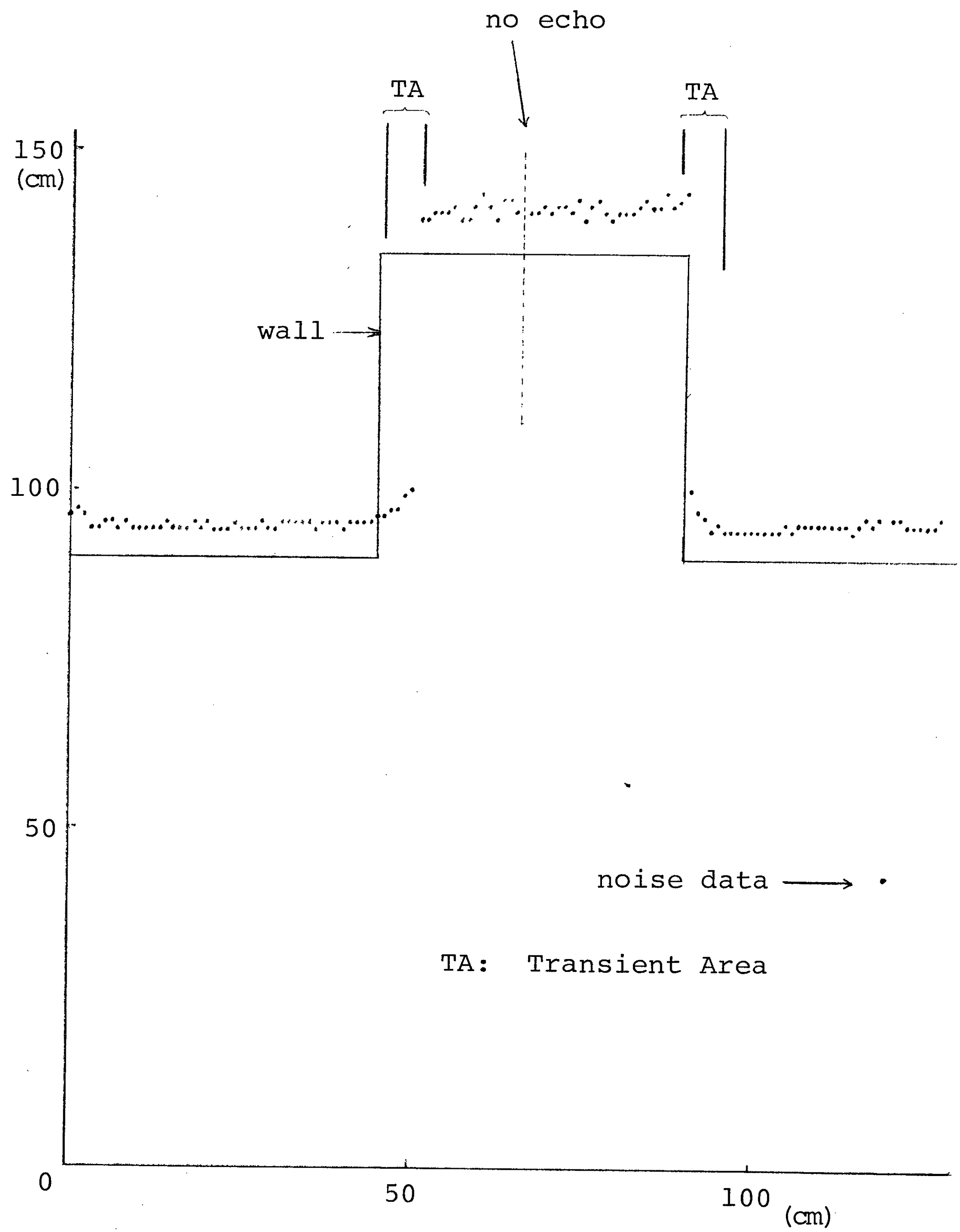


Figure 5. Uneven walls scanned by a moving eye

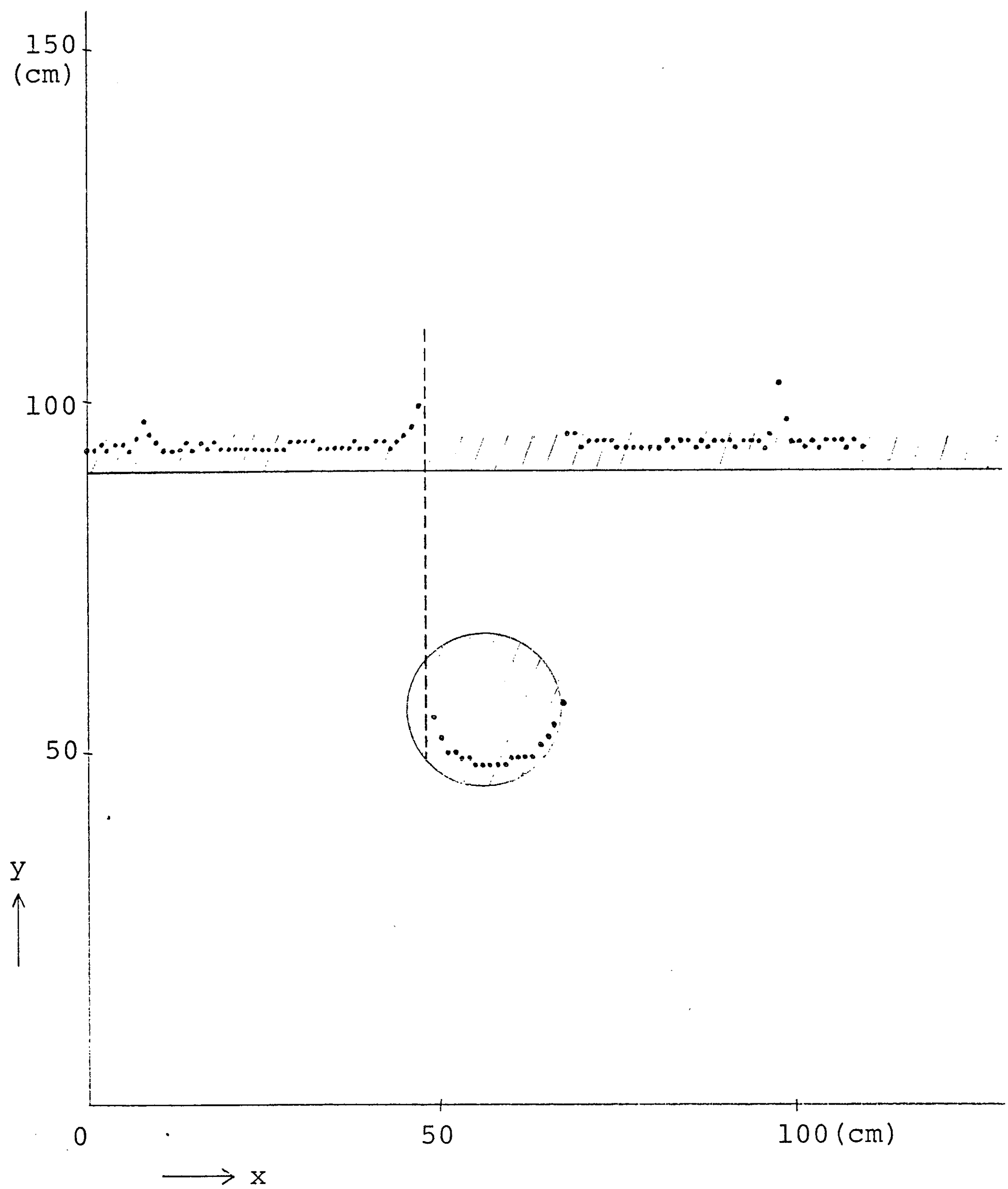


Figure 6 A cylinder placed in front of a wall, as seen by a moving eye

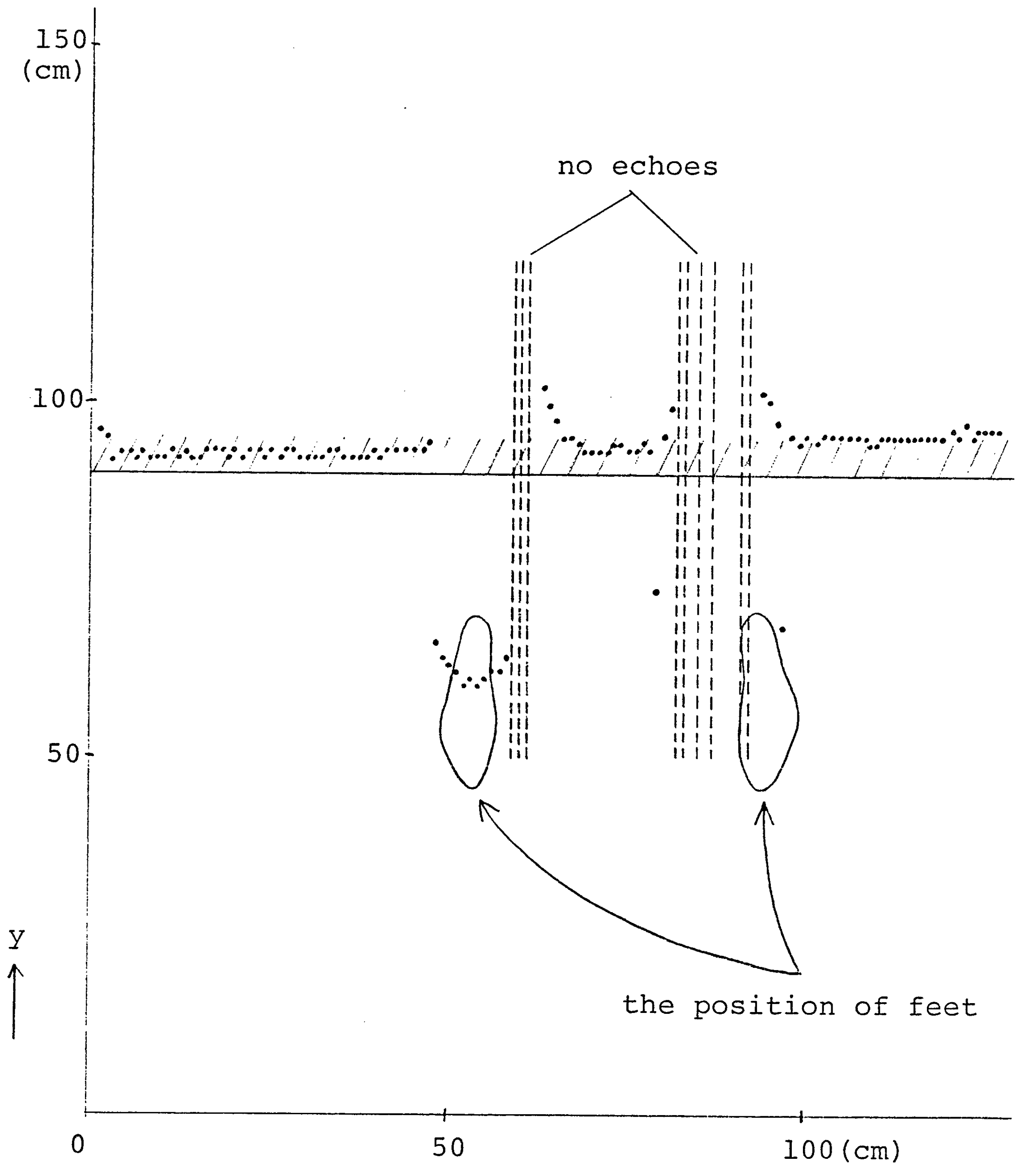


Figure 7 A person standing in front of a wall, looked at by a moving eye

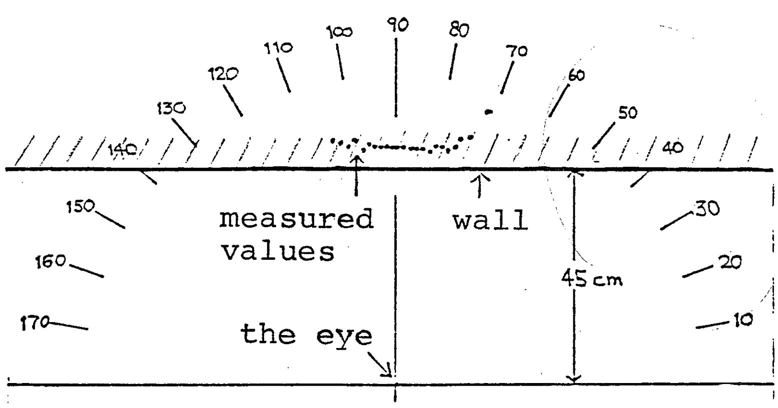


Figure 8 A wall, looked at by a rotating sonic eye

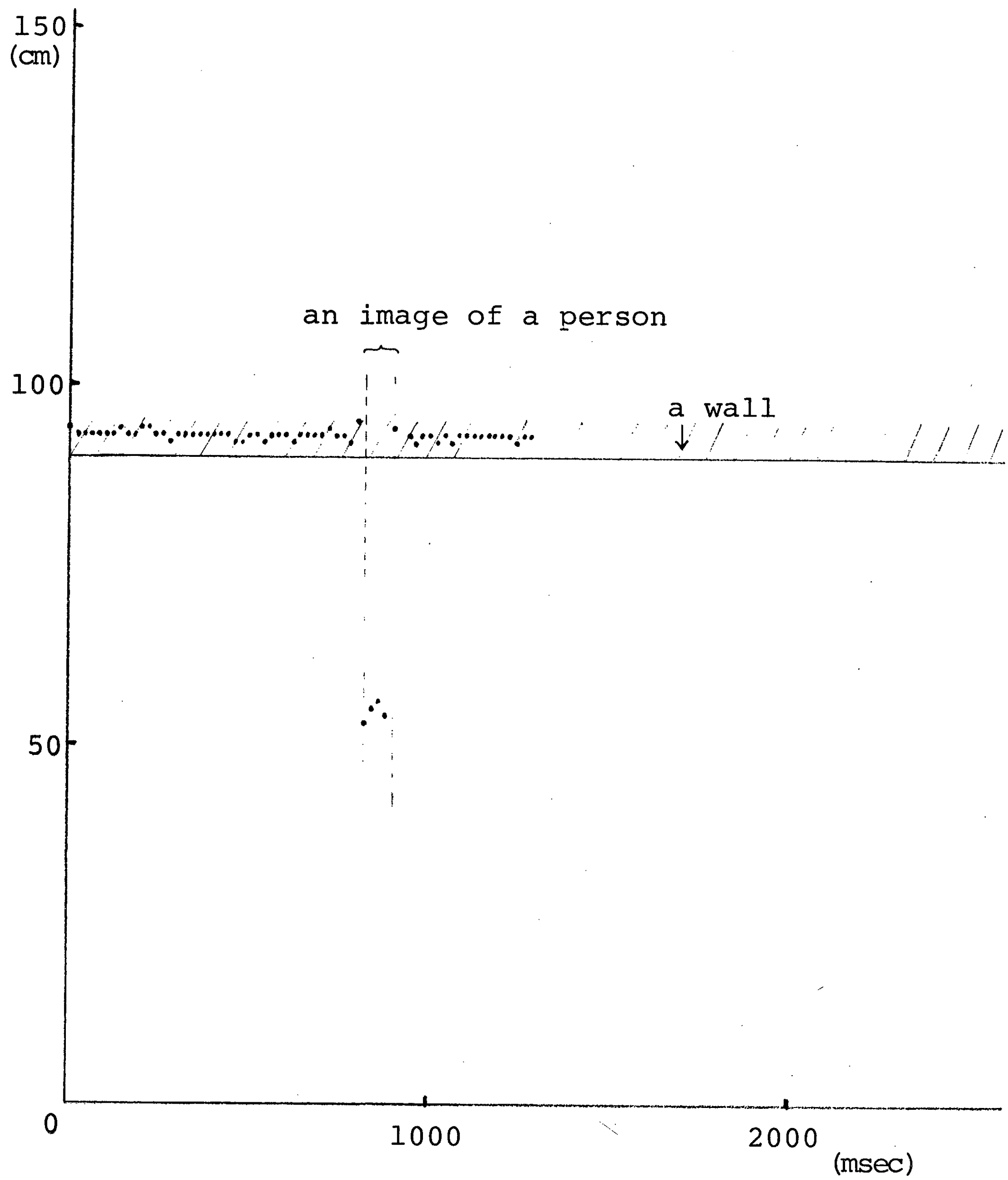


Figure 9. Walking person, as seen by a fixed eye

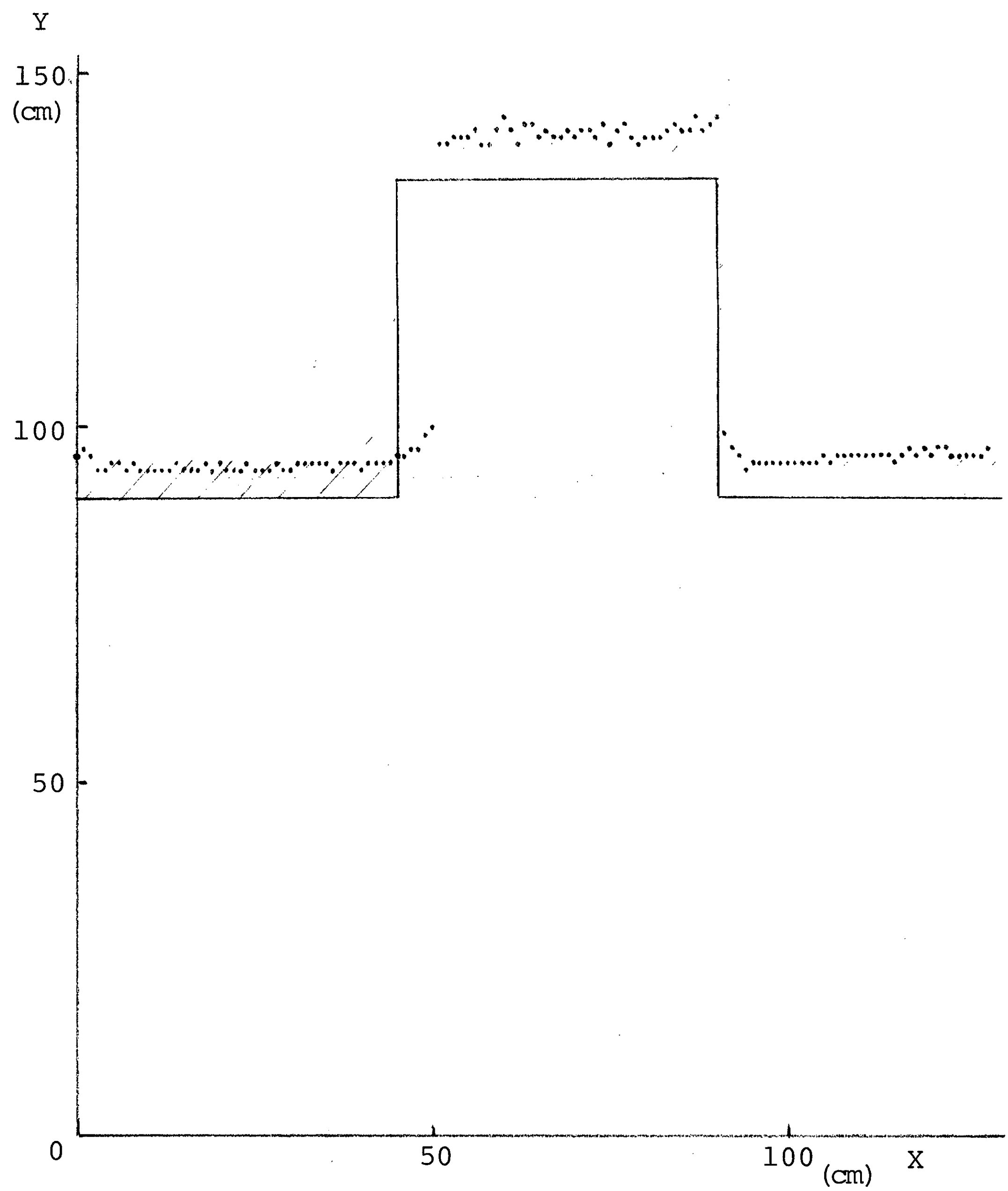


Figure 10. Uneven walls after noise elimination

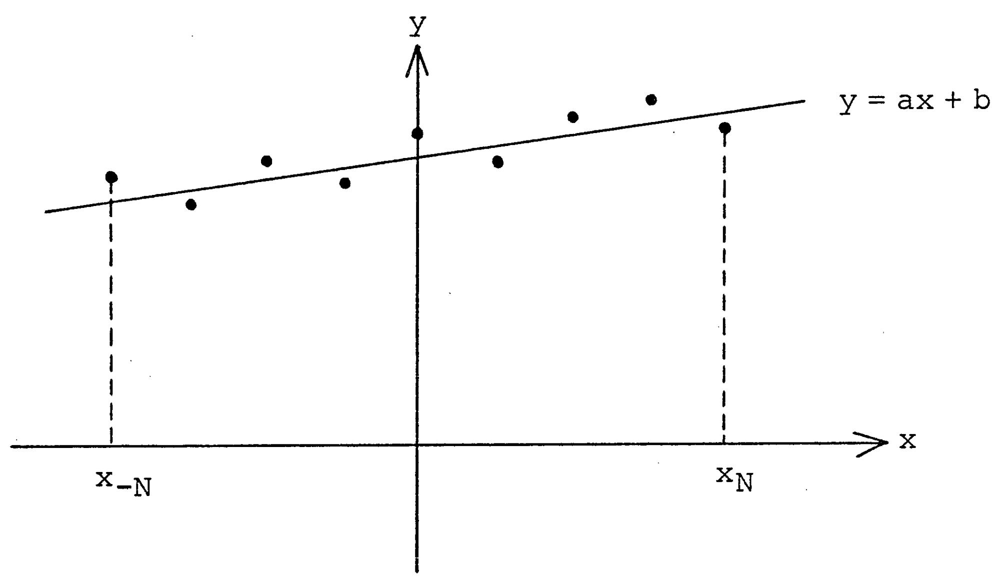


Figure 11 Least squares fitting of 2N+1 observations

(a) declaration

```
const maxm = 101;
var  sig, m, n, j : integer;
     sumy, sumxy, sumyy, y, dx, x0 : real;
     z : array [1..maxm] of real;
```

(b) initialization

```
begin sumy := 0;  sumxy := 0;  sumyy := 0;
      sig := 0;
      m := 2 * n + 1;
      x0 := n * dx;
      for j := 1 to m do z[j] := 0
end
```

(c) updating with new y

```
begin sumyy := sumyy + sqr(y) - sqr(z[m]);
      sumxy := sumxy + x0 * y + x0 * z[m] - (sumy - z[m]) * dx;
      sumy := sumy + y - z[m];
      if y ≠ 0 then sig := sig + 1;
      if z[m] ≠ 0 then sig := sig - 1;
      for j := m downto 2 do z[j] := z[j - 1];
      z[1] = y
end
```

Figure 12 An algorithm for least squares fitting

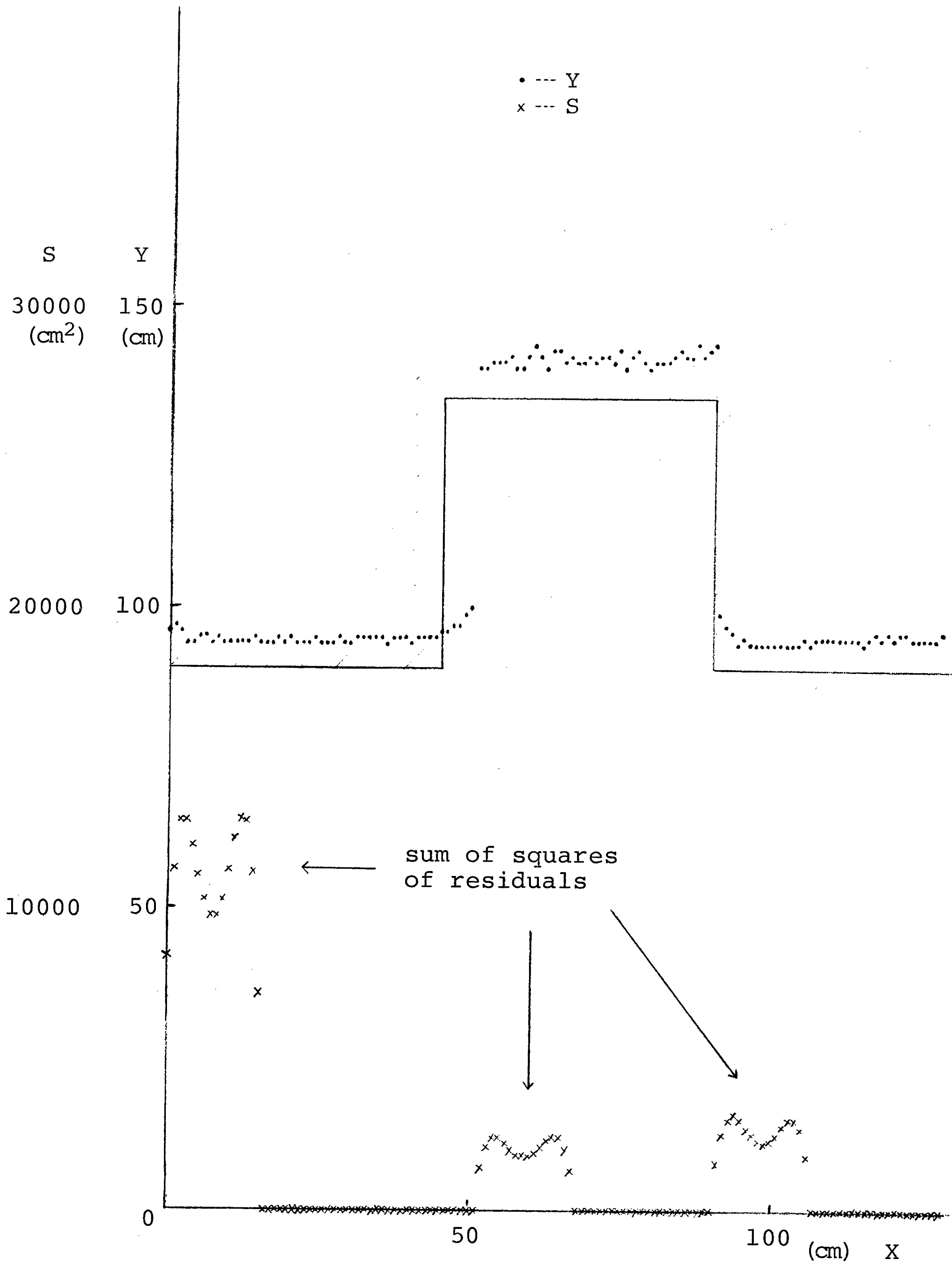
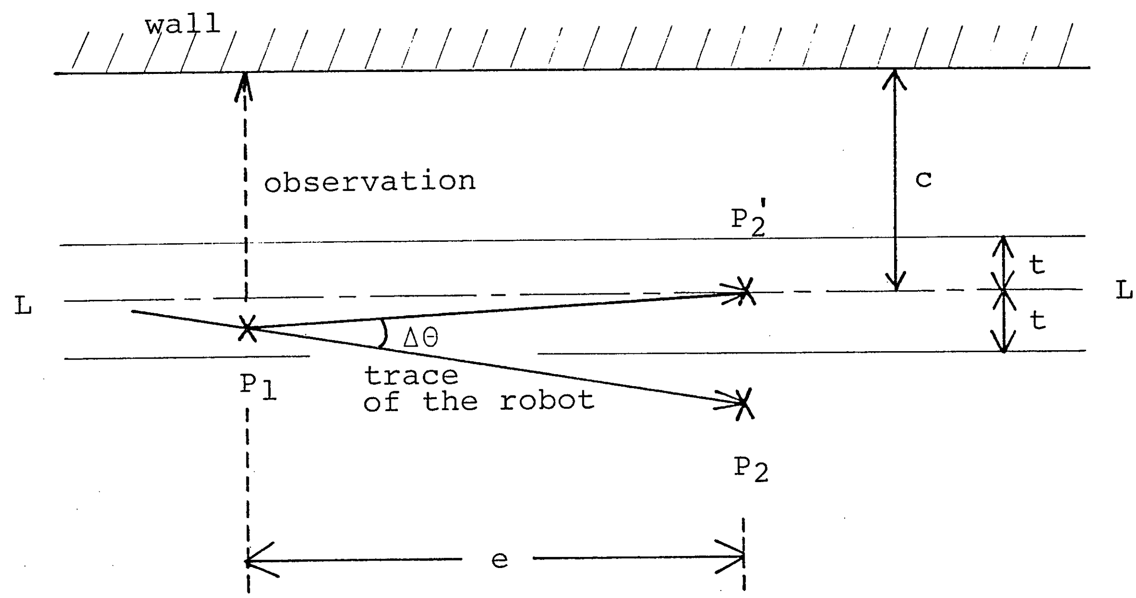


Figure 13. A result of wall recognition



P_1: current position

P_2: predicted position

P_2': modified predicted position

Figure 14 modification of the walking direction

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AUTHOR(s)

Yutaka Kanayama
University of Tsukuba, Sakura, Ibaraki 305 Japan

Shin'ichi Yuta
University of Tsukuba, Sakura, Ibaraki 305 Japan

Jun'ichi Iijima
The University of Electrocommunications,
Chofu, Tokyo 182 Japan

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SUPPLEMENTARY NOTES