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An alternative method of distance measurement walked by the blind

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Summary :

The blind person cannot often take advantage of skilled learned, such as taking care of day to day needs without the capacity to successfully travel. Therefore, there is a need for navigation aids to help the blind to be independant from the help of a normal sighted person, and to be able to walk journeys which have not previously been rehearsed. As part of this, there is a particular need for a device to enable the distance travelled by a blind walker to be determined continiously as the journey progresses. In this paper, the proposed method of measuring distance is to use the acceleration of a moving body which in this case is the blind person. The technique well known in air-craft navigation systems of using an accelerometer and double integrating its output gives a measurement of distance travelled. This method suffers from drift of the integrators and offset of the accelerometer. An innovation in the present paper is a suggested way to overcome this problem by the use of a footswitch when the blind walks.

Keywords: Navigation, Accelerometer, Footswitch, Blind.

I) Introduction

Among the problems of independant mobility for blind pedestrians is the accuracy of the distance travelled [Bentzen, Mitchel, 1995],[Blenkhorn, Evans, 1997] when they wish to establish routes around their home and workplace. Because the idea of using a mercury tilt switch [Freeston, Callaghan, Russel, 1984] was not very effective and the idea of using an ultrasonically device[Hollyfield, Trimble, 1983] was not very appropriate, it was felt that a system which measures distance directly or indirectly would be more accurate since it would not depent on a predetermined value of average pace length.

Some different possible methods to measure the distance can therefore be considered . An accelerometer of force-balance type [Lemkin, Boser, Auslander, Smith, 1997], followed by two integrators is used to measure a distance travelled by the blind person. This technique is considered in inertial navigation systems [Fournier, Hamelin, 1983]. In this paper the method of drift correction is analysed based on simplifying assumptions to see if changes in accelerometer and double integrator can indeed be reduced or cancelled when the feedback correction has been made by using the footswitch. From this, a judgement can be formed on whether this idea can succed and if it has any advantage over not using a footswitch at all.

II) Analysis details

2.1) The model system

The model is a necessity to allow the analysis of this method. The bock diagram shown if figure1 represents the whole system and identifies the main causes of errors. An analysis is next performed on the effect of these errors on the indicated distance.

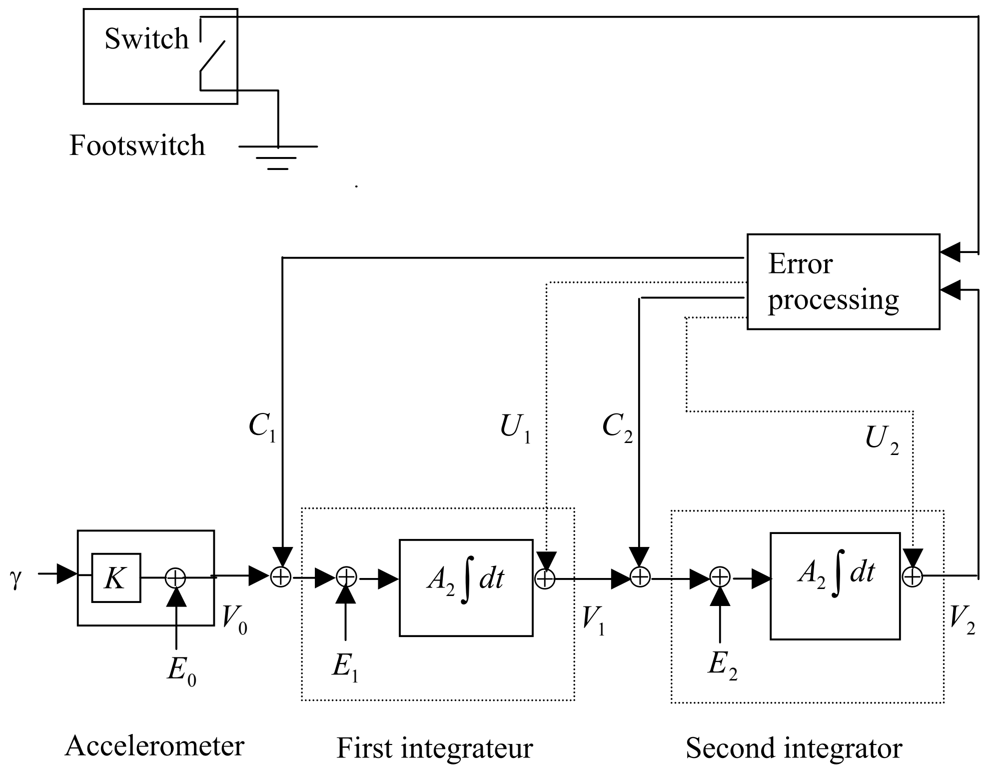


Figure 1: Block diagram of system.

The model shows an error processing block which uses the presence footswitch closure to identify the numerical values of the sources of these errors and applies feedback corrections [Kuo, 1991].

The various parameters and signals in the model have the following meanings :

K: Constant of the accelerometer.

E_0 : Error due to the accelerometer.

V_0 : Output of the accelerometer.

C_1 : First feedback signal for correction.

E_1: Error due to the first integrator.

A_1 : Constant of the first integrator.

U_1 : Initial condition of the first integrator.

V_1 : Output of the first integrator. It represents the velocity voltage.

C_2 : Second feedback signal for correction.

E_2 : Error due to the second integrator.

A_2 : Constant of the second integrator.

U_2 : Initial condition of the second integrator.

V_2 : Output of the second integrator. It represents the distance voltage.

2.2) Mathematical analysis of the system

The distance voltage is given by :

$$V_2 = K A_1 A_2 \int_0^t \int_0^t \gamma\, dt dt + A_1 A_2 \int_0^t \int_0^t (E_0 + E_1 + C_1) dt dt + A_2 \int_0^t (E_2 + U_1 + C_2) dt + U_2 \tag{1}$$

Defining $V_2 = V_{2a} + V_{2e}$ (2)

Where V_{2a} is the actual distance voltage and V_{2e} is the total error on estimated distance voltage, then :

$$V_{2a} = K A_1 A_2 \int_0^t \int_0^t \gamma\, dt dt \tag{3}$$

and the total error is :

$$V_{2e} = A_1 A_2 \int_0^t \int_0^t (E_0 + E_1 + C_1) dt dt + A_2 \int_0^t (E_2 + U_1 + C_2) dt + U_2 \tag{4}$$

2.3) Timing

Let us assume in this analysis that all footsteps are equally spaced. Practical situations would not have constant T_{step} but the general desirability, or otherwise, can be expected to carry over from the present analysis to the practical situation.

The total elapsed time on each footstep is given by :

$$T_{end}=(N_{step})(T_{step}) \tag{5}$$

Where

N_{step} is the number of elapsed footsteps, and

T_{step} is the period of each footstep.

<u>2.4) Errors when corrections are not applied</u>

Let us assume initially that errors E_0, E_1, E_2 and initial conditions U_1, U_2 are constant and examine the errors that occur when corrections are not applied as in the case of the conventional technique.

Therefore, to signify they are constants, the following notation is defined :

$E_0=E_{00}$, $E_1=E_{10}$, $E_2=E_{20}$, $U_1=U_{10}$, $U_2=U_{20}$

Substituting these constants into equation (4) yields :

$$V_{2e}=A_1A_2\int_0^t\int_0^t(E_{00}+E_{10}+C_1)dtdt+A_2\int_0^t(E_{20}+U_{10}+C_2)dt+U_{20} \tag{6}$$

If no corrections are applied as presently assumed, then

$C_1=0$, and $C_2=0$

Initial conditions U_{10} and U_{20} are assumed to be equal to zero because at the start the velocity and the distance are known to be equal to zero. Therefore equation (6) becomes

$$V_{2e}=A_1A_2\int_0^t\int_0^t(E_{00}+E_{10})dtdt+A_2\int_0^t E_{20}dt \tag{7}$$

Because E_0, E_1, E_2 are assumed for the present to be constant, then the integration is performed from equation (6), and we have :

$$V_{2e}=\frac{1}{2}A_1A_2(E_{00}+E_{10}+C_1)t^2+A_2(E_{20}+U_{10}+C_2)t+U_{20} \tag{8}$$

For convenience are defined the following constants:

$$m_0 = U_{20}$$
$$m_1 = A_2(E_{20} + U_{10} + C_2)$$
$$m_2 = \frac{1}{2} A_1 A_2 (E_{00} + E_{10} + C_1)$$

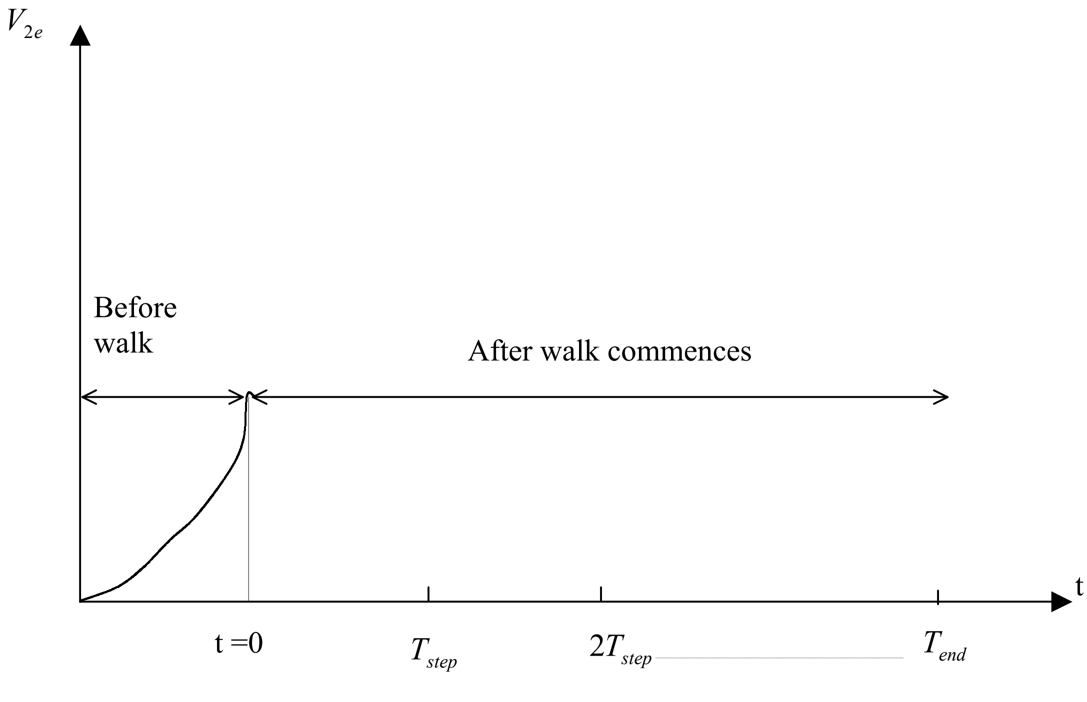
Then

$$V_{2e} = m_2 t^2 + m_1 t + m_0 \qquad (9)$$

This is the equation of a parabola and indicate that the size of drift errors in the conventional technique accelerates as time progresses.

2.5) Errors when corrections are applied

Corrections are initially applied by requiring the user to indicate the walk is about to start [Freeston, Callaghan, Russel, 1984] at t = 0, this could be done by pressing a button or a footswitch could be used. This is valid because it is one point where it is definitely known that the distance voltage error V_{2e} is equal to zero (not changing). Figure 2 illustrates this in more detail.



T_{end} : Total time of walk

Figure 2 : Corrections procedure.

From equation (9) the processor can give estimates of m_0, m_1, m_2, then it can choose values for C_1, C_2 to make the new set of m_0, m_1, m_2 parameters equal to zero.

Hence we have,

$C_1 = -(E_{00} + E_{10})$, $C_2 = -E_{20}$, $U_{20} = 0$

With these conditions, the error in indicated distance voltage would remain zero as indicated by figure 2. However, in practice further changes in E_{00}, E_{10}, E_{20} (due to temperature coefficients for example) will cause the actual values for m_0, m_1, m_2 to become non-zero and the error will again build up. Fortunately the occurrence of the switch closure with each footstep can be used to again apply new corrections.

2.6) Corrections applied when error sources are not constant

As the previous section has shown, if errors E_0, E_1, E_2 can be assumed constant, then once a correction has been applied at the start of the journey, distance voltage errors do not occur due to this source. However, in practice, these errors will not stay exactly constant. In this section, the more realistic case of non-constant error sources is examined. Let us assume for simplicity that errors drift linearly.

Then,

$$E_0 = E_{00} + X_0 t \tag{10}$$

$$E_1 = E_{10} + X_1 t \tag{11}$$

$$E_2 = E_{20} + X_2 t \tag{12}$$

Where X_0, X_1, X_2 are drift coefficients (due to temperature,…etc.) Their maximum or expected values may be specified but their actual values are not known a priori.

Substituting equations (10),(11),(12) into equation (6) yields.

$$V_{2e}=A_1A_2\int_0^t\int_0^t(E_{00}+X_0t+E_{10}+X_1t+C_1)dtdt+A_2\int_0^t(E_{20}+X_2t+U_{20}+C_2)dt+U_{20} \quad (13)$$

Because initial conditions U_{10},U_{20} are assumed to be equal to zero, then equation (13) becomes:

$$V_{2e}=A_1A_2\int_0^t\int_0^t(E_{00}+X_0t+E_{10}+X_1t+C_1)dtdt+A_2\int_0^t(E_{20}+X_2t+C_2)dt \quad (14)$$

Re-arrangement yields :

$$V_{2e}=A_1A_2\int_0^t\int_0^t(E_{00}+E_{10}+C_1)dtdt+A_1A_2\int_0^t\int_0^t(X_0+X_1)tdtdt+A_2\int_0^t(E_{20}+C_2)dt+A_2\int_0^t X_2tdt \quad (15)$$

Evaluating these expressions gives:

$$V_{2e}=A_1A_2(E_{00}+E_{10}+C_1)\frac{t^2}{2}+\frac{A_1A_2}{6}(X_0+X_1)t^3+A_2(E_{20}+C_2)t+A_2X_2\frac{t^2}{2} \quad (16)$$

As mentioned previously, when corrections are applied then

$C_1=-(E_{00}+E_{10})$ and $C_2=-E_{20}$

Therefore

$$V_{2e}=\frac{A_1A_2}{6}(X_0+X_1)t^3+A_2X_2\frac{t^2}{2} \quad (17)$$

What happens with no corrections applied is illustrated in figure 3. At t = T_{step}, the footswitch can be used to indicate a new correction and make m_0,m_1,m_2 again equal to zero by modifying C_1,C_2,U_1,U_2 to compensate for the change with time in E_0,E_1,E_2. If the E_0,E_1,E_2 stop drifting (for instance go to zero or remain constant) at this time, there would be no further errors. But assuming that X_0,X_1,X_2 stay present, the errors at each correction (once every step) will build up is significantly better than if no corrections are applied.

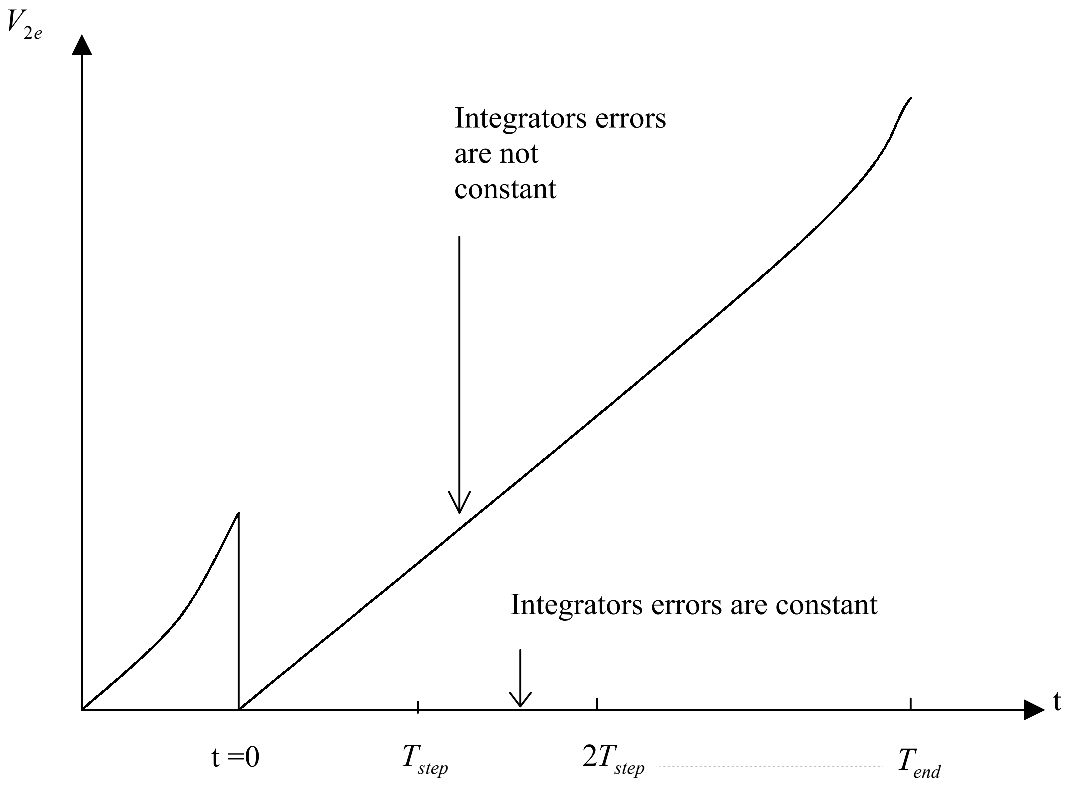


Figure3: Corrections are not applied.

2.7) Comparison of the error distance voltage when the footswitch is used and when it is not used.

For the first step and from equation (17), the error on estimated distance voltage is given by :

$$V_{2e}(T_{step}) = \frac{A_1 A_2}{6}(X_0 + X_1)T_{step}^3 + \frac{A_2}{2} X_2 T_{step}^2 \qquad (18)$$

In the worst case, which is for N steps, the error on estimated distance voltage is :

$$V_{2e}(T_{step}) = N\left[\frac{A_1 A_2}{6}(X_0 + X_1)T_{step}^3 + \frac{1}{2} A_2 X_2 T_{step}^2\right] \qquad (19)$$

Suppose we do not use the footswitch to generate corrections, then equation (17) gives :

$$V'_{2e}(T_{step}) = V_{2e}(N.T_{step}) \qquad (20)$$

For $t=N.T_{step}$, the error on estimated distance voltage becomes equal to:

$$V'_{2e}(T_{step}) = \frac{A_1 A_2}{6}(X_0 + X_1)N^3 T_{step}^3 + \frac{1}{2}A_2 X_2 N^2 T_{step}^2 \qquad (21)$$

Re-arranging this equation gives :

$$V'_{2e}(T_{step}) = N^2\left[\frac{A_1 A_2}{6}(X_0 + X_1)N.T_{step}^3 + \frac{1}{2}A_2 X_2 T_{step}^2\right] \qquad (22)$$

Equations (19) and (22) can be written in the following form :

$$V_{2e}(T_{step})=K_1.N \qquad (23)$$

and

$$V'_{2e}(T_{step})=K_2.N_2 \qquad (24)$$

where

$$K_1 = \frac{A_1 A_2}{6}(X_0 + X_1)T_{step}^3 + \frac{1}{2}A_2 X_2 T_{step}^2 \qquad (25)$$

and

$$K_2 = \frac{A_1 A_2}{6}(X_0 + X_1)N.T_{step}^3 + \frac{1}{2}A_2 X_2 T_{step}^2 \qquad (26)$$

III) Conclusion

A comparison of equations (23) and (24) shows that the error with the footswitch correction applied increases linearly with the number of steps_taken N. However, the error when correction is not applied increases at best quadratically with N.

The difference between these two equations depends on the size of constants K_1 and K_2. The size of K_2 is bigger than the size of K_1 because it is a function of N. Therefore, equation (23) is better than equation (24), hence we can conclude that this correction method offers worthwile advantages.

It should be noted in the above analysis that certain simplifying assumptions have been made. In practice, it can be expected that these assumptions do not exactly occur. In these cases, equations (18) and (19) do not apply. However, it could be expected that even so the advantages of the footswitch correction are still obtained.

In this analysis, a solution to the problem of being unable to measure accurately the distance travelled by the blind person has therefore been provided. On the other hand, and from the information given by this study, more compatible electronic aids [Shoval, Borenstein, Koren, 1998], [Snaith, Lee, Pobert, 1998] can be designed for blind travellers and visually impaired individuals.

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