Principle of free-fall detection by a 3-axis accelerometer

An accelerometer is an inertial sensor to measure the acceleration, which is obtained by deducting the gravitational acceleration (g) from the movement acceleration (a) along the direction of the input axis (sensing axis).

In short, the measured acceleration (A) is expressed by the following formula.

$$A = a - g$$

Here, g is +1g when for the gravitational acceleration, the downward direction perpendicular to the earth surface is defined as positive. And when the sensing axis leans by the angle of θ from the perpendicular direction to the earth surface, the gravitational acceleration is obtained by multiplying +1g by -cos θ .

Therefore, an accelerometer (a= 0), fixed on the earth, indicates +1g when the positive direction of the sensing axis is upward and perpendicular to the earth-surface, and when the sensing axis inclines from an upward plumb line by angle θ , it indicates the value which multiplies +1g by cos θ . On the other hand, since a equals g under free-fall condition, an accelerometer indicates zero whatever the tilt angle of an sensing axis is. Therefore, a 3-axis accelerometer indicates zero about all of the sensing axes simultaneously during free-fall, and never zero except during free-fall. (Note 1)

From this theoretic characteristic, when the indicated values (output value) of three axes show zero simultaneously, it can be judged that this accelerometer is in the condition of free-fall. Here, the free-fall means the state where there is no external force to be added to the accelerometer except for the gravity. On the occasion that the object is thrown upward, the object will be in the condition of free-fall from the moment of leaving a hand. When air resistance is large, it acts as external force. And, when an accelerometer is equipped in the point except for the rotation center of the object (for example, sphere), is rotating and falling, the centrifugal force acts by its rotation. Then, none of these above cases can be strictly called free-fall.

(Note 1) In the specific phase of vertical vibration, it may sometimes be in the state equivalent to free-fall.

Zero-Gravity detection system built in H48C

The Zero-Gravity (ZeroG) detection system is constituted as shown in **Fig. 1**. The ZeroG detector compares the absolute value of the acceleration outputted from the 3-axis accelerometer with threshold Gt for every axis. When the absolute value is smaller than threshold about all axes, the detector judges the state is Zero-Gravity and a ZeroG flag is outputted. The comparison is performed repeatedly every about 0.4ms, and if it stops satisfying the judgment conditions, the flag will disappear. The standard specification of Gt is 0.4g. Although Gt accuracy is ±0.05g, the effective accuracy will become ±0.1g if the offset voltage error (±0.05g) of the

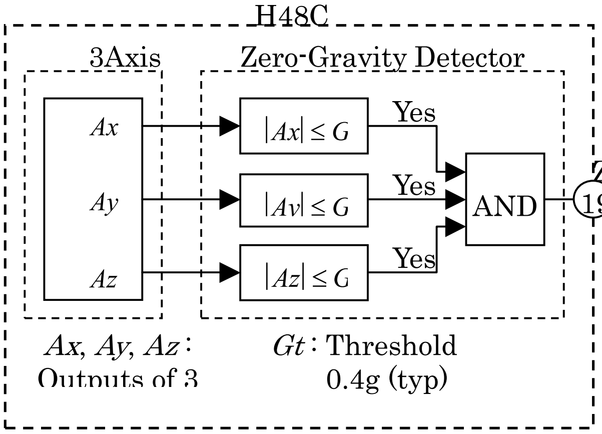

Fig.1 Blockdiagram of the ZeroG detector

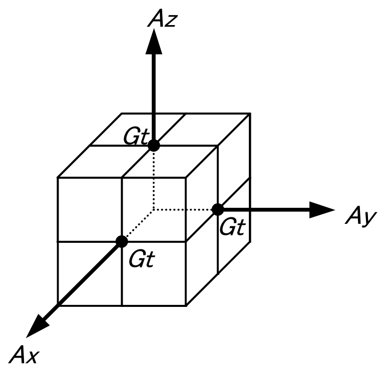

Fig.2 ZeroG detection range

acceleration detection voltage *Ax*, *Ay*, and *Az* is taken into account. In addition, the ZeroG detection range can be expressed as shown in **Fig. 2**, and a cubical inner side is the detection range.

Example of ZeroG flag waveforms

Fig. 3 shows the sensor block used for the fall experiment. H48C is mounted in a sensor block and three wires, a power supply, a ground, and a ZeroG flag, are pulled out from the block.

The example of the ZeroG flag is shown in **Fig. 4** when the sensor block was dropped from a height of 60cm. Once ZeroG is detected, a flag, which is equal to Vcc, is outputted. In the figure, the duration time of zero to about 350ms corresponds to free-falling, and the next duration corresponds to the period of a collision and a rebound. The graph on the upper side shows the waveform of the ZeroG flag observed directly, and the graph on the lower side shows the waveform observed through CR low pass filter (time constant is 10ms).

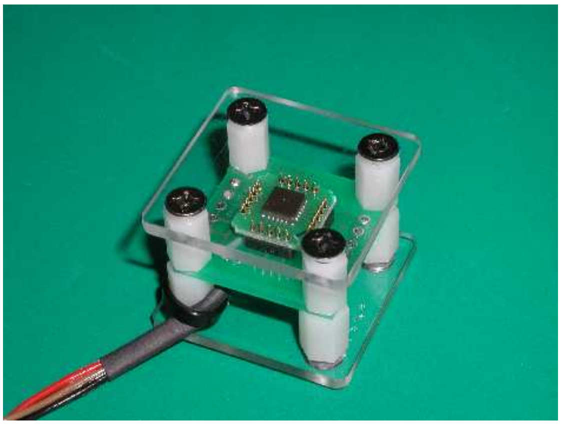

Fig.3 Photo of the sensor block

Next, the flag waveforms are simulated when the walking is done, holding a mobile apparatus with the sensor H48C. In the experiment, the vertical vibration was applied to the sensor block by hand with the magnitude of about 3 cmp-p. The result is shown in **Fig. 5**. The flag waveforms of the width for several 10ms occurred according to the cycle of the vibration. Moreover, chattering was also generated.

Thus, there is a case that ZeroG flags are also generated under the conditions other than free fall. However, when the above-mentioned two cases are compared about waveform width, it is clear that the waveform width is wide in the case of free fall and narrow in the case of the vibration. Therefore, it is considered to be possible to discriminate the free-fall from other cases with high accuracy by using the difference in these characteristics between the above-mentioned two cases, free-fall and vibration.

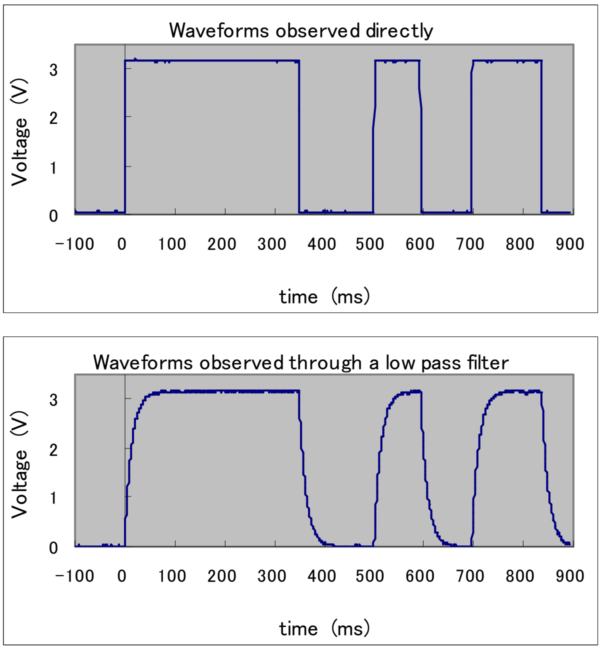

Fig.4 ZeroG Flag waveform in free-fall

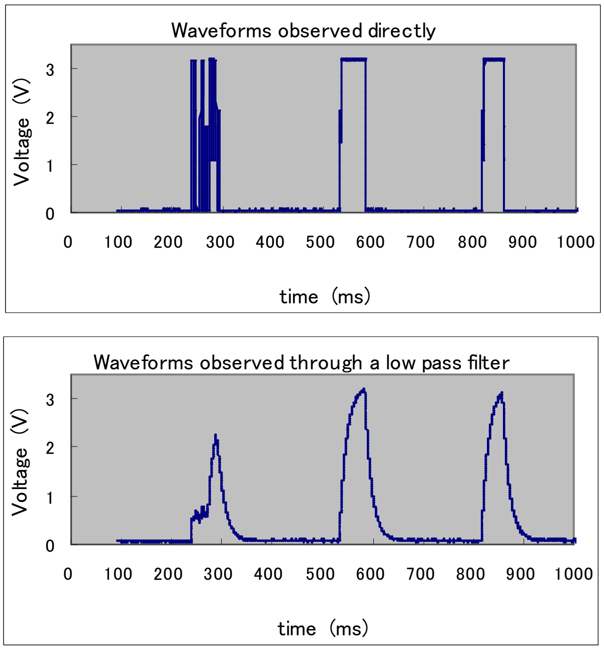

Fig.5 ZeroG Flag waveform in vibration

The method of free-fall judgment

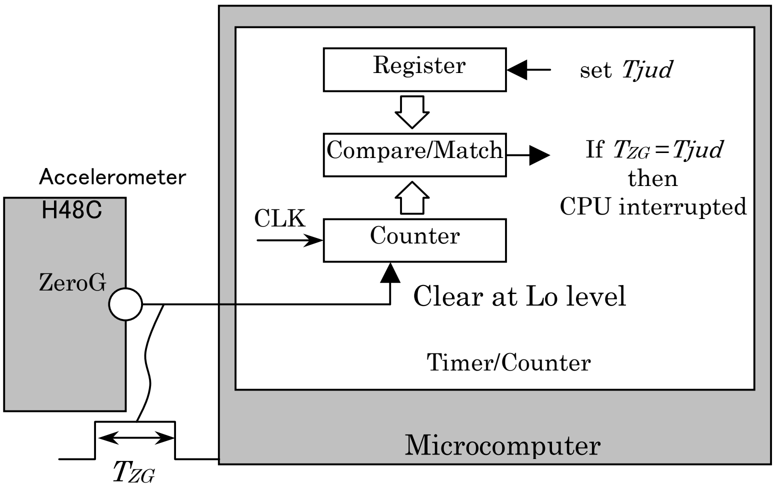

Fig. 6 **Block diagram of the free-fall judging**

Fig. 6 shows the block diagram of the free-fall judging based on the above-mentioned idea.

Below, a series of operation for a free-fall judgment is explained briefly.

The width T_{ZG} of the pulse of a ZeroG flag is equivalent to the continuation time of the Zero-Gravity condition. T_{ZG} is compared with the continuation judging time (*Tjud*), set in the resister in advance, by using the timer-counter function of a microcomputer, and when T_{ZG} becomes equal with *Tjud*, the alarm of free-fall is generated. And the CPU, interrupted by the alarm, starts the protective action to minimize the damage by the collision to the floor as a task of the 1st priority.

Supplementary explanation is given below. The counter is controlled by the T_{ZG} pulse in the operation, only Hi-level period of a T_{ZG} pulse counts up CLK, and the period of Lo level continues clearing a count value. Therefore, when a T_{ZG} pulse rises to Hi from Lo level, a count value is surely started from zero. The compare-match part is continuously watching the count value and the register value. And when a count value reaches the register value corresponding to *Tjud*, an output is generated, and high priority interruption is passed to the CPU.

In addition, since the timer-counter operates independently of the CPU, the operation of the above-mentioned free-fall detection does not become load excessive for the CPU during free-fall monitoring.

Among the number (*B*) of bits of a counter, the clock frequency (*fclk*), and the continuation judging time (*Tjud*), the restrictions conditions exist, expressed with the following formula.

$$fclk < 2\ B/Tjud$$

For example, since it is required in the case of *B*= 16 and *Tjud*=100ms that a clock frequency should be 650kHz or less, the count down ratio from a main clock must be set up along with these values.

For the lower probability to misjudge the vibration as free-fall, the longer continuation judging time *Tjud* is desirable. However, attention must be paid to that the time for the protection processing, performed after free-fall judgment, decreases if *Tjud* is too long. There is some reports referred to *Tjud* for which around 100ms was suitable.

A logic circuit can also be substituted for a microcomputer. **Fig. 7** shows the example of a logic circuit for free-fall judging. When free-fall is judged, an LED drawn on the upper right part lights up. This circuit is convenient, when examining the optimal value of *Tjud*, since a setup of *Tjud* can be performed in the combination of the 8-bit DIP switch drawn on the right end of a figure. In addition, in this example of a circuit, the low pass filtering and the pulse reforming circuits with a comparator are used for avoiding the influence of chattering. However, these are not necessarily required.

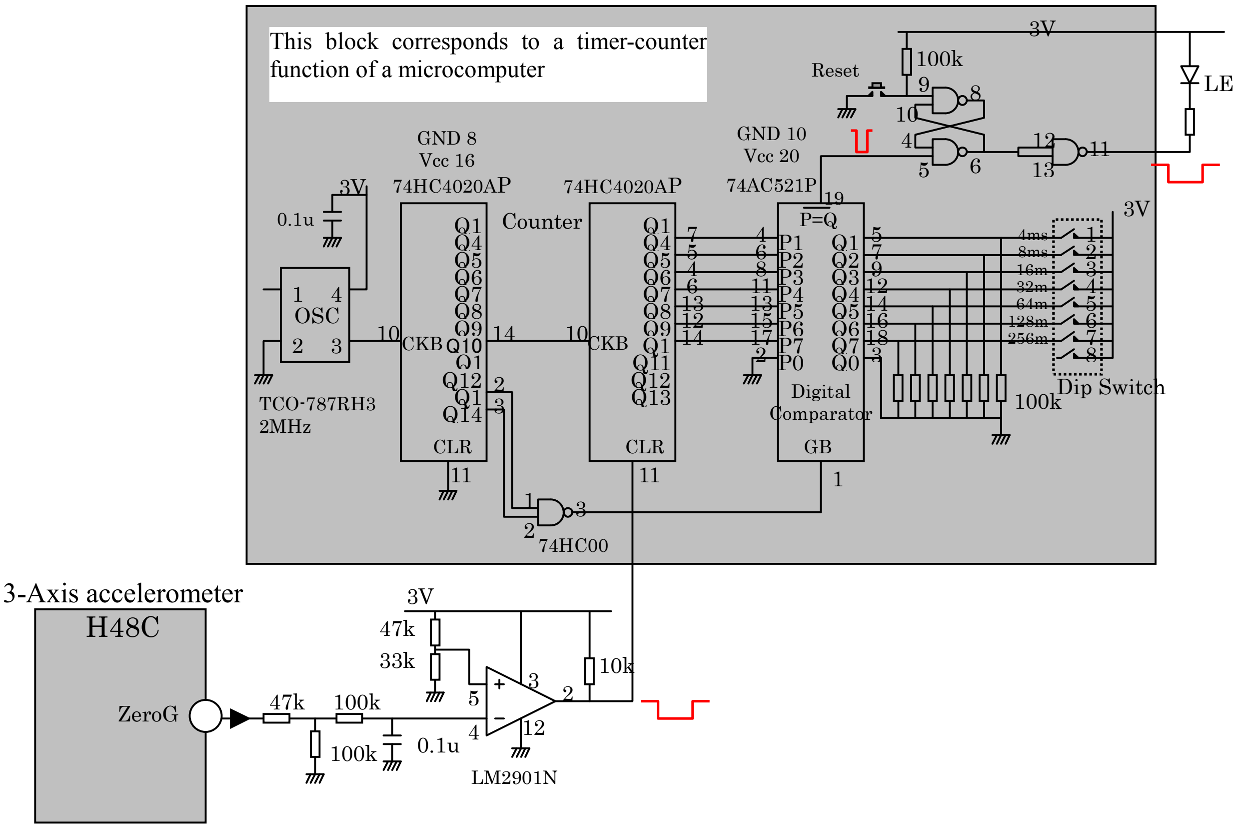

Fig.7 Example of a logic circuit for free-fall judgment