Exploring a Human-Machine Interaction Method

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ABSTRACT: Human-machine interaction (HMI) technology directly affects the experience and efficiency of computer users. Graphical interface first allowed us to operate machines with the ease of point-and-click and touchscreens removed the mouse altogether. Now, a new revolution begins as we imagine operating computers with just our heads. We intend to use the user's head as a mouse, with point-and-nod instead of point-and-click. This new technology can solve shortcomings of both mice and touchscreens. To construct a "head mouse," an earphone is embedded with a 3-axis angular velocity sensor that follows and measures the head's angular velocities in three-dimensional space. The theoretical analysis and tested data indicate that the moving direction and nod/shake of head movements can be identified through the polarity and value of the angular velocity of the three-axes. As a result, pointing is done by detecting and identifying the direction of head movements and clicking is done by identifying a nod motion. By using the head mouse, a more convenient HMI can be realized

KEYWORDS: Head Mouse; Pointing; Clicking; Head Movement Detection; Human-Machine Interface; Bluetooth Earphone; Human Interface Device; Gyroscopen.

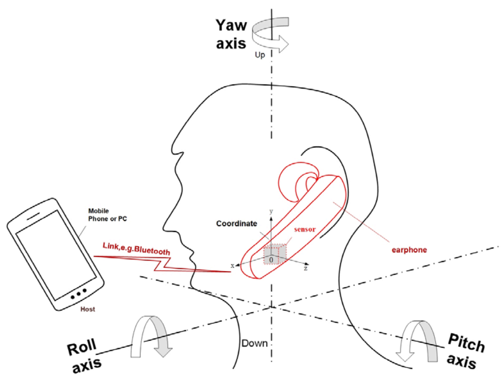

Figure 1: Conception of the head mouse, a human–machine interaction apparatus, and illustrates the mounting position of the angular velocity sensor in the earphone, the coordinate system used, and the direction of rotation of the head movement in ³D space.

INTRODUCTION

Background

Human-machine interaction (HMI) technology directly affects the experience and efficiency of users. Every advancement in HMI technology changes the IT industry. The graphical interface known for its implementation in Windows® and Macintosh® in the computer age allowed us to operate a computer with a mouse.[1] However, a flat surface is required for mice, thus making it difficult to apply this technology to small electronic products. Nowadays, mobile phones use touchscreens and move-and-touch rather than a mouse and point-and-click. As electronic devices become smaller, the touchscreen also becomes smaller. With this, many users find it difficult to press a specific key one their phone's small, virtual QWERTY keyboard. In some instances, even a touchscreen can be inconvenient, especially for those who are drivers, firefighters, or disabled. Wearing gloves also renders touchscreens unusable. The question of whether we can find a more convenient and natural input method becomes important.

HYPOTHESIS

To solve the issues discussed above, this project intends to use a user's head as a "mouse" with point-and-nod instead of the traditional point-and-click method. To detect the head movement, we initially wanted to use facial recognition technology as it is very popular. We assumed that a technology so mature would easily recognize head movements. However, facial recognition technology based on optical photography has low recognition rate in low light and results in high power consumption. Although Apple, Inc. used an infrared camera to solve the problem of low light recognition rate, it still has the power consumption problem. Therefore, facial recognition was deemed unsuitable for HMI.

Optical emitters and photo detectors or time of flight (TOF) sensors are also used to track the head or eyeball movement. These methods use infrared light or lasers to emit and reflect in the eyeball, which is not good for human eyes.

The most ideal technology for HMI is motion sensors through the installation of sensors in an earphone that follows head movement. Compared with eyeglasses or other wearable devices, an earphone is preferred because it not only tracks the movement of the head in the direction of the eye's sight but also reduces the foreign body sensation and avoids the situation in which individuals who already wear glasses must wear an extra pair of glasses.

By studying the characteristics of head motion while browsing a screen and utilizing the look-and-nod operation (assuming that the person is sitting or standing, the body is immobile and only the head moves), it is found that the head cannot move freely due to neck limitations. The head movement is not a translation, a uniform movement without rotation,[2] but rather it rotates around the neck. Therefore, the rotation sensor (also called an angular velocity sensor or 3-axis gyroscope) is used to detect the head motion as shown in Figure 1.

Goal

This research aims to find an HMI method that enables user interaction with an electronic device by turning the user's head to provide the mouse's point-and-click functionality.

Turning your head will cause the cursor to move with the distance of the cursor movement being proportional to the amplitude of rotation, nodding to click, and shaking your head to "escape" or backspace.

Conception

A Bluetooth earphone was selected as a carrier for following head movements and a 3D rotation sensor (3-Axis Digital Micro Electro Mechanical Systems Angular Velocity Sensor) was added to the earphone to detect and sense head movement following the eye movement, including its direction, displacement, and the nodding/shaking head action.

As long as we find a way to recognize the head movement direction, movement displacement, nodding and shaking head action, the actions can be used as a mouse.

The remaining project parts are the standard human interface device (HID) processes, such as like encoding the head motion recognition outputs and mapping to corresponding mouse axis code and left or right button code.[3] For example, the left and right movement of the head and the displacement are mapped to the x-axis code of the standard mouse device: +/- d, which is used to report the displacement of the cursor along the x-axis, where d means displacement, + means right movement, and - means left movement. Up and down head movement and the displacement are mapped to the y-axis code of the standard mouse device: +/- d, which is used to report the displacement of the cursor along the y-axis, where d means displacement, + represents upward movement, and - represents downward moving. Nodding is mapped to the mouse's LEFT buttons, and then transmitted to the mapped axis codes packed by the standard HID protocols service to the host to be controlled via wireless or wired connectivity. The host responds to the motion events and dispatches the mapped axis codes to corresponding APP to control the cursor and complete the point-and-click. The host may be any electronic device including a cell phone, PC, or iPad.

The 3D sensor identifies different movement directions (up/down/left/right) via the rotation sensor. The sensor is mounted in a position that its y-axis is parallel to the head's y-axis and the z-axis is parallel to the pitch axis of the user's head rotation. The x-axis is parallel to the roll axis of the user's head to detect and recognize the head rotation. This allows for the motional characteristic that the head rotates around the z-axis when moving up and down and rotates around the y-axis when moving left and right.

The rotation sensor is a digital 3-axis angular velocity sensor similar to the ST® L3GD20H[4], BOSCH® BMG250[5], and NXP® FXAS21002C[6] models. The sensor used is 3mm x 3mm x 1 mm and has very low power consumption, which is different from the traditional analog angular velocity sensors that output analog signals. The digital sensor can directly output the angular velocity value.

The angular velocity sensor reports the angular velocity along three coordinate axes with positive and negative signs; a positive value indicates rotation counterclockwise and a negative value indicates rotation clockwise. The direction of the angular velocity is obtained by the righthand-thread rule.

Additionally, the angular velocity sensor has a built-in high-pass filter and a low-pass filter. This makes it easy to delete the DC component of the measured angular rate and removes some noise interference.

The angular velocity sensor usually provides an interrupt function; detecting that the angular velocity value is greater or less than the set threshold will trigger the interruption and handle the event by microprocessor. The interrupt register can also define a detection time where once the time is reached and the threshold is exceeded, an interrupt is triggered. A practical movement and wake-up interrupt are provided for power management; the earphone goes into power-saving mode when not moving and only enters the normal working mode when it is rotated.[4]

Summary

Based on the above conception of a head mouse, we analyzed the head movement characteristics of the point-and-nod operation and performed an experimental verification. The tested data indicated that the moving direction and nodding/shaking of one's head can be identified by detecting the polarity and value of the 3-axis angular velocity and the moving distance can be obtained by integrating the measured angular velocity. Thus, a more natural and convenient human-machine interaction method can be realized because where you are watching is where the cursor will point.

Characteristics & Advantages

Compared with other HMI methods, the present method has the following advantages:

- The operation is natural (for example, where you are watching is where the cursor will point) because it does not occupy surface space when used and frees your hands to do other things.
- The head movement is the rotation around the neck and the rotation angle does not exceed +/-180 degrees. Therefore, an angular velocity sensor that measures rotational motion is more suitable than an accelerometer that detects linear motion.[2]
- Compared with head gesture recognition based on optics (such as camera, optical emitters and photo transistors), head point-and-nod recognition based on an angular velocity sensor has the advantages of small size, low power consumption, and low cost.

- With wireless remote operation capabilities, it is no longer necessary to sit at a table and move the mouse or wave a laser pointer as well as reserve surface space for mouse movement. The head mouse can be used in free 3D space to achieve convenience of operation.
- Instead of eyeglasses or other wearable devices, an earphone can not only track the movement of the head in the direction of the eye's sight, but also reduce the foreign body sensation and avoid having to ask people to wear multiple glasses simultaneously.

RESULTS AND DISCUSSION

Based on the head mouse conception, we analyzed and tested the head movement characteristics of the point-and-nod operation. There were six cases to analyze and test.

The following is brief instructions for the experiment: the evaluation board (EVB) supplied by the sensor vendor is strapped onto the Bluetooth earphone and the earphone is worn on the head to simulate the head mouse device assumed in this research. The EVB is connected to the PC via a USB cable. The software tool attached to the EVB can be used to test real-time angular velocity and can automatically draw the angular velocity versus time curve. The evaluation kits (EVB+ PC software tool) were used to test data under the following cases.

Case 1: Turn head from right to left

When the head turns left, it rotates around the y axis and there is no rotation around the pitch and roll axes. Therefore, the characteristic of the head turning left should be that the angular velocity on the y-axis is positive (indicating rotating in counterclockwise direction), and the measured angular velocity on the x- and z-axis is zero. The test results for case 1 is shown in Figure 2. The experimental results are mostly consistent with the theoretical analysis.

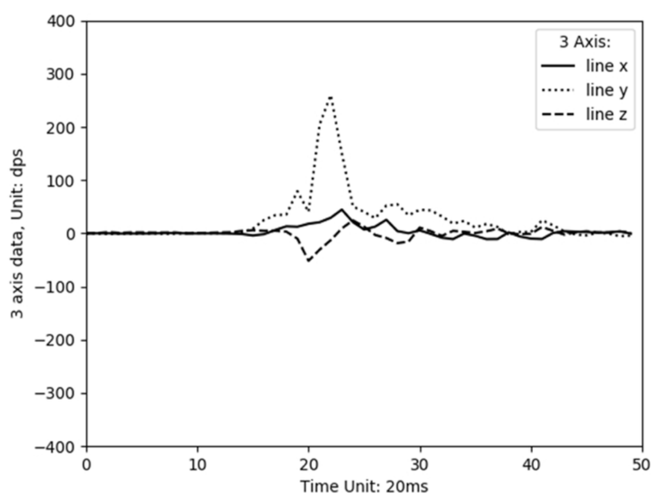

Figure 2: The measured angular velocity versus time curve of the triaxial in case of turning the head left.

Case 2: Turn head right (from left to right)

When the head turns right, it rotates around the yaw axis. while there is no rotation around pitch and roll axes. The characteristic of head turning right should be that the angular velocity of the y-axis is negative (indicating rotating in clockwise direction) and the angular velocity of the x- and z-axis is zero. The actual test results for case 2 is shown in Figure 3. It shows that the experimental results are mostly consistent with the theoretical analysis.

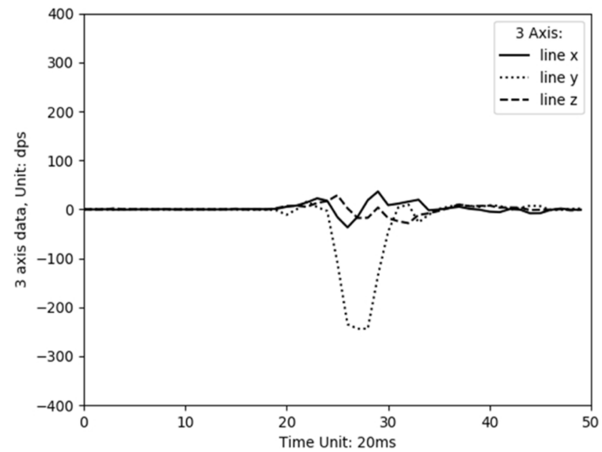

Figure 3: The measured angular velocity versus time curve of the triaxial in case of turning the head right.

Case 3: Turn head up

When the head turns up, it rotates around the pitch axis and there is no rotation around yaw or roll axes. The characteristic of the head should be that the angular velocity of the z-axis is negative (indicating rotating in clockwise direction) and the angular velocity of the x- and y-axis is zero. The actual test results for case 3 is shown in Figure 4, which show that the experimental results are mostly consistent with the theoretical analysis.

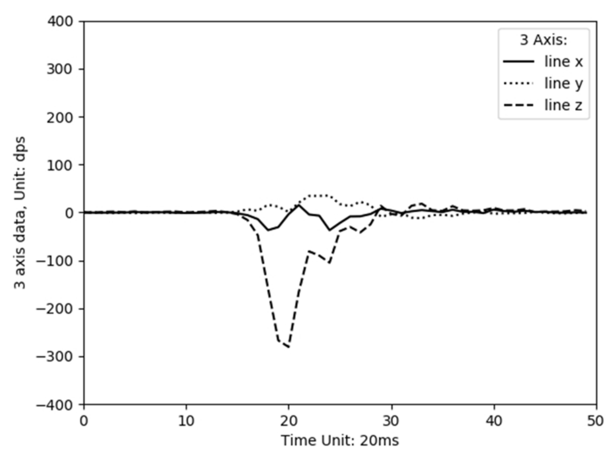

Figure 4: The measured angular velocity versus time curve of the triaxial in case of turning the head up.

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Case 4: Turn head down

When the head turns down, it rotates around the pitch axis while there is no rotation around the yaw or roll axes. The characteristic of head down should be that the measured angular velocity of the z-axis is positive (indicating counterclockwise rotation) and the measured angular velocity of the x- and y-axis is zero. The actual test result for case 4 is shown in Figure 5. We can see that the experimental results are mostly consistent with the theoretical analysis.

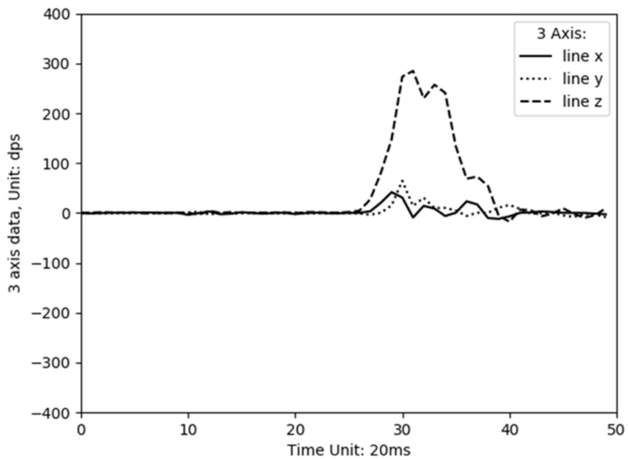

Figure 5: The measured angular velocity versus time curve of the triaxial in case of turning the head down.

Case 5: Nodding head action

When the head is nodding (moving quickly up and down), it rotates around the pitch axis while there is no rotation around yaw or roll axes. The characteristic of the nodding action should be that the angular velocity of the z-axis alternates between positive and negative and the angular velocity of the x- and y-axis is zero. The actual test result for case 5 is shown in Figure 6. The experimental results are mostly consistent with the theoretical analysis.

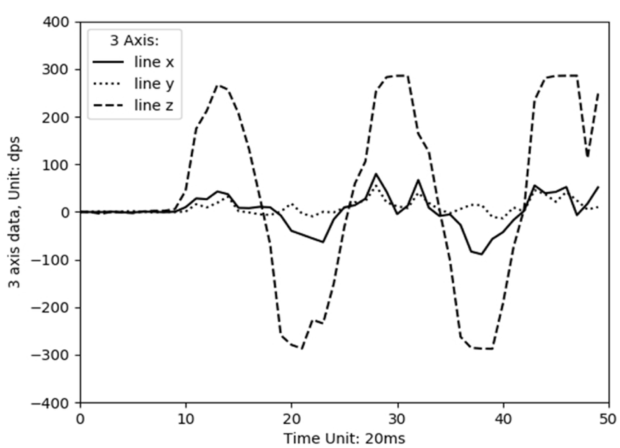

Figure 6: The measured angular velocity versus time curve of the triaxial in the case of nodding head.

Case 6: Shaking head action

When the head shakes (moving quickly left and right), it rotates around the yaw axis while there is no rotation around the pitch or roll axes. The characteristic of the shaking action should be that the angular velocity of the y-axis alternates between positive and negative and the measured angular velocity of the x- and z-axes is zero. The actual test result for case 6 is shown in Figure 7. We can see the experimental results are mostly consistent with the theoretical analysis.

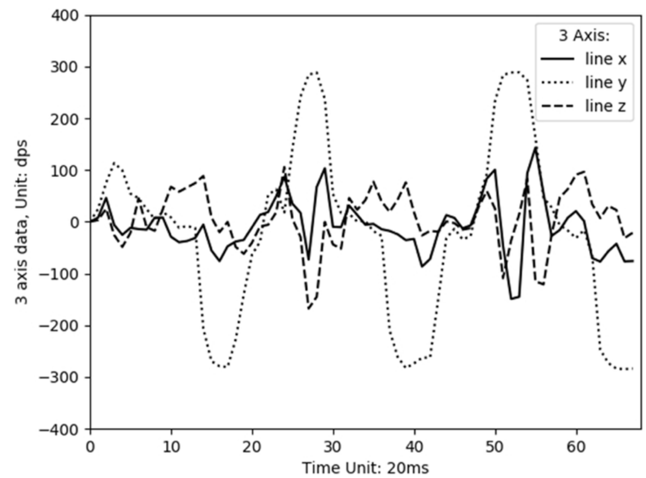

Figure 7: The measured angular velocity versus time curve of the triaxial in case of shaking head.

DISCUSSION

We found the results were slightly different from our expectations. For example, when the head turns left, theoretical analysis shows the measured angular velocity of the x- and z-axes should be zero. However, it was not zero but had a certain amount of change. There are two reasons for this. One is that when the head turns left, it is difficult to ensure that the head is only translated (moved horizontally, a movement without rotation) because there may be up and down movements. Another reason is that it is difficult to guarantee the rotation sensor is mounted in a position such that the x-, y-, and z-axes are parallel to the roll, yaw, and pitch axes of the head, respectively. Using the experimental data, however, when compared with the large change in the y-axis angular velocity, the angular velocity of the x-axis and z-axis changes very little, which is easily distinguishable. By setting a certain threshold we can filter out these effects.

The angle information is obtained by integrating the angular velocity. Although the angular velocity sensor has a built-in high-pass filter and low-pass filter for removing noise interference, slight deviations in the angular velocity signal causes a cumulative error after the integral calculation. This error will gradually increase with time. To eliminate the cumulative error of the gyroscope, it can be calibrated through the angle information obtained by another acceleration sensor. For this project, the gyroscope angular velocity sensor in the 6-axis inertial measurement unit (3-axis digital accelerometer and 3-axis digital gyroscope 2-in-1 component) is used to identify the head's rotation angle and an acceleration sensor is used to

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calibrate. The joint implementation ensures the stable recognition of the head's rotation angle.

Summary

According to the above theoretical analysis and experimental data, we can develop a recognition method of the head point-and-click.

For movement left, if the measured y-axis angular velocity in a certain duration exceeds a certain threshold value, then the polarity is positive. If this is true and the angular velocity of the x- and z-axis change is small, then the head is considered to be turned left. This is expressed as:

$Ay>0$ & $Ay>threshold$ & $Ax<|threshold_{min}|$ & $Az<|threshold_{min}|$ (where Ax, Ay, and Az represent the angular velocity of x-, y-, and z-axes, respectively)

For movement right, if the measured y-axis angular velocity in a certain duration exceeds a certain threshold value, then polarity is negative. If this is true and the angular velocity of the x- and z-axis change is small, then the head is considered to be turned right. This is expressed as:

$Ay<0$ & $Ay>|threshold|$ & $Ax<|threshold_{min}|$ & $Az<|threshold_{min}|$ (where Ax, Ay, and Az represent the angular velocity of x-, y-, and z-axes, respectively)

For movement up, if the measured angular velocity of the z-axis in a certain duration exceeds a certain threshold value, then polarity is negative. If this is true and the change in angular velocity of the x- and y-axis is small, then the movement of the head up is considered to have occurred. This is written as the following expression:

$Az<0$ & $Az>|threshold|$ & $Ax<|threshold_{min}|$ & $Ay<|threshold_{min}|$ (where Ax, Ay, and Az represent the angular velocity of x-, y-, and z-axes, respectively)

For movement down, if the measured angular velocity of the z-axis in a certain duration exceeds a certain threshold value, then polarity is positive. If this is true and the angular velocity of the x- and y-axis changes little, then the head is considered to be down. This is written as the following expression:

$Az>0$ & $Az>|threshold|$ & $Ax<|threshold_{min}|$ & $Ay<|threshold_{min}|$ (where Ax, Ay, and Az represent the angular velocity of x-, y-, and z-axes, respectively)

It is also necessary to detect the displacement of the head movement to determine the distance that the cursor will move. Since the head moves with the neck as the axis of rotation (see Figure 1), the distance is the radians of the head's rotation. This is obtained by integrating the measured angular velocity.

The definition of angular velocity is:

$\because A = d\theta / dt$ (θ is radians traversed, t is time, A is angular velocity, unit is rad/s)

$\therefore \theta = \int A\, dt$ (t is the time, A is angular velocity, unit is rad/s)

The amplitude of rotation(θ) is used to determine the cursor movement.

For nodding, if the measured angular velocity of the z-axis in a certain duration exceeds a certain threshold value, then the polarity alternates between positive and negative. If this is true and the angular velocity of the x- and y-axis changes little, then the movement of the nodding is considered to have occurred. This is expressed as:

$|Az|>threshold$ & $Ax<|threshold_{min}|$ & $Ay<|threshold_{min}|$ (where Ax, Ay, and Az represent the angular velocity of x-, y-, and z-axes, respectively)

For shaking, if the measured angular velocity of the y-axis in a certain duration exceeds a certain threshold value, then the polarity alternates between positive and negative. If this is true and the angular velocity of the x- and z-axis changes little, then the movement of the shaking head is considered to have occurred. It is written as the expression:

$|Ay|>threshold$ & $Ax<|threshold_{min}|$ & $Az<|threshold_{min}|$ (where Ax, Ay, and Az represent the angular velocity of x-, y-, and z-axes, respectively)

CONCLUSION

This project found a method to recognize head movement direction, displacement, and nodding/shaking actions. It can be used to construct a "head mouse". Pointing is obtained by detecting and identifying the direction of head movements; clicking is obtained by identifying a nodding motion. This utilizes look-and-nod motions instead of point-and-click motions with a mouse. Through this method, a more natural and convenient human-machine interaction method can be realized, in which the direction you are watching is where the cursor will point.

METHODS

Procedures

We purchased demonstration and evaluation kits from the vendor of angular velocity sensors (NXP Semiconductors, ST Microelectronics, and Bosch Sensortec GmbH). The kits include a sensor daughter board and an MCU controller board with a USB port. The kits communicate via USB with a host computer and provides a visualization software tool to support the collection and analysis sensor data through the MCU controller board combo connected to a computer via a USB port. This enables quick visualization of sensor data based on the pre-configured sensor settings in the firmware. The real-time sensor evaluation enables easy changes to critical sensor settings and data logging during sensor demonstrations. The register level interface provides a register map for the sensors thus allowing quick reading and writing of different register bits and enabling detailed sensor evaluation.[7]

The evaluation board (EVB) is strapped to a Bluetooth earphone and is worn with an earphone to simulate the head mouse device assumed in this research. The earphone used in this experiment only serves as a fixed carrier to follow the movement of the head without any electrical connection. The EVB must be mounted in a position such that the y-axis of

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the sensor is parallel to the yaw axis of the user's head rotation, the z-axis is parallel to the head's pitch axis, and the x-axis is parallel to the head's roll.

We powered on the EVB and ran the software tool attached to the kits. After initializing the various registers of the sensor, you can measure the angular velocity in real-time. Since it can directly draw the angular velocity versus time curve, we just turn the head in left/right/up/down directions, nod or shake head to simulate the point-and-nod operation and export the angular velocity versus time curve in different test cases.

The experiment needed to control the initialization parameters registers setting such as the following: X/Y/Z axis enable; power mode: normal mode; high Pass filter mode: enable, high pass filter cut off frequency:16Hz; ODR(Output Data Rates): 60Hz; interrupt: enable.

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