Roly-poly: A Haptic Interface with a Self-righting Feature

Seung-Chan Kim[1], Byung-Kil Han[1], Soo-Chul Lim[1],
Andrea Bianchi[1], Ki-Uk Kyung[2], and Dong-Soo Kwon[1]

[1] Human Robot Interaction Research Center, KAIST
335 Gwahangno, Yuseong-gu, Daejon 305-701, Republic of Korea
{kimsc,hanbk,limsc,andrea}@robot.kaist.ac.kr, kwonds@kaist.ac.kr
http://robot.kaist.ac.kr, http://touch.kaist.ac.kr
[2] POST-PC Research Group,
Electronics and Telecommunications Research Institute
138 Gajeongno, Yuseong-gu, Daejeon, 305-700, Republic of Korea
kyungku@etri.re.kr

Abstract. In this paper, a human-computer interface equipped with self-uprighting feature and haptic feedback functionality as a PC peripheral is proposed. Device motion triggered by a user is sensed through embedded inertial sensors. Taking advantage of a mechanical structure incorporating a weighted bottom and mass symmetry, the device uses restorative uprighting force to right itself, making erratic motion once tipped over. The acceleration values are counterbalanced once yaw motion is applied by a user. The haptic feedback in this system is intended for both the realization of subtle detent effects and surface transmitting vibrations. Providing impulse tactile feedback according to gestural input, the device can function as a rotatable knob which is mechanically ungrounded. Moreover, surface transmitting vibration generated by linear actuators provides notifications of events important to the user in the form of ambient haptic feedback. With the utilization of the proposed features, it is expected that both intuitive information input and practical use of haptics in a desktop environment can be achieved.

Keywords: haptic interface, self-centering interface, ambient haptic feedback.

1 Introduction

Allowing users to perform a task with the appropriate mapping of captured sensor data using gestures such as strokes, shaking, tilting and twisting, gestural interface systems have been utilized in a variety of application fields. Sreedharan et al. proposed a method for interaction with a 3-D virtual world using a commercial interface [1]. For social interaction in the virtual world, gestures by virtual characters, such as waving, were controlled from a hand-held device. Additionally, based on the gestural information, numerous life-log systems were proposed for a context-based service [2] and for abnormality detection [3]. For gesture-based affective communication, haptic functionality was recently embedded [4]. However, because haptic feedback requires

A.M.L. Kappers et al. (Eds.): EuroHaptics 2010, Part I, LNCS 6191, pp. 332–339, 2010.

visual attention while physical contact is established and cognitive attention while transmitting the physical feedback, it ironically results in heavy user loads at times, despite the fact that the objective of haptic feedback is to help users. This inherent contradictive problem of haptics has prevented the applications related to haptics from being developed in practice. In this paper, inspired by typically perceived phenomena such as the vibration from a mobile phone located on a desk without any attention in the event a notification call arrives, notification using tactile feedback in the form of surface transmitting vibration is proposed. This paper introduces and explains the features of the gesture-based human-computer interface with both direct and indirect haptic feedback functionality.

2 Motion Input

In this section, the proposed human-computer interface with restorative uprighting force which can be used for desktop work is described. Having a center of mass located below its geometrical center, it returns to its undisplaced configuration when released. Fig. 1 shows the mechanical structure of the developed device. The system follows the structure of a roly-poly toy which rocks when touched due to the weighted and rounded bottom. This feature has several advantages during user input, each of which will be explained in turn.

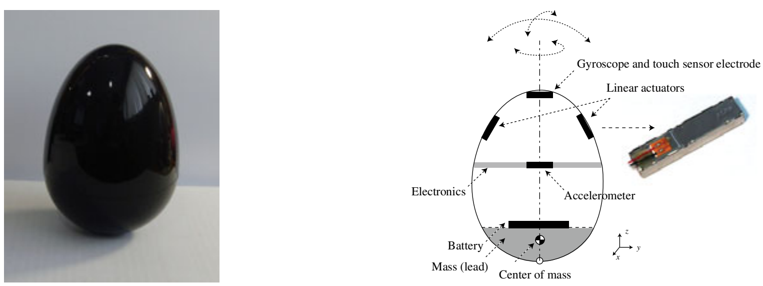

Fig. 1. Developed system which can be categorized as an inertial proprioceptive device [5] and corresponding mechanical diagram in an undisplaced configuration

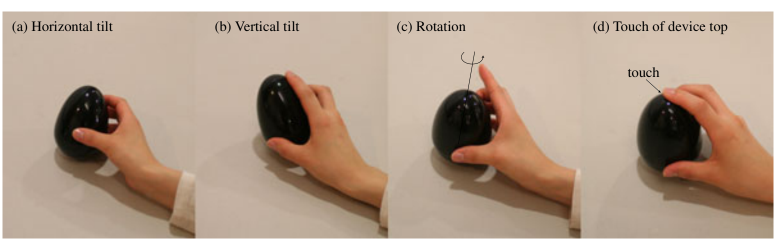

Fig. 2. Different types of motion that can be sensed

2.1 Return to the Original Position

As the proposed system tends to return to its original home position once tilted, the accumulative drift error of the acceleration signals can be easily offset in a repeated manner. Providing subtle kinesthetic feedback caused by the restoration movement, the returning functionality also allows a user to input 2-DoF signals as an isometric joystick which senses the force and adopts a returning function using mechanical grounding [6]. Owing to the absence of additional external structures, akin to an isometric joystick, the entire system can remain small and move freely on a desk or even in space.

2.2 Various Patterns

As gestures are stylized motions that contain meaning, various patterns can be created in an HCI context using a gesture-based interface. These patterns are generally utilized as control input data. Due to the limited capability of humans [7], however, the spectral feature of the gesture signal is limited in terms of its bandwidth. Moreover, it has a single dominating frequency. With the utilization of the proposed system, a wide variety of patterns can be achieved with the benefit of irregular device motions such as rolling, spinning, oscillating and wobbling. Information with both intentional and unintentional frequency components can be used for entertainment applications. Fig. 3 shows an example of a pattern generated from a system with an initial external force.

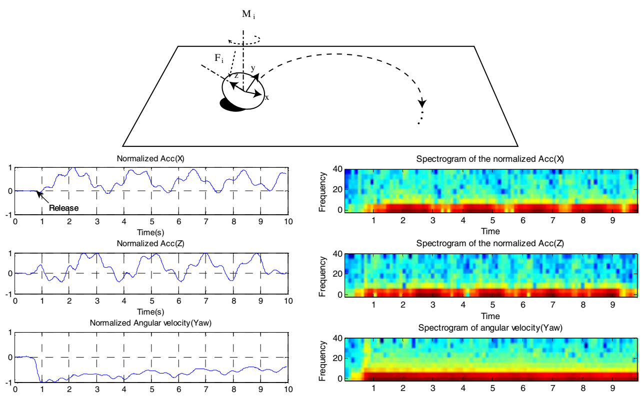

Fig. 3. Example of erratic motion triggered by initial force (F_i) and moment (M_i) provided by the user. Resultant motion signal in the time domain and the corresponding spectrogram shows that two or more frequency components dominate.

2.3 Coordinate Calibration for Input-Output Correspondence

Once rotated with respect to the inertial vertical line (z-axis), the coordinates of the sensors are changed. As this problem raises the issue of kinesthetic correspondence [6, 8], the coordinates must be calibrated after the rotation motion is applied. This section introduces a counterbalancing method that resolves the described usability issue. Acceleration data at a specific time is utilized for the estimation of rotated angle, α, rather

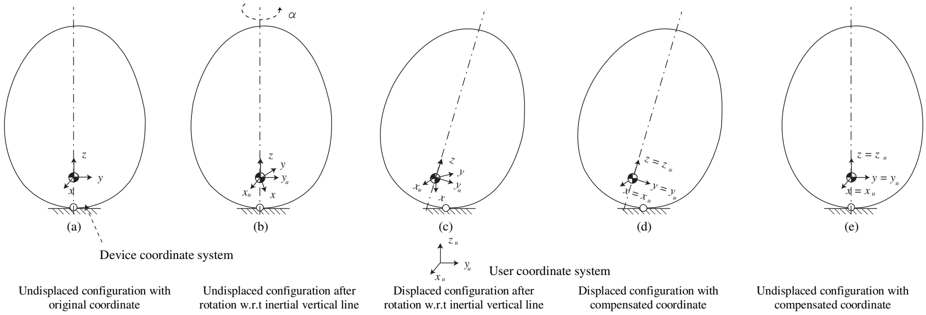

Fig. 4. After counterbalancing, a user can manipulate the device in its initial state

than using data from a gyroscope due to the accumulative measurement error that arises with a gyroscope. The proposed calibration method starts with the predefined actions of tilting to the y-axis in user coordinate followed by the touching of the device top.

Given that the rotation occurs with respect to the z-axis of the accelerometer, the inertial vertical axis, the calibration of the coordinate can be expressed by Eq. (1).

$$Rot_z(\alpha)A = \tilde{A} \tag{1}$$

To estimate the rotation angle, α, instantaneous acceleration data at a predefined position, the positive y-direction of the user coordinates is utilized.

$$\begin{aligned} &\begin{pmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} = \begin{pmatrix} 0 \\ \tilde{a}_y \\ \tilde{a}_z \end{pmatrix}, \ \alpha = \arctan(a_x / a_y) \\ &\tilde{a}_y = a_x \sin\alpha + a_y \cos\alpha \\ &\quad = a_x \sin\left(\arctan\left(a_y / a_x\right)\right) + a_y \cos\left(\arctan\left(a_y / a_x\right)\right) \end{aligned} \tag{2}$$

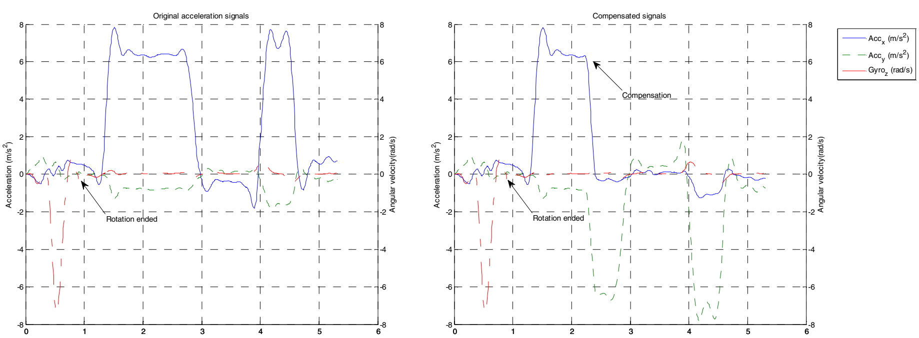

Fig. 5. An example of the calibration process

Once the rotation angle, α, is determined, noncorrespondence between the perceptual coordinates of the user and the actual coordinates of the device when issuing the tilt-based commands can be resolved.

3 Haptic Feedback

In this system, haptic feedback is mainly delivered in the form of tactile feedback. One functionality of tactile feedback in this system involves providing information about gestures issued by the user [9]. For attention-free interaction, the indirect use of tactile feedback is also considered.

3.1 Ungrounded Haptic Wheel

Numerous haptic effects have been researched, such as detents, ridges, friction and snaps to a specific position in the form of a haptic dial or a rotary knob [10]. The concept of tactile feedback for detents in a rotary configuration is similar to that of a haptic grid [11], which divides the workspace using haptic planes. The virtual detents faced while making a gesture allows a user to acquire a sense of velocity if the spatial interval is constant, although the amount of this content is uncountable. Providing impulse tactile feedback with an actuation time of approximately 10ms, a subtle detent effect was represented. The objective of the detent effects according to the gesture information is to give a user sense of tilting. The graph below shows the gesture patterns and corresponding tactile pulses.

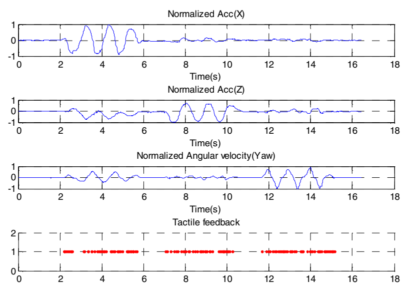

Fig. 6. Issued tactile feedback according to the gesture. The red dot in the fourth graph represents the fired tactile feedback for a subtle detent effect.

3.2 Indirect Haptic Feedback

Inspired by phenomena that are commonly perceived, such as the vibration from a mobile phone located on a desk without any attention in the event a phone call arrives, notification using indirect tactile feedback is proposed in this section. These types of haptic feedback events can be categorized as *indirect haptic feedback*. As feedback can be transmitted to the wrists, which are typically resting on the desk, it can be considered that implementing the indirect haptic functionality is an alternative means of providing additional information to users. The transmitted information has advantages in that the form of the information is private [12] and can be perceived by any part of the body. Moreover, it also allows low-attention interaction, as addressed in previous research [13]. Considering that the integration of a desk system with haptic feedback is complicated, inducing the surface transmission of vibrations using an external interface on the surface may be advantageous. Fig. 7 illustrates the concept of indirect haptic feedback using a desktop interface.

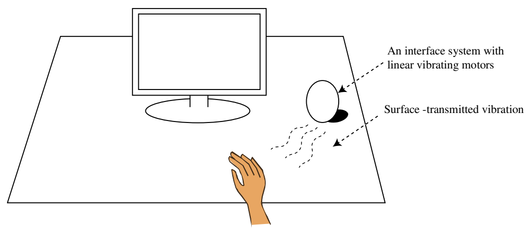

Fig. 7. Concept of indirect haptic feedback. Surface-transmitted vibrations are perceivable even when users are not concentrating on the incoming stimulus.

Utilizing the tendency of the vibrotactile threshold on the palm, or the thenar eminence, which is most sensitive at around 250Hz in general [14] (although the contact area affects the sensitivity), the frequency of the vibrotactile feedback in this system was set to 250 Hz.

4 System

The figure below shows the electronics architecture and developed electronics system.

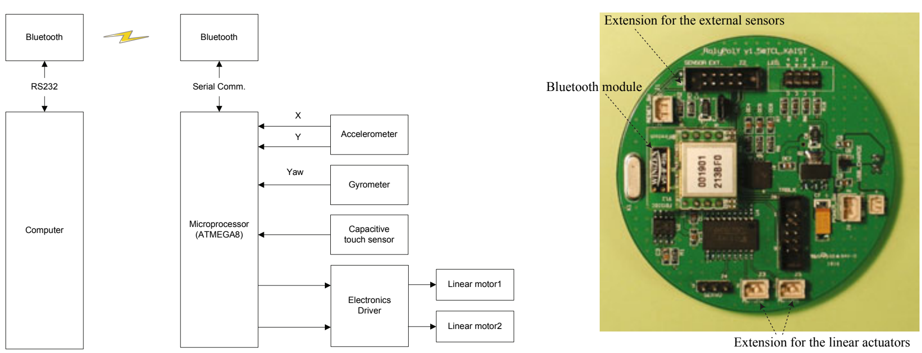

Fig. 8. The developed electronics system. Actuators and some sensors are attached through an extension cable, as shown in the mechanical diagram.

The sensor parts consist of an accelerometer, a gyroscope, and a capacitive touch sensor. The gyroscope, model IDG-300 of InvenSense Inc., is located along the z-axis. It uses an extension cable to measure the yaw motion of the device. The onboard accelerometer, model MMA7260Q by Freescale Semiconductor, Inc., located on the center of the electronics board, measures the amount and direction of the tilting. For the detection of touch and/or near-proximity, a sensing electrode used for charge-transfer touch sensor, model QT113 by Quantum Research Group Ltd., is attached underneath the top of the device. Data is measured at 15ms intervals, which is sufficient for measuring human movement [5] using an onboard microprocessor (ATmega8L). Signal processing of the converted four-channel data is then done in the host PC after the data is transmitted wirelessly. The actuation parts consist of two linear motors (L-type Force Reactor™ provided by Alps Electric Co.) with a source current transistor array. The embedded linear motors show a reliable broad frequency response up to 250Hz. Continuous vibration and short tactile pulses can be represented using linear actuators. A recharging module, model MAX1555 by Maxim Integrated Products, Inc., which charges a single-cell lithium-ion (Li+) battery, is also included in the system, allowing its continuous use as a PC peripheral.

5 Applications

5.1 Bimanual Input

While users typically use their dominant hand for mouse control in a desktop environment, the non-preferred hand is also actively used when key inputting is required in a functional combination with the mouse. For example, pressing the space bar key for panning action and pressing the ctrl key for zooming are frequently used with the mouse. Considering that people use both hands for everyday tasks, this can be considered as a natural phenomenon, although the task load should be measured. Given that the proposed system can complement the mouse by providing additional input modalities in a comfortable manner, it can be used with current desktop environments.

5.2 Tactile Notification and Assist tick

A considerable amount of important information is usually provided in the form of audio feedback in a desktop environment. Considering that the most frequently used cue is an alert or a notifying sound that may accompany an event, touch information can be alternatively used for these notifications, as described in Section 3.2. For an entertainment application, tactile notifications can be extended to the realization of an assist tick, which is generally audio-based. The use of this type of tactile assist tick can also enhance the sense of rhythm of a user in a realistic manner.

6 Conclusion

In this paper, a human-computer interface with a self-centering feature and tactile feedback functionality was proposed. Utilizing a mechanically ungrounded structure with low structural damping and a rounded and weighted bottom, the device produces erratic patterns in the event it is tipped over. Available input means such as tilting, rotation, and touch allow a user to give commands in a comfortable manner. The system also embraces the functionality of tactile feedback using linear actuators for both direct and indirect contact conditions. While the haptic information provides a type of notification as the device is being manipulated, it can also provide indirect tactile feedback that can notify a user of events from a computer. Mapping vibration patterns with events from the computer, the proposed system could be extended as a desktop ambient haptic display. For the implementation of robotic feedback, dynamic allocation of the center of mass will be researched as a further work.

Acknowledgments. This work was supported by the IT R&D program of MKE/KEIT, [2009-S-035-01, Contact-free Multipoint Realistic Interaction Technology Development].

References

1. Sreedharan, S., Zurita, E., Plimmer, B.: 3D input for 3D worlds. In: OzCHI, Adelaide, Australia (2007)
2. Abe, M., et al.: A Life Log Collector Integrated with a Remote-Controller for Enabling User Centric Services. IEEE Transactions on Consumer Electronics 55(1), 295–302 (2009)
3. Lee, M., et al.: Unsupervised Clustering for Abnormality Detection Based on the Tri-axial Accelerometer. In: ICROS-SICE International Joint Conference, Fukuoka International Congress Center, Japan (2009)
4. Brown, L., Williamson, J.: Shake2Talk: Multimodal Messaging for Interpersonal Communication. In: Oakley, I., Brewster, S. (eds.) HAID 2007. LNCS, vol. 4813, pp. 44–55. Springer, Heidelberg (2007)
5. Verplaetse, C.: Inertial proprioceptive devices: Self-motion-sensing toys and tools. IBM Systems Journal 35(3), 639–650 (1996)
6. Hinckley, K.: Input technologies and techniques. In: The human-computer interaction handbook: fundamentals, evolving technologies and emerging applications, pp. 151–168 (2002)
7. Stiles, R.N.: Frequency and displacement amplitude relations for normal hand tremor. Journal of Applied Physiology 40(1), 44–54 (1976)
8. Britton, E., Lipscomb, J., Pique, M.: Making nested rotations convenient for the user. ACM SIGGRAPH Computer Graphics 12(3), 222–227 (1978)
9. Norman, D.A.: The design of everyday things. Basic Books, New York (2002)
10. Swindells, C., MacLean, K.: Capturing the Dynamics of Mechanical Knobs. In: Proceedings of the Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. IEEE Computer Society, Washington (2007)
11. Kim, S., Kwon, D.: Haptic and sound grid for enhanced positioning in a 3-D virtual environment. In: Oakley, I., Brewster, S. (eds.) HAID 2007. LNCS, vol. 4813, p. 98. Springer, Heidelberg (2007)
12. Luk, J., et al.: A role for haptics in mobile interaction: initial design using a handheld tactile display prototype.
13. Oakley, I., Park, J.: Designing Eyes-Free Interaction. In: Oakley, I., Brewster, S. (eds.) HAID 2007. LNCS, vol. 4813, p. 121. Springer, Heidelberg (2007)
14. Verrillo, R.: Psychophysics of vibrotactile stimulation. The Journal of the Acoustical Society of America 77, 225 (1985)