Pingu: A new miniature wearable device for ubiquitous computing environments

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***Abstract*—Around Device Interaction (ADI) is recently introduced in the field of Human Computer Interaction (HCI) to provide touchless, more intuitive way of interaction using space beyond the physical boundary of the computing devices. In this paper, we introduce a new ADI input device called *Pingu* in the form factor of a fingering that allows users to interact with any nearby computing device with wireless connectivity in a ubiquitous environment. Fingering form-factor is chosen for our prototype design, as it is socially acceptable and is commonly worn in everyday social contexts, and based on the previous research, the information entropy of interaction by fingers is greater than the entropy for any other parts of the human body. The current *Pingu* prototype is consisted of an extensive set of sensors, visual and vibrotactile feedback mechanisms with wireless connectivity that make it a unique input device for human-computer or human-human interaction in the form of gestures, tactile and touch. Its usage can range from advanced, tiny and novel gestural interaction with a variety of devices to mobile and networked sensing, and social computing. We present a few potential applications of *Pingu* such as social interaction, context recognition, in-car interaction, and physical activity analysis.**

Keywords-component; around device interaction; wearable device; fingering; smart environments

I. Introduction

Touch sensing surfaces have evolved the way that humans interact with computing devices for years. Touch screens allow humans to interact with computers directly by fingers in more natural way instead of using the traditional user I/O devices like keyboards, and mice. Despite tremendous progress in developing touch-based technologies, this form of human-computer interaction (HCl) depends primarily on the human factors such as size of users' fingertips.

While many computing devices are continuously decreasing in size, their touch screens interface cannot be scaled smaller due to the surface area required for user interactions [1]. On the other hand, touch-based interactions occlude parts of the display screen that reducing the usability of the computing devices. To address these limitations, Around Device Interaction (ADI) techniques are recently introduced that provide possibility of extending interaction space beyond the physical boundary of the computing devices [2].

However, most of the current ADI systems are restricted to the immediate space around the devices and support only

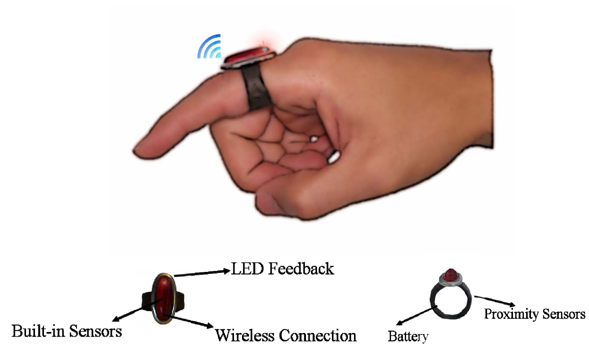

Figure 1. The *Pingu* design concept.

1D or 2D gesture commands that prevent the user to interact with smart environments in more natural ways. On the other hand, users are required to perform hands or body movements in the direct line of sight of sensors (e.g. Kinect).

In this paper, we present *Pingu*, a new miniature wearable and tangible device in the form of a fingering (Figure 1), which allows interaction with any electronic device in ubiquitous computing environments in more intuitive and natural ways. *Pingu* is equipped with an advanced set of sensors and wireless connectivity in a tiny size, worn on a finger. Fingerings are commonly used due to different beauty, fashion, cultural or family reasons. We believe these features allow *Pingu* to become a valuable device in the field of human-computer or human-human interaction.

II. Related Work

Over the last few years, the demand for ADI has been strongly increased due to the limitations of conventional human-computer interaction (HCl) approaches. The existing ADI techniques, based on the type of sensory information used in gestural recognition, can be classified into two major categories: optical ADI methods, and non-optical methods. Optical based ADI techniques such as SixthSense [3] and Gesture Pendant [4] use optical sensors (e.g. cameras or infrared (IR) based sensors [5]) to track user's hands or fingertips and interpret them as interaction commands. However, the major drawback of this class of ADI techniques is that the gesture should be made in line of sight of the optical sensors (i.e. occlusion challenge). Moreover, they are sensitive to the lighting conditions (i.e. illumination challenge); therefore, they are solely applicable for certain types of environments.

Non optical-based methods employ different kind of sensory information such as proximity sensors [6], magnetometer [1, 7], and accelerometer [8, 9] to overcome the limitations of optical ADI approaches while each has its own weakness.

Whilst proximity based interaction mitigates the illumination challenge of optical ADI it still suffers from occlusion problem since every gesture action should take place in the line of sight of the sensors. Magnetometer based ADI techniques [7] deform the magnetic fields around computing devices in order to send interaction commands. The advantage of this type of ADI approach is that it can interact with devices even if they are occluded. Accelerometer [9] has previously been used for ADI by employing the acceleration data to sense the orientation and motion of the device. However, the accelerometer data itself is very sensitive to noise and requires complementary sensory information.

Additionally, ADI approaches can be classified based on the types of wearable devices that they are embedded in. Most of the ADI techniques like glove-type ADI methods [10] require users to put on additional gloves to interact with digital devices. While performing natural gestures with this type of ADI seems sometimes inconvenient, they can even be obtrusive and socially unacceptable. Besides, those ADI methods that require users to wear special hat such as SixthSense [3] or pendant over the cloths like Gesture Pendant [4] suffer from similar problems.

One possible solution is to place such gestural input devices into more commonly wearable accessories such as wristwatch or rings. For instance, Gesture Watch [6] uses five infrared proximity sensors on the top of a wristwatch to sense hand gestures made over the watch. GestureWrist [11] utilizes a capacity and acceleration sensors to detect forearm movements and wrist-shape changes. One drawback of the wrist-based ADI methods is that it requires the coarse movement of hands and arms to perform a gesture command.

Unlike wrist-based ADI methods, fingering based ADI techniques require only simple, sharp, and tiny gestures using a finger to interact with computing devices. Abracadabra [1] and MagiTact [7] are the two examples of this type of ADI technique that employ a magnet placed on a finger to interact with mobile devices with magnetometer embedded in. However, both Abracadabra and MagiTact require users to perform gesture close to the devices contain magnetic sensors.

More recently, Nenya [12] a magnetically-tracked fingering is introduced that consists of a strong permanent magnet in a shape of a regular ring along with a wrist-worn wireless tracking bracelet to detect the ring position via magnetism and transfer the commands to other users' computing devices. The problem with the Nenya setup is that it requires two pieces of devices to put on. In contrast, in our prototype design all the sensing components and wireless communicator are embodied in a single regular fingering (Figure 2). On the other hand, Nenya is only support 1D finger input gestures while our prototype is able to process 3D gestures.

III. THE *PINGU* PROTOTYPE DESIGN

The major challenge facing today wearable input devices is to ensure that they are socially acceptable and as unobtrusive as possible [11]. One possible way to design such devices is to embed them to traditional wearable accessories such as pendants [4], fingerings [9] or wristwatches [11]. Among common accessories, fingerings are commonly worn in everyday social contexts due to different beauty, fashion, cultural or family reasons. Hence, they are suitable accessories to embed sensory devices for natural and unobtrusive human-computer interaction.

According to the experiments conducted by Card et al. [13], the information entropy of interaction by finger is much larger than any other body parts that are currently used for interaction. It is shown that the arm is rated at 11.5bits/s, the wrist at 25bits/s while the entropy of interaction by finger is at 40bits/s. Hence, the user interface devices that are operated by a finger have a great potential for faster interaction.

In this section, we introduce a new prototype in a form factor of fingering called *Pingu* that allows interaction in an ubiquitous computing environment. As the device is installed on a finger, it allows for simple, sharp, and tiny gestures using finger movements. *Pingu* comprises of 6 Degree Of Freedom (DOF) inertial sensing system, 3-DOF magnetometer and two channels of proximity sensing. In addition, *Pingu* is equipped with wireless connectivity and visual and vibrotactile feedback mechanisms, which can make it a unique device for human-computer or human-human interaction in the form of gestures, tactile and touch.

Pingu can sense absolute orientation and direction, linear and rotational movements and the proximity of other fingers with its proximity sensing plates. The current prototype dimension excluding battery and battery charging connector is 10mm* 22mm* 4.2mm with the total mass of 50 gr. In our first prototype the battery is located under the sensory platform (see Figure 2) although in the final version it will be augmented at the ring band (Figure 1). *Pingu* contains rechargeable Lithium-Polymer battery, which can be connected to power supply with internal micro-USB connector. The typical operating time per battery charge is about 2 hours with up to 6 hours in a standby mode.

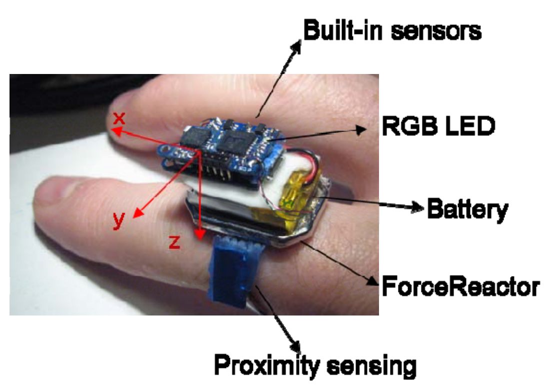

Figure 2. The *Pingu* prototype.

Pingu can detect motion using accelerometer and gyroscope sensors. This allows the device to be used for gestural interaction. The accelerometer senses linear acceleration along three axes as indicated in Figure 2. When the device is stationary, it can be used to extract static orientation relative to gravity. The Gyro (i.e. angular rate sensor) measures the angular rate movement of the ring. There are 3 channels of sense data, one for each of Pitch (rotation about the Y axis), Roll (rotation about the X axis) and Yaw (rotation about the Z axis). This sensor complements the accelerometers to provide a full six degree of freedom inertial sensing capability that can be utilized for detecting the dynamic 3D trajectories of the ring.

In addition, the device is equipped with a magnetometer allowing for orientation detection, as well as intra finger interaction. The magnetometer senses the magnetic field in 3-D space around the ring along its x, y, and z-axes. It is the only sensory information that can provide the orientation with respect to the fixed Earth's magnetic field. Besides, the magnetic field around *Pingu* can be deformed by a permanent magnet worn on any other finger of the user [7]. This will open the possibility of more complex intra finger interaction.

Pingu also has several channels of capacitive proximity sensing allowing for touch based interaction. Installation of the proximity sensors also allows for intra finger interaction. Combination of proximity and motion sensing on *Pingu* can provide many options for flexible and usable interactions. We will explain some of the possible applications of *Pingu* proximity sensors in the next section.

Finally, *Pingu* has an RGB LED and tactile feedback mechanisms. *Pingu* contains an in-built Alps ForceReactor vibration transducer that allows haptic sensations to be feedback in response to movements or gestures. The RGB LED can also be used to visualize track of a gesture in air.

Pingu has an integrated Bluetooth module, which enables interaction in a ubiquitous and networked fashion. *Pingu* can connect, transfer data and interact with any computing devices that have Bluetooth wireless connectivity in real time. The output data rate for all sensor channels is set to 200Hz. The current *Pingu* setup has one onboard DSP microcontroller to handle real time data filtering and communication protocols. The list of sensors embodied in the current *Pingu* prototype and their specifications are summarized in Table I.

TABLE I. LIST OF THE BUILT-IN SENSORS AT CURRENT *PINGU* PROTOTYPE.

Type of Sensor	Description
3-axis Accelerometer	+/- 8g
3 axis Magnetometer	+/- 2 gauss
3-axis Gyro	+/- 2000 deg/s
LED	configurable RGB LED for visual feedback
ALPS ForceReactor	vibration transducer
proximity sensing	2 channels
Bluetooth	range 2 meters or greater
Temperature	-20/ 85 degree C

IV. APPLICATIONS

Pingu is a general e-companion wearable device that is designed in the form of socially acceptable fingering. In this section, we present and discuss several potential applications of *Pingu* and preliminary results from mobile device interaction, to social computing and human-to-human interaction.

A. *General Gesture Interaction*

The main application of *Pingu* is for gestural interaction with computing devices. Based on previous research on gestural interaction [7], the user can interact with mobile and tangible devices that have embedded magnetometer by moving a permanent magnet around the device in the form of different hand gestures. This approach requires the user to perform gestures by hand only near the device with embedded magnetometer. However, *Pingu* can be utilized not only for ADI with mobile and tangible devices, but also for gesture based interaction with smart environments, where a user may want to interact with devices even though they are not in the vicinity of a user. Besides, the *Pingu* form factor requires a user to perform simple, sharp, and tiny gestures using finger movements.

The three dimensional accelerometers and gyroscope embedded in *Pingu* can be exploited to provide relative finger/hand movement in the 3D space. This capability can be applied for controlling household appliances in a smart home.

In order to evaluate *Pingu* for general gesture usages in smart environments we have defined a set of nine simple hand and finger movements shown in Figure 3. We recruited 24 participants for the experiments and asked each of them to repeat each gesture for 15 times. A set of features such as average, variance, magnitude, and frequency contents are extracted for each sensory data. The extracted features are grouped together in a feature vector and passed to the Multi-Layer Perceptron (MLP) classifier using 10-fold cross-validation scheme to avoid over-fitting. The results show an overall accuracy of 97% for recognizing different gestures.

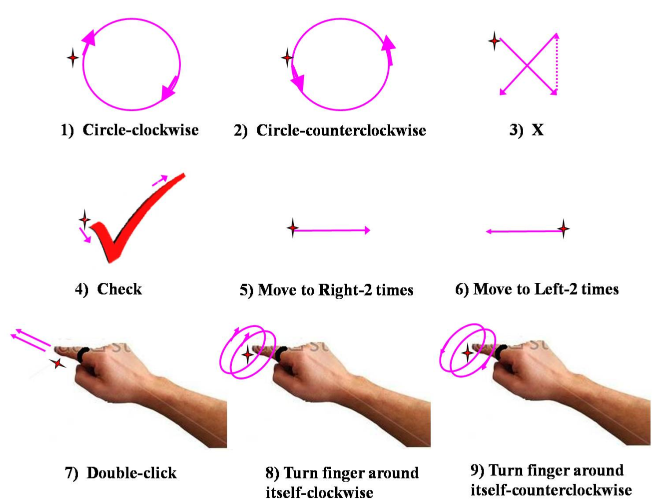

Figure 3. Nine different gestures used in the first experiment.

Figure 4. Interaction with smart TV using *Pingu* prototype.

Figure 4 depicts an example application of *Pingu* to interact with a smart TV. The user moves his hand while wearing *Pingu* in different directions to select desired TV menu sections. At current design, user is required to touch the proximity sensing plate in order to indicate the start of a gesture command. This mechanism helps the system to differentiate the user's gesture command from the user's normal hand movements that happens during everyday life.

This gesture based interaction does not suffer from occlusion problems which occur in vision-based systems (e.g. Kinect); hence, it can be used in noisy environments, where partially or the whole part of the user body is occluded.

B. *Social Interaction*

Humans use their hands' gestures in a daily human to human communications, and it would be helpful if a system can track such movements in different social contexts. *Pingu* provides a powerful framework for context based human-to-human interaction modalities. Therefore, we introduce a new concept for studying and analyzing the human-human interaction using *Pingu*.

For instance, detecting and analyzing human relations (e.g. handshakes, social proximity in conferences or meetings) can provide a rich source of information about the social network of *Pingu* users. Based on this information, the system can suggest people to a *Pingu* user to connect through online social networks (e.g. Facebook, LinkedIn). This is different from the current "People You May Know" suggestions in online social networks that are only based on user's current networks (i.e. circle of friends) and friend lists (Figure 5).

C. *Physical Activity Analysis and Recognition*

Fingers are commonly used in many activities and tasks during human daily life explicitly as well as implicitly. Pointing to things, drawing on a table, and gesturing are natural movements that humans do – often without attention (e.g. to support the spoken word). It appears that the movements of the finger reflects many activities – ranging from micro-activities such as walking, running to fine motor movements called macro-activities such as writing, typing, driving, and eating.

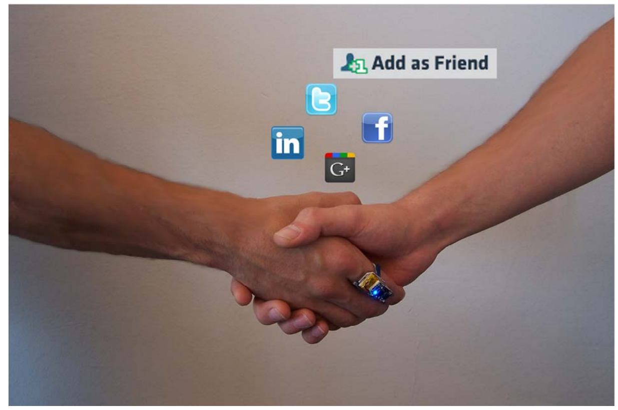

Figure 5. Detecting handshake using *Pingu*.

Therefore, analyzing motions and behaviors of human fingers provides rich source of information about physical activities of the users. Such activity monitoring can be applied to wide range of applications such as healthcare monitoring for elderly people and emergency help services. *Pingu* can store or send information about physical activities of users. It can send data using Bluetooth, or over a network via data services of a mobile phone. In this case, *Pingu* is connected to the mobile device via Bluetooth and uses data service facilities in the mobile phone to send data over network. Data can be stored or monitored in a remote server. In this manner, the user can constantly get reports of his physical activities and extracted health related factors using the data stored in *Pingu* or a remote server. A medical assistance can also analysis data in more detail or provides warning in case of irregular or unregulated physical activities. As *Pingu* can send data to network in a constant and online manner using e.g. data services in a mobile phone, it can be used for online monitoring of elderly people or people after surgery.

Not only the activity of one user can be monitored by wearing *Pingu*, but also activities of a group of users living or working in the vicinity can be tracked and recognized in a network sensing fashion. Group activity recognition among network of *Pingu* users opens a new window for social human behaviors analysis.

D. *Context Recognition and User Interface*

As mentioned in the previous section, fingers motion can be provide a lot of information on human activity and status. With the same argument, some contextual data may also be extracted from finger motions which can be captured by *Pingu*. Most of these contextual data is related to the context of user's physical activity or a group of *Pingu* users. For instance, *Pingu* can detect if a user is walking, running, eating, sleeping, typing, etc.

We propose such context/activity detection for adapting smart devices. These smart devices can be smart facilities in a smart home environment such as illumination facilities, TV and Music set, or a mobile device, or laptop/workstation. We assume that *Pingu* is connected to these devices using a Bluetooth link. Depending on the level or status of physical activity of a user reported by *Pingu*, illumination or background music in a smart environment can be adjusted. If

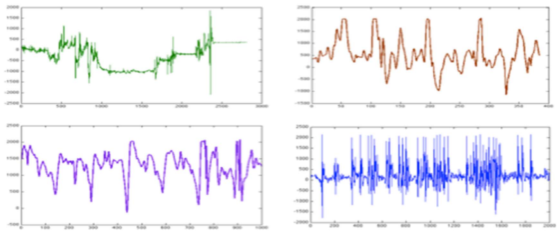

Figure 6. Accelerometer readings (along X-axis) for each of the four activities.

the user is sleeping, the lights and TV set can be turned off. User interface of a mobile device or a workstation can also be adapted based on actual status of the user reported by *Pingu*. Figure 6 illustrates accelerometer readings along the x-axis captured for one user for four activities: running, walking, resting (i.e. relax) and writing. As it is shown, the spatial and frequency characteristics of activities are clearly differentiable.

Context detection by *Pingu* can have marketing potentials too. For instance, it can be used for semantic advertisement based of context of physical activities of a user during daily life, or his interaction with other users.

As *Pingu* is equipped with force/vibration feedback facilities, it can be used for receiving alerts from smart devices and environments. As *Pingu* can be constantly and remotely available using e.g. communication facilities in a mobile phone, it can receive remote alerts. For instance, a user can be informed by a tactile feedback if something is going wrong in the kitchen, or somebody is entering the apartment or if lights are left on! Obviously, the user can send interaction commands back in order to deal with the situation using gestural or touch facilities embedded in *Pingu*.

E. *In-car Interaction*

Nowadays, cars are equipped with a variety of built-in devices and systems that require drivers' attention. Interacting with these devices such as navigation, information and entertainment systems may influence driving performance and increase the risk of driving [14].

A *Pingu* user can perform tiny gestures with his fingers while diving to control music in car, interact with navigator, check emails, make calls, etc. On the other hand, combining gestural modality with speech interface may improve the current in-car user interfaces. Figure 7 shows a *Pingu* user controlling the navigation system by moving both fingers similar to the zoom gesture in touch-screen devices.

V. Summary and Conclusion

We have presented *Pingu*, a new miniature wearable device in the form of fingering. *Pingu* integrates a collection of different sensors, wireless connectivity module, touch and feedback facilities on a regular fingering. The integrated sensors and communication facilities enable *Pingu* to be used in different ubiquitous computing contexts. We have presented different applications provisioned for *Pingu* ranging from gestural interaction to context and activity

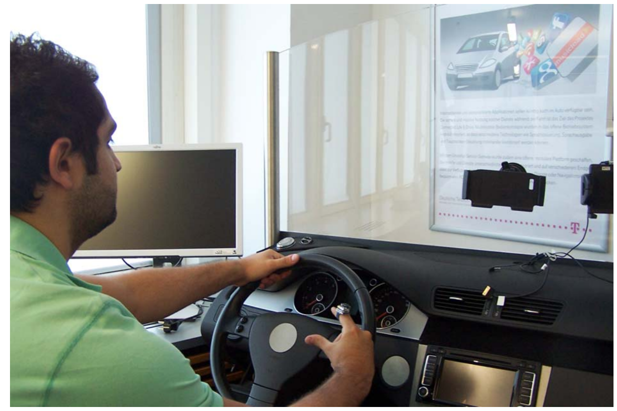

Figure 7. In-car interaction using *Pingu*.

recognition, and social interaction. Proper installation of different sensory and feedback facilities can turn *Pingu* to a general purpose e-companion. We are currently working on realization of the presented applications on different platforms.

References

[1] C. Harrison, S. E. Hudson, "Abracadabra: Wireless, High-Precision, and Unpowered Finger input for Very Small Mobile Devices", UIST'09, 2009.

[2] S. Kratz, M. Rohs, "HoverFlow: expanding the design space of around-device interaction", Proc. of the 11th International Conference on Human Interaction with Mobile Devices and Services, 2009.

[3] P. Mistry, P. Maes, and L. Chang "WUW - wear Ur world: a wearable gestural interface", Proc. CHI, 2009.

[4] T. Starner, J. Auxier, D. Ashbrook and M. Gandy "The Gesture Pendant: a self-illuminating, wearable, infrared computer vision system for home automation control and medical monitoring", Proc. ISWC, 2000.

[5] A. Butler, S. Izadi, and S. Hodges "SideSight: multi-touch interaction around small devices.", Proc. ISWC, 2000.

[6] J. Kim, J. He, and K. Lyons and T. Starner "The Gesture Watch: a wireless contact-free gesture based wrist interface.", Proc. ISWC, 2007.

[7] H. Ketabdar, K. Yüksel, and M. Roshandel, "MagiTact: Interaction with Mobile Devices Based on Compass (Magnetic) Sensor.", IUI'10, 2010.

[8] J. Wu, G. Pan, et al., "Gesture recognition with a 3-d accelerometer.", UIC 2009:

[9] M. Fukumoto, Y. Tonomura, "Body-coupled FingerRing: wireless wearable keyboard.", Proc. CHI, 1997.

[10] J. K. Perng, B. Fisher, S. Hollar and K. Pister "Acceleration sensing glove (ASG).", Proc of The Third International Symposium on Wearable Computers, 1999.

[11] J. Rekimoto, "Gesturewrist and gesturepad: Unobtrusive wearable interaction devices", Proc. ISWC, 2001.

[12] D. Ashbrook, S. White and P. Baudisch "Nenya: Subtle and Eyes-Free Mobile Input with a Magnetically-Tracked Finger Ring", Proc. CHI 2011.

[13] S. K. Card, J. D. Mackinlay and G. G. Robertson "A morphological analysis of the design space of input devices.", ACM Trans. Inf. Syst. 9, 2, April 1991, 99-122.

[14] A. Schmidt, A. Dey, A. Kun, and W. Spiessl "Automotive User Interfaces: Human Computer Interaction in the Car", Proc. CHI 2010.