A Literature Review: Form Factors and Sensor Types of Wearable Devices

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***Abstract*— Wearable devices provide a new way to recognize the users context with high accuracy. Selecting suitable form factors and sensors are important to recognize users' contexts. In this study, the form factors and sensor types of released, prototype, and concept products were explored. A total of 175 literatures were collected and analyzed in terms of sensor and form factor. Thirty sensors were collected and classified according to measurands. Twenty-three form factors were listed by nine applicable body parts.**

Keywords-wearable device; form factor; sensor; body part.

I. INTRODUCTION

Wearable devices can provide new ways of sensing users' contexts [1]. Since they can be worn, wearable devices tend to have a higher context recognition rate than existing personal mobile devices [2]. For that reason, wearable devices can provide new functions based on context recognition to improve the usability and efficiency of services [3].

There are several body parts on which suitable wearable products can be worn. The wearable products can be classified into several "form factors." These form factors are such wearable devices as necklaces and glasses. Form factors and sensors are used to develop wearable devices [4][5]. However, it is difficult to find papers discussing current form factors and sensors of wearable devices.

In this paper, sensors and form factors of wearable devices are investigated based on a literature survey. Sensors are classified according to the measurands. Form factors and sensor types are listed according to their applicable body parts.

II. METHOD

Information on the released, prototype, and concept products was collected from journal papers, proceeding papers, news, and patents. A total of 175 literatures published between 2001 and 2013 were collected.

Sensors were classified according to their measurands, based on the study of Richard [6]. Image/vision and gas sensors were added to the sensors found in the literatures.

Form factors and sensors were listed according to their wearability on the body parts. The body parts are classified according to the kinesiological classification: head, neck, shoulder girdle, Trunk, arm, forearm, hand, pelvis, thigh, leg, and foot [7].

III. RESULT

A. Sensor classification

The sensors are classified into nine types (Table I).

- Photo sensor: sensor which detects characteristics of visible, infrared, and ultraviolet light.
- Image/vision sensor: sensor which identifies the visual pattern, shape, location, and movement from the image and video information.
- Electro-magnetic radiation sensor: sensor which detects the electro-magnetic waves.
- Electrical activity sensor: sensor which detects the electric properties of devices and the body.
- Magnetic field sensor: sensor which detects the magnetic field through the property of solid matter and voltage change.
- Gas sensor: sensor which recognizes the property of gas, and it measures the components, concentration, and pressure of the gas.

TABLE I. SENSOR CLASSIFICATION

Sensor Type	Sensor
Photo sensor	• Free space optical communication • Proximity sensor • Pulse oximetry sensor • Photoelectric sensor • RGB/illuminance sensor
Image/Vision sensor	• Motion detection sensor • 3D depth camera • Infrared camera • Eye-tracking sensor • Vision/Image recognition
Radiation sensor	• GPS sensor • Near field communication module
Electric sensor	• EEG/EMG/ECG/EOG sensor • GSR sensor • Capacitive sensor • AC current sensor
Magnetic sensor	• Magnetic field variation sensor • Geomagnetic sensor
Gas sensor	• Gas component analysis sensor • Atmospheric pressure sensor • Humidity sensor
Acoustic sensor	• Microphone • Phonomyography
Mechanical sensor	• Pressure sensor • Gyroscope • E-textile • Acceleration sensor • Physical button
Thermal sensor	• Body temperature sensor • Heat flux sensor • Temperature sensor

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- Acoustic sensor: sensor which detects the sound waves of the dial tone, voice, and ultrasonic waves.
- Mechanical sensor: sensor which recognizes the physical movement and other mechanical properties of the human and the device.
- Thermal sensor: sensor which measures the size and flow of temperature.

B. *Form factors and sensors with body parts*

Form factors and sensor types were listed by their applicable body parts (Table II). There is no form factor found to be applicable to neck, shoulder girdle, and pelvis.

The biggest number of form factors was related to the head. The smallest number of form factors was related to the arm, thigh, and leg. Module/clip, patch, clothes were used for various body parts.

Mechanical sensors were combined with most form factors.

TABLE II. FORM FACTORS AND SENSOR TYPE WITH BODY PART

Body Part	Form Factor	Sensor Type
Head	Hat	Image/Vision, acoustic, mechanical
	Helmet	Image/vision, gas, mechanical
	Glasses	Photo, image/vision, acoustic, mechanical, electro-magnetic radiation, magnetic field
	Headset	Mechanical, image/vision, electrical activity, acoustic, photo, electro-magnetic radiation
	Earphone	Photo, electrical activity, mechanical
	Ear Wrap	Electro-magnetic radiation
Trunk	Necklace	Image/vision, mechanical, acoustic, electro-magnetic radiation, electrical activity
	Chest Band	Electro-magnetic radiation, electrical activity
	Belt	Photo, electro-magnetic radiation, magnetic field, gas, acoustic, mechanical
	Bag	Gas
Arm	Arm Band	Electrical activity, magnetic field, mechanical, thermal
Forearm	Wristwatch	Photo, image/vision, acoustic, thermal, electro-magnetic radiation, mechanical, electrical activity, magnetic field
	Bracelet	Photo, image/vision, acoustic, thermal, electro-magnetic radiation, mechanical, electrical activity, magnetic field
Hand	Gloves	Magnetic field, mechanical
	Stick	Photo, electro-magnetic radiation, gas, mechanical, thermal
	Ring	Photo, image/vision, electrical activity, acoustic, mechanical
Thigh	Robot	Mechanical
Leg	Ankle Band	Magnetic field, mechanical
Foot	Shoes	Magnetic field, mechanical
	Socks	Electro-magnetic radiation, electrical activity
Whole body	Module/Clip	Image/vision, mechanical, electrical activity, electro-magnetic radiation
	Patch	Photo, electrical activity, magnetic field, mechanical, thermal
	Clothes	Photo, image/vision, electro-magnetic radiation, magnetic field, acoustic, mechanical

IV. DISCUSSION

Most form factors are related to terminal body parts: head [8], hand [9], forearm [10], foot [11], and leg [12]. It is easy to wear things on terminal body parts. There are also various signals that can be detected on terminal body parts easily. For example, the head is a useful location to detect the gaze direction, pulse, breath. The hand is useful to detect the pulse and the signal of user's activity. The foot is useful to sense body pressure and walking pattern.

Modules/clips form factors have been used to detect non-physiologic signals that can be detected on any body parts [13]. The existing modules/clips can be transformed to another form factors using additional accessories [14]. Modules/clips [13], patches [15], and clothes were used when the wearable devices needed to capture signals in several body parts simultaneously [16].

V. CONCLUSION

This paper classified the sensors according to the measurands, and listed form factors and sensors according to various applicable body parts. Although, form factors were applicable to several body parts, most form factors were found on the terminal body parts. This paper helps the designers of wearable devices to understand the various form factors and sensor types.

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