Implied Aesthetics: A Sensor-Based Approach towards Mobile Interfaces

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Abstract. This article focuses on the implied aesthetics resulting from the affordances of 4th generation mobile devices, and in particular: motion-awareness. It draws connections between web standards, open source platforms, and their implications on diverse output media. Motion-awareness is rooted in the possibility to detect and interpret device orientation and acceleration — thus by extension the movements and gestures of individuals interacting with handheld devices. The article introduces the *KETAI* platform, designed to aid mobile applications that rely on motion analysis. Faster and more accurate detection of device attitude, context, and transportation mode enables a variety of novel applications in the traffic, gaming, and heath care sectors.

Keywords: Mobile interface, user experience, motion-awareness, sensor platform, gyroscope.

1 Introduction

Ubiquitous computing represents, after mainframe computing and personal computing, the "third paradigm"[1] where computation is integrated into the built environment. Souza e Silva denotes cell phones as "interfaces of hybrid spaces" [1], asserting a merger between physical and imaginary spaces through nomadic technologies. This article focuses on the implied aesthetics resulting from the affordances of 4th generation mobile devices now entering the product mainstream, and in particular: motion-awareness. A smaller sibling to geolocation, motion-awareness is rooted in the possibility to detect and interpret device orientation and acceleration — thus, by extension, the movements and gestures of individuals interacting with handheld devices. Electronic sensors that pertain to motion-awareness include accelerometer[2], magnetometer[3], and gyroscope[4] sensors. Fused with additional sensors, including "proximity sensor, accelerometer, touch input panel, ambient light sensor, ambient noise sensor, temperature sensor, gyroscope, a hinge detector, a position determination device, an orientation determination device, a motion sensor, a sound sensor, a

[1] (Weiser, 1996), referencing Allan Kay's term for the third era of computing.
[2] Sensing orientation and acceleration relative to g-force, including vibration, shock, or falling.
[3] Measures orientation in relation to the earth's magnetic field.
[4] Measures rotation around axis, able to detect rotation around gravity (in contrast to accelerometer).

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radio frequency electromagnetic wave sensor, and other types of sensors and combinations thereof" [2], handheld devices are destined to evolve into motion-aware game consoles and universal remote controls. Particularly mobile augmented reality and navigation applications can benefit from data fusion between accelerometer and gyroscope, allowing detection of device orientation and rotation around gravity. Jumping, chipping, riffing, and drumming — Nintendo Wii has already conditioned millions of end-users with the digital haptics of gesture-based human computer interaction (HCI) during family pastime. Introduced in 2006 with built-in three-axis accelerometer and infrared motion tracking, the addition of the MotionPlus [3] dual-axis gyroscope in 2008 ultimately completed "the missing piece of the puzzle" [4]. Gyroscope-equipped[5] 4th generation cell phones, tablet computers and personal digital assistants are now challenging this application space. Motion-awareness leverages gesture-based interaction principles towards a portable, public, and ubiquitous space, with applications reaching from traffic, to gaming and health care. The *KETAI*[6] software platform [5] introduced in this article is designed to aid the development of mobile applications and services that rely on native sensors and motion analysis.

2 Context

The Xerox Palo Alto Research Center's Computer Science Laboratory coined the term ubiquitous computing in 1988, proclaiming: "Just as electric motors have disappeared into the background of everyday life, PARC scientists have envisioned a future mobile computational devices will be similarly transparent" [!6]. Mark Weiser, chief scientist at Xerox PARC described ubiquitous computing as "roughly the opposite of virtual reality". In this model, computers "live out here in the world with people," as opposed to "putting people inside computer-generated worlds". Weiser's highest ideal was the "invisible" interface: "so imbedded, so fitting, so natural, that we use it without thinking about it" [7]. The intimate language suggests a very personal device — disappearing like a piece of undergarment. Weiser did not assert gradual societal adaptations as a catalyst for technological 'transparency' or 'invisibility', as HCI expert Donald Norman did in *The Invisible Computer* (1998). Bolter and Gromala refuted the "myth" of transparency in 2003 as a "story that artists and designers have told us (and themselves) in order to justify their designs" [8]. In contrast, PARC's definition #1 clearly constitutes ubiquitous computing as "different from PDA's, dynabooks, or information at your fingertips. It is invisible, everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere" [7]. Weiser's deliberate differentiation between "everywhere computing" on the one hand, and "information at your fingertips" through personal devices on the other, is challenged in this article. The majority of the motion-aware applications described here do not adhere to this dichotomy. They are designed to move seamlessly between embedded infrastructure, "the cloud", and mobile devices.[7] The "inch-, foot-, and

[5] The gyroscope was introduced to Apple iOS4 on June 24, 2010, Samsung Galaxy S Android followed July 15, 2010.

[6] *Ke-tai* is the term for cell phone used in Japan, it means: "extension of one's hand".

[7] "Seamlessness" references "calm technologies" (Weiser's and Seely Brown's,1995), referring to computational devices that move seamlessly from the periphery to the center of people's attention.

yard-sized computers" coined "Tabs, Pads, and Boards"[8] [7] in the early 1990s affirm how influential PARC's vision still is today.

3 Implied Aesthetics

This article draws connections between web standards and their implications on diverse output media. It proposes an implied aesthetics that arises in conjunction with the sensory affordances of 4th generation mobile devices. Due to the scope of this article, no attempt will be made to trace individual histories. Rather, particular aspects of HTML5, CSS3, JavaScript, jQuery [10], Processing.js [11], and mobile sensors are juxtaposed to outline their combined innovative potential, resulting in HTML5-based, JavaScript-processed, and sensor-powered mobile applications. The notion of implied aesthetics is considered 'impartial' in this context. It is not reacting to a visual style, but acknowledges a momentary sense of innovation, followed by the successive transformation into a visual norms and tropes soon after.

Hereby, the inch-, foot-, yard-sized computers consumed today pose particular design challenges, often rooted in the range of fragmented standards, device sizes, and screen resolutions. These client-side 'unknowns' can either be accommodated by common-denominator compromises, or, multiple media- and device-specific solutions[9]. Fragmentation through multiple solutions has never been a desirable prospect, as it requires redundant efforts for the same problem, hence additional costs and room for error. Standardized and customized solutions are held in balanced by the number of targeted output media and the afforded native implementation detail. Centralized databases have propelled another 'unknown' through the separation of design and content, emphasizing durable content alongside adaptable design. Hence, the database as "symbolic form"[10] has played a crucial role in the predominance of dynamic web sites, web applications, and native apps that scale seamlessly in size, performance, resolution, storage, bandwidth, and platform. When groups of co-creators 'come together' to collaboratively author documents, centralized version control systems (VCS [9]) play an important role to facilitate cooperation, administrate hierarchies, and negotiate common goals and standards.

Because all major web browsers support the HTML5, CSS3, and JavaScript standards, web applications represent a competitive choice for developing cross-platforms applications. On the other hand, native applications provide access to hardware-specific features, as for instance device sensors and camera(s). To bridge this gap, application frameworks such as Appcelerator Titanium and PhoneGap support native development[11] via JavaScript and HTML5, with the goal to leverage versatility and productivity towards native features.

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[8] i.e. *Tablet Computers* (Microsoft Corp., 2000), *iPad* (Apple Inc., 2010), and *Galaxy Tab* (Samsung, 2010).

[9] Paralleled by the dialectic between open and proprietary industry standards such as XHTML/CSS and Macromedia/Adobe Flash.

[10] Referencing Lev Manovich's writings on the database as symbolic, cultural form, and genre of new media (1998-2001).

[11] Tinanium compiles HTML5-JavaScript code into native apps, PhoneGap makes native feature available to create HTML5-JavaScript-based web apps.

Technically, the abovementioned design tools do not constitute an implied aesthetics per se. These standards deploy access to standardized HTML as well as native UI elements — hence maintain a hybrid visual canon of 'extended' standards. While CSS3 and JavaScript provide comprehensive tools to manipulate visual properties, the Canvas[12] element represents the most versatile, and for this line of argument most influential addition to the HTML5 package. The element is designed to render scriptable drawings and images, and therefore the least predefined, most customizable, and aesthetically neutral. In the discussion of the most influential visual design additions, one should also mention the CSS3 @font-face property, providing the first comprehensive cross-browser solution for embedding non-system fonts into web sites and applications. Both elements eliminate a significant legacy of compromises for designers and developers, opening up animation features that were previously implemented within proprietary containers. In 2006, John Resig released the first version of jQuery, "a fast and concise JavaScript Library that simplifies HTML document traversing, event handling, animating, and Ajax interactions for rapid web development" [10]. Now used by Google, Dell, Netflix, Mozilla, etc., it has grown into a web standard in its own right. In 2008, Resig ported the Processing[13] language to JavaScript using the Canvas element [11], opening up development to "tens of thousands of students, artists, designers, researchers, and hobbyists who use Processing for learning, prototyping, and production" [12]. A selection of HTML5 creations and applications is collected at Chrome Experiments under the tag line: "Not your mother's JavaScript" [13]. Tens of thousands of artists, designers, and researchers utilizing Processing will arguably play an important role in making the Canvas element, and the web browser, a site for visual innovation [14-16]. The resulting aesthetics are implied by the following aspects: a) the possibility to render complex data visualizations and generative designs via JavaScript, combined with b) the possibility to retrieve data asynchronously from the server in the background (Ajax). Powered by significantly improved JavaScript performance (particularly via WebKit and V8 engines), HTML5 and JavaScript-based web applications are well equipped to challenge the status quo of visual culture on the Web. This is particularly the case for applications that can leverage GPU-based graphics processing, including GPU-accelerated WebGL 3D computer graphics.

GPU-accelerated 2D and 3D real-time graphics are destined to produce a significant visual impact on (web) applications in both exiting, and exuberant ways (see "rich" animations of the 1990). Co-creation and open source principles have produced about 100 Processing extensions [17] over the last decade, extending into open hardware, data protocols, sound, and simulations. This number is a testament to the collaborative power of online communities, and a foretaste of what can be adapted to native handheld applications.

The 'native' user experience is largely defined by the refined degree of haptics and interactivity due to by native hardware. Augmented reality (AR) applications that leverage pitch, roll and yaw angles (gyroscope) in conjunction to g-force (accelerometer) is one example where decades of research can bow be leveraged due to ubiquitous mobile devices. Pointing the device camera towards the horizon and following

[12] Introduced by the WebKit open source web browser engine.
[13] Developed by Ben Fry and Casey Reas in 2001.

the horizon line is a typical scenario where the gyroscope can contribute to detect rotation around gravity, instead of relying on the magnetometer's attempt to find a reference point (geographic north). Wikitude [21] and Spot Crime [22] augment a 'world browser' and crime locations onto a live image, one example out of many mapping and navigation use cases that could be improved by more accurate device attitude. Sun Seeker [18], DishPointer [19], and See Breeze [20] augment the sun, satellite location and wind. A detailed discussion of educational [23] and gaming scenarios [24], as well as human factors (finger tips: 9.2 mm for discrete and 9.6 mm for serial tasks [25]) exceeds the scope of this article.

4 KETAI Platform

Ubiquitous mobile devices equipped with gyroscope and accelerometer sensors enable a variety of novel applications. Targeted for sectors such as traffic [26-27], gaming [24], health care [28,29], and public safety, *KETAI MOTION* is a software framework designed for approximating the physical device path. This approximation is based on a dynamic data fusion method that captures and analyzes data from accelerometer, magnetometer, and gyroscope sensors, complemented by sensors that are relevant within a particular context (e.g. light sensors and digital cameras). Determining vehicle speed, sudden breaking, or collecting statistical data on traffic congestion [35] requires a flexible software framework that accommodates dynamic data fusion for multiple sources. Deployed on 4th generation mobile devices, it is designed to capture, abstract, archive, and analyze device attitude, movement, and gestures. *KETAI* manages data streams, and makes those resources available to other applications as a content provider. It is designed to extract motion features and differentiate between modes of transportation, gait, kinematic velocity, and hand gestures. It can dynamically reduce data granularity based on power or performance settings. By fusing gyroscope, accelerometer, and magnetic field sensors, *KETAI* complements existing interpretation methods of existing research, predominantly relying on geolocation [30-31, 53]. The ability to distinguish between device rotation and translation is the foundation for "Wii-like" [32] mobile gaming applications. The *KETAI* platform offers a novel approach to motion analysis, building on increased data granularity. The platform allows to emphasize resources and accuracy for the most relevant sensors in a given device context. For instance, if a mobile device is carried in a pocket or bag, only a low level of data granularity is required (reserving resources), whereas if a user is looking at the screen (face recognition), it enables a higher level of granularity. In comparison to existing work in the context of motion-awareness, *KETAI* offers the following advantages:

Integration. The platform is capable to register and manage all electronic sensors (e.g. accelerometer, gyroscope, magnetic field, light, temperature, etc.). As a platform, it remains adaptable for a variety of applications. It offers dynamic data fusion and provides machine learning (Hidden Markov Model (HMM)) and signal processing algorithms (i.e. onset detection). A content provider for other services on a device, it makes interpretative data available to other applications.

Abstraction. The platform analyzes device attitude vectors in real-time, extracting points of interest based on detected changes via motion analyzer (Fig. 1). By dynamically removing data granularity, and adding time-stamped metadata, the framework can continuously capture and summarize device movement at the desired level of accuracy. The ability to shift sensor and power resources opportunistically towards particular sensors allows *KETAI* to limit capture, analysis, and resources.

Aggregation. The platform will enable motion comparison between multiple devices in close proximity via unregulated wireless networks [33-35], enabling assertions about transportation mode etc., by enumerating devices and comparing their relative motion difference. If proximate devices share similar device attitude vectors, the transportation mode might output "car", "bus", or "train". If a significant amount of devices share nearly identical attitude vectors, the transportation mode can be refined to "bus" or "train". In the gaming context, this feature supports applications that rely on real-time interaction and collaboration.

Interpretation. By integrating (front- and back-facing) digital cameras into the *KETAI* platform, assertions can be made about device context and gestures. Frame differencing between front- and back-facing camera images affords a distinction between device rotation and hand gestures. Face recognition provides an additional contextual resource for interpreting device context.

Gyroscope and accelerometer data is continuously refined by magnetometer and geolocation sources. Existing work related to device motion [36, 37, 38, 39, 29, 40], transportation mode [41, 28, 42], gait [43-49], or device context [50-52], does not meet our application goals. These systems often rely on external devices [43, 44],

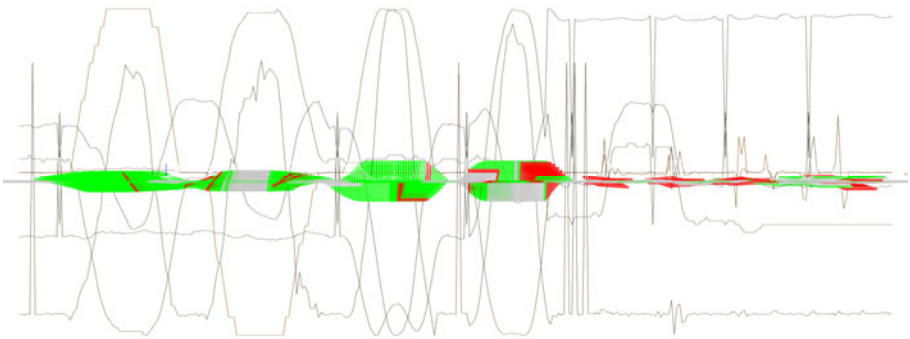

Fig. 1. Sensor fusion visualized by *KETAI MOTION* on Android OS[14] over the duration of 60 seconds (horizontal axis). Figure is based on accelerometer and gyroscope data, showing device orientation and signal peaks.

[14] While not limited to a specific operating system, a preliminary version of the *KETAI* library for Processing has been implemented for the Android OS, first released at the Processing.Android Conference (http://processingandroid.org) on Oct. 2nd, 2010, at the University of Illinois at Chicago Innovation Center (organized by the author). Android OS accounts for 53 percent (Feb. 2011 [58]) of smartphones sold in the U.S.

hence are inconvenient and not ubiquitous. They offer sufficiently accurate data only for a limited range of use cases, and lack accuracy due to a single [30-31, 53], or two combined sensor sources [36, 41]. Preexisting classification models transportation mode rely predominantly on geolocation [30-31, 53], or accelerometer combined with GPS data [36]. The addition of the gyroscope adds the crucial level of improved accuracy to determine transportation mode and device context. Furthermore, detection of rotation around gravity [21] allows novel applications in the context of gesture recognition [54] and gait analysis [43-46].

While processing real-time sensor data, *KETAI MOTION* determines "points of interest", motion peaks, duration, and momentum [55]. Augmented with timestamps (millisecond accuracy), device attitude vectors describe the first layer of abstracted data. Abstraction allows managing, packaging and compression of motion data over extended periods of time. The information is then stored locally in SQLite [56] databases, enabling post-analysis, and intermittent data transfer to the cloud.

5 Conclusion

Web standardization and comprehensive support of HTML5 (Canvas), CSS3 (@fontface), and JavaScript (jQuery), represents the basis for visually innovative, interactive (Ajax), dynamic (Processing.js), and rich (WebGL), high-performance (GPU-accelerated) applications. The large developer base already utilizing those standards will play a major role in the transition towards a new software-based visual culture. The most innovative approaches successfully merge native device features such as gyroscope sensors. With the onset of multi-touch displays as ubiquitous interfaces the mouse button and rollovers became obsolete. Motion sensors can play a role in complementing some of the absent, mouse-related 'pseudo classes'. Within the operating system for example, leveling and tapping the device can assist in scrolling applications where the screen would otherwise be obstruct by fingertips. Motion- and context-aware applications can seamlessly toggle perspectives for mobile navigation applications. Transportation mode detection can improve safety and provide transportation-relevant information for a particular geolocation.

The *KETAI* platform leverages the affordances of 4th generation mobile devices, and in particular motion-awareness. It manages all built-in electronic sensors, focusing on gyroscope, accelerometer, and magnetic field sensor, offering a comprehensive approach for detecting motion and gesture. Faster and more accurate information about device attitude, context, and transportation mode enables a variety of novel use cases, ranging from traffic, to gaming, and heath care. Seventy percent of executives state that their companies regularly create value through Web communities [59, 60]. Open source platforms such as Processing(.js), Titanium, WebKit, and Android, have never played a more pivotal role in leading the way towards a mobile visual culture.

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