Lecture Summary 3: Sensors

We are observing an aggregation of sensors on mobiles, because advances in MEMS[1] engineering have made them cheap, and the environment of a phone is the same as the operator. Having a contextual awareness about the person, and also due to their lightness and physical size, makes them universally more useful for carrying sensors compared to a desktop. It opens up a range of uniquely interesting applications (both existing and potential near-future). For example, identifying ones location is widely adopted in Google maps and location-oriented social networking. In addition; motion, visual and audio processing can enable phones to make inferences about the environment, such as information on nearby objects or people. Motion sensors also have applicability in some interaction techniques, such as control and having knowledge where the camera is pointed.

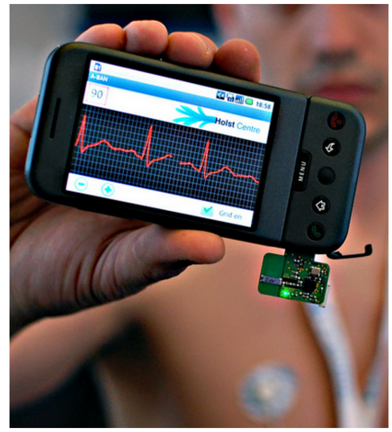

Figure 1: A phone attached to an external biological sensor, an indicator of yet further aggregation and contextual awareness than observed today.

While context awareness, the capacity for collecting data and the ubiquitous nature of mobiles opens up interesting, and yet unexplored territory, there are limitations on the phone, as a developer, we need to design with these taken into account. Many of the sensor systems are coarse and incur errors. The mobile has limited processing capacity and power, data proliferations may cause problems with consistency and fragmentation between formats and system, and can cause privacy issues. There are also different sensor accuracy, and range of available sensors between different phones.

Sensor Overview

Accelerometer Enables measurement acceleration in three directions (x,y,z) aligned with respect to the phone (z pointing perpendicularly upwards with respect to the screen). The measurements are achieved by variations in electric current than run through a proof mass. The mass is usually subjected to naturally occurring gravity ($g = 9.8ms^{-2}$), the measurements are therefore calculated with respect to this free-falling frame of reference (if the phone is stationary, a constant gravity $z = -g$ is observed. The constant presence of gravity is a useful indicator of the absolute orientation of the phone, in the Nexus1 for example, the landscape and portrait modes of the phone is inferred from this measurement alone.

Gyroscope The gyroscope uses tiny vibrating proof masses for measuring rate of change in angular velocity (based on the Coriolis effect), measurements similar to the accelerometer, depends on variation in currents. There are three degrees of freedom, the pitch is planar to the phone, while the yaw and roll are perpendicularly aligned to the phone. The gyroscope does not provide any absolute sense of measurements because of lack of external reference, but it is a useful addition in motion detection particularly suitable for detecting fine changes in orientation.

Compass The compass measures the phone's external magnetic field. This is done using the Hall effect, that depends on changes in electric current over a flat conductor. On modern phones this is also measured in the (x,y,z) frame relative to the phone. Because magnetic field lines run parallel to the earth's surface, and point towards the earth's magnetic north. Measurements of magnetic field can both be used as a coarse estimate of both direction and orientation of the phone. The estimates are coarse because natural magnetic fields are weak (which necessitates slower sampling rate), and the physical structure and internal currents of the phone itself causes interference.

GPS One of the principles methods of obtaining fixes for absolute geographical position (there are other ways of obtaining geographical estimates such triangulation with base-stations, and Google services that maintain knowledge of location of IP addresses). The GPS service is equivalent to conventional satellite navigation that depends on the time difference from line-of-sight with a handful of satellites overhead (communication is by radio-frequency like other wireless technologies).

Camera Measures absorption of photons that fall on CCD plate, which is converted into a 2D bitmap. Quality of vision capture is adversely affected of both dark and light environments. Problems of darkness is due to shot-noise where finite number of photons carry random uncertainty, and lightness has problems with overexposure. The camera lens is by design circular, which is corrected algorithmically but causes slight degradation of quality around the edges.

Microphone Audio frequencies are detected by electret materials that carry permanent static charge. Vibrations are detected by these in changes in distance between plates. A young adult has a hearing range of 12Hz-20KHz which some models will try to cover, while a cut-off at about 5KHz is present in some designs (iPhone).

[1] http://en.wikipedia.org/wiki/Microelectromechanical_systems

Precision & Implications

The MEMS sensors on the phone suffer bias instability, caused by environmental influences such as frequency and thermal drift. Single sensor measurements are usually taken as the mean across some sequence of data. For short averaging times the standard deviation (the noise) of the output improves over increasing times and is in proportion to the Allen deviation. But measurements over a certain duration causes the Allen deviation to increase, the bottom of the curve is considered the bias instability.

In strapdown navigation systems (where absolute reference points are missing) we are interested in monitoring position and orientation of the device. Positional estimates require a double integration of the acceleration (since it measures the rate of change of velocity), which means the bias instability compound errors quadratically. Similarly, estimations of orientation require a single integration of the gyroscopic measurements which will cause the error to grow linearly. The implication is, regardless of the accuracy of the underlying sensor, that inertial navigation can only provide accurate information on motion for very short sequences.

For application designers that rely on inertial motion control, need to take the drifts of error into consideration. Obvious solutions are to sample absolute reference points, which may be done by various techniques; by position (GPS), direction (compass), acceleration (related to free-falling reference), when standing still (by considering environmental situations) or computer vision (by analysing visual input).

Applications and Considerations

A critical technology for augmented reality (AR) is real-time tracking and processing of the viewpoint. Some existing computer vision algorithms are too expensive for mobiles, SIFT is a strong and computationally expensive feature descriptor, Ferns classification is fast, but requires large amounts of memory. A less resource demanding algorithm based on the techniques above has been described by Wagner and Reitmay indicate that solutions are about to emerge [1].

Consider the existing system Google's Googles[2], uploads the image to the server that returns processed results. Future systems will probably be analogous to the way Google Map works in that local environmental data is preloaded, and processing will take place on the phone.

Inertial sensors also have some applicability as an input mechanism, consider for exmaple the Wii[3] console. The controlling device uses an accelerometer for inertial control, together with infrared sensors on the stationary console to obtain the necessary absolute estimates on positions.

It is interesting to consider some of the future implications of the proliferation of sensors and pervasiveness of mobiles. HPLabs[4] suggestions for an Internet of Things to produce a planetwide sensing network to monitor a wide variety of environmental conditions. For example traffic conditions, or for collectively gathering data for research. Future sensors, that weren't included in this lecture may include sensors for biological information for patient care devices, which may open up a valuable data for collective and individual health benefits. Biological sensors may also be used in security, for example finger-print recognition to verify the owner of a particular device.

Conclusion

From a developers point of view, applications that are sensor related usually depend on their explicit presence, so the variance between phones may not always be such an issue. One consideration are applications that depend on visual processing, where camera quality and processing capabilities of the phone may vary. Application performance related to motion control may vary greatly depending on device, and in these cases we need to consider the degree of precision necessary in estimating the extent of necessary support by the device.

In widely pervasive applications that collect data we need to consider the nature of the data with respect to privacy, such as location information. For example if we use location data for drawing maps, one would need to appropriately disassociate information pertaining to any particular user. Which is true in general for any private data that collectively has wider interest.

[2] http://en.wikipedia.org/wiki/Google_Goggles
[3] http://en.wikipedia.org/wiki/Wii
[4] http://www.hpl.hp.com/research/intelligent_infrastructure/

References

[1] Wagner D. and Reitmay G. Real-time detection and tracking for augmented reality on mobile phones. *International Symposium on Mixed and Augmented Reality (ISMAR)*, 2010.