Chapter 3.19
Inertial Sensing in Biomechanics:
Techniques Bridging Motion Analysis and Personal Navigation

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ABSTRACT

Sensing approaches for ambulatory monitoring of human motion are necessary in order to objectively determine a person's level of functional ability in independent living. Because this capability is beyond the grasp of the specialized equipment available in most motion analysis laboratories, body-mounted inertial sensing has been receiving increasing interest in the biomedical domain. Crucial to the success of this certainly not new sensing approach will be the capability of wearable inertial sensor networks to accurately recognize the type of activity performed (context awareness) and to determine the person's current location (personal navigation), eventually in combination with other biomechanical or physiological sensors — key requirements in applications of wearable and mobile computing as well. This chapter reviews sensor configurations and computational techniques that have been implemented or are considered to meet the converging requirements of a wealth of application products, including ambulatory monitors for automatic recognition of activity, quantitative analysis of motor performance, and personal navigation systems.

INTRODUCTION

At present, human motor performance can be accurately assessed with several measuring instruments, the use of which is spread in many motion analysis laboratories throughout the world. The most important technology used to detect and track human body motion is video-motion sensing. In common with other motion tracking technologies, such as infrared, electromagnetic, ultrasound, video-motion sensing is externally referenced, in the sense an external source — optical, magnetic, acoustic — is needed to determine position and orientation information concerning the moving object of interest (Meyer, Applewhite, & Biocca, 1992). Usually, this source is effective over a relatively small working space. In addition to the range restriction, interference, distortions and occlusions can easily result in erroneous location and orientation information, thereby leading, in critical situations, to a complete loss of track (You, Neumann, & Azuma, 1999). The availability of dedicated laboratory setups is, therefore, a prerequisite for the application of externally referenced sensing techniques. However, from a clinical viewpoint, motor performance measured in laboratory settings may not accurately reflect functional ability in daily-life environments, since behavior of patients in laboratory is not necessarily representative of their daily-life behavior. There is a need for ambulatory monitoring systems that are able to provide objective assessment of human functional ability in the absence of the behavioral modifications induced by performing within constraining laboratory settings.

The capability of inertial sensors of sensing their own motion is the sourceless feature that makes them so attractive for the development of ambulatory monitoring systems (Verplaetse, 1996). Body-mounted sensors of this kind make it possible to determine position and orientation information based on the measurement of physical quantities (acceleration, angular velocity), which are directly related to the motion of the body part where they are positioned. Being internally referenced, inertial sensors can then be proposed to detect and track body motion over a virtually unrestricted working space. Until recent years, inertial sensors have only found use to monitor the motion of man-made vehicles, including spaceships, planes, ships, submarines, cars, and, more recently, wheeled and legged robots. Recent advances in microelectromechanical systems (MEMS) technologies have led to the development of a new generation of inertial sensors (Bachmann, Yun, McKinney, McGhee, & Zyda, 2003), the specifications of which — in terms of encumbrance, robustness, power consumption, measuring performance and cost — seem to be appropriate for applications in the biomedical field.

In inertial systems, the main problem is that position and orientation are found by time-integrating the signals from accelerometers and gyroscopes, as well as any sensor drift and noise superimposed to them. As a result, position and orientation errors tend to grow unbounded. This problem is especially acute when low-cost MEMS inertial sensors are used. Their sensitivity and bias stability are, in fact, orders of magnitude less than the sensitivity and bias stability of the high-grade inertial sensors that are embedded in military and aviation navigation systems (Foxlin, 2002). Another drawback of inertial sensors is that they are not well-suited for determination of absolute position and orientation. In order to be accurate, the integration process needs to be started from accurately known initial conditions, which inertial sensors are unable to provide at all (position and velocity), or can provide to just a limited extent (orientation). Hence, the use of inertial systems is most effective in those applications which involve relative motion.

In this chapter, we are not interested in the viewpoint of those who aim at designing new and better sensors. Rather, we intend to survey the main computational techniques that have been investigated so far, in the effort to take measurements from available sensors and construct the best possible characterization of human body motion. The traditional approach to data processing for navigational purposes has involved the development of filtering algorithms to fuse measurements from inertial sensors and other sensors, such as global positioning system (GPS) receivers and Earth's magnetic field sensors. It has also involved the exploitation of suitable environment maps so as to deal with the person's location uncertainty during indoor and outdoor navigation. Other computational techniques have been designed with a stronger biomechanical inspiration. They specifically aim at obtaining valuable information about either absolute or relative motion of body parts from simple configurations of single or multiple inertial sensors, in the effort to gain a deeper understanding of how we

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