Sensor network for inertial data acquisition

Introduction

Since early 90's, actigraphs has been manufactured and used for monitoring of human activity. Typical actigraph is placed on wrist and consist of an accelerometer, digital circuitry and memory. Numbers of threshold crossings during time periods were recorded as a measure of activity. In Parkinson's disease, tremor and dyskinesias (abnormal involuntary movements) are typical symptoms, whose occurrence is needed to be known for proper diagnosis and treatment evaluation. Both are shown as periods of high activity by actigraphs. More advanced sensors and algorithms are, thus, needed for monitoring of patients.

Tremor can be detected from signals of one wrist-mounted sensor but other symptoms are worse distinguishable from normal state or even indistinguishable when only one sensor is accomplished. This implies use of several sensors placed over the body.

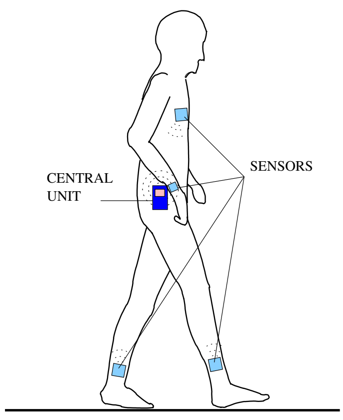
General requirements

Cable connection of a number of sensors fixed on a patient's body is cumbersome for him. A wireless connection appears to be a more suitable method for data collection on a patient (body area network, personal area network). The network consists of several measurement units accomplished with inertial sensors and a wireless comunication interface and of central unit synchronizing data collection, resolving patient's state and storing the results in a memory or storing all the measured data for later processing in a standard personal computer. As different algorithms are to be developed and studied, the second variant is now of interest.

One of specific requirements is low power consumption. Batteries in all units have to suffice at least for a day-long measurement if the data acquisition is supposed to measure patient's movements through whole day. Batteries can be recharged at night. Weight of the units is also critical, it can neither affect measurements nor encumber the patient (weight about 50 grams including the battery should be acceptable, but lower weight is desirable). On the other hand the transmition range is not needed to be greater than size of human body.

Sensor units for inertial measurement embody an accelerometer, gyroscope, or both. There exist three-axis accelerometers, which have no size, power consumption, nor price greater significantly than those with low number of axes, while gyroscopes are more expensive, need much more power, and most of them measures only rotation in one axis. Due to this facts three following variants put up as most preferable

- 3D accelerometer + 3D gyroscope as complete (sometimes named 6D) inertial measurement unit,



Obrázek 1: Principal spatial arrangement of the network nodes

- 3D accelerometer as low-cost and low-power measurement unit offering only acceleration data,
- 3D accelerometer + 1D gyroscope for applications where angular rate measured in one direction is very useful and other axes give no marked benefit.

Incorporation of magnetic field sensor measuring the Earth magnetic field would enable stable estimation of full orientation, not only inclination from vertical direction. Azimuth orientation of the body is not of the interest, but from full orientation of adjacent segments angle of corresponding joint can be computed and used for the monitoring.

To describe human movement a sufficient acquisition frequency has to be chosen. Bouten et al. (1997) concluded from a number of previous studies that signal frequencies up to 20 Hz are sufficient to assess all activities they studied. This implies acquisition frequency of about 50 Hz should be provided, but possibility to measure at higher frequency can be handy. As Bouten et al. (1997) noted, accelerations may reach 12 g in ankle during running, and 6 g at waist level. In Parkinsonian patients lower acceleration is supposed, range of 5 g will not be overpassed except extreme movements and impacts. Range of about 5 g's is preferable, greater range leads to lower sensitivity. For gyroscopes, Wu and Ladin (1996) observed maximum angular rate of 650 deg/s in low extremities. For detection of tremor, Salarian et al. (2003) reported use of gyroscope with range of 1200 deg/s, which was found to be needed to overcome signal saturation during very high speed movements of hand. But they hypothesized that sensitivity (no better than 0.58 deg/s per bit with 12bit A/D converter) may limit detection of tremor of very low amplitudes. The range of 600 to 1200 deg/s should be appropriate. The lower range will improve the sensitivity while enabling signal saturation during extreme movements.

Synchronization and data storage are hold in the central unit. Memory capacity should be sufficient for storage of all-day measurements from all sensors. Size of several hundreds of MBytes per day should be sufficient (for example, 2 bytes $\times$ 6 (axes) $\times$ 6 (measurement units) $\times$ 50 Hz $\times$ 3600 $\doteq$ 12.4 MB per hour). Maximum number of connected measurement units should not be less than 6 (number of accelerometers used successfully by Keijsers et al. (2003) for detection of dyskinesias). Central unit enables synchronization with an external measurement system (e. g., video) at least by generation of periodic pulses. Additive functions as A/D converter in the central unit or free computational capacity for simple algorithms is welcome. Detection of long periods with no movement and its signalization to the patient is an example of algorithm – periods of time when the patient have not moved due to his will can be distinguished from disability.

As an example of wireless network for data collection on human body we can mention work by Jovanov et al. (2005) based on the ZigBee protocol (Zigbee Alliance, 2006), interconnection of devices developed by Dynastream Innovations (Dynastream Innovations, 2005) (inertial pedometer, cyclocomputer, watch) using network ANT (Dynastream Innovations, 2006), or reference design by Freescale Semiconductor (2006a). A single device conected by Bluetooth was developed as master thesis at CTU by Brutovský (2006).

First prototype

Due to lower power compsumtion of accelerometers, and device complexity as low as possible, I highly recommend to focus on a prototype embodying only accelerometer at first, but mind the extensibility of the design to measurement of more quantities. Integrated triaxial accelerometers with appropriate ranges (or even with configurable range) are produced for example by Freescale Semiconductor (2006b). Some of them can be ordered as free samples, other types should be purchased from a distributor (for example SPOERLE Group (2006)).

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