Frequency Responses of Two Sensors for Measuring Knee Angle

Background

In the human body, different sensors exist which help a person know the location of a limb in space or whether one is leaning to the right or left. Scientists and engineers have also developed sensors which yield this information in real time when placed on different body segments. Angular position obtained from two sensors used for such motion tracking is shown in Fig. 4.1 and repeated here in Fig. 1. These sensors use two different technologies to obtain their estimate of angular position. Depending on the task, one sensor may be more appropriate than another.

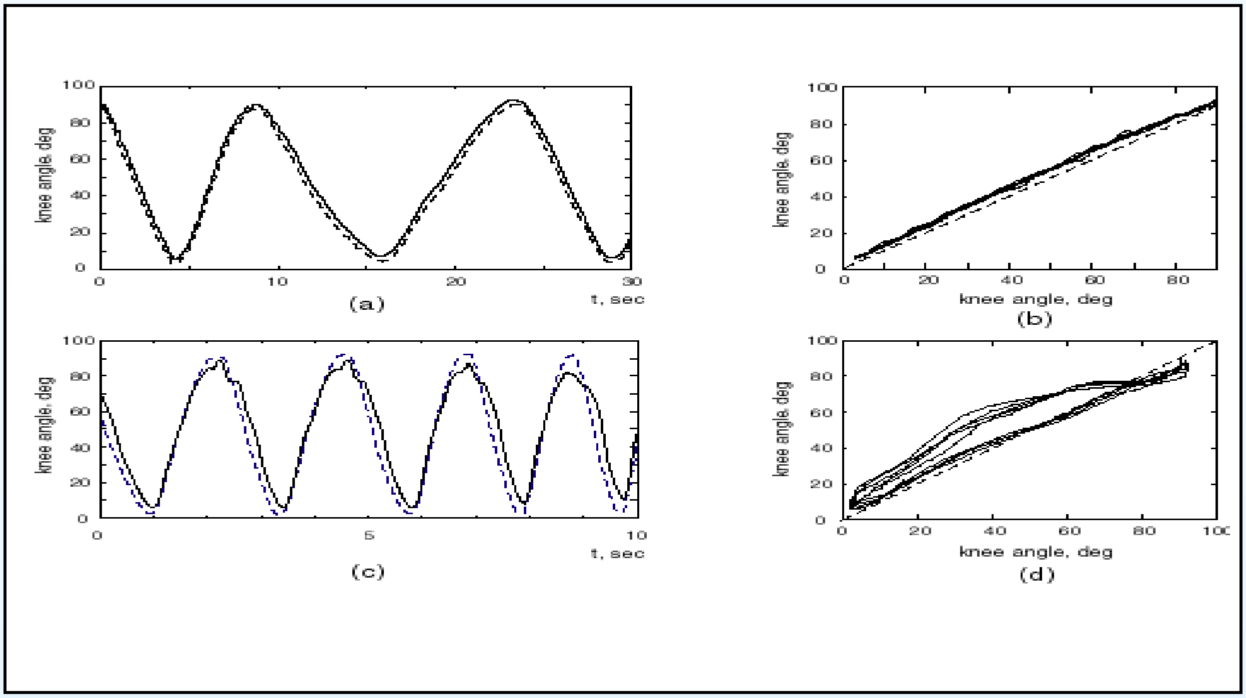

Fig. 1. The data from Fig. 4.1. (a,c) Outputs from the tilt (solid) and electromagnetic (dashed) sensors during oscillation of the lower leg about the knee at two different frequencies of oscillation. (b,d) Plots of tilt sensor output vs. electromagnetic sensor output for the traces in (a,b).

Fig. 2. The electromagnetic sensor (left, Ascension Technology) and the tilt sensor (right, Microstrain). A quarter is shown for size comparison.

One of the sensors yielding angular position is a tilt sensor. This transducer contains damped electrolytic fluid in a narrow channel. This sensor produces a signal which is proportional to angular position with respect to Earth's gravitational field. The other sensor is an electromagnetic sensor. For this device, a transmitter (that must be within 8 feet of the sensor) emits a pulsed DC electromagnetic field and the orientation of the sensor is determined with respect to the magnetic field. When attached to the human body, these sensors can be used in a variety of situations from virtual reality systems to performance enhancement in exercise and athletic activities.

These angular sensors might not only be used to monitor the relationship of limb segments with respect to each other, but may also be used within a movement and postural control system. In Functional Neuromuscular Stimulation systems, electrical stimulation is used to activate weakened or paralyzed muscles. In these systems, the angular measurement is sometimes used in the determination of the stimulation that is sent to the motor neuron to activate the contraction of the muscle to produce movement. In these situations, any inaccuracy in the measurement from the sensor would be transmitted through the system and result in poor control of the movement or posture.

Fig. 3. The electromagnetic sensor attached to the leg of a subject using a stiff pad to reduce movement of skin relative to bone.

Whether the angular sensors are being used within a system or to evaluate the system, the frequency response of that sensor plays an important role in the use of the devices. One biomedical use for the sensors is in a rehabilitation lab to monitor the control of posture and movement of the body. The choice of the sensor used for a specific task depends on the speed of the movement, the size of the sensor and the location of placement, and the accuracy of the measurement that is required. Movements in the control of posture over time have a tendency to be slow. In this case, the tilt sensor might be used. As the speed of the movement increases the electrolytic fluid may have a tendency to "slosh" about more. When the speed of the movement is faster like when a person takes a step to reach for an object, the electromagnetic sensor may be chosen. This sensor is not as sensitive to the speed of movement as the tilt sensor, although drawbacks with this device include increased noise in the signal when the sensor is operating near metal.

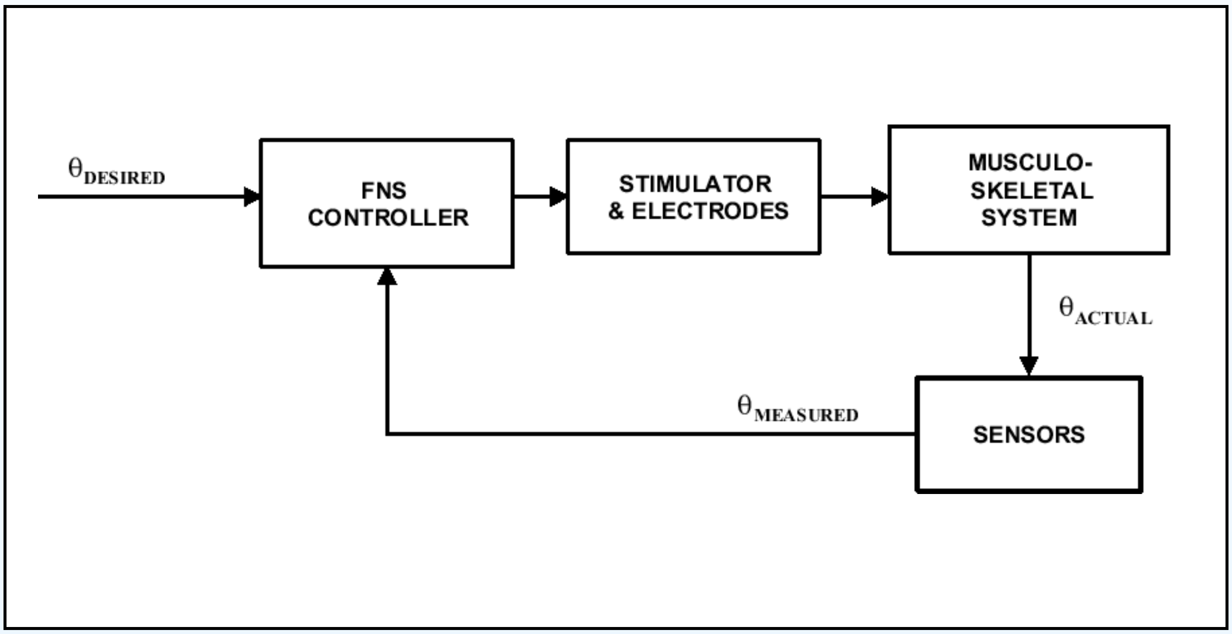

Fig. 4. An example of using motion sensors for feedback control of a system for Functional Neuromuscular Stimulation.

Another application for these types of sensors is for feedback control of a system for Functional Neuromuscular Stimulation (Fig. 4). In this case the signal from the motion sensor is compared to the desired motion trajectory by the FNS Controller, and the resulting electrical stimulation applied to the muscle(s) is adjusted according to the deviation of the actual motion from the desired motion.

How the data were acquired

The data in figure 1 were acquired from a device composed of a lever which rotated about a pin in one plane to represent the lower leg rotating about the knee in flexion and extension. 0° corresponds to having the lower leg aligned with the vertical (as if a person were sitting in a chair with his or her feet hanging free). Both sensors were attached to the simulated leg and manually rotated through 90° as if the person were extending his or her leg. The data from the electromagnetic sensor were collected via the serial port of a laboratory computer and the data from the tilt sensor was sampled using a National Instruments DAQ-Card 1200 I/O data acquisition board at a frequency of 20 Hz.

The simulated leg is used to calibrate the different angle sensors that are used in the laboratory. Some of the sensors can be calibrated by using pre-specified programs (like the electromagnetic sensor) while others need to be mapped independently (i.e. the tilt sensor). A two point linear fit was used to calibrate the tilt sensor in this case at 0 and 90° of extension.

The program *snsr_show.m* presents data collected from the sensors during movements at different speeds. The difference between the two sensors is displayed at the end of the simulation.

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