

**UNIVERSITY OF NOTRE DAME**  
**DEPARTMENT OF AEROSPACE AND MECHANICAL ENGINEERING**  
AME30362: Design Methodology, Fall 2009

**P5 – Concept Design – Sensor Development Trade Study**

**Project Due Date: Tues. Nov. 17, 2009**

This project will provide you the opportunity to contribute to the design of a device that will be a component in an engineering system. During this project you will perform a parametric design trade study in order to define the performance characteristics for this device. This project will provide you the chance to evaluate information associated with the performance of the device, use that information to define key parameters and to set performance criteria that will influence the performance of the complete system.

**Project Description:**

This project is a part of the continued development of subsystems required for the design of a team of robots designed to play the game of Mechatronic Intercollegiate Football. A key component of such a mechatronic device is a knock-down-fall-down (KDFD) sensor. This sensor will be used to indicate whether a player has been tackled, slipped, tripped or has run into an obstacle. Every time the KDFD sensor is activated, it will send a signal to the robot's controller, disabling the robot for a predetermined period of time.

The KDFD sensor is a single-board, electronic component comprised of an accelerometer and a dedicated microcontroller. The accelerometer 'chip' is model MMA7455L from Freescale. The device has the following characteristics:

- Three-axis accelerometer
- 8g range
- Sensitivity of 1/64 g (resolution per bit)
- Data rates of up to 250 Hz (250 Hz is the sample rate used for this application)
- Shock survivability of 5000g

The accelerometer interfaces with the dedicated microcontroller that processes the accelerometer signals and communicates with the robot's on-board processor. In this project you conduct a parametric trade study to assist in the design of the data processing algorithm that will be used to indicate when a player has been knocked down or fallen. It is quite similar to the design of the system that deploys an airbag during a car accident or is used in other equipment protection systems.

You can assume that the accelerometer is mounted such that the accelerometer's x-y axes are in the horizontal plane and these two components of acceleration will be used to indicate either an impact or excessive acceleration that could cause the player to "fall down." You will be provided with sample data taken from an accelerometer for a number of events and using that information, you will specify key design variables to implement a useful sensor for this application. Some technical issues that you will need to consider are:

**Smoothing (Filtering) the data:**

The raw data from each axis of the accelerometer is in integer format with a resolution of 1/64<sup>th</sup> of a "g" (i.e. 1 sensor unit = g/64) and it is sampled 250 times per second. The accelerometer is very sensitive and the data is noisy. It has been suggested that a simple moving average filter be applied to this digital data to reduce the noise. The simple moving average filter takes the form:

$$\text{accel}_{\text{avg}}(i) = (1 - \alpha) \text{accel}_{\text{avg}}(i - 1) + \alpha \text{accel}_{\text{measured}}(i)$$

The parameter  $\alpha$  ( $0 < \alpha < 1$ ) is used to control the characteristics of this simple filter. This is one of the parameters you will define as part of this trade study.

### **Computing the magnitude of the total acceleration in the horizontal plane:**

Once both the x and y components of the acceleration have been filtered, the magnitude of the instantaneous acceleration in the x-y (horizontal) plane can be estimated:

$$|\text{accel}_{\text{total}}(i)| = \sqrt{(\text{accel}_x(i))^2 + (\text{accel}_y(i))^2}$$

### **Computing the jerk:**

Once the magnitude of the acceleration is computed, it has been proposed that the microcontroller compute the rate of change of the acceleration with respect to time as an indicator of an upsetting (knock-down or fall-down) event. The derivative of acceleration is referred to as the jerk. The microcontroller can compute the jerk using a simple, one-sided numerical differentiation technique.

$$\text{jerk}(i) = \frac{(\text{accel}_{\text{total}}(i) - \text{accel}_{\text{total}}(i - n))}{n\Delta t}$$

Since performing numerical differentiation on noisy data is problematic, you have the option of varying the time increment (n in the above equation) to try to reduce the influence of the noise and of very high frequency events in the data. Increasing the value of “n” effectively increases the “delta t” over which you are computing the slope of the acceleration versus time curve. Thus “n” is a second parameter you will need to define for this device.

### **Setting the threshold:**

Once the jerk has been computed, the designer must select a threshold value for the jerk,  $\text{jerk}_{\text{MAX}}$ , that will define if an event has occurred that should be indicated as a knock-down or fall-down. The microcontroller will continuously compare the current value of jerk with the threshold value. If it exceeds the threshold value it will emit a KDFD signal and disable the robot.

A series of tests have been performed and the raw acceleration data (for x and y) have been recorded for different events. Some of the data are for events that involved different types of collisions between two robots and there are events where no collision took place. These data records are posted as text files on the course web site, along with brief video clips of the collision for each data set.

### **Project Requirements:**

This is an individual project in which you will perform a parametric trade study and use that study to recommend the most appropriate values for  $\alpha$ , n, and  $\text{jerk}_{\text{MAX}}$ . Your contribution to this project should be documented as a formal technical memorandum. The memorandum should describe how you processed the data you were provided, assumptions that you made, the criteria you used to make your selection of the parameters, observations and concerns and your **specific recommendations with justification for the three parameters,  $\alpha$ , n, and  $\text{jerk}_{\text{MAX}}$ .**

The format for the memorandum is at your discretion but figures, tables, charts, etc. should be used when appropriate. The document **MUST** be no longer than 3 pages and any text elements should be 12-pt font, single-spaced. **NO** consideration will be given to any information on pages 4 or greater so concise and efficient presentation of your results and recommendations are critical. The memorandum should be submitted in hard-copy form in class and electronically in .pdf form.

### **Project TA Coordinator:**

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