AN ONLINE MEASUREMENT SYSTEM OF TRANSPORTATION SAFETY AND COMFORT

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Abstract: *In this work an arm based microprocessor system is designed to implement the algorithm recently developed for a ride comfort measurement for transportation. To obtain an effective online measurement, the rapidly changing transport comfort index signal is passed from a proper digital low pass filter so that previous data is combined with the newly coming values. The system uses an on board digital acceleration sensor, a graphical LCD touch screen, and a computer interface through USB port. The measured data can be displayed, recorded, and reported for future evaluation. The device is used on transportation vehicles such as cars, buses, trams, and planes. The resulting graphs of these sample trials are provided.*

Keywords: RIDE COMFORT, ACCELERATION, ACCELERATION SENSORS, DIGITAL FILTERING, MICROPROCESSORS

1. Introduction

One of the early works of measuring comfort levels for human transportation through a rugged device begins with a patent regarding the effect of machine vibrations on U.S. army personnel [1]. The device gets the three dimensional signals from an analog accelerometer mounted on the seat supporting the human being. The total average absorbed power of these signals is obtained using analog circuits with filtering, squaring and averaging operations to measure human comfort (or discomfort).

From then on, many theoretical and practical works are proposed to properly measure the human ride comfort [2-8]. In a current patent application [9], based on the changes of acceleration on the moving vehicle, a ride comfort measurement method is developed for transportation. After the acceleration signal in the forward moving direction is received using a digital acceleration sensor, the developed algorithm is applied to this incoming data. Here mainly a band pass filter and a Root Mean Square operation is used first and then a Gaussian function is employed to obtain a measure called Transport Comfort Index (TCI). This method effectively provides a measure for the quality of the transformation for human comfort [10].

In this work an arm based microprocessor system is developed to implement the measurement algorithm described above. The necessary system, algorithms, and resulting graphs of some sample trials are provided in the following sections.

2. Description of the Method

In [10], a novel method is presented in detail for providing a proper measure for ride comfort of human transportation. In summary, the corresponding equations are used to obtain an average measurement for Transport Comfort Index (TCI):

$$TCI(n) = 100 \cdot \exp\left(-\frac{1000}{n} \sum_{k=1}^{n} q_x^2(k) \right)$$

where q_x is the band-pass filtered version of a_x, the acceleration signal in the forward moving direction:

$$H(z) = \frac{Q_x(z)}{A_x(z)} = \underbrace{\left(\frac{1+\alpha}{2} \frac{1-z^{-1}}{1-\alpha z^{-1}} \right)}_{HPF} \underbrace{\left(\frac{1-\beta}{2} \frac{1+z^{-1}}{1-\beta z^{-1}} \right)}_{LPF}$$

here,

$$\alpha = (1 - \sin \omega_h)/\cos \omega_h ,$$

$$\beta = (1 - \sin \omega_l)/\cos \omega_l ,$$

$$\omega_h = 2\pi / f_s ,$$

$$\omega_l = 10\pi / f_s ,$$

where for the current application the sampling frequency, f_s, is chosen to be 100 Hz. For this case, the band-pass filter becomes:

$$H(z) = \frac{0.1326(1 - z^{-2})}{1 - 1.6656 z^{-1} + 0.6823 z^{-2}} .$$

TCI represents the total average assessment of the ride comfort throughout the trip between 0 and 100. The values 0 to 50 represent a level of unacceptable driving for most passengers. The range of 50 to 70 is bad, 70 to 80 is tough, 80 to 90 is normal, and 90 to 100 is gentle driving in general.

Instead of a single average value for whole trip, we may need a time function representing how the driving is changing during the trip. For this purpose, the last 10-second calculation of TCI is defined in [10] as given by the formula:

$$TCI_{10}(n) = 100 \cdot \exp\left(-\frac{1000}{10 f_s + 1} \sum_{k=n-10 f_s}^{n} q_x^2(k) \right)$$

The drawback about the above description is that it needs to keep a huge amount of q_x values, and, it uses the same equal weight for the last 10-second acceleration values. Instead of this, we can employ a low pass filtering approach to properly asses the current value of TCI. The following equations can be used for this purpose:

$$E(n) = \gamma E(n-1) + (1-\gamma) q_x^2(k)$$

$$TCI_C(n) = 100 \cdot \exp(-1000 E(n))$$

where TCI_C represents the (low pass filtered) current value of the transport comfort index assessment. The low pass filter rate could be chosen with the cut-off frequency of 0.05 Hz, which will make the measurement smooth enough having a time constant of 3.2 seconds. Therefore the parameter γ is chosen to be 0.997.

3. Implementation of the Algorithm

An arm microcontroller based system is used to implement the algorithm for calculating various values of TCI. The system, shown in Fig. 1, uses an on board digital acceleration sensor (LIS302DL), a graphical LCD touch screen, and a computer interface through USB port. The above algorithm can be implemented using a program partially shown below.

```
/**************   MAIN PROGRAM   **************/
int main (void) {
  int lisreadno =  0;   // Sensor reading number
  signed char lisx=0;  // Current sensor reading
  signed char lisxb=0;  // Previous sensor reading
  double Px=0.0;       // Pre Filtered acceleration
```

```
  double Pxb=0.0;     // Pre Filtered acceleration before
  double Pxbb=0.0;    // Pre Filtered acceleration before before
  double Qx=0.0;      // Filtered acceleration (q) value
  double Qxb=0.0;     // Filtered acceleration (q) value before
  double Qxbb=0.0;    // Filtered acceleration (q) value before before
  double Clbx=56.0;   // typical calibration constant
  double lpfcoefx;    // Low pass filter b coefficient
  double Esumx=0.0;   // Sum of Qsqr
  double Qsqrx=0.0;   // Qx^2
  double Ecx=0.0;     // TCI current filter variable
  double Ecmaxx=0.0;  // Ec max value
  double TCITx=0.0;   // TCI Total (Mean)
  double TCICx=0.0;   // TCI Current
  double TCIMinx=0.0; // TCI Minimum
  const double lpfb=0.7265; // pre LPF value

//Initial values
lisreadno=0; Esumx=0.0; Ecx=0.0; Ecmaxx=0.0;

//LIS302DL Configuration
LIS302DL_Init();  // Initilize I2C
LIS302DL_Write(0x20,1,0x47);
// Write to CTRL_REG1 (XYZ enabled, ODR 100 Hz, +-2g)
//Read registers to clear overrun
LIS302DL_Read(OUTX,1);

for (;;) {  /*   Main Loop   */

  // Read status register
  LIS302DL_status=LIS302DL_Read(0x27,1);

  if (LIS302DL_status & (1 << 3))     {
        // xyz new data available

        lisxb=lisx;  // Save the previous values
        // Read sensor values
        lisx=LIS302DL_Read(OUTX,1); lisreadno++;

        Pxbb=Pxb;Pxb=Px;
        if (lisreadno==1) {  // this is to prevent jump for the HPF
                Px=(double)lisx/Clbx;Pxb=Px;Pxbb=Px;
                lisxb=lisx;}

        // Pre Low Pass Filtering of Acceleration Input Signal
        lpfcoefx=(1.0-lpfb)/2.0/Clbx;
        Px = lpfb*Px + lpfcoefx*((double)lisx+(double)lisxb);

        //Band Pass Filtering
        Qxbb=Qxb;Qxb=Qx;
        Qx=1.6656*Qxb-0.6823*Qxbb+0.1326*(Px-Pxbb);

        Qsqrx = Qx*Qx;
        Esumx = Esumx + Qsqrx;

        // TCI Current filter with 0.05 Hz cut off frequency
        Ecx = 0.997*Ecx + 0.003*Qsqrx;

        // TCI Minimum
        if (Ecmaxx<Ecx) {
          Ecmaxx=Ecx;     // Ec max value
          TCIMinx = 100.0*exp(-1000.0*Ecmaxx);  }

        // TCI Total (Mean)
        TCITx= 100.0*exp(-1000.0*Esumx/lisreadno);

        // TCI Current
        TCICx= 100.0*exp(-1000.0*Ecx);

        // Display Results
        }   // end of lis read cycle
  }  // end of for (;;)
}  // end of main
/*************************************************/
```

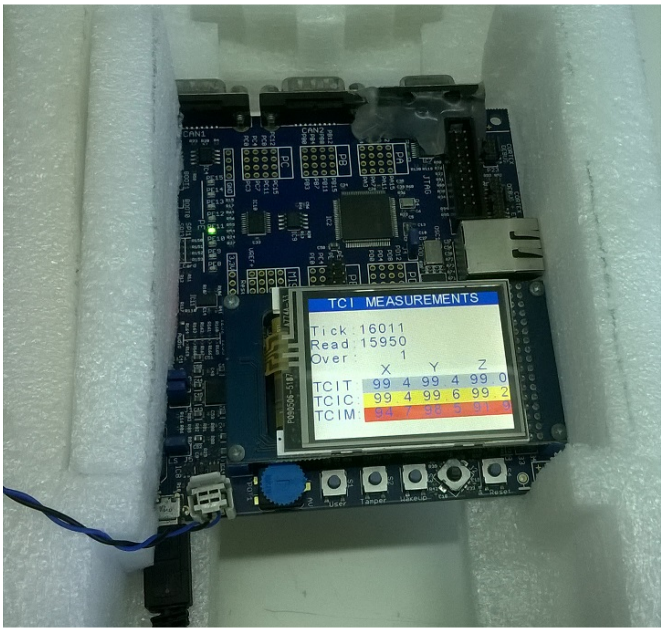

***Fig. 1** An arm based microcontroller system for TCI measurement.*

a)

b)

c)

d)

Fig. 2 *TCI measurements for various test cases: a) Gentle driving, b) Tough driving, c) Unacceptable driving, d) Actual airplane landing.*

4. Measurement Results

60-second driving tests are carried out using different styles as shown in Fig. 2. Figures (a) to (c) are corresponding to gentle, tough and unacceptable driving. As seen from the plots, the algorithm stably and quickly tends to the correct levels as expected. Fig. 2(d) shows a sample of an actual airplane landing. As seen from the graph, the landing is at normal comfort level.

Other driving tests are carried out for actual public bus trips in Istanbul, Turkey. In Fig. 3, total of 338-minute trip is reported. The average TCI is 93.37, and, the average TCI min 77.94 for this case. Table 1 summarizes the detailed values for different trip times. In Fig. 4, on the other hand, a 212-hour test is reported. It is calculated that 66.1 hour of this time (31.2%), the bus was actually moving. The average TCI is 85.2, and, the average TCI min is 55.8 for the working times, and, Table 2 summarizes the detailed values for different trip blocks.

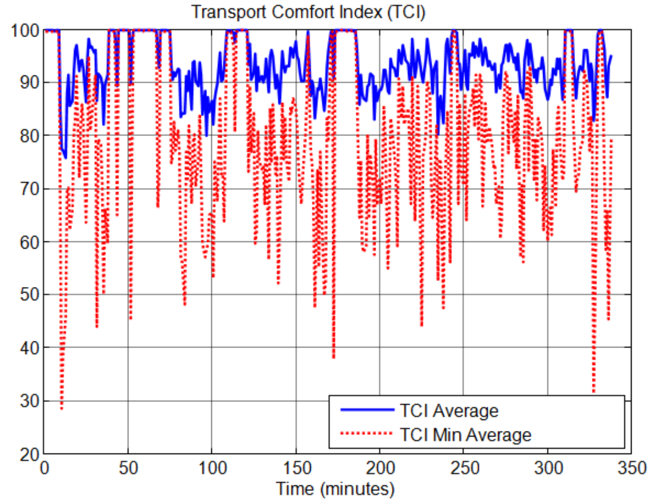

Fig. 3 *TCI measurement for a public bus trip.*

Table 1: *TCI Average and TCI Min Average values.*

Trip Times (Minutes)	TCI Averages	TCI Min Averages
9-39	90.44	70.07
75-109	89.58	70.96
121-171	92.28	74.14
186-244	91.63	73.50
245-311	93.23	77.47
316-331	92.41	74.79

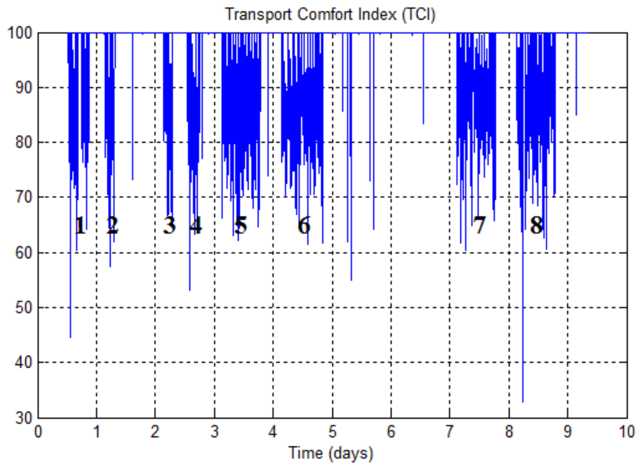

Fig. 4 *TCI measurement for a public bus trip.*

Table 2: *TCI Average and TCI Min Average values.*

Trips	TCI Averages	TCI Min Averages
1	84.4	55.8
2	82.6	52.9
3	84.9	55.7
4	80.7	50.5
5	85.5	52.4
6	85.1	57.7
7	86.3	59.8
8	86.0	57.7

5. Conclusions

As seen from the measurement results, the proposed system provides a useful measure to compare different transportation vehicles and drivers for human transport comfort. TCI average gives a single number for evaluation of the whole trip. TCI min indicates values for the worst times during the trip. TCI current value, on the other hand, gives an on-line measure for an assessment of the current value (about last 10 seconds but weighted higher for the recent times) which may be shown on a display for the passengers to continuously observe the driving comfort.

The proposed system can be employed for the purpose of checking and improving the driving quality, therefore assuring the proper operation of the vehicles and the satisfaction of the passengers. The drivers can be evaluated for each trip by automatically recording and displaying the average, current and minimum values of TCI. This may be very useful for public transport vehicles as well as for private company cars since the evaluation of driving skills will lead to the improvement of drivers' quality in transportation.

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