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REVIEW OF MASS FLOW RATE MEASUREMENT METHODS IN PNEUMATIC CONVEYOR

HERLINA ABDUL RAHIM[1*], AKMAL HAYATI RUSLI[2] & NOR SARADATUL AKMAR ZULKIFLI[3]

Abstract. This paper describes several types of sensor use in measuring mass flow rate of solids flowing in pneumatic conveyors. Each sensor will applied different principle but most of them are able to achieve 10% homogeneity error. These sensor techniques include capacitance sensor, electrostatic sensor, microwave sensor, radiological sensor, combination of electrostatic and digital imaging sensor and others. The sensing filed designs need to be uniform, thus particles exist within the sensing field will contribute equally to the flow signal.

Keywords: Mass flow rate; sensor; pneumatic conveyor; measurement methods

Abstrak: Kertas kerja ini menjelaskan beberapa jenis penggunaan penderia untuk mengukur laju aliran pepejal yang mengalir di penghantar pneumatik. Setiap penderia akan menggunakan prinsip yang berbeza tetapi kebanyakan darinya mampu mencapai kesilapan homogen sebanyak 10%. Teknik-teknik ini termasuk penderia kapasitan, penderia elektrostatik, penderia gelombang mikro, penderia radiologi, kombinasi penderia elektrostatik dan digital imej dan lain-lain. Reka bentuk penderiaan harus seragam, maka zarah yang ada dalam kawasan penderiaan akan memberikan hasil yang sama terhadap isyarat mengalir.

Kata kunci: Aliran pepeja; penderia; penghantar pneumatic; kaedah pengukuran

1.0 INTRODUCTION

Mass flow rate is measured inside the pneumatic conveyor, which is a tool use for transportation of a wide variety of pulverized and granular materials. Non- invasive mass flow measurement has become rapidly important in process of increasing productivity and improved the quality of products as well as the efficiency of process [1]. Particle velocity and solids volumetric concentrations are the two importance parameters that need to be measured simultaneously.

[1-3] Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru
* Corresponding author: herlina@fke.utm.my

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Capacitance sensor is one of the non-invasive instrumentation systems type. It is used to determine the component concentration at two-phase flows in the industrial processes. This sensor can be found in two ways either in a single-pair electrode system and an implementation of optimum design of strip-type. While for electrostatic sensor, it consists of three type of electrode geometry form. There are pin type, quarter ring type and full ring. Among three of them, full ring electrode will give the best homogeneity characteristic for the mass flow rate measurement

Some other researchers develop novel instrumentation system that uses a combination of electrostatic and digital imaging sensor to measure the mass flow rate. The digital imaging system is able to measure particle size distribution and volumetric concentration of particles. While electrostatic velocity metering technology was possible to derive absolute mass flow rate. When combine these two systems along with absolute material density, it's able to derive the mass flow rate.

2.0 OBJECTIVE

The objective of this technical review paper is to explain and differentiate three methods used to measure the mass flow rate of randomly distributed solids flowing in pneumatic conveyors. It is recommended that a problem of highly inhomogeneous solids distribution and non-uniform velocity profile tends to happen over the pipe cross section. This is due to several factors such as the pipe orientation, measuring location and conveying air velocity. Thus, it is in the industry to develop system that can measure various flow parameters especially absolute mass flow rate of particles and particle size distribution on an on-line continuous basis.

3.0 RESEARCH METHODOLOGY

Each sensing has its own method and principle. But all of them reached almost same results with 10% of homogeneity error [1]. There are several types of sensor.

3.1 Capacitance Sensor

Capacitance sensor work based on the principle that the solids presence within the sensing volume will increase the measured capacitance when referred to a gas [1][2]. The homogeneity of capacitance sensing depends on several reasons such as:

i. Pipe wall thickness (R_2-R_1)
ii. Electrode screen radius (R_3)
iii. Electrode angular size (θ)
iv. Pipe wall permittivity

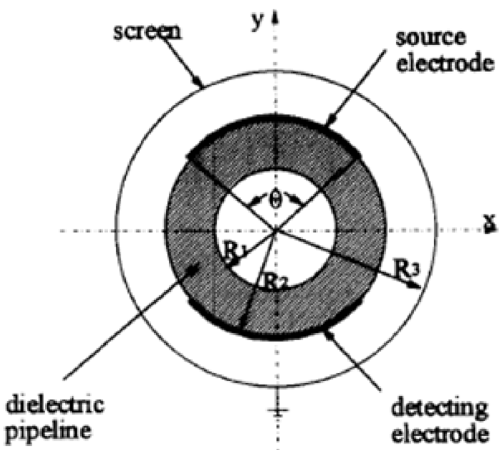

Figure 1 Capacitance sensor [1]

To assess the homogeneity of a particular type of sensor and to compare different types, a parameter known as homogeneity error is introduced, which is defined as:

$$e_r = \frac{\Delta S_{\max}}{S_{ave}} \tag{1}$$

Based on Equation 1, it is obtained approximately 10% of homogeneity error. There are two ways to implement an optimum design of strip-type capacitance sensor which are by optimum it sensitivity distribution and pipe wall permittivity. An optimum sensitivity distribution can be achieved using very thick pipe wall. The sensitivity distribution may higher closer to the electrodes compared to the center of the sensing area. In order to maintain its optimum sensitivity, some problem may occur as the sensor is not suitable for applications to large pipe sizes such as those used by coal-fired power station. As for get an optimum pipe wall permittivity; a material with low permittivity should be used. But this entire characteristic depends on conveying air pressure, pipeline temperature, corrosion and abrasion of the fluid.

3.2 Electrostatic Sensor

Electrostatic sensor working principle is based on three principles which are the collision between particles, impact between particles and pipe wall as well as friction between particles and air stream [1][3][4]. As shown in the figure, ratio of the axial width to the diameter (W/D) is a dominant parameter influencing the homogeneity of the sensor. Poor repeatability may occur in the measurement of particle velocity if an excessive increase in W/D which may cause significant spatial filtering effects on the flow signals.

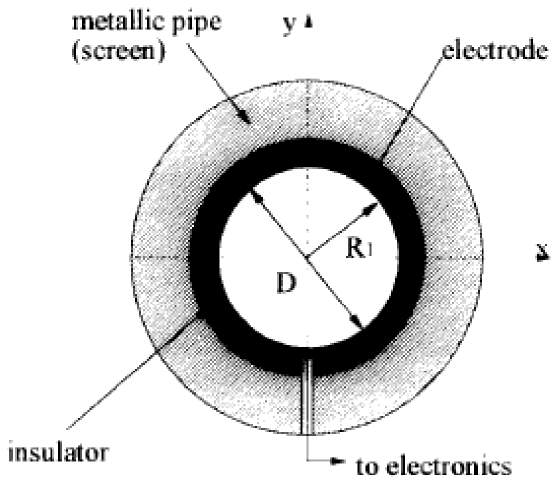

Figure 2 Electrostatic sensor [1]

It is difficult to interpret the data in terms of absolute value of solids concentration as the charge signal derived from the sensor depend on the particle size, moisture content and conveying air velocity [5][6]. Thus, to solve this problem a pair of electrostatic sensor is used in combination with a capacitance sensor for solids concentration measurement.

3.3 Microwave Sensor

This sensor is figured out as a section of cylindrical dielectric material covered with conducting metallic pipe can form a microwave cavity resonator [1]. This sensor used an approach of analysis the electric field intensity within the cavity. Based on this structured, homogeneity of the sensor depends upon the ratio of R_2/R_1. The more thickly the pipe wall, the more uniform distribution it makes. At $R_2 = 2.5R_1$, its achieved 10% homogeneity error.

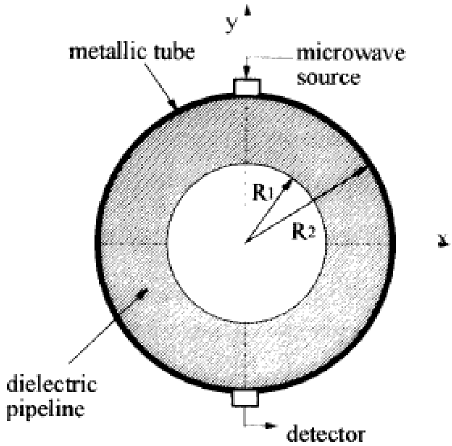

Figure 3 Microwave Sensor [1]

3.4 Radiological Sensor

Ionizing radiation in the form of gamma – rays or x-rays had been used as a method for radiological sensors [1]. The whole system is based on thing that the further the point source is located away from the pipe section, the weaker is the field. Thus, it can achieved more uniform sensitivity distribution. By using radiological sensor, its achieved 10% of homogeneity when L/D = 10.

3.5 Radiometric Sensor With Parallel Beam Geometry

A pair of strip sources situated in the same plane generates two mutually perpendicular sets of parallel radiation beams interrogating the entire pipe cross section [7]. The use of this method can minimizes geometrical error as well as can accommodate a wide range of velocity and concentration profiles.

An attenuation data were provided when the transmitted beams detected by a multi-element photo-diode array. Tests are done on several locations in a pneumatic conveyor samples. Each location gives different effect to the value of mass flow rate.

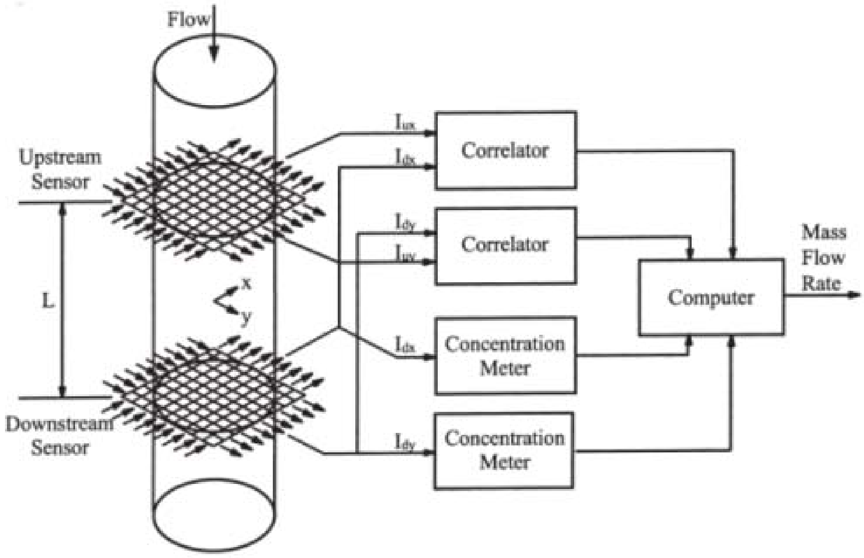

Figure 4 Proposed Radiometric system employing parallel beam geometry [7]

3.6 Combination of Electrostatic and Digital Image Sensor.

For evaluation purposes, a small flow loop has been set up. This loop is approximately six meters in total length and used 40 mm ID pipe [8]. Vibratory feeder introduces material that controlled accurately to adjust mass flow rate and suction fan is used to draw the material through the rig. The power of suction fan is adjustable, allow for varying material velocities.

First experiment was performed using table salt as a test material. The results recorded at four different solids concentrations, velocity of 20 m/s and it is shown in Figure 5.

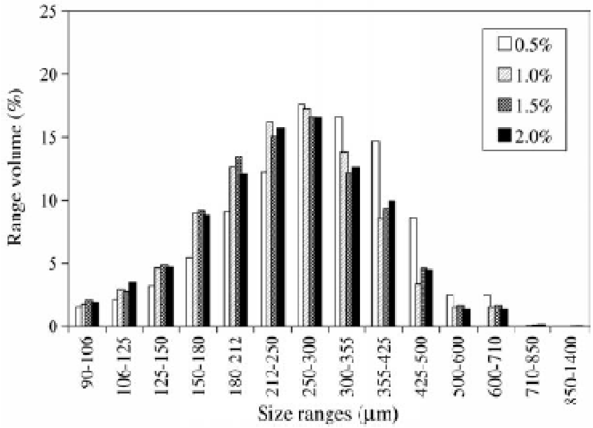

Figure 5 On-Line particle size distribution at four solids concentration [8]

A second experiment is to compare on-line results with the accepted off-line laser diffraction based size analyzer. Both system take 'in-flight' particle measurement. From figure 6 shows that the imaging result represents a mean of the results in figure 5.

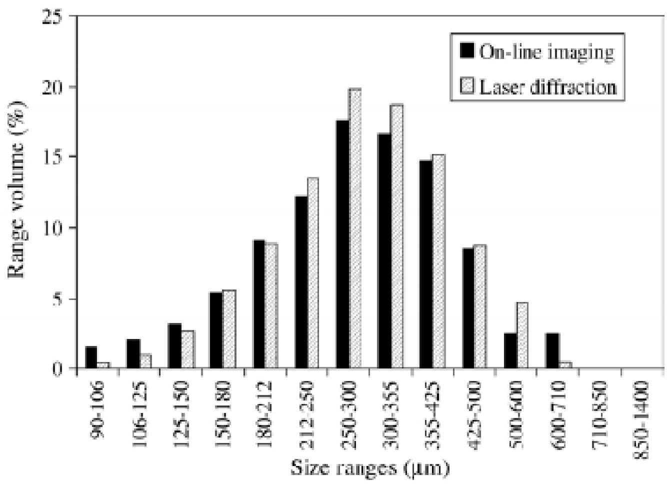

Figure 6 Comparison between off-line laser diffraction and on-line imaging result [8]

Therefore, it shows that the discrepancies between the two methods are no greater than ±2.5% and in conclusion imaging sensor is suitable for the imaging size measurement.

For repeatability of the size measurement, five experiments is perform using material from same batch and normalized standard deviation results established and similar procedure was performed with laser diffraction system for the comparison. Results show that standard deviations seem high and assumed that fundamental repeatability the instruments are swamped by the variations in material. The imaging sensor gives better results in the lower size ranges. With the imaging approach, the difference between measurement techniques may explain the lower deviations in small size ranges.

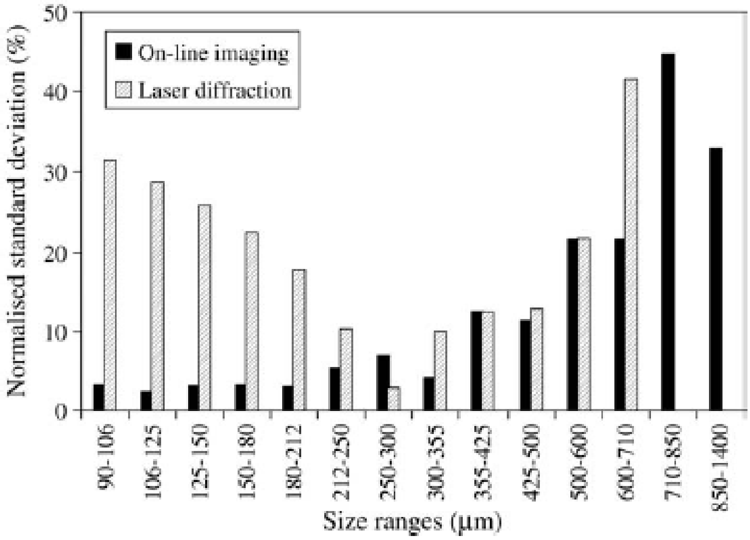

Figure 7 Repeatability of on-line imaging compared to laser diffraction [8]

For the measurement of mass flow rate, total of 16 experimental runs were performed at four flow rates and four velocities. Problems occur that the same flow rates could not be established at each velocity. The 3 graph is form due to this experiment that is showed in Figure 8, Figure 9 and Figure 10.

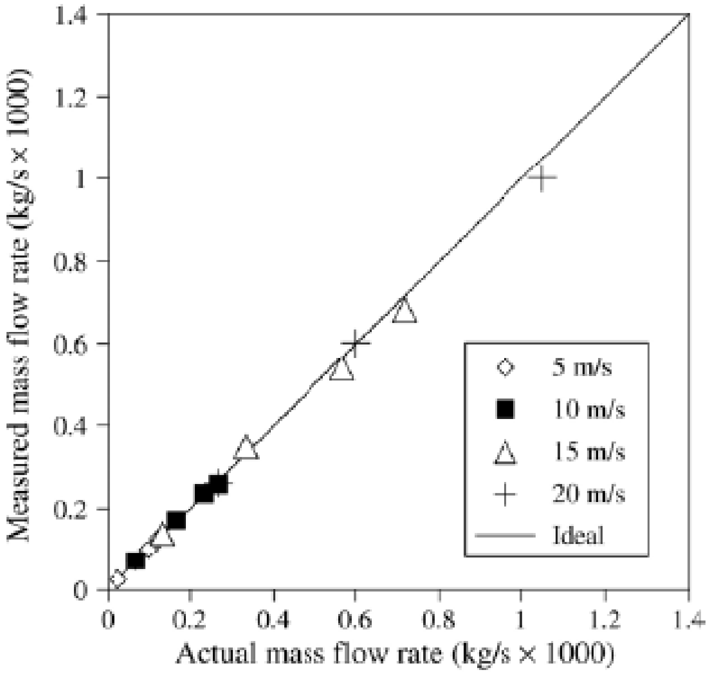

Figure 8 Comparison between measured actual mass flow rates [8]

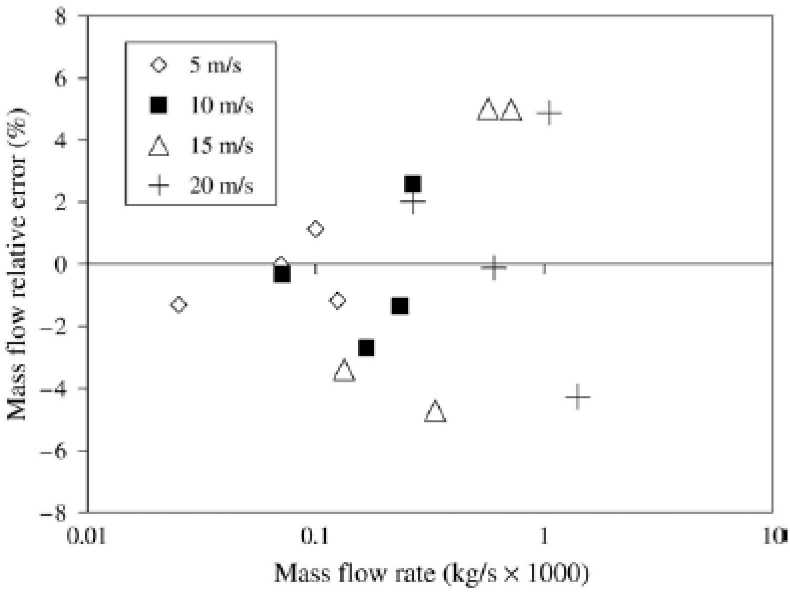

Figure 9 Relative errors of mass flow measurement [8]

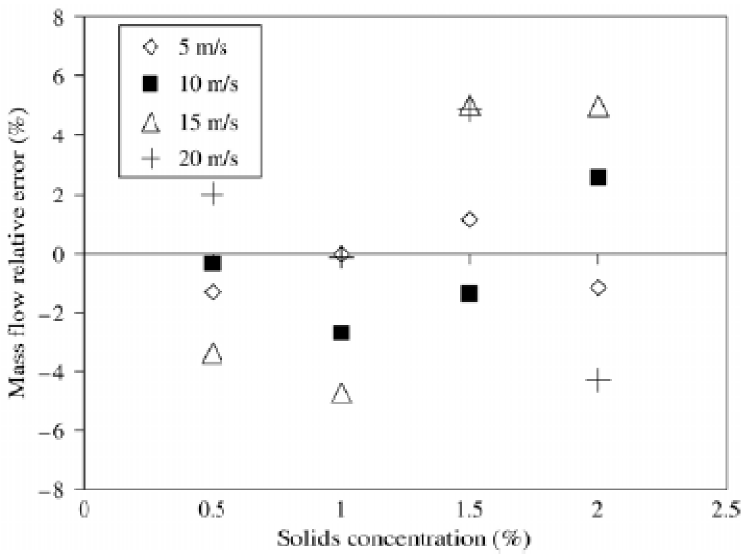

Figure 10 Relative errors of mass flow measurement versus solids concentration [8]

4.0 DISCUSSION

Based on the difference sensing method applied, difference outcome might obtain via several experiments done by previous researchers. To compare the arrangement of all sensors, none of them will give the perfect results.

For the combination of electrostatic sensor and digital imaging sensor, there are list of result that need to analyze. Figure 7 show the great linearity and the velocity point is higher demonstrated that errors are no greater than ±6%. However Figure 8 shows that errors increase with mass flow rate while in Figure 9 can be seen clearly that error tends to increase with velocity when the concentration constant. As the result this can attribute to fluctuations in the correlation velocity data highly repeatable deviate from the true spatially averaged velocity. Therefore this useful mass flow measurement has been achieved in an on-line non-intrusive manner [8].

For radiometric sensor, every location in the experiment will give different result in the mass flow measurement. Table 1 shown the summary of results experiment.

Table 1 Summary results of radiometric sensor [7]

Sensor location		Measured solid fraction	superficial air velocity	Measured mass flow rate	Mass flow rate from load cells
A	X	6.2±0.4	23.9~25.0	-	0.95
	Y	6.4±0.3	23.3~24.6	-	0.96
B	X	3.0±0.2	23.9~25.0	0.74±0.05	1.00
	Y	3.8±0.2	23.3~24.6	0.74±0.05	0.98
C	X	1.2±0.1	27.1~28.3	-	0.95
	Y	1.1±0.1	27.6~28.9	-	0.95
D	X	2.5±0.1	27.1~29.1	0.82±0.05	0.92
	Y	2.3±0.1	27.3~29.4	0.95±0.05	0.96

From the table 1, solid fraction measured is depending on the distribution of the solids within the pipeline of the sensing location. The lower error in calculating mass flow rate occurred at location B and D due to the high velocity. The best location due to measuring the mass flow rate is in location D. the measurement error in mass flow rate is reduce due to the higher phase velocity and distribution of the more dispersed flow regime. The very low error measured in location D that is 1% [7].

From this three results obtain, found that the lower error when measured the mass flow rate is radiometric sensor at location D that is 1%. Follow by combination of electrostatic and digital imaging sensor that is ±6% and for capacitance sensor is 10%. From the value of velocity, for radiometric sensor the error tend to decrease with the higher velocity. However for the combination sensor, the higher velocity tends to increase the error.

5.0 CONCLUSIONS

In conclusion, between these three types of sensor, the most sensor that is suitable for measuring the mass flow rate is combination of electrostatic sensor and digital imaging sensor. This is because the results obtain is refer to the industrial setting and ISO13320. Although the error values for this type of sensor is higher compare to the radiometric sensor, this combination sensor gives good result and produced a level of accuracy that is acceptable in industrial setting.

REFERENCES

[1] Yong Yan, Ben Byrne and John Coulthard. 1994. *Sensing Field Homogeneity in Mass Flow Rate Measurement of Pneumatically Convenyed Solids*. School of Science and Technology, University of Tesside, UK.

[2] G. C. Xie, A. Plaskowski, and M. S. Beck. 1990. Design of Capacitance Electrodes for Concentration Measurement of Two-Phase Flow. *Measurement Sci. Technol.* 1: 65-78.

[3] Lihui Peng, Yan Zhang and Yong Yan. 2008. Characterization of Electrostatic Sensors for Flow Measurement of Particulate Solids in Square-Shaped Pneumatic Conveying Pipelines. *Sensors and Actuators A: Physical.* 141(1): 59-67.

[4] Jiaqing Shao, Jan Krabicka, and Yong Yan. 2010. Velocity Measurement of Pneumatically Conveyed Particles Using Intrusive Electrostatic Sensors. *IEEE Transactions on Instrumentation and Measurement.* 59(5).

[5] Y. Yan, B. Byrne, S. Woodhead, and J. Coulthard. 1995. Velocity Measurement of Pneumatically Conveyed Solids Using Electrodynamic Sensors. *Measurement Sci. Technol.* 6.

[6] Y. Yan, B. Byrne, and J. Coulthard. 1994. Radiological measurement Of Dilute Inhomogeneous Solids Loading In Pneumatic Conveying Systems. *Measurement Sci. Technol.*5: 110-119.

[7] I.R. Barrat, Y.Yan, B.Byrne and M.S.A Bradley. 2000. *Mass Flow Measurement Of Pneumatical ly Conveyed Solids Using Radiometric Sensors*. In Advanced Instrumentation and control Research Centre, UK.

[8] Robert M.Carter, Yong Yan and Stuart D. Cameron. 2005. *On Line Measurement of Particle Size Distribution and Mass Flow Rate of Particles in a Pneumatic Suspension Using Combined Im aging And Electrostatic Sensors*. Department of Electronics, University of Kent, UK.