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A Cost Effective Sensor Design for Granular Flow Visualization

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A Cost Effective Sensor Design for Granular Flow Visualization

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ABSTRACT

This paper presents a cost-effective sensor design based on an arrangement of light dependent resistors (LDRs) to determine the particle flow velocity and the particle concentration of granular material flow. The sensor is designed for both dense phase and dilute phase flow and can be applied wherever a transparent sightglass is used in material conveying. The measurement setup and its applicability for industrial conveying processes are discussed and measurement results utilising plastic pellets are presented.

Keywords Particle Concentration, Flow Velocity Profile, Light Dependent Resistor (LDR)

1 INTRODUCTION

The flow determination of granular flow has become an important task in many industrial conveying processes. In dilute phase flow, the particle concentration and the particle velocity are of interest for reliable conveying with minimal damage to the conveyor pipe and the conveyed material itself, while in dense phase flow, the length, the shape and the velocity of material plugs affect the achievable mass flow rate and the stability of the flow. Many approaches have been undertaken to determine flow velocity and particle flow density (Wypych 1992), as well as optical methods like Laser Doppler Velocimetry (LDV) (Tsuji 1981; Woodhead 1995), Particle Image Velocimetry (PIV) (Jakobsen 1996) and the use of fibre optic probes (Zhu 2000). The non-invasive optical approach used for this sensor design correlates the derived light intensity signals of two measurement layers to obtain a flow velocity profile for several horizontal layers.

The principle to obtain a mean particle flow velocity by correlating light intensity signals of two layers that are influenced by absorption, scattering and reflection of bypassing material is well known (Beck 1987) – an enhancement of this principle by measuring the particle velocity at several cross-sectional pipe positions and by determining the particle concentration for those positions with the same intensity signals is presented in this paper.

2 MEASUREMENT SETUP

The measurement setup used to determine flow velocity and particle concentration is shown in Figure 1. It consists of two measurement layers, with either 3 or 6 light dependent resistors (LDRs) each, that are illuminated by a spotlight through a transparent pipe section, perpendicular to the flow direction.

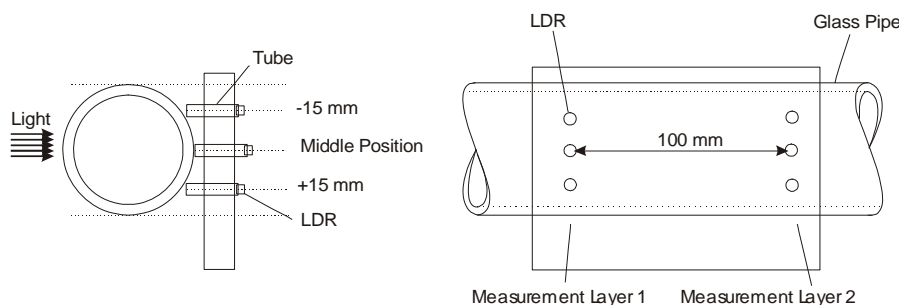


Figure 1 – Measurement setup with sightglass and fixed LDR arrangement.

To avoid unintentional stray light, the LDRs are housed inside an opaque tube and secured mechanically to the sightglass via a timber support plate.

White plastic pellets of approximately 3.8 mm diameter have been chosen to test the through-light principle with special emphasis on applicability as a tomographic velocity and particle concentration sensor.

Each bypassing particle throws a well-defined shadow on the back of the glass pipe and causes a change in the resistance of an LDR if the particle is within the sensing volume of the light detector. Using the cross-correlation function (CCF):

$$\Phi_{12}(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T x_1(t) \cdot x_2(t - \tau) dt \quad (1)$$

with $x_1(t)$ as the signal for a particular LDR in measurement layer 1 and $x_2(t)$ for the corresponding LDR in layer 2, the time delay of a particle travelling from layer 1 to 2 can be obtained. With the known distance between the two layers, the particle velocity can be calculated for each LDR position in the pipe cross-section.

The variation of the light intensity and hence the electrical resistance of each LDR, caused by particle “shading”, is used to count the number of bypassing particles and to determine the particle concentration within each set of measurement data. To increase spatial resolution, 6 LDRs are used per layer.

The observed volume through the cylindrical-shaped glass pipe is not the same for all LDR positions and this has to be considered in the particle concentration profile. Figure 2 shows the observed pipe volume for the LDR assembly of one measurement layer used for the flow experiments.

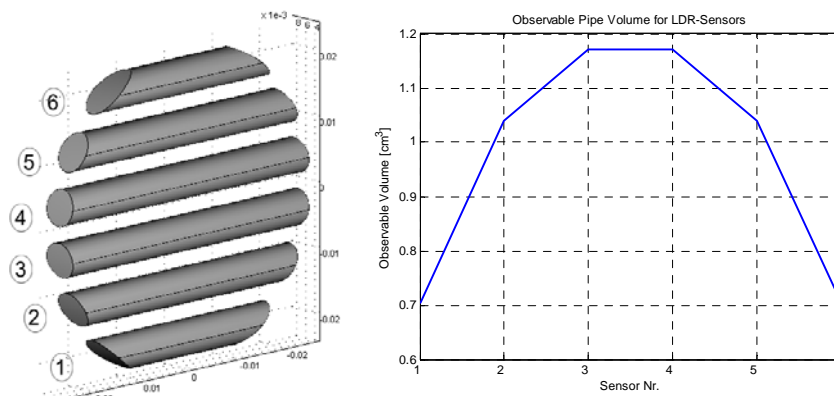


Figure 2 – Geometry of observed pipe volume for LDR assembly (left); Observed in-pipe volume considered for particle concentration profile (right).

3 RESULTS

Experiments with different conveying velocities have been performed while the LDR resistance has been recorded. The two main types of conveying that have been tested with the sensor are:

- dense phase flow with its slug-shaped sequences of high and low particle concentrations and relatively low conveying velocity; and
- dilute phase flow with much lower particle concentrations but faster particle velocities.

3.1 Dense Phase Flow

For dense phase flow, the length of a plug, its velocity, and the profile of the start and end of a plug are important parameters for flow description. The applicability for dense phase flow quality determination is shown in Figure 3, where the resistances of two corresponding LDRs have been recorded for four successive material plugs. Compared to the readout of the capacitive sensor, which recorded the flow at the same time, the signal to noise ratio is remarkably high, allowing not only an accurate velocity determination but also a determination of the plug shape and length.

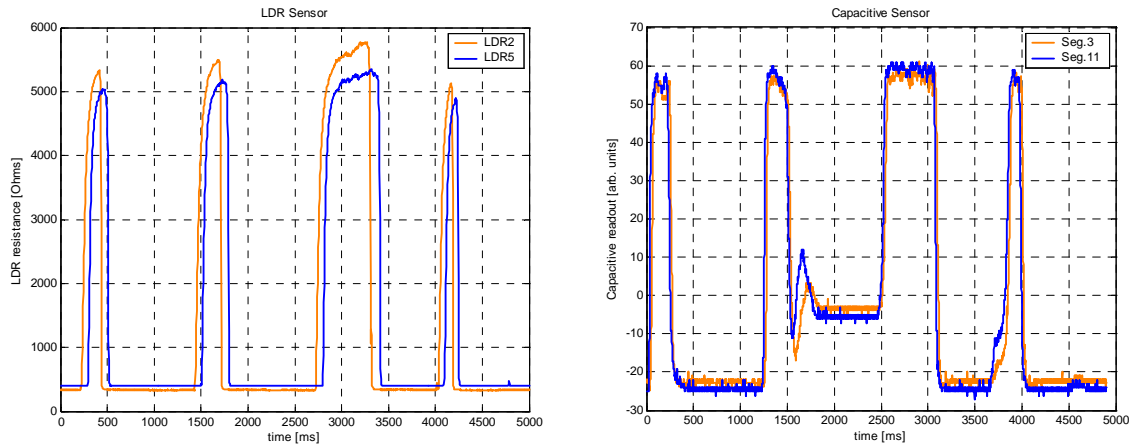


Figure 3 –Resistance of corresponding LDRs over time for dense phase flow (left); capacitive reference measurement (right).

While the time delay between both signals is a measurand for the plug velocity, the time of high impedance in the signal is used to determine the plug length. The low impedance sections in the signals indicate the absence of material (time or length between the end of the previous plug and the start of the next one).

3.2 Dilute Phase Flow

For dilute phase flow, the velocity as well as the particle concentration in the flow may vary dramatically, so a reliable sensor for both is of interest for many industrial conveying applications.

With the setup shown in Figure 1, several experiments with different conveying velocities have been conducted. Figure 4 shows a typical readout for two corresponding LDRs and their cross-correlation function Φ_{12} .

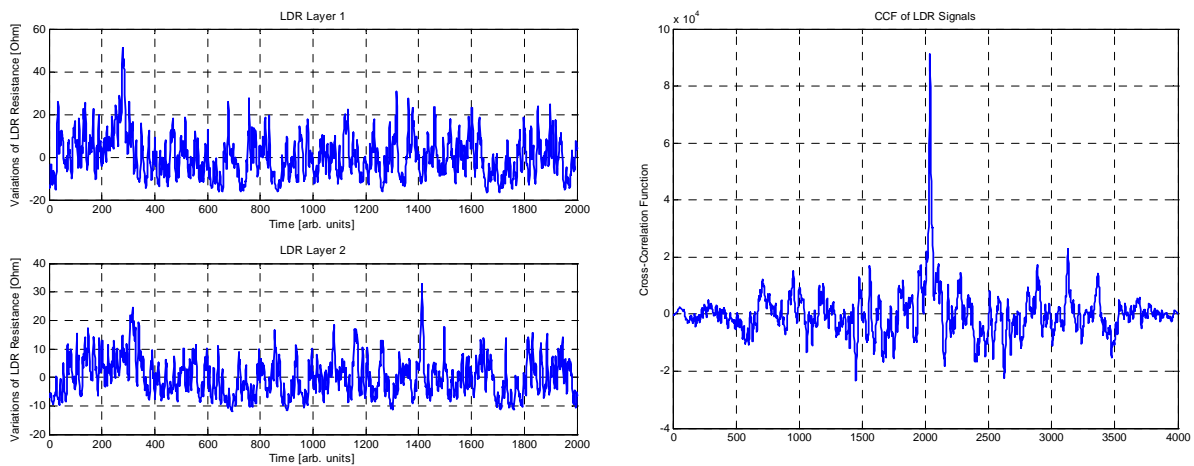


Figure 4 – Variation of electrical resistance over time for two corresponding LDRs (left); Cross-correlation function for plotted resistance vectors showing a peak at tick number 2036 (right).

With the deviance from the CCF centre and the known LDR distance, the particle velocity for each horizontal layer of LDRs can be determined.

Figure 5 shows the obtained velocity profiles for all 6 LDR positions in the pipe. It can be seen that there is an increase of measured particle velocity for each pair of LDRs with an increase of air velocity.

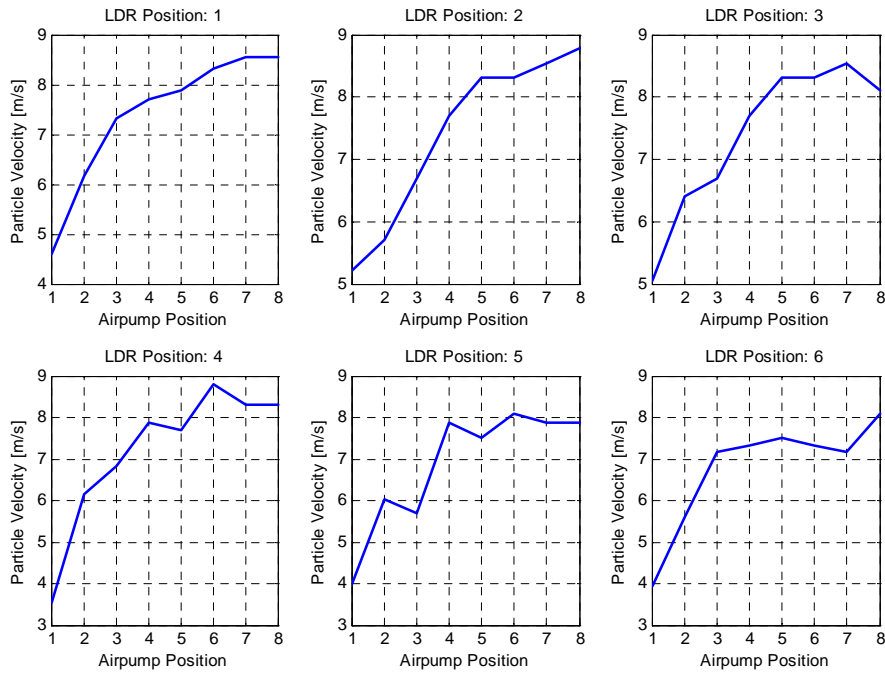


Figure 5 – Particle velocity for all different LDR positions in the pipe versus air pump setting (a higher value for the airpump position signifies higher air supply pressure and air flow).

Since more particles were available for LDR positions closer to the pipe bottom (LDR position 1) than the pipe top (position 6), the amplitude of the CCF peak is more significant and the peak position is more stable. This results in a smoother curve in the velocity diagram for LDR positions 1 and 2 than for 5 and 6.

The cross-sectional particle velocity profile can also be seen in Figure 6, where the measured particle velocities at different pipe positions are plotted for a constant transport air velocity in each diagram.

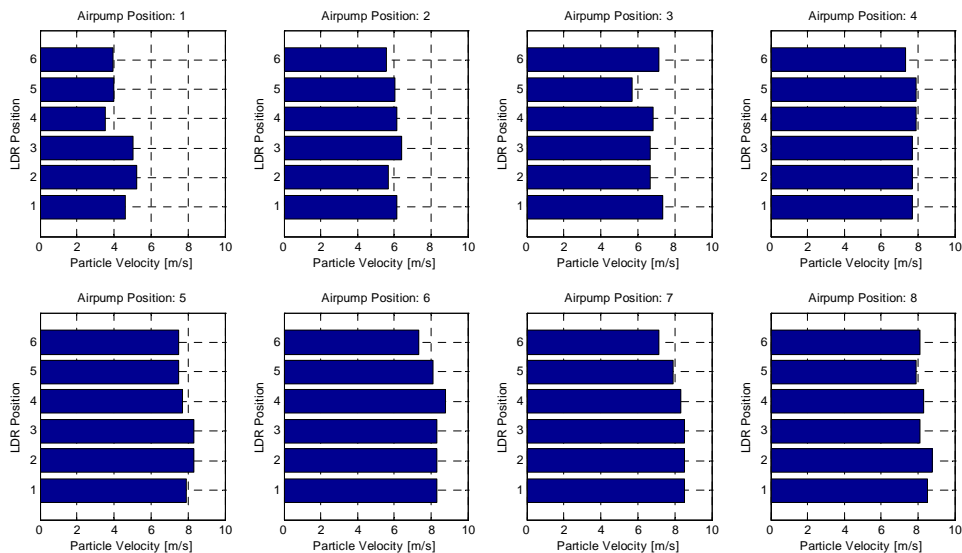


Figure 6 – Particle velocities at different LDR positions plotted for 8 different transport air settings.

The particle concentration is determined by an automated pattern search algorithm that identifies variations in the resistance of the LDR as a shading of a bypassing particle. The same LDR signals that have been used for velocity determination can also be used for obtaining particle concentration. Figure 7 shows a set of measured data for an LDR close to the pipe bottom (left) and pipe top (right).

The determined particle velocity and particle concentration profiles were compared to the results of an optical reference system (high-speed video camera). The results are in good agreement.

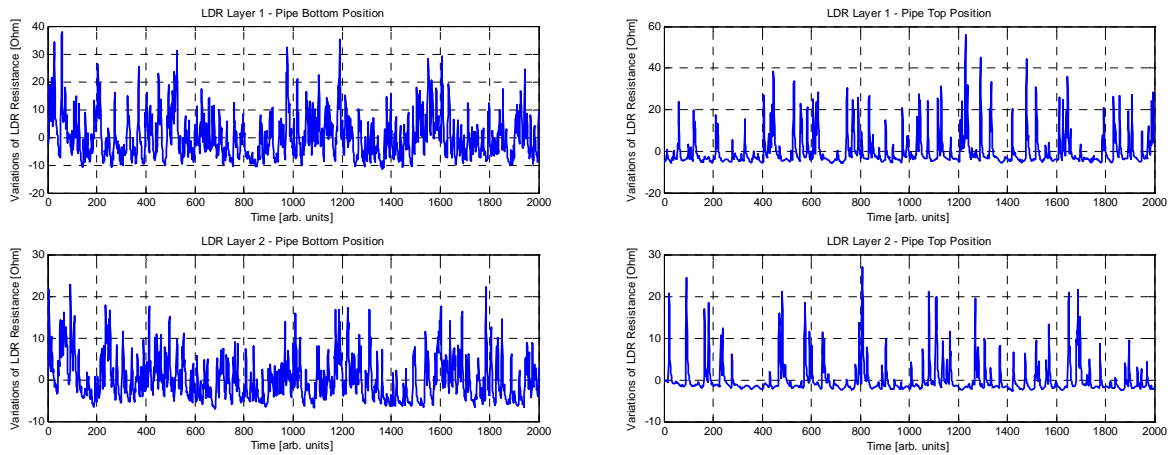


Figure 7 – Variation of LDR resistance caused by bypassing particles for LDR close to pipe bottom (left) and pipe top (right).

It is obvious that the particle concentration diminishes when the LDR position is closer to the top of the pipe and when the transport air is increasing. Figure 8 shows the particle concentration again for 8 different transport air velocities.

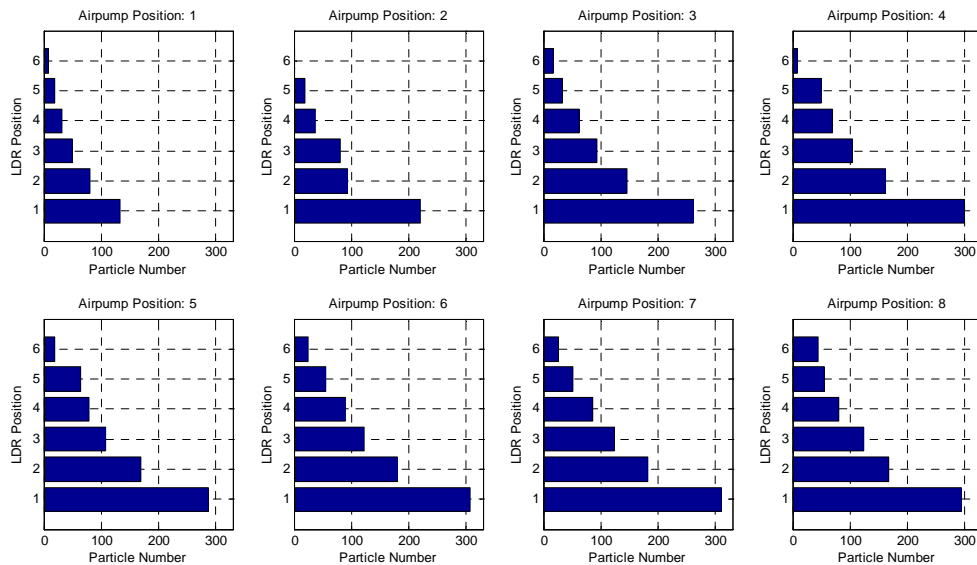


Figure 8 – Number of counted particles (in one set of data) subject to LDR position in pipe.

4 OUTLOOK

For an optimal velocity determination, the correlation distances between the measurement layers has to be adapted to the particle velocities due to curved particle trajectories. A future setup will include the automated adjustment of the distance between the measurement layers as shown in Figure 9.

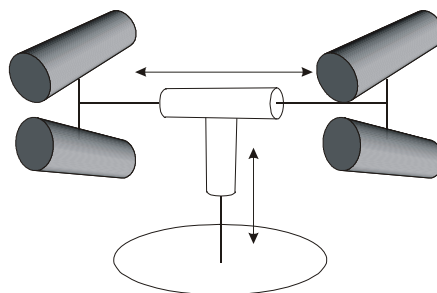


Figure 9 – Enhanced setup with adjustable height and distance between measurement layers.

To overcome the restriction of having only horizontal layers for the velocity profile and the particle concentration, a circular setup is shown in Figure 10. The two mechanically coupled annular rings contain the LDR sensors as well as corresponding light sources and perform a 120° rotation to cover the whole pipe circumference and hence the whole pipe volume.

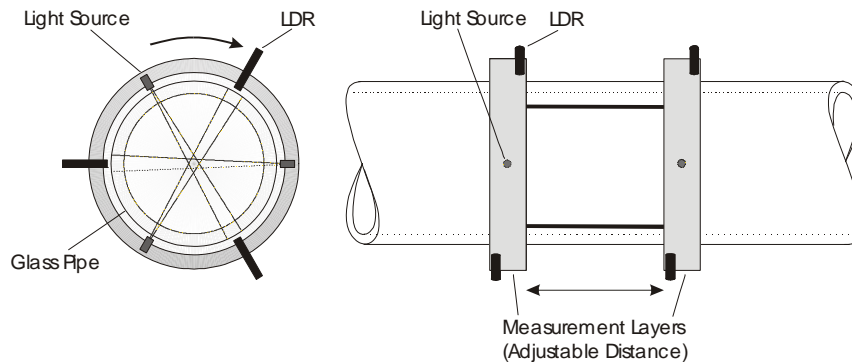


Figure 10 – Enhanced setup performing 120° rotation to monitor entire cross-sectional flow.

Note: The airpump used for this research was a full-bore annular design. Increasing the air supply pressure to the pump increased the air flow through the pump and also its suction and feeding capacity. Eight different air supply (flow) settings were used for the dilute-phase tests; it was not possible to measure the suction air flow through the pump; hence, it was not possible to measure or determine the actual conveying air flow through the pipeline. The main focus for this research was to measure particle velocity and concentration at different positions along and across a pipeline – the measurement of corresponding air flow/velocity and solids loading and the development of relationships between these parameters was beyond the scope of the current work and can be pursued in the future.

5 CONCLUSION

A cost effective sensor for flow velocity profile and particle concentration determination is presented. Since light intensities through two measurement sections are recorded, this sensor requires a transparent pipe section. The determination of both the flow velocity profile and the particle concentration is accurate and reliable for the presented arrangement. To enhance the quality of the measured data and the determined profiles, two future setups are proposed, both able to be adapted to the distance between the measurement layers.

The application of the sensor is limited to granular material of approximately monodisperse size in the range of some millimeters. For this purpose, the non-invasive principle, the cost-effectiveness and the robustness of the sensor make this sensor design well suited for many industrial applications.

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