Technical vision system for analysing the mechanical characteristics of bulk materials

A V Boikov, V A Payor and R V Savelev
Saint-Petersburg mining university, 21 line V.O, Saint-Petersburg, 2, 199106, Russia
e-mail: boikov_av@mail.ru

Abstract. In this article actual topics concerned with mechanical properties of bulk materials, usage of computer vision and artificial neural networks in this research are discussed. The main principles of the system for analysis of bulk materials mechanical characteristics are described. Bulk material outflow behaviour with predefined parameters (particles shapes and radius, coefficients of friction, etc.) was modelled. The outflow was modelled from the calibrated conical funnel. Obtained dependencies between mechanical characteristics and pile geometrical properties are represented as diagrams and graphs.

1. Introduction
Bulk materials are widely spread in nature and are also actively used in different industries. In spite of their wide application, there is no united theory that could predict the behaviour of flowing medium or classify the mechanical characteristics of particle interaction based on simple and fast manipulations. Accurate mathematical description of flowing medium behaviour is becoming impossible because of huge amount of contemporaneous affecting factors. In the majority of cases, table values of friction parameters for individual materials are used to define the mechanical characteristics of bulk material, but such method doesn’t consider all aspects of particle interaction, such as particle shape, grain-size composition, cohesion/adhesion, etc. Defining the friction parameters of flowing medium has huge applied significance in technical sciences, particularly while designing technological facilities for concentrating and mining industries. Those parameters are affecting the whole technological process, the performance of facilities and their durability.

Modern devices for defining the properties of bulk materials represent mechanical aggregates that are way too complex and expensive in exploitation [1]. They don’t presume determination of flowing medium status parameters in dynamic and are able to define only one or two parameters into one device, thus, automation of this process within one universal machine are unsolved problems.

Proposed system with technical vision, created in LabVIEW, allows simplify the construction of devices using for bulk material analysis and also is able to contemporaneously define not single, but variety of parameters [2]. The advantages of technical vision for defining the mechanical characteristics of flowing medium are obvious – digital image can be processed different ways and unlimited times. Moreover, hardware GPU acceleration based on NVIDIA CUDA technology (NVIDIA Corporation) provides desirable soft real-time system.

Developed system was tested on bulk materials that were modelled using DEM (Discrete Element Method) in Rocky DEM software (Engineering Simulation and Scientific Software). Received modelling results, exported as video files, were pre-processed using NI Vision Toolkit (National Instruments) and then were passed to artificial neural network. Using of neural network provides structured data and allows reveal more accurate trends and dependences (Figure 1).
2. Problem description and modelling
Static or dynamic particle-particle and particle-boundary friction analysis is a complex technical problem. The triboprocess study is complicated by mechanical, electrical, magnetic and other nature of the friction process. Physical mechanical properties of bulk materials are directly associated with triboprocess, but nowadays there are lack of theoretical or experimental dependences to consider specific flowing medium as uniform object with precisely known parameters. On the other hand, lots of industries daily face the lack of information problem about mechanical parameters of bulk materials therefore decreasing efficiency of technological processes and frequently occurs accidents [3].

One of the way to resolve this problem is experiential dependency detection between parameters of bulk materials and properties that are approachable to measure in static or dynamic. At the moment, there are huge amount of different approaches to define such properties but all of them are based on real devices with low level of automation and require huge time expenditures and high qualification. Another way is discrete element modelling which allows model the behaviour of flowing medium with desired parameters, such as particle shape, grain-size composition, coefficients of dynamic and static friction, boundary condition, percentage of moisture, etc. In this case, modelling was held in Rocky DEM software with partnership of CADFEM CIS specialists from Saint-Petersburg [4]. It was decided to model outflow of bulk material from the calibrated conical funnel. The funnel has simple geometry and usually is used to define such important characteristic as fluidity, angle of repose and other parameters (Figure 2).

3. Data processing
The computer vision system was developed with NI LabVIEW, including NI Vision Toolkit (National Instruments). Virtual Instrument captures a video stream from file or camera. In this research we used only videos of bulk material simulations modeled with Rocky DEM software. Video processes frame-by-frame, each frame processing consists of following stages (Figure 3):
- Preparing. Image binarization for further processing and contour analysis
- Filtering. Removing waste particles, construction elements, etc.
- Contour capture. Pile surface detection and converting it to array of points coordinates
- Geometry analysis. Taking contour points

Video processing results are displayed on screen (Figure 4), computed pile geometry parameters, such as height, width, angels of repose, surface radius – are highlighted directly on the video recorded to the MS SQL Express database (Microsoft Corporation) for further analysis and approximation. Communication between database and virtual instrument is implemented by LabVIEW Database Connectivity Toolkit (National Instruments).

**Figure 3.** Simplified block diagram of developed system.

**Figure 4.** Example of data processing.
Frame-by-frame video processing requires valuable computational resources, thus, suggested system uses a hardware computing acceleration on GPU. LabVIEW provides this function with GPU Analysis Toolkit (National Instruments) for NVIDIA CUDA. The application of this approach allows significantly increase the program's performance and provide the necessary processing speed of the video, which is important in a real experiment data processing. GUI of developed vision system is presented in Figure 5.

Figure 5. GUI of developed system

Experimental data analysis is carried out by neural network, configured and trained to trace dependency between conical pile geometry parameters and matter friction coefficients. Neural network was realized on C++ with OpenNN library (Artelnics).

4. Results

The neural network was trained on the basis of the parameters of the flowing medium specified in the Rocky models. The neural network analyzed the static and dynamic parameters obtained during the processing of video files. Table 1 shows an example of the result of processing one of the models.

Table 1. Example of model processing.

| Friction coefficient | Parameter | tan(angle of repose) | Height, mm | Base length, mm | Radius, mm |
|----------------------|-----------|----------------------|------------|----------------|------------|
| 0.1                  | Height    | 0.174                | 118        | 810.5          | 75         |
| 0.2                  | Base length | 0.312             | 136        | 751.6          | 40         |
| 0.3                  | Radius    | 0.338                | 141        | 735.2          | 45         |
| 0.4                  |           | 0.384                | 147        | 726.3          | 90         |
| 0.5                  |           | 0.391                | 148        | 716.2          | 30         |
| 0.6                  |           | 0.387                | 148        | 709.4          | 40         |

In virtue of received parameters neural network automatically computed coefficients of friction of given bulk materials. Results of computing are presented in Table 2.
Table 2. Post-execution comparison.

| Given coefficient | 0.1  | 0.2  | 0.3  | 0.4  | 0.5  | 0.6  |
|-------------------|------|------|------|------|------|------|
| Computed coefficient | 0.11 | 0.193| 0.313| 0.391| 0.519| 0.58 |

Calculated relative error is 1.3% what is quite precise result. Moreover, neural network formed the dependencies between coefficient of friction and parameters from video processing (Figure 6).

![Figure 6. Experimental dependencies.](image)

**Conclusion**

At present, system is still under development, the laboratory stand is being designed (Figure 7) for carrying out experiments with real bulk materials, primary using conical funnel.

![Figure 7. Basic concept of the future real stand.](image)

Neural network is supposed to be trained on several virtual models created with Rocky DEM and applied to real experiment. This approach will make system developing faster. Based on obtained dependencies it is possible to predict bulk materials behaviour in certain conditions, this knowledge in needed at many technical applications. It is planned to conduct experiments using other types of stand with movable elements (Figure 8). On the other hand, the system proposed above might be useful in industrial engineering and mining machine construction and the design of process equipment with the required parameters, in order to increase economic efficiency and reduce the costs of their design and production.
**Figure 8.** Prototype of new experiment stand with movable elements.

**References**

[1] Hu G, Liu M, Liu Y, Wan H and Liu L A DEM simulation system for equipment of powder processing and bulk materials transportation 2010 *International Conference on Mechanic Automation and Control Engineering* pp 923–926 DOI: 10.1109/MACE.2010.5536021

[2] Wouters I M F and Geldart D Characterising semi-cohesive powders using angle of repose *Particle and Particle Systems Characterization* vol 13 is 4 pp 254-259 August 1996

[3] South China Morning Post Accessed data: 05.06.2017 http://www.scmp.com/news/china/policies-politics/article/1894877/shenzhen-landslide-declared-industrial-accident-not

[4] Oficial Rocky DEM software website in Russian Accessed data: 05.06.2017 http://www.rocky-dem.ru/