Preliminary Study: Instrumentation Design for Studying Granular Segregation

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Abstract. Rice winnowing is a process of separation of small and large rice grains by air flow practiced by farmers. This process shows interesting phenomenon but has never been documented by previous researchers. Based on the movements performed within rice winnowing, we tried to design a simulation instrument that resembled rice winnowing process. This research aims to investigate the process of granular segregation with different size or density. We also observed carefully using manually released objects were captured for 60 seconds by digital camera (Nikon L840, 16 megapixel and 30 fps) in a video mode. Every video tracked using video tracker then analyzing the results. Furthermore, the results of study can be useful to develop a model of granulars segregation based on size or density.

1. Introduction
Granulars segregation is interesting physical phenomena to be investigated. Many researchers have developed granular segregation method such as kinetic sieving to produce a mechanism for granular segregation that is influenced by gravitational forces and the principle of granular flow [1]. This method is also used to observe granulars segregation phenomena in rivers [2] and studied particles separation with different sizes and densities [3]. Furthermore, the modulation method is used to control granular segregation [4]. In addition, another method developed are the experiment of granular flow as a mechanism for layer formation [5] and prediction of particle separation by sieving method in flour milling [6].

The purpose of this paper is to design an instrumentation for studying granular segregation. This instrumentation resembles the traditional in rice winnowing by tray flapping. Rice winnowing process takes advantages of natural wind blowing that often used by farmers who are harvesting rice to separate the filled grains from empty grains [7] or unwanted matters like weeds, straws, sand, dust particles, etc to give cleaner outcome [8]. Lack of winnowing rice using natural wind is often less favorable for natural wind speeds such as direction and random wind intensity. Therefore, if it's done in a closed room where no natural wind blow, the common method for producing air flow is by flapping a tray above where the rice grains are placed.
Experimental method was also conducted to compare the results of granulars segregation by winnowing manually. The motion profile of the granulars is taken using a camera, and then processed using video processing by video tracker. The results of this study can be an alternative method for granulars segregation process with a very simple way and can be useful to develop a model of granulars segregation based on different size and density.

2. Modeling
For simplicity, we assume the granulars segregation due to wind blowing is caused particle motion in vortex. Vortex motion is generated by winnowing motion using winnow flapping. The total force on particle motion in vortex are gravitational force (F_g), the force due to gradien leading to the center of vortex (F_p), the centrifugal force (F_c) and the air friction force (F_f).

\[ \vec{F}_{tot} = \vec{F}_g + \vec{F}_p + \vec{F}_c + \vec{F}_f \]  

With

\[ \vec{F}_g = -mg\hat{j} \]  

\[ \vec{F}_p = -\frac{\pi}{6} \rho d_p^3 \frac{u_r^2}{r} \hat{r} \]  

\[ \vec{F}_c = \frac{\pi}{6} \rho d_p^3 \frac{v_t^2}{r} \hat{r} \]  

\[ \vec{F}_f = -C_D \frac{\rho d_p^2}{8} |\vec{v} - \vec{u}| (\vec{v} - \vec{u}) \]

The equation must be solved based on the total force in particle motion in vortex are

\[ a_x = -\frac{1}{\sqrt{2}} \frac{\rho}{\rho_p} \Omega^2 x + \frac{1}{2} \left( -yv_x + xv_y \right)^2 x \]  

\[ a_y = -g - \frac{1}{\sqrt{2}} \frac{\rho}{\rho_p} \Omega^2 y + \frac{1}{2} \left( -yv_x + xv_y \right)^2 y \]

3. Design Instrument
We designed the granulars segregation instrument using a motor gear box (1:25) which set on a series of devices connected to a power source. The gearbox pushes pulley that connected to the tray due to it swings up and down to resemble the arms of human winnowing rice. At the bottom of tray was assembled the holder which connected to two springs (spring constant = 15 N/m). The springs were used to provide elastic force when tray moved up and down. Illustration of procedures for experimental methods is shown in Figure 1.

Furthermore, we designed the experimental methods using hardware and software. Hardware include granular segregation instrument, one unit camera (Nikon L840, 16 Mpixel ; 30 fps) along with a tripod, a memory card, and a laptop (Intel Core I7 Spec.). The software were used OS Windows, video tracker and microsoft office excel 2016.
4. Experimental Results

Firstly, we demonstrated the effect of swings tray on the segregation of granulars mixtures from two different size and density (rice + basil seeds; soybean + basil seeds). The granulars mixtures were placed on a tray with diameter of around 0.6 m. Initially the granulars were mixed homogeneously on the tray surface. The granulars motion was recorded to obtain profile particle motion. We also observed the motion profile of each grain by tracking using a video tracker.

Figure 2 shows the profile of the granular mixture motion when manually winnowing from the initial position at maximum height then falls to the winnower surface. Large rice grain trajectories marked with blue circles and small basil seeds grain are marked with red triangle (see Figure 2 (a)). The Figure 2 (b) shows the condition of the granular mixture before winnowing process. The Figure show that both grains is mixed well. Figure 2 (c) shows the final position of the two types of granules after the swing movement execute within winnowing process. There was a change in each type of grains position, where smaller grains are pushed in front of the bigger grains. These results were achieved after 5 winnowing attempt.
Figure 2. Profiles for falling motion of the mixture granulars by manually winnowing. (a) The trajectories of mixture granulars: rice (circle symbol, blue) and basil seeds (triangle symbols, read), (b) before winnowing and (c) after winnowing by 5 times.
Figure 3. Profiles for falling motion of the mixture granulars by manually winnowing. (a) The trajectories of mixture granulars: rice (circle symbol, green) and basil seeds (triangle symbols, yellow), (b) before winnowing and (c) after winnowing by 5 times.

Figure 3 shows a similarity pattern of granular motions that occur during the winnowing process using different samples. Figure 3 (a) shows x-y position chart for larger samples of soybean grain trajectory pattern represented by a green dot while the pattern of basil seed with smaller size represented by a yellow triangle. Figure 3 (c) shows the experimental results where granules position were change in two types of sample. The position of the basil seeds which smaller are pushed in front of larger sized soybean granules.

The manual winnowing only produces qualitative data in an attempt to explain segregation process. Then, we designed equipment that can produce an airflow mimicking that of produced by manual flapping to obtain more quantitative results. This result is similar to a formation in a riverbed where the top of a riverbed is typically lined with larger cobbles, while finer sand and small gravel particles make up the deeper layers. This process could be related to the Brazil nut effect [9,10]. One of the main concerns within this experiment was the hand movement speed when winnowing cannot be controlled. Therefore, a tool that resembles human hand movements is designed when manually winnowing.
Figure 4. Profiles for falling motion of the mixture granulars using artificial arm instrument. (a) The trajectories of mixture granulars: rice (circle symbol, blue) and basil seeds (triangle symbols, read), (b) before winnowing and (c) after winnowing by 5 times.

Figure 4 shows the profile of the granular mixture motion when winnowing using artificial arm instrument from the initial position at maximum height then falls to the winnower surface. Large rice grain trajectories marked with blue circles and small basil seeds grain are marked with red triangle (see Figure 4 (a)). The Figure 4 (b) shows the condition of the granular mixture before winnowing process. The Figure show that both grains are mixed well. Figure 4 (c) shows the final position of the two types of granules after the swing movement execute within winnowing process. There was a change in each type of grains position, where smaller grains are pushed in front of the bigger grains. these results were achieved after 5 winnowing to attempt.
Figure 5. Profiles for falling motion of the mixture granulars using artificial arm instrument. (a) The trajectories of mixture granulars: rice (circle symbol, green) and basil seeds (triangle symbols, yellow), (b) before winnowing and (c) after winnowing by 5 times.

Figure 5 shows a similarity pattern of granular motions that occur during the winnowing process using different samples. Figure 5 (a) shows x-y position chart for larger samples of soybean grain trajectory patterns represented by a green dot while the pattern of basil seed with smaller size represented by a yellow triangle. Figure 5 (b) shows the condition of the granular mixture before winnowing process. The Figure show that both grains are mixed well. Figure 5 (c) shows the final position of the two types of granules after the swing movement execute within winnowing process. There was a change in each type of grains position, where bigger grains are landing far behind the smaller grains.

From the experiments results, we found that there are differences in profile granular trajectories between manual winnowing movements compared to winnowing movements using tools. It appears that the maximum grain height is only 32 cm (Figure 4 (a)) and 38 cm (Figure 5 (a)). While the maximum height of the mixture position is around 75 cm (Figure 2 (a)) and 70 cm (Figure 3 (a)). This result occurs due to the differences of flexibility between human arm and the instrument. But it still produces the same mixture separation pattern. Based on the experiment using granular with variations of different sizes and densities indicate that smaller grains were pushed and landing in front of the large grains in the tray surface.
5. Simulation

The iterations of equations (6) and (7) were solved numerically to simulate the trajectory of the granular mixture.

\[ v_y(i + 1) = v_y(i) + a_y(i) \Delta t \]  
\[ v_x(i + 1) = v_x(i) + a_x(i) \Delta t \]  
\[ x(i + 1) = x(i) + v_x(i) \Delta t \]  
\[ y(i + 1) = y(i) + v_y(i) \Delta t \]

Equations (10) and (11) are used to obtain the trajectory profile of the mixed particles. By substituting parameters in the form of rice density (1.065 gr / cm³), basil seeds (2.192 gr / cm³), soybeans (1.44 gr / cm³), green beans density (0.546 gr / cm³) and air density \( \rho_a \approx 1 \text{ kg / m}^3 \), the simulation results obtained as shown in Figure 6.

![Figure 6](image)

**Figure 6.** Profile the path of granulars of different sizes and densities. Granulars mixtures (a) rice (blue) and basil (red); (b) Bean (green) and basil (yellow).

Figure 6 is a graph of the profile profile of granular mixtures of different sizes and densities based on simulation using equation 10 and 11. Figure 6 (a) shows profile profile of rice granules, large grains (lines, blue), basil seeds, small grains (lines, red). It appears that at the initial position of the track at the maximum height, initially it is still mixed and after reaching the surface of the surface, the mixture undergoes separation. This is indicated by the difference in the final position of the mixture with blue and red coinciding lines. The same is also seen in the profile of the granular mixture (Figure 6 (b)). Based on the above simulations results (Figure 6), profiles for falling motion of the mixture granulars similar to the experiment results. Therefore, these are indicated that granulars segregation due to particle motion in vortex.

6. Conclusion

We have designed a simple granular segregation instrument and studied the profile of particle motion with video processing using a video tracker. The granular motion profile of the experimental results resembled simulation model of particle motion equations in vortex. This vortex arises from the motion of a swinging arm or instrument. This phenomenon shows that granular segregation due to the motion of vortex particles.
7. References

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