SIMULATING TONER AND CARRIER PARTICLES IN ELECTROPHOTOGRAPHY

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ABSTRACT

We simulate the flow of charged granular materials with a discrete particle simulation. Aside from the general scientific interest of charged granular flow, the simulations are aimed at illuminating the charged toner particle flow in electrophotography. The mechanical interactions are simulated in a discrete-cell approach which is compuatationally far more efficient than the standard N^2 algorithm algorithm. However, the Coulombic interactions cannot be modeled in this discrete-cell approach. This research discusses a different algorithm which potentially makes the charged particle interaction calculation more efficient.

By regarding groups of particles as one with the same properties, the number of calculations necessary to calculate the electrostatic forces is much lower; for large numbers of particles and strong forces of attraction by as much as 50%. This paper discusses the implementation and testing of this algorithm.

INTRODUCTION

When Chester Carlson invented electrophotography, the process on which most modern photocopiers and laser printers relies, he and the scientific community knew little about many of the processes involved in it. Nevertheless, electrophotography, or xerography, as it has also come to be known, was evidently a major success. Over five billion copies are made each day by machines relying on the process, and the xerographic industry employs over 500,000 people worldwide and makes about $5 billion annually (Pai and Springett, 164).

The xerographic process produces an image by placing millions of tiny thermoplastic toner particles, usually consisting of mostly of mostly of resin, an amorphous polymer (styrene-acrylic, epoxy, or polyester), and about ten percent Carbon Black or some other color pigment, on a sheet of paper and fusing it to it (Mort, 133). The process centers around forming a latent image on a central piece called the photoreceptor and then transferring this image onto paper. In order to do this, the xerographic machine must go through a number of well coordinated steps.

First of all the photoreceptor must be charged, usually with the aid of a corotron or scorotron. In each device, a high voltage from 3 to 8kV causes an air breakdown around a wire near the photoconductor which becomes uniformly charged in the process (Pai and Springett, 166; Burland and Lawrence, 46).

The second step is exposure. Light either reflected from the original paper in copying, or light produced by a laser in laser printing, strikes the photoconductor and makes the usually insulating photoconductor surface temporarily conductive wherever light shines on it. At places where it is conductive, electrons from different layers of the photoconductor can then neutralize the charge created in step one. The net effect of the exposure step is that a charge pattern mirroring the original image is formed on the photoconductor, dark areas replaced by charged areas (Pai and Springett, 167; Burland and Lawrence, 46).

The next step is called the development. Here electrostatically charged toner particles (their charge is opposite to that of on the photoconductor) are brought near the photoconductor so that they will stick to it in charge areas. (Pai and Springett, 169; Burland and Lawrence, 46).

Now the developed toner on the photoconductor is transferred to paper. A charge opposite that on the photoconductor is created either through corona charging or a conducting roller applied to the back side of the paper so that the force on the toner particles due to the charge on the paper outweighs that due to the charge on the photoconductor (Pai and Springett, 172; Burland and Lawrence, 46).

In the fifth step, the toner is fused to the paper. There are many different ways this fusing can be accomplished; some of the more common ones include hot rolls, cold pressure rolls, and flashing (Pai and Springett, 173; Burland and Lawrence, 46).

And finally, in the sixth step the photoconductor is cleaned of any residual toner. The usual methods for this task include brushes, wiper blades, or magnetic rolls (Pai and Springett, 174; Burland and Lawrence, 46).

One of the major problems in the design of electrophotographic printers and copiers is the development step. Before the toner particles can be transferred to the photoconductor, they have to be electrostatically charged, or tribo-charged. This task is usually accomplished by mixing millions of toner particles with thousands of metal carrier particles with diameters usually about ten times larger than that of the toner particles. As these two type of particles rub against one another, electrons migrate from one type to the other. Whether negative charge moves from the toner particles to the carrier particles or vice versa depends on the surface composition of each particle (Mort, 119).

The problem of this charging step arises because of two opposing factors: it is desirable to have large degrees of electrostatic charging on the particles, an objective which calls for mixing the particles for a relatively long time; however, longer mixing times create serious problems (Yang and Chou,127). Considerable electrodynamic forces amounting to several thousand g's act on the toner and carrier particles and can cause abrasion or even rapture of both kinds of particles (Mort, 122). If the forces pressing a toner particle against a toner particle happen to be strong enough to crush the toner particle, it might stick to the carrier's surface permanently and act as a coating preventing further charge exchange between this carrier and other toner particles (Mort, 123). As their name implies, carrier particles are used not only for the charging of the toner, but also as a means of transporting the toner to the photoconductor in the development step. After giving off their toner particles to the photoconductor, they are reused, so it is vital to the electrophotographic machine that they not be rendered useless by being coated or broken.

Therefore in designing a xerographic device, the optimal mixing time and stress within the dispenser (where the mixing takes place) must be found for given toner and carrier particles, a goal that requires a good understanding of the flow properties and stresses involved in the mixing process. It was the purpose of my SURF to change an already existing soft particle program to make it more suited for simulating charged particles representing the toner and carrier particles in electrophotography.

MATERIALS AND METHODS

The program used was a non-dimensionalized discrete particle simulation. The computer calculates the all forces acting on each individual grain using classical mechanics. For example, for the collision force between two particles, the computer calculates two force vector components, one normal and the other tangent to the particles' surfaces. The normal one is basically $F = k \cdot \Delta ij + v \cdot dn / dt$, where k is the spring constant that corresponds to the particles' elasticity, Dij is the distance overlap of the two particles, v is a damping coefficient, and dn/dt is the change in overlap over change in time. The tangential force is more complicated; there two cases: in one slippage between the particles occurs and their kinetic friction imparts torques on each other, and in the other the particles stick together and the static friction between them creates torque. Electrostatic force is also considered. The basic idea is that Coulomb's force is found between one particle and every other particle in the simulation and is integrated over time. In the calculation of both the electrostatic and the contact forces, the algorithms are written to make the program run more efficiently. The contact force is actually determined between only neighboring particles, and the Coulombic force is found only between particles within a certain distance of one another.

RESULTS

The goal of making the program run faster for simulations with charged particles has so far not been reached because of a bug in the code. The author is still trying to straighten this problem out.

DISCUSSION

There were two main objectives: making the program run faster and making the electrostatic force model more accurate. Of particular interest in the latter is the physics of toner adhesion, i.e. the understanding of how and by what forces the exceedingly small toner particles (~10 microns in diameter) are attracted to the much larger carrier particles, which is currently only inadequately understood.

In our simulation program we used a very simplified approximation of the triboelectric attraction between the particles, used quite commonly also by the rest of the researchers in this area. Each particle is assumed to be a perfect sphere that is either an ideal conductor or has uniform charge distribution across it. In this case, Coulomb's law,

$$F = \square q_1 q_2 / 4\square\square_0 r^2 ,$$

can be used to calculate force between the two particles, where q_1 and q_2 are the charges on the two carriers, separated by distance r, □ is a polarization correction, and $\square_0$ is the permittivity of free space. Experiments have shown, however, that this approximation is often inadequate for abutting particles: there seems to be more force between the two than Coulomb's equation would predict (Eklund and Wayman, 142-5).

In an effort to make this approximation more accurate, researchers have proposed several different contact models. In one such attempt, a group of researchers proposed that Van der Waals forces could account for the discrepancy. These forces arise from random synchronous electron movements inside the charged particles, and even though they show no effect on macroscopic particles, the toner particles are so small that for them this force may indeed be significant. From most other articles I have read, however, I get the sense that this model does not really agree with experiments, and that researchers are turning their attention to models that focus more on the shape of toner particles, their charge distribution, and their exact contact with the carrier particles. (Eklund and Wayman, 142-45, Lee 9-14).

Most experiments seem to favor a contact model that assumes that the side of the irregularly shaped toner particle that would touch the carrier particle with the largest surface area is most likely to face it. Now, since the carrier particle is so much larger than the toner particle (about a thousand times), from the point of the toner particle, it looks very much like a plane surface. If □ stands for the surface charge density on the carrier particle, then it can be proven readily using Gauss' Law that the force between the two charges is

$$F = \square\ q\ \square /2\ \square_0 ,$$

where q is the charge on the toner particle and is a parameter that takes the polarization and local charge non-uniformity on the carrier particle into account. Our program could thus be improved by using the last formula in place of Coulomb's law for cases where the toner and carrier particles are in contact.

The other issue is the calculation time of the computer simulation, a problem that would become even more pressing with this contact model change and the need to have many more toner particles in the simulation (several thousands instead of the only one thousand or so we currently simulate) to make the simulation more meaningful. It seems to me that a decent approach to this problem would be regarding each carrier particle with the hundreds of toner particles spread on its surface as one sphere with a dipole moment summing all the irregular charge distributions due to toner particles on its surface up into one unity. When calculating forces on a particular carrier particle due to all other charges around it, it would no longer be necessary to sum up all the small contributions due to the thousands of little toner particles; simply calculating the forces due to these few dipoles would be sufficient. Only when a toner particle is in danger of leaving one carrier particle for another would it be necessary to be more accurate. The remainder of my Surf was spent on implementing this model in the simulation program.

CONCLUSIONS

The model for the electrostatic force between particles is in some ways inadequate. However, employing better models requires much more complexity and is likely to make the calculation time prohibitively long. Therefore it appears that using an efficient algorithm for calculating coulombic forces is most rewarding since it allows relatively accurate qualitative simulation. Grouping carrier particles with neighboring toner particles in the simulation and regarding it as a dipole will increase the speed of the code.

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