Understanding the Discrete Element Method. Simulation of Non-Spherical Particles for Granular and Multi-body Systems

Description: Gives readers a more thorough understanding of DEM and equips researchers for independent work and an ability to judge methods related to simulation of polygonal particles

- Introduces DEM from the fundamental concepts (theoretical mechanics and solidstate physics), with 2D and 3D simulation methods for polygonal particles
- Provides the fundamentals of coding discrete element method (DEM) requiring little advance knowledge of granular matter or numerical simulation
- Highlights the numerical tricks and pitfalls that are usually only realized after years of experience, with relevant simple experiments as applications
- Presents a logical approach starting with the mechanical and physical bases, followed by a description of the techniques and finally their applications
- Written by a key author presenting ideas on how to model the dynamics of angular particles using polygons and polyhedral
- Accompanying website includes MATLAB-Programs providing the simulation code for two-dimensional polygons

Recommended for researchers and graduate students who deal with particle models in areas such as fluid dynamics, multi-body engineering, finite-element methods, the geosciences, and multi-scale physics.

Contents:

About the Authors xv
Preface xvii
Acknowledgements xix
List of Abbreviations xxi
1 Mechanics 1
1.1 Degrees of freedom 1
1.1.1 Particle mechanics and constraints 1
1.1.2 From point particles to rigid bodies 3
1.1.3 More context and terminology 4
1.2 Dynamics of rectilinear degrees of freedom 5
1.3 Dynamics of angular degrees of freedom 6
1.3.1 Rotation in two dimensions 6
1.3.2 Moment of inertia 7
1.3.3 From two to three dimensions 9
1.3.4 Rotation matrix in three dimensions 12
1.3.5 Three-dimensional moments of inertia 13
1.3.6 Space-fixed and body-fixed coordinate systems and equations of motion 16
1.3.7 Problems with Euler angles 19
1.3.8 Rotations represented using complex numbers 20
1.3.9 Quaternions 21
1.3.10 Derivation of quaternion dynamics 27
1.4 The phase space 29
1.4.1 Qualitative discussion of the time dependence of linear oscillations 31
1.4.2 Resonance 34
1.4.3 The flow in phase space 35
1.5 Nonlinearities 39
1.5.1 Harmonic balance 40
1.5.2 Resonance in nonlinear systems 42
1.5.3 Higher harmonics and frequency mixing 44
1.5.4 The van der Pol oscillator 45
1.6 From higher harmonics to chaos 47
1.6.1 The bifurcation cascade 47
1.6.2 The nonlinear frictional oscillator and Poincaré maps 47
1.6.3 The route to chaos 51
1.6.4 Boundary conditions and many-particle systems 52
1.7 Stability and conservation laws 53
1.7.1 Stability in statics 54
1.7.2 Stability in dynamics 55
1.7.3 Stable axes of rotation around the principal axis 56
1.7.4 Noether's theorem and conservation laws 58
1.8 Further reading 61

2 Numerical Integration of Ordinary Differential Equations 65
2.1 Fundamentals of numerical analysis 65
2.1.1 Floating point numbers 65
2.1.2 Big-O notation 67
2.1.3 Relative and absolute error 69
2.1.4 Truncation error 69
2.1.5 Local and global error 71
2.1.6 Stability 74
2.1.7 Stable integrators for unstable problems 74

2.2 Numerical analysis for ordinary differential equations 75

2.2.1 Variable notation and transformation of the order of a differential equation 75

2.2.2 Differences in the simulation of atoms and molecules, as compared to macroscopic particles 76

2.2.3 Truncation error for solutions of ordinary differential equations 76

2.2.4 Fundamental approaches 77

2.2.5 Explicit Euler method 77

2.2.6 Implicit Euler method 78

2.3 Runge–Kutta methods 79

2.3.1 Adaptive step-size control 79

2.3.2 Dense output and event location 81

2.3.3 Partitioned Runge–Kutta methods 82

2.4 Symplectic methods 82

2.4.1 The classical Verlet method 82

2.4.2 Velocity-Verlet methods 83

2.4.3 Higher-order velocity-Verlet methods 85

2.4.4 Pseudo-symplectic methods 88

2.4.5 Order, accuracy and energy conservation 88

2.4.6 Backward error analysis 89

2.4.7 Case study: the harmonic oscillator with and without viscous damping 90

2.5 Stiff problems 92

2.5.1 Evaluating computational costs 93

2.5.2 Stiff solutions and error as noise 94

2.5.3 Order reduction 94

2.6 Backward difference formulae 94

2.6.1 Implicit integrators of the predictor–corrector formulae 94

2.6.2 The corrector step 96

2.6.3 Multiple corrector steps 97

2.6.4 Program flow 98

2.6.5 Variable time-step and variable order 98

2.7 Other methods 98
3.3.3 Frictional linear chain 151
3.3.4 Higher dimensions 152
3.4 Modeling and regularizations 153
3.4.1 The Cundall–Strack model 153
3.4.2 Cundall-Strack friction in three dimensions 155
3.5 Unfortunate treatment of Coulomb friction in the literature 155
3.5.1 Insufficient models 156
3.5.2 Misunderstandings concerning surface roughness and friction 158
3.5.3 The Painlevé paradox 158
3.6 Further reading 158
4 Phenomenology of Granular Materials 161
4.1 Phenomenology of grains 161
4.1.1 Interaction 161
4.1.2 Friction and dissipation 162
4.1.3 Length and time scales 162
4.1.4 Particle shape, and rolling and sliding 163
4.2 General phenomenology of granular agglomerates 164
4.2.1 Disorder 164
4.2.2 Heap formation 165
4.2.3 Tri-axial compression and shear band formation 166
4.2.4 Arching 168
4.2.5 Clogging 168
4.3 History effects in granular materials 168
4.3.1 Hysteresis 169
4.3.2 Reynolds dilatancy 170
4.3.3 Pressure distribution under heaps 171
4.4 Further reading 173
5 Condensed Matter and Solid State Physics 175
5.1 Structure and properties of matter 176
5.1.1 Crystal structures in two dimensions 176
5.1.2 Crystal structures in three dimensions 178
9 Alternative Modeling Approaches 335
  9.1 Rigidly connected spheres 335
  9.2 Elliptical shapes 336
    9.2.1 Elliptical potentials 337
    9.2.2 Overlap computation for ellipses 337
    9.2.3 Newton–Raphson iteration 339
    9.2.4 Ellipse intersection computed with generalized eigenvalues 340
    9.2.5 Ellipsoids 344
    9.2.6 Superquadrics 344
  9.3 Composites of curves 345
    9.3.1 Composites of arcs and cylinders 345
    9.3.2 Spline curves 345
    9.3.3 Level sets 347
  9.4 Rigid particles 347
    9.4.1 Collision dynamics ('event-driven method') 347
    9.4.2 Contact mechanics 348
  9.5 Discontinuous deformation analysis 349
  9.6 Further reading 349

10 Running, Debugging and Optimizing Programs 353
  10.1 Programming style 353
    10.1.1 Literature 354
    10.1.2 Choosing a programming language 355
    10.1.3 Composite data types, strong typing and object orientation 356
    10.1.4 Readability 356
    10.1.5 Selecting variable names 357
    10.1.6 Comments 359
    10.1.7 Particle simulations versus solving ordinary differential equations 361
  10.2 Hardware, memory and parallelism 362
    10.2.1 Architecture and programming model 362
    10.2.2 Memory hierarchy and cache 364
    10.2.3 Multiprocessors, multi-core processors and shared memory 365
10.2.4 Peak performance and benchmarks 365
10.2.5 Amdahl's law, speed-up and efficiency 367
10.3 Program writing 369
10.3.1 Editors 370
10.3.2 Compilers 370
10.3.3 Makefiles 371
10.3.4 Writing and testing code 372
10.3.5 Debugging 377
10.4 Measuring load, time and profiles 378
10.4.1 The 'top' command 379
10.4.2 Xload 379
10.4.3 Performance monitor for multi-core processors 380
10.4.4 The 'time' command 380
10.4.5 The Unix profiler 383
10.4.6 Interactive profilers 383
10.5 Speeding up programs 383
10.5.1 Estimating the time consumption of operations 383
10.5.2 Compiler optimization options 384
10.5.3 Optimizations by hand 389
10.5.4 Avoiding unnecessary disk output 390
10.5.5 Look up or compute 390
10.5.6 Shared-memory parallelism and OpenMP 390
10.6 Further reading 391
11 Beyond the Scope of This Book 395
11.1 Non-convex particles 395
11.2 Contact dynamics and friction 395
11.3 Impact mechanics 396
11.4 Fragmentation and fracturing 396
11.5 Coupling codes for particles and elastic continua 396
11.6 Coupling of particles and fluid 398
11.6.1 Basic considerations for the fluid simulation 398
11.6.2 Verification of the fluid code 398
B.4.1 Projection of a vector onto another vector 441
B.4.2 Rejection of one vector with respect to another vector 442
B.5 Lines and planes 442
B.5.1 Lines and line segments 442
B.5.2 Planes 444
B.6 Oriented quantities: distance, area, volume etc. 446
B.7 Further reading 449
References 449
Index 451

Ordering:
Order Online - http://www.researchandmarkets.com/reports/2674177/
Order by Fax - using the form below
Order by Post - print the order form below and send to

Research and Markets,
Guinness Centre,
Taylors Lane,
Dublin 8,
Ireland.
Fax Order Form
To place an order via fax simply print this form, fill in the information below and fax the completed form to 646-607-1907 (from USA) or +353-1-481-1716 (from Rest of World). If you have any questions please visit http://www.researchandmarkets.com/contact/

Order Information
Please verify that the product information is correct.

Product Name: Understanding the Discrete Element Method. Simulation of Non-Spherical Particles for Granular and Multi-body Systems
Web Address: http://www.researchandmarkets.com/reports/2674177/
Office Code: SCPLYNJP

Product Format
Please select the product format and quantity you require:

Quantity
Hard Copy (Hard Back): ☐ USD 136 + USD 28 Shipping/Handling

* Shipping/Handling is only charged once per order.

Contact Information
Please enter all the information below in BLOCK CAPITALS

Title: Mr ☐ Mrs ☐ Dr ☐ Miss ☐ Ms ☐ Prof ☐
First Name: _____________________________________ Last Name: _____________________________________
Email Address: * ________________________________
Job Title: ______________________________________
Organisation: __________________________________
Address: _____________________________________
City: _________________________________________
Postal / Zip Code: ______________________________
Country: _____________________________________
Phone Number: ________________________________
Fax Number: __________________________________

* Please refrain from using free email accounts when ordering (e.g. Yahoo, Hotmail, AOL)
Payment Information

Please indicate the payment method you would like to use by selecting the appropriate box.

☐ Pay by credit card: You will receive an email with a link to a secure webpage to enter your credit card details.

☐ Pay by check: Please post the check, accompanied by this form, to:
Research and Markets,
Guinness Center,
Taylors Lane,
Dublin 8,
Ireland.

☐ Pay by wire transfer: Please transfer funds to:
Account number 833 130 83
Sort code 98-53-30
Swift code ULSBIE2D
IBAN number IE78ULSB98533083313083
Bank Address Ulster Bank,
27-35 Main Street,
Blackrock,
Co. Dublin,
Ireland.

If you have a Marketing Code please enter it below:

Marketing Code: ____________________________

Please note that by ordering from Research and Markets you are agreeing to our Terms and Conditions at http://www.researchandmarkets.com/info/terms.asp

Please fax this form to:
(646) 607-1907 or (646) 964-6609 - From USA
+353-1-481-1716 or +353-1-653-1571 - From Rest of World