

2D SIMULATION OF ASSISTIVE GROUSER
MECHANISM USING DISCRETE ELEMENT
METHOD (DEM) FOR TRAVERSING ON
UNCONSOLIDATED SOFT SAND

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MASTER OF SCIENCE

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.



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ABSTRAK

Robot beroda adalah salah satu jenis robot bergerak yang digunakan diatas permukaan kasar kerana mempunyai daya tarikan yang baik di atas permukaan yang rata. Salah satu cabaran robot beroda dalam situasi sebenarnya adalah kecenderungan roda tenggelam ke dalam permukaan pasir ketika melalui permukaan pasir yang tidak sekata. Banyak kajian daripada beberapa penyelidik telah dilakukan untuk memperbaiki prestasi robot beroda. Salah satunya ialah kajian yang mengusulkan "*assistive grouser*" yang dipasang pada sisi roda untuk mengurangkan masalah roda tenggelam ketika melalui cerun curam yang mempunyai pasir lembut. Tetapi semasa ujikaji dijalankan, interaksi antara *grouser*-pasir tidak dapat dilihat dengan jelas. Oleh itu, dalam kajian ini, satu model simulasi dijalankan untuk memerhati penggunaan *assistive grouser* terhadap interaksi antara pasir-*grouser*. Simulasi ini dibahagikan kepada tiga fasa, Fasa 1 mensimulasikan beberapa *fixed grouser* dan *assistive grouser* yang dipasang pada roda (*Conventional Wheel* - CW 80 mm dan *Assistive Wheel*- AW 90 mm), Fasa 2 mensimulasikan *fixed grouser* tunggal dan *assistive grouser* tunggal yang dipasang pada roda (CW 20 dan 80 mm, AW 50 dan 90 mm), dan Fasa 3 mensimulasikan satu *assistive grouser* tunggal dengan panjang *grouser* yang tenggelam berbeza (10, 20, 30 dan 40 mm) dan penggunaan *grouser angle* yang berbeza (0 dan 30-darjah). Pemerhatian memfokuskan pergerakan pasir apabila *grouser* bergerak sama ada ia menghasilkan tenaga untuk menggerakkan roda ke hadapan atau tenaga itu dibazirkan dengan menggali permukaan pasir. Daripada Fasa 1, ia disimpulkan bahawa CW 80 mm dan AW 90 mm akan mempunyai tenaga yang cukup untuk menghasilkan daya untuk roda bergerak ke hadapan hasil daripada purata anjakan pasir yang tinggi (CW 80 mm tinggi sebanyak -6 mm), purata had laju pasir yang tinggi (CW 80 mm tinggi sebanyak -0.414m/s), dan jumlah anjakan pasir yang tinggi (AW 90 mm tinggi sebanyak 9790 pasir). Walau bagaimanapun, penggunaan CW 80 mm menunjukkan roda berpotensi untuk mengalami masalah tersekat/tenggelam di dalam permukaan pasir disebabkan *fixed grouser* mengangkat butiran pasir ke atas permukaan semasa ia bergerak tetapi ini tidak berlaku apabila menggunakan AW 90 mm. Daripada Fasa 2, di permukaan cerun 0 dan 30-darjah, *grouser* yang panjang (CW 80 mm dan AW 90 mm) mempunyai prestasi yang lebih baik dari segi mengerakkan roda ke hadapan berbanding *grouser* yang pendek (CW 20 mm dan AW 50 mm). Tetapi, dengan menggunakan CW 80 mm, nilai daya tolakan pasir (kearah atas) adalah tinggi (-100 N di cerun 0-darjah dan -190 N di cerun 30-darjah). Situasi ini menunjukkan *fixed grouser* mengalami rintangan apabila berputar. Tetapi apabila menggunakan AW 90 mm, situasi ini tidak berlaku kerana pergerakan *assistive grouser* adalah dalam bentuk traslasi justeru mengurangkan potensi untuk *assistive grouser* menggali permukaan pasir. Daripada Fasa 3, ia dapat disimpulkan bahawa *grouser* yang lebih panjang (40 mm) memberi prestasi yang lebih baik berbanding *grouser* yang pendek berdasarkan nilai purata anjakan pasir yang tinggi (-55 mm untuk paksi X, 54 mm untuk paksi Y), daya penolakan *grouser* yang tinggi (688N) dan kawasan yang terjejas akibat pergerakan *grouser* yang besar (1803.53 mm²). Prestasi penggunaan *assistive grouser* menurun apabila mendaki cerun 30-darjah dengan anjakan purata pasir dan daya penolakan lebih rendah. Tetapi ia telah diselesaikan dengan menetapkan *grouser angle* sama seperti kecenderungan cerun. Pada cerun 30-darjah, *grouser angle* 30-darjah adalah lebih sesuai digunakan kerana ia boleh menghasilkan daya penolakan serta purata anjakan pasir yang tinggi. Kesimpulannya, simulasi ini berjaya mengesahkan andaian berkaitan pergerakan pasir dan prestasi *grouser* yang digunakan di dalam kajian lepas untuk menerangkan

kelebihan prestasi *assistive grouser* pada permukaan cerun yang mempunyai pasir lembut.

ABSTRACT

Wheeled rovers are one type of mobile robot used to drive over rough terrain, with an advantage for being energy efficient on a flat surface with reasonable traction force. One of the challenges of wheeled rovers in actual operation is the tendency for the wheel to sink into the sand surface when traversing on an unconsolidated sand surface incline. Many previous studies have been done to improve rover mobility performance. One of the studies proposed an “assistive grouser” attached to the side of the wheel to minimize the sinkage problem when traversing on a steep slope of soft sand. However, during the experimental test alone, the interaction between the grouser-sand cannot be seen clearly. Therefore, in this study, a simulation modelling was carried out to observe the effect of assistive grousers on sand-grouser interaction. This simulation was divided into three phases, Phase 1 simulates multiple fixed and assistive grousers attached to a wheel (Conventional Wheel - CW 80 mm and Assistive Wheel - AW 90 mm), Phase 2 simulates a single fixed and assistive grouser attached to a wheel (CW 20 and 80 mm, AW 50 and 90 mm), and Phase 3 simulates a single assistive grouser with different sinkage length (10, 20, 30 and 40 mm) and grouser angle of attack (0 and 30-degree). The observation focuses on the flow of sand particles during grouser movement, whether the grouser transfers its energy to push the wheel forward or waste energy excavating sand from below the surface (digging). From Phase 1, it can be concluded that CW 80 mm and AW 90 mm will generate a significant amount of traction force for the wheel to move forward from high values of average particle displacement value (CW 80 mm has higher -6 mm), high values of average particle velocity magnitude (CW 80 mm has higher -0.414 m/s) and high values of total displaced particle (AW 90 mm has higher 9790 particles). However, usage of CW 80 mm has also shown an increased tendency for the wheel to enter the stuck stage as the grouser lifts more sand from under the surface upward but not when using AW 90 mm. From Phase 2, the results show that for both 0 and 30-degree inclination slope, longer grouser (CW 80 and AW 90 mm) has better performance in generating forward traction force than shorter grouser (CW 20 mm and AW 50 mm). However, when using CW 80 mm, the value of negative pushing force (upward push) is higher (-100 N on 0-degree slope and -190 N on 30-degree slope). This condition indicates that the grouser experiences resistance when moving from under the wheel toward the surface. However, by using AW 90 mm, there is minimal negative force value because of the translational movement of the assistive grouser. So, there is less tendency for the grouser to dig the sand surface. From Phase 3, it was concluded that longer grouser sinkage length (40 mm) gives better performance compared to shorter sinkage length because of high average particle displacement (-55 mm for X-axis, 54 mm for Y-axis), high grouser pushing force (688 N) and larger destructive area (1803.53 mm²). The performance of the assistive grouser was reduced when climbing the inclination slope. When climbing the 30-degree slope, the average particle displacement and the grouser pushing force is smaller. But this has been solved by setting the grouser angle of attack to be the same as the slope inclination angle. On a 30-degree slope, the grouser angle of attack 30-degree is more suitable to be used because it can generate higher grouser pushing force and a higher average particle displacement. In conclusion, the simulation carried out by this study has successfully verified the assumptions and justifications related to the flow of sand particles and grouser performance that was applied during previous work to explain the better performance of assistive grousers on a steep slope of soft sand inclines.

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LIST OF SYMBOLS

Φ_d	Absolute angle
l_s	Grouser length under the sand surface
θ_{slope}	Inclination slope angle
θ_g	Grouser angle of attack
A	Destructive area
l_d	Total distance of the traveled area
h_s	Sand height in the box
E	Equation
S	Simulation

LIST OF ABBREVIATIONS

NASA	National Aeronautics and Space Administration
CWR	Conventional Wheel Rover
MWR	Modified Wheel Rover
3D	3-Dimensional
2D	2-Dimensional
DEM	Discrete Element Method
FEM	Finite Element Method
CFD	Computational Fluid Dynamic
CW	Conventional Wheel
AW	Assistive Wheel

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