Gripping Mechanisms for Microgravity and Extreme Terrain and Vertical Climbing Micro Ground Vehicle

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Asteroids and comets may provide insight into the origins of our solar system and the precursors to life on our planet. Near Earth objects offer an accessible target of opportunity, but are small and lack the gravity necessary for conventional wheeled travel. Therefore, it is necessary to develop alternative methods for maneuvering in these environments. This project researched and developed a method for gripping rock surfaces. Work has been completed on the design and prototyping of several possible hooked gripping mechanisms. Future work includes quantitative testing, downselection to a final design, and attachment to the robotic platform, Lemur IIb.

A second project focuses on the development of a 100g, crash-proof robot capable of climbing vertical surfaces using a novel silicone adhesive. Capable of carrying video/audio payloads the robot may serve as a surveillance tool for the Department of Defense or as a method of pre-flight spacecraft inspections. A specialized track was developed to provide the specific loading conditions necessary for proper engagement of the adhesive. Both of these projects rely heavily on the shape deposition manufacturing process, being researched at JPL, and 3D printing.

I. Introduction

Developments in robotic locomotion have allowed many robots to transition from the horizontal to the vertical operating environment. This transition was possible through the development of various climbing and gripping mechanisms, each typically adapted to a specific climbing media. While running or waling robots move by generating forces laterally, climbing robots have the added requirement of generating forces normal to the climbing surface to keep them securely attached. These normal forces are solely dependent on the ability of a mechanism to attach to the surface. Each of the two projects discussed here, Gripping Mechanisms for Microgravity and Extreme Terrain (GMMET) and Vertical Climbing Micro Ground Vehicle (MGV), is concentrated on providing robotic platforms with a secure method of attachment to a specific range of surfaces. GMMET seeks to attach to unstructured, natural media while MGV is primarily concerned with manmade surfaces.

A key component to both projects was the ability to produce parts capable of meeting the very specific design needs. Developments in manufacturing processes have opened a range of options for the construction of these mechanisms. Shape Deposition Manufacturing (SDM), for example, is a manufacturing method relatively new to robotics which allows for the creation of multi-material parts with embedded components (Fig. 1). Both projects rely heavily upon the SDM process and other rapid prototyping methods.

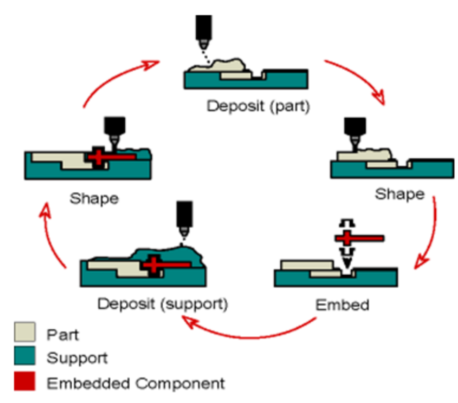

Figure 1. Shape deposition manufacturing cycle. (http://biorobotics.harvard.edu/research/SDM.html)

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A. Gripping Mechanisms for Microgravity and Extreme Terrain

The motivation behind GMMET is the robotic exploration of asteroids in close proximity to Earth, aptly termed Near Earth Objects (NEO). The structure and composition of the asteroids that litter our solar system may provide a direct link to understanding the formation of the solar system and the life within. Asteroids are likely to have delivered the vital organic chemicals and prebiotics to the planets of our inner solar system. (Lauretta). Asteroids located with a few months travel time from Earth are of the highest interest for missions in the immediate future. US President Barack Obama has also prioritized manned missions to NEOs as a precursor to sending the first human to Mars (Obama). Robotic exploration is necessary and wise to increase the safety and success of any future manned mission to NEOs.

NEOs in range of easy accessibility are often much smaller than asteroids found farther out in the solar system, typically ranging in size up to a maximum of 150m in diameter, and are comprised of materials similar to vesicular basalt rocks found here on Earth. From their small size we know that NEOs offer only a small fraction of the gravity found on our planet; approximately 0.00003 of that on Earth. On bodies with diminished gravity such as this the exit velocity is often not more than 10 cm/s and typical locomotion methods, like wheeled driving, are not viable mobility options. GMMET addresses this problem by creating a gripping mechanism of minimal size, weight, and power consumption that will securely anchor a robot in a microgravity environment. Additionally, the exposed rock outcroppings and cliff faces on Mars that are currently inaccessible to existing rovers are high value science targets. The stratified layers of rock common to these outcroppings and cliff faces will be a crucial resource toward understanding the history of the planet (Parness).

The most commonly employed climbing mechanisms make use of suction cups, magnets, adhesives, or microspines to accomplish gripping (Asbeck). Of these climbing technologies, microspines have shown to be an efficient method for maneuvering over natural, unstructured media, such as stone or wood (Fig. 2)(Provancher). Gripping systems based on microspines are, therefore, a highly desirable technology for use on most asteroids and several extraterrestrial planets, including Mars, where natural rock surfaces are present. Building on the success of previous designs using microspines, GMMET will improve the typically linear range of operation of existing microspine climbing devices by creating an omni-directional system to allow climbing in all orientations. Using this kind of anchoring mechanism on a legged robot will provide mobility in microgravity environments and offer a stable base for sample drilling operations (Parness).

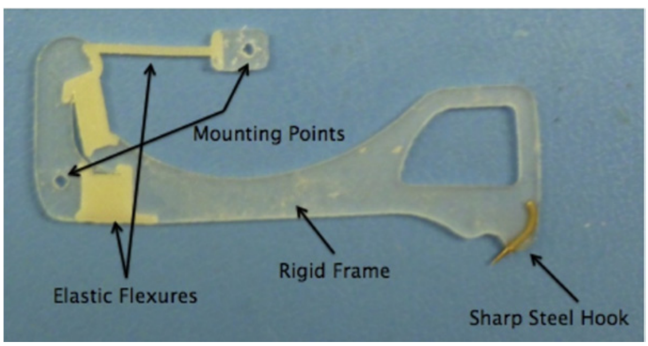

Figure 2. Microspine gripping part created via SDM with embedded components and multi-material construction.

B. Vertical Climbing Micro Ground Vehicle

The role of many robots is limited not only by the functionality of their design, but by their size and mobility. Nowhere is this a greater concern then the defense and aerospace industries. The demand for tough, modular, light-weight, and inexpensive robots dominate in both these fields. Successfully merging these requirements into any robot is a challenge, however including them in a climbing robot has not been extensively explored and is often met with great difficulty when attempted. Using a novel silicone adhesive created by Dr. Aaron Parness the MGV project seeks to develop a crash-proof climbing robot weighing less than 100g with payload carrying capacity.

The MGV will generate adhesion using a hierarchical, microfibrillar structure similar to that found on the pads of a gecko’s foot (Fig. 3). Using atom-to-atom interactions to provide adhesive van der Waals forces this unique material demands a specific loading pattern to function properly, but does not require cleaning and works on a variety of surfaces. This specific loading pattern was a driving factor in the design of the MGV mobility mechanism and robotic platform.

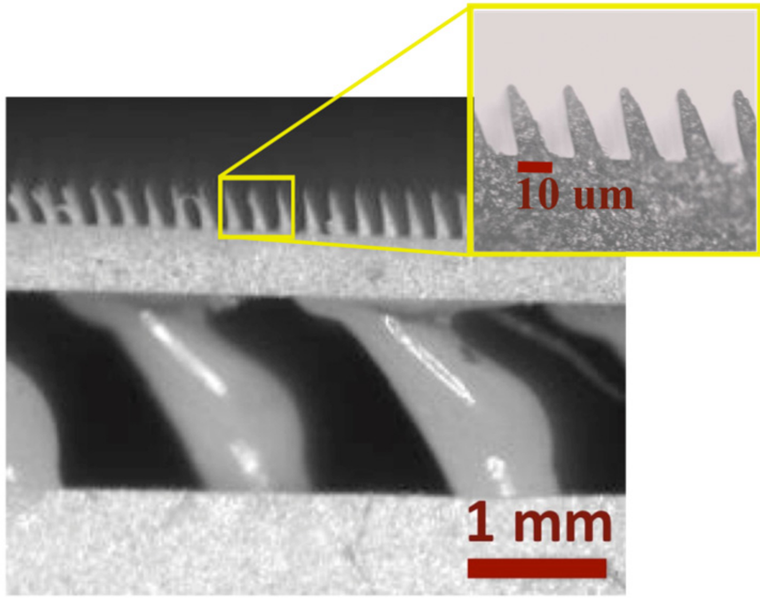

Figure 3. Magnified micro-fibrillar adhesive cross-section displaying hierarchical structure.

II. Objectives

While each project has a unique set of goals there are several objectives that are tied to both GMMET and MGV. Both projects rely on the use of the SDM process to construct multi-material parts on the millimeter scale. The SDM process has not been refined for the manufacture of robotic parts, particularly on the small scale, and requires some research to be a useful tool for either GMMET or MGV. The objective of further developing SDM does not have well defined goals as it is largely dependent on the demands of the individual projects, and will be adjusted accordingly when new problems arise.

A. Gripping Mechanisms for Microgravity and Extreme Terrain

Using microspine gripping devices in microgravity and extreme environments requires several advances over current technology. The primary objectives for GMMET include:

- Create a microspine gripping mechanism capable of adapting to varied unstructured rock terrain and supporting omni-directional forces up to 120N (26.98 lbs)
- Develop an actuation and latching mechanism to allow for a zero-power ‘on’ state

Because individual microspines generate adhesion forces in a single linear vector, they must be designed into a mechanism that distributes these forces radially. This mechanism must also balance the forces between microspines and arrays of microspines to avoid overloading any individual spine or array. Increasing microspine travel tangent to the face of a rock directly increases the chances of microspine engagement and attachment and therefore is a desirable characteristic that will drive the above objectives.

B. Vertical Climbing Micro Ground Vehicle

The novelty of the microfibrillar adhesive presents a unique set of challenges for the MGV project. While the end goal of the project is to create an entire robotic platform capable of both rapid horizontal and vertical travel, there are several milestones that needed to be addressed first. Immediate objectives for MGV include:

- Refine microfibrillar adhesive to extend existing compliant behavior
- Prototype and revise compliant limb/locomotive mechanism to provide desired loading conditions and adapt to varying terrain

III. Current State of Research

In January 2011 both the GMMET and MGV were in the very early stages of development. At that time GMMET had an initial prototype, in its first iteration, that was capable of gripping a rock but that lacked compliance in specific areas and had no actuation mechanism. The MGV project had no such prototype and only initial work done to improve the microfibrillar adhesive production process.

A. Gripping Mechanisms for Microgravity and Extreme Terrain

From January, 2011 to May, 2011 the GMMET project has made significant strides toward reaching the aforementioned objectives. There are currently five working prototypes, all of which use microspine arrays, and one prototyped actuation mechanism.

1. Gripping Mechanism

Contributions to this project by the lead author include the design and construction of a gripper prototype and the actuation mechanism (Fig. 5 – 8). The gripper prototype was based on a rotating sprocket design that was intended to maximum spine travel tangent to the rock face without increasing forces normal to the surface.

Sprocket elements underwent several iterations, pictured in Fig. 5 & 6 from left to right. Compliance was built into the sprockets to ensure the engagement of one hook did not hinder the engagement or travel of adjacent hooks. This was accomplished by first casting the hooks in a rigid plastic (Fig. 5, black) and later casting flexures from Shore 60A soft urethane (Fig. 5, green). These flexures enable each sprocket to operate independently; allowing sprockets on the same axle to continue rotation in the event a neighboring sprocket became engaged.

The first iteration of the gripping mechanism that served to actuate the sprockets is pictured in Fig. 7. Pulling the red filament pictured in Fig. 7 engages the primary rotary motion, causing the sprockets to rotate up to 270°. The conical spring connecting the two sections of the mechanism allows for further travel tangent to the rock face should the sprockets travel their entire range of rotation and not engage.

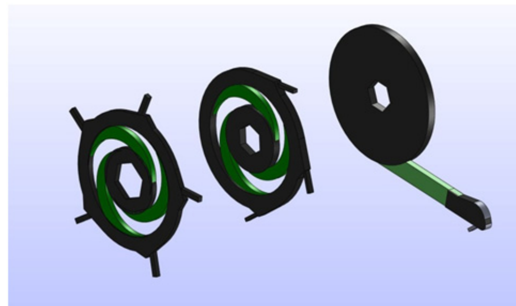

Figure 4. Sprocket prototypes developed for GMMET. Version 1 thru 3 pictured sequentially from left to right.

Figure 6. Sprocket V2 (left) and V3 (right) prototypes. Shown with standard US quarter for reference.

Iteration 2 of the gripping mechanism uses a similar mechanism to rotate the microspine sprockets (Fig. 8, 10); however, changes to the design include the removal of the central conical spring, the addition of adjustable connection points at the top of the mechanism, and a redesign of the central pulley.

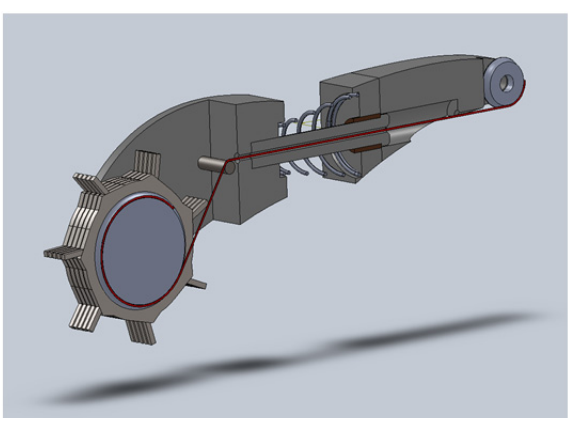

Figure 7. Initial design of sprocket gripping mechanism.

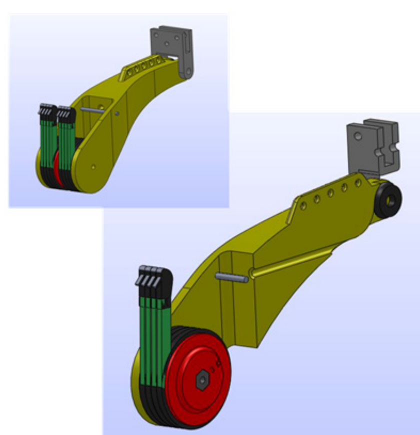

Figure 8. Second iteration of sprocket gripper.

The redesigned mechanisms were arrayed circularly around a central housing to create a total of 16 mechanisms, each in opposition with another, for a complete system capable of omni-directional adherence (Fig. 9, 10).

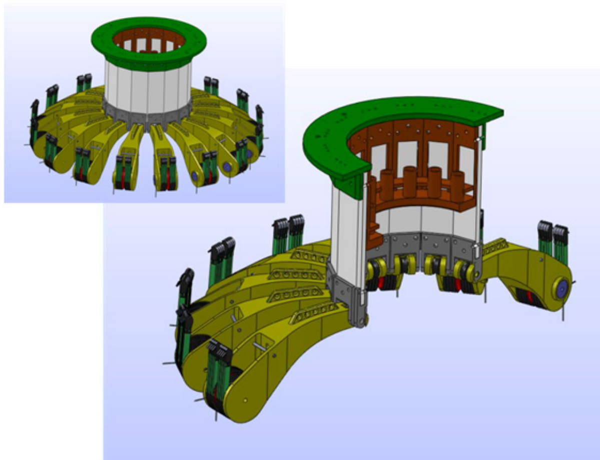

Figure 9. Complete system of 16 sprocket gripping mechanism with housing (white & brown) and actuator attachment plate (green).

Figure 10. Sprocket gripper system prototype with 2 of 16 gripping arms and V3 sprockets.

2. Actuation Mechanisms

A universal actuation mechanism was developed as a method to consistently engage the gripping mechanism prototypes (Fig. 11, 12). Using constant force springs on a sliding fixture the mechanism allows even force distributions on cable driven gripper mechanisms, which encompasses four out of the five designs. The system is designed modularly to allow for the easy replacement of springs and interchangeability between gripping mechanisms. Cable tension can be adjusted from 0.66lbs to 2.63lbs by changing the 16 constant force springs in the mechanism. Attachment to grippers is made possible through the four slide/mounting rods running the length of the mechanism which bolt to attachment plates, each custom fit to a particular gripper. This system provides a repeatable, hand-operated method of evaluating gripping mechanisms quantitatively.

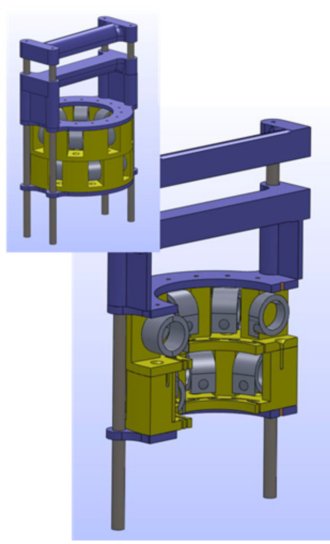

Figure 11. Universal actuation mechanism using arrayed constant force springs.

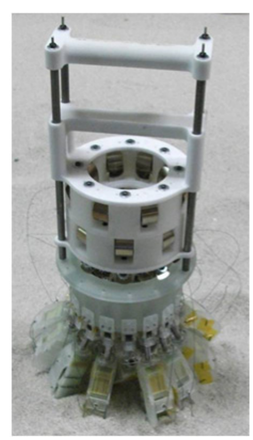

Figure 12. Universal actuation mechanism attached to lateral travel gripper designed by Dr. Aaron Parness.

B. Vertical Climbing Micro Ground Vehicle

Contributions to the MGV project include the design and construction of a tread mechanism to provide the desired loading pattern for the microfibrillar adhesive. The treads feature a floating adhesive plate, connected via flexible urethane filaments to a rigid housing (Fig. 13). The urethane connectors provide the adhesive plate 6 degrees of compliance for attaching to uneven surfaces. The design maximizes the degrees of freedom of each plate while directing the weight of the robot evenly though the adhesive patch. The full track (Fig. 14, 15) is created by joining the plates around a standard #25 chain sprocket.

The objective of keeping the weight below 100g meant the size and weight were of critical importance for this design. Each plate measures 31mmx12mm and weighs a mere 0.9g. The entire system measures approximately 89mm in length and weighs only 20g.

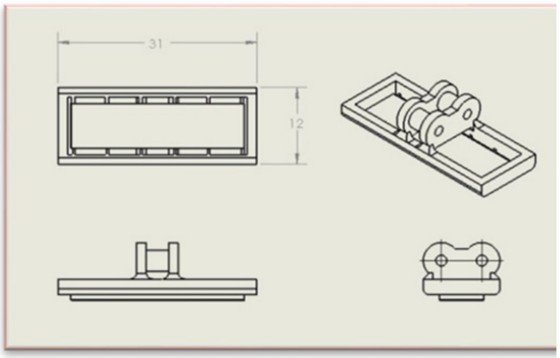

Figure 13. Single MGV tread. Floating central plate containing microfibrillar adhesive can been seen in bottom view (top left). Dimensions in mm.

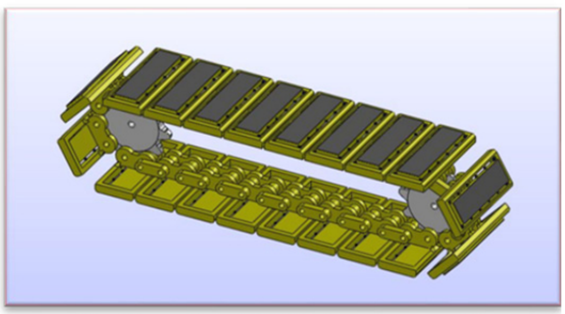

Figure 14. Complete MGV tread assembly with plates (yellow) and adhesive (grey).

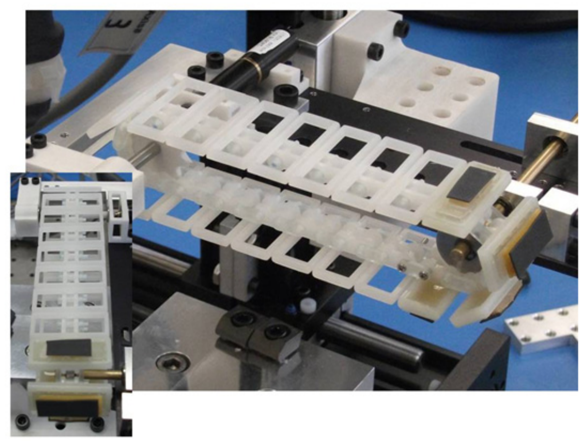

Figure 15. Prototype of MGV track mounted on test setup. Black areas are temporarily attached microfibrillar adhesive patches.

C. Shape Deposition Manufacturing

The use of shape deposition manufacturing was critical to the success of both GMMET and MGV. A large percentage of time for this project was spent refining the SDM process for the production of very small parts and improving the process for the production of more intricate components. The methods employed in these projects were recorded and made available to other members of section 347 and to the JPL community as a whole via the JPL Wired website.

IV. Conclusions

Existing research and development efforts will continue in the near future and will grow to include the collection of quantitative test data for both projects. Test setups for both GMMET and MGV are currently being developed and should be operational by the Fall of 2011.

A. Gripping Mechanisms for Microgravity and Extreme Terrain

While the current state of research is promising there are few conclusions to be drawn at this point. The gripping mechanisms for GMMET function as designed and are capable of gripping rocks of various topologies and scales. The sprocket gripper was vastly improved during subsequent iterations by adding rigidity to the design, both of the sprockets and the mechanism, and thereby removing much of the variability in its success rate. Additional work will be done to address remaining issues that exist in the repeatability of the current sprocket design.

A common issue for all mechanisms is lack of structural stability when exposed to varying loads. The application of external forces to the housing, such as those the gripper would see while drilling, often results in a change in the angle between the individual arrays of microspines and the housing. This change causes a subsequent change in the angle of engagement between the hooks and the rock surface. The result is often that a once secure grip becomes compromised when external forces are applied to the system as a whole. To combat this the next phase of research will be to develop a locking mechanism for each microspine array and/or a method of preloading the system to negate the effects of externally applied loads.

B. Vertical Climbing Micro Ground Vehicle

The adhesive track for MGV is fully functional and has undergone initial tests in the lab. The design appears to work well; however, the development of the microfibrillar adhesive has not progressed to the point of reliably evaluating the design based on quantitative data.

Much of the work done with MGV to has been concentrated on the production of very small parts via the SDM process. Creating these parts to sub millimeter tolerances has presented several unforeseen challenges that have taught the researchers much about the behavior and use of SDM for future projects.

Acknowledgments

C. McKenzie would like to thank Aaron Parness, Matt Frost, Norman Aisen, John Leichty, Joel Johnson, and Brett Kennedy for their guidance and support throughout his time at the Jet Propulsion Laboratory. He would also like to thank the Petra Kneissl-Milanian and the JPL education office for their hard work and for making this opportunity possible. Lastly he would like to acknowledge the selfless bravery exhibited by Lemur IIb in the name of science during the testing of early gripper mechanisms (Fig. 16).

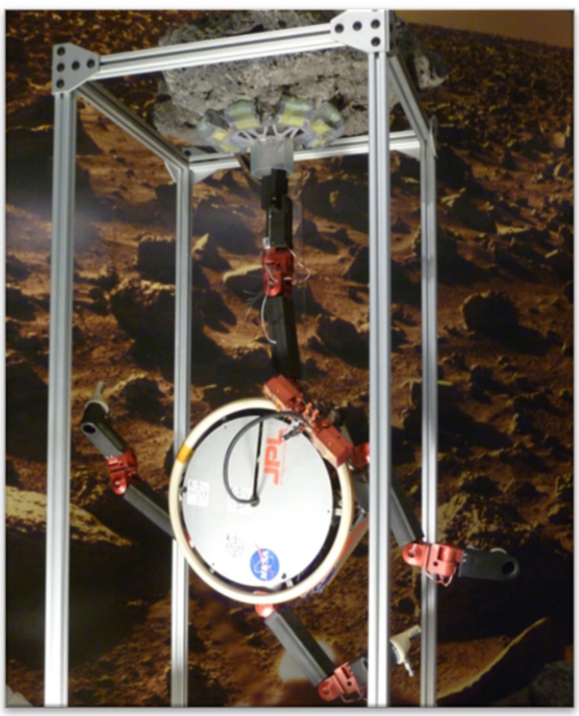

Figure 16. The robotic platform Lemur IIb hangs inverted using an early model gripping mechanism developed for the GMMET project.

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This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the University Student Research Program and the National Aeronautics and Space Administration.