Mechatronic Design of a Treaded Mobile Robot for Mine Sweeping

Dr. Andrew B. Wright

Department of Applied Science

University of Arkansas at Little Rock

Little Rock, AR 72204

Abstract

Autonomous mobile robots, which can be programmed to exhibit cooperative behaviors, are ideal mechanisms for sweeping land mines. They can spread out to hunt for the mines, using a dispersal rule. Once a mine is located, they can congregate to surround it using a clustering rule. Should a robot be destroyed by tripping an unseen mine, the cost is minimal compared to a human life. UALR has been experimenting with coupled oscillator based rule generators for several years using fragile, indoor robots in a laboratory setting to validate the clustering and dispersal behaviors. In order to accomplish outdoor trials, a rugged robot, which can negotiate uneven terrain, needed to be designed. Energy efficiency and mechanical efficiency were paramount in the selection of the batteries, motors, and controller electronics to extend the running time between recharging. An eight-wheel treaded design was selected, in order to provide best traction on uneven terrain and to provide the ability to climb over obstacles or steep slopes.

Introduction

Mechatronics is an area of design which synergistically combines mechanical design, electrical design, sensor design and integration, control system design, and software design (Craig, 1999). A conventional mechanical designer combines purely mechanical elements in achieving desired specifications. Such elements include gears, linkages, and other mechanisms. A mechatronic designer augments his mechanical toolbox with other elements, including sensors and actuators, software routines, and control algorithms. By adding this design flexibility, a larger map of solutions is available, and a design which is closer to the optimum can be achieved.

In traditional design, the mechanical design is accomplished first using purely mechanical elements. Sensors and actuators are usually placed next or are retrofitted on an existing mechanical design. The control system and software are added last. The control system is usually designed for this final system. As each stage in the process develops, it becomes increasingly expensive to return to an earlier stage and perform a redesign. An optimal design can only result from the traditional design sequence through pure chance or through long, multi-product redesigns.

An example from the automotive industry illustrates this concept. Steering is accomplished through a mechanical linkage connecting the steering wheel to both front wheels (a rack-and-pinion). With the advent of power steering, the steering wheel’s turning force is “servoed” by the power steering system to increase the turning force, eliminating the need to have the steering system mechanically amplify the driver’s force. However, the mechanical linkage to maintain both wheels in their proper relative orientation remains. A mechatronic design would include a controller, which takes a command signal from the driver and delivers an appropriate signal to either a hydraulic system or an electric motor coupled independently to each front wheel. Feedback would be delivered to the controller through sensors placed on the front wheels. The mechatronic design is less expensive because it contains fewer mechanisms and uses either motors or hydraulics which are already present in the power steering. Since both wheels can be controlled independently, more creative steering strategies can be employed.

Whereas most mechanical systems (automobiles, airplanes, power generation equipment) can be made to function adequately through traditional design techniques, autonomous mobile robotic systems require a mechatronic design approach. Autonomous systems do not have a human element to direct the system. Rather, an autonomous mobile robot will have an on-board controller which must process sensor information and provide actuator signals. Autonomous systems have much more stringent energy requirements than conventional systems, since efficient transduction of battery power into mechanical motion extends the life of the vehicle. Coordination between mechanical, electrical, and control elements must be done simultaneously and synergistically from the beginning of the design process.

Many autonomous mobile robot designs have been proposed and built (Steele and Ebrahimi, 1986). The tasks which these robots perform range from pure research to planetary exploration. There are many design configurations for mobile robots. Most are either wheeled or legged configurations. There are few treaded configurations in the literature. Many of the wheeled configurations, especially the two wheeled, differential drive configurations (Gentile et al., 1996;Wu, 1994), are only workable on a hard flat floor.

More robust systems have been designed through the Rover planetary exploration program (Gentile et al., 1996; Zimmerman, 1994). While early prototypes had eight wheels and no tread, the final design, which was used on Mars, was a six wheeled design. The choice of wheels over a treaded design was a compromise between complexity of the control strategy versus the problem associated with tread slipping from the drive wheel. In the multiple wheel design, each wheel must be controlled independently which requires more controller outputs, more motors, and more electronics to deliver power to each wheel motor. In a situation where a tread cannot be replaced if it slips, this added complexity is justified.

Mobile robots, which can be programmed to exhibit cooperative behaviors, are ideal mechanisms for sweeping land mines. They can spread out to hunt for the mines, using a dispersal rule. Once a mine is located, they can surround it using a clustering rule. Should a robot be destroyed by tripping an unseen mine, the cost is minimal compared to a human life. UALR has been experimenting with coupled oscillator based rule generators for several years using fragile, indoor robots in a laboratory setting to validate the clustering and dispersal behaviors (Anderson and Clark, 1999). In order to accomplish outdoor trials, a rugged robot, which can negotiate uneven terrain needed to be designed. For the present mine-sweeping application, a treaded design was chosen. This design preserved the differential drive configuration used in earlier UALR experimentation and allows the vehicle to negotiate hilly and rugged terrain.

Mechanical Design of Drive System

There are three components in a vehicle: frame, suspension, and drive mechanism. The frame contains the suspension, the drive mechanism, and any passenger or payload. The suspension transmits forces from the ground to the frame and from the frame to the ground. Ideally, it will decouple terrain uncertainties (pits, pot holes, bumps) from the frame motion. The drive mechanism transfers power from the drive motors to the suspension.

Requirements: The robot interior, which contained the sensors and electronics, needed to be isolated from dirt and water. Although it did not have to be completely water-proof, the housing needed to tolerate splashes. The controller electronics needed to be mounted to provide shock and vibration resistance. The suspension and drive train needed to be sturdy so as to survive the wear and tear caused by an outdoor, uneven terrain. Energy efficiency and mechanical efficiency were paramount in the selection of the batteries, motors, and controller electronics so as to extend the running time between recharging. The treaded design employs differential steering, which allowed the control algorithms designed on the indoor robots to be used without modification.

The target for vehicle mass, excluding controller electronics, was 13.5 kilograms. Although there was no exact space claim, the weight requirement limited the vehicle to a frame of 30 centimeters by 50 centimeters. The vehicle top speed was to be limited to running pace (about 2 meters per second) so that, in the event of a controller instability, the vehicle could be caught by a human observer. Maneuverability was not a primary concern, so turning rate was not considered in the design.

The Frame: The Frame is split into two halves connected by supporting cross rods (see Fig. 1). The cross rods support a plate which holds the controller electronics and battery. The plate is attached to the frame through vibration isolating mounting posts (Small Parts part number PM-832-18SS). These posts attenuate vibrations from the frame.

The Suspension: The Suspension consists of a tread (Belt Corporation of America, part number 125L), which is driven by the drive sprocket, wraps around the primary idler wheel, and loops over four road wheels (see Fig. 2). This is duplicated for each side. There are a total of eight wheels potentially in contact with the road at any given time. An eight-wheel treaded design was selected, so as to provide best traction on uneven terrain and to provide the ability to climb over obstacles or steep slopes.

The road wheels are decoupled from the frame through spring-loaded shock absorbers (Traxxas part number 3780). Each wheel travels in a circular path, pivoting about a fixed point attached to the frame (see Fig. 3). The length of the supporting link is 60 mm and the vertical travel of the wheel is limited to about 5 mm before the shock reaches its stop. The eight shock springs support the approximately fifty pound vehicle and payload, and the spring/shock combination forms a first order damper to attenuate transmission of ground-induced disturbances from affecting the frame.

The road wheels are machined from Delrin with an oilite bushing (Small Parts part number Y-FBB-2/4) pressed into the wheel bore. The bushing rides on a steel axle. The road wheels contain a hub to prevent the tread from slipping. Traditional treaded vehicles contain a sprocket which grips in notches in the tread. Given the timing belt tread which was chosen, this was not feasible. Should tread slip become a problem, this aspect of the design would have to be revisited.

Although a timing belt tread is not as ideal an arrangement as manufacturing linked treads, it is much less expensive. Since this vehicle is a prototype, issues of tread slippage and traction are being investigated. The road wheels have a 3 millimeter hub, to prevent the 3.6 mm thick tread from slipping sideways. Although the tread only extends beyond the hub by 0.6 mm, the vehicle is totally supported by the tread under most circumstances. If a thicker tread becomes necessary, the timing belt can be replaced with a thicker belt or an outer covering can be applied to the belt.

The Drive Mechanism: The Drive Mechanism is the main element. The tread is driven by a timing belt drive gear made from timing gear stock (Stock Drive Products part number AGA4-18L08), which is coupled to the drive motor (Crouzet part number 82830002) through two brass gears (Stock Drive Products part number A1B1MYKH7072 and A1B2MYKH7030). The gear ratio is 72:30. The motor maximum speed is 2100 rpm and the sprocket pitch diameter is 54 mm. This yields a maximum tread speed of 2.5 meters per second (2100 rpm * 2π radians per rev * (54 mm)/2 * 30/72). Although this is faster than the target speed, this is the no-load speed. The actual maximum speed is close to the design goal. See Fig. 4 for a close-up of the gear train.

An encoder (Hewlett Packard part number HEDS5500 A06) is also coupled to the primary drive gear through a 16 tooth brass gear (Stock Drive Products part number A1B2MYKH7016). The encoder measures position, velocity, and acceleration of the timing belt gear. This can be used for feedback to provide regulation of the vehicle velocity. It can also provide position information for performing odometry on the vehicle. The encoder resolves one revolution of the encoder gear into 512 equal slices. By providing a 72:16 gear ratio that increases the number of revolutions of the encoder relative to the drive sprocket, the resolution of the position is increased. Therefore, the motion of the drive sprocket is divided into 512*4.5=2304 equal slices. Velocity resolution is likewise increased, which is crucial when the vehicle is moving very slowly. This has been a problem with the previous robot design and represents an area where mechatronic design techniques have been applied.

Another solution to increasing resolution is to use an encoder with more divisions, in this case, 2048. Since encoders become geometrically more expensive with increasing resolution (in this case from $50 to $200), the cost of the higher resolution encoder exceeds the cost of adding a gear and a bearing (in this case $50). Further, once the cost of adding a gear and a bearing has been absorbed, further increasing resolution can be accomplished by changing the number of teeth on the encoder gear. Since the price of gears changes slowly with the number of teeth, this design allows resolution to be increased with minor increases in cost.

The drive sprocket uses a double bearing design in an aluminum hub to support bending loads. The drive hub (see Fig. 5) is supported by a steel spindle, which is mounted to the main support bracket. Steel was chosen for two reasons. The spindle is a small diameter shaft, which must support cantilevered bending loads. Because the diameter is so small (to fit through the inner race of the bearings), steel was chosen for its superior strength. The second reason is that the end of the shaft had to be threaded to accommodate the jam nut, which keeps the hub on the spindle.

The hub has two angular contact bearings (Fafnir part number 7201K) pressed into it. These bearings are arranged back-to-back to support thrust loads. The hub is held onto the spindle with a jam nut, which presses against the inner race of the outer support bearing. The timing drive gear stock and the end plate are affixed to the hub with three screws. An oil seal (CR Seals part number 5840) fits between the spindle and the hub and prevents dirt and grime from penetrating the sealed area containing the bearings.

The idler wheel (see Fig. 6) supports the tread and redirects its motion towards the road wheels. It also has a double bearing design identical to the drive sprocket. In place of the timing gear stock, the idler wheel is machined as one piece.

Conclusions

An eight wheeled, treaded vehicle has been designed and built. This vehicle will serve as a mobile platform to test cooperative behavior algorithms over rough, uneven terrain. The treaded design will allow the vehicle to traverse steep inclines and surface discontinuities, such as pits and rocks, which a wheeled design would find difficult or impossible.

Mechatronic principles were applied to this design such as the integration of an encoder for feedback in the drive system. The overall mechanical architecture was chosen so as to minimize control system complexity. The transmission and the choice of motors was driven by the need to extend battery life.

Acknowledgments

This work was performed through support from the U. S. Army Research Office, grant number DAAG55-98-1-0011.

Literature Cited

Anderson, G. T., M. R. Clark, 1999, “Navigation of Autonomous Robots with an Intelligent Oscillator Controller,” Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 1003-1006.

Craig, K. C., 1999, “Mechatronics at Rensselaer: A Two-Course Senior-Elective Sequence in Mechanical Engineering,” Proceedings of the 1999 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 452-458.

Gentile, A., A. Messina, A.Trentadue, 1996, “Dynamic Behaviour of a Mobile Robot Vehicle with a Two Caster and Two Driving Wheel Configuration,” Vehicle System Dynamics, 25: 89-112.

Lee, S., R. M. Brown, Y. Yang, T. Yuan, C. Chao, D. Patel, R. Kelley, G. K. Lee, J. Bouck, T. Anderson, J. Wang, T. Pare, M. Floyd, H. Lacey, 1994, “A Mars Surface Exploration Vehicle Testbed for Control Algorithm Verification,” Proceedings of the Fifth International Symposium on Robotics in Manufacturing, 5: 173-178.

Steele, J. P., N. D. Ebrahimi, 1986, “Control of Mobile Robots,” International Journal of Robotics and Automation, 1: 40-45.

Wu, K. C., 1994, “Fuzzy Logic Control of a Robot Mouse,” Proceedings of the Fifth International Symposium on Robotics in Manufacturing, 5: 315-319.

Zimmerman, W., 1994, “JPL Rover Technology Program,” Proceedings of the Fifth International Symposium on Robotics in Manufacturing, 5: 345-354.

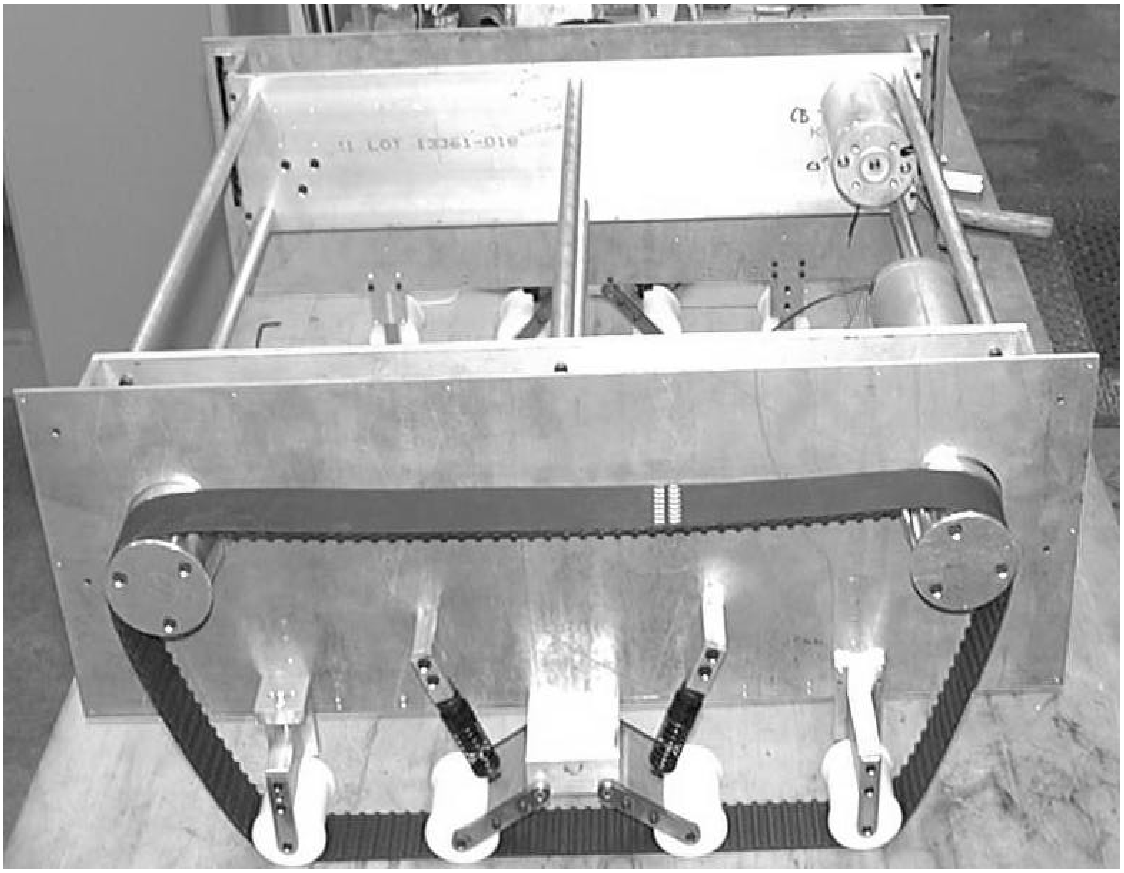

Figure 1. Schematic of Assembled Vehicle

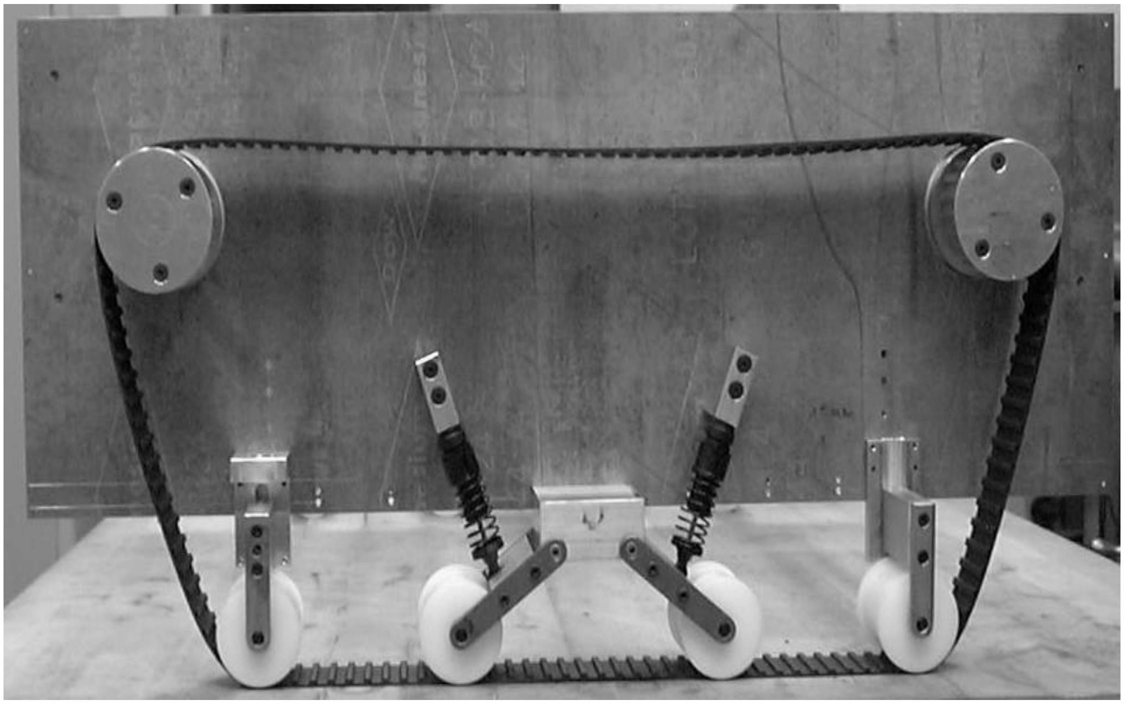

Figure 2. Side view of Drive Mechanism

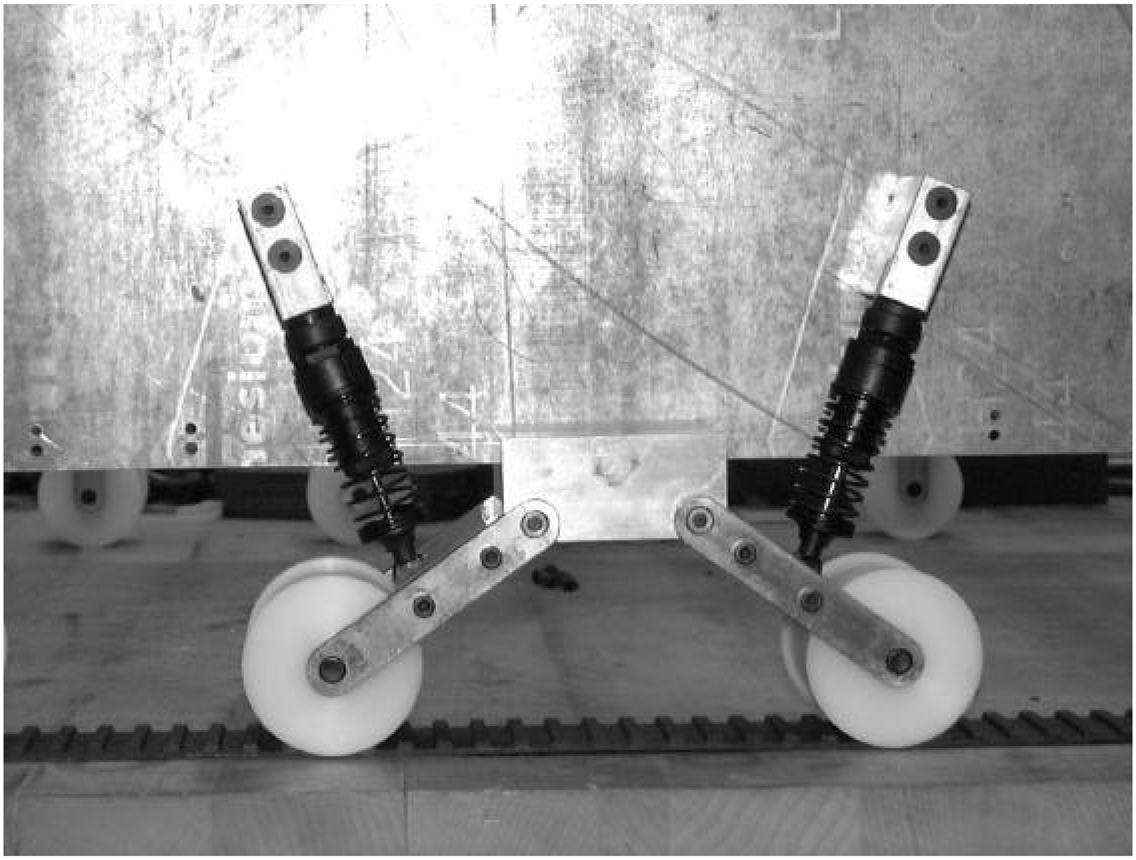

Figure 3. Close Up of Suspension

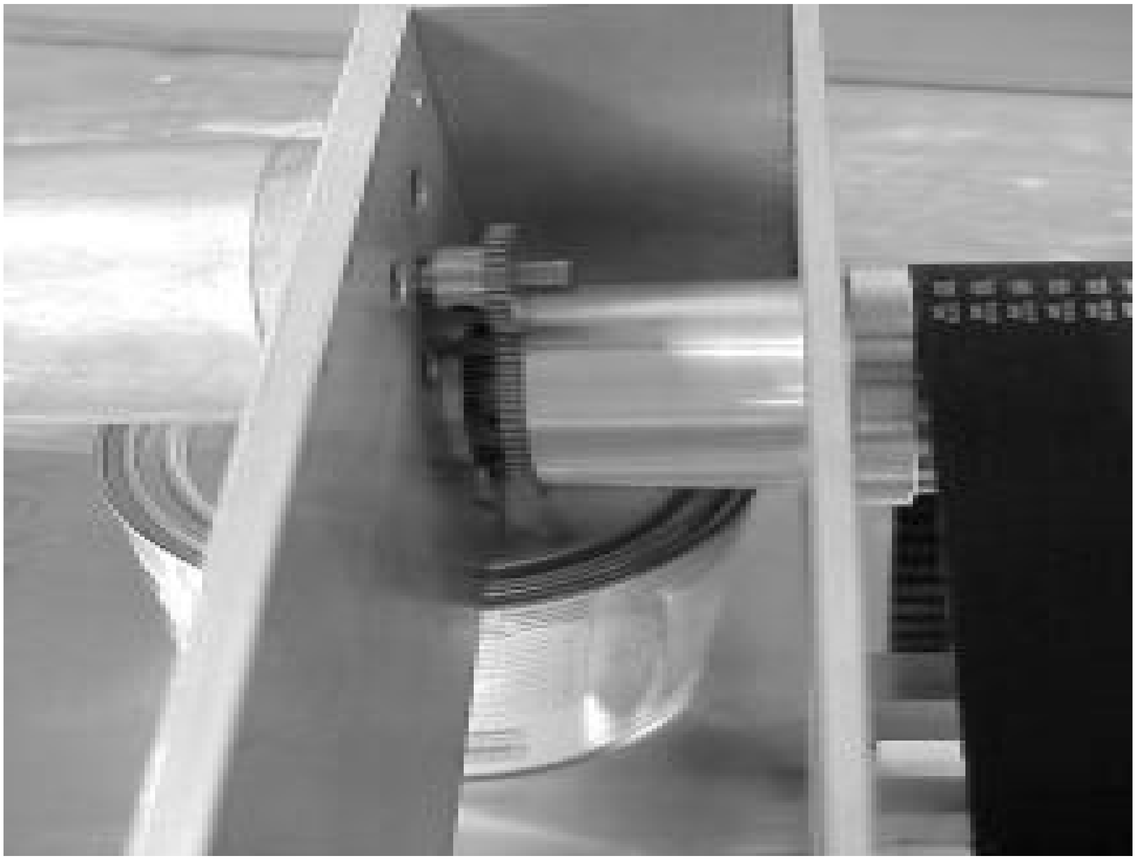

Figure 4. Close Up of Motor Transmission Mechanism

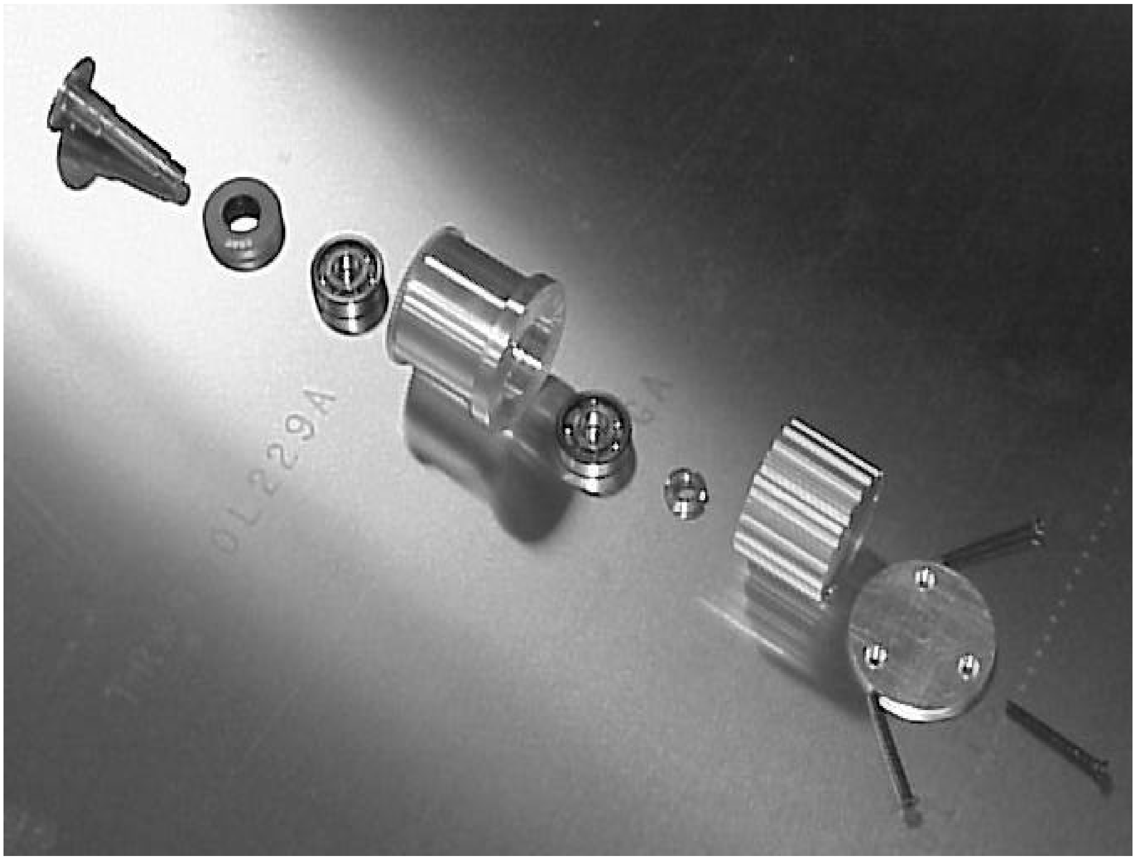

Figure 5. Assembly of Primary Drive Sprocket

Figure 6. Assembly of Idler Wheel