

Design, Manufacture, and Testing of Unmanned Ground Vehicle for Field Service Operation

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Abstract— This paper was describe the concept, modelling, simulation, fabrication and testing of an Unmanned Ground Vehicle (UGV). This UGV was to be used in field service operation. It had to be able to operate in hazardous environment and various terrain. In our work, we had developed a small vehicle equipped with belt track and flipper that can be controlled remotely.

Keywords— unmanned ground vehicle, field service operation, mechanical design.

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I. INTRODUCTION

UNMANNED Ground Vehicle (UGV) is a vehicle with special purpose that can be operated without human presence. The vehicle contains a set of sensors to observe environment. The vehicle will send the information to the remote operator. So, with the information, operator can make further decision for special purpose mission.

In field service operation, such as military mission or mining operation, human often have to deal with high risk situation. Human have to deal with unknown object that can be explosive or poisonous. It can endanger their lives. So during the past few years, robot or UGV have been used to replace human for this operation. Advance technologies has made it possible to UGV to fulfill the operation.

Our research now is developing an UGV that can be used for explosive ordinance mission. The UGV later will be integrated with 6 degree of freedom manipulator.

II. DESIGN METHODOLOGY

To achieve the desired functionality of the UGV, the procedure starts with benchmarking of other UGV, determining design requirements and objectives, concept design, detail design, and structural analysis.

We started with benchmarking of other UGV that already exist in the market to get the appropriate design requirements and objective standards.

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Basic concept is determined by integral mechanical and electrical solutions to the problem at hand. The control scheme of electrical parts, sizes, and weights determine the needed mechanical supporting parts and vice versa.

A. Benchmarking

We compared some of the main parameters on the UGV that already exist in the market. The parameters we compare are dimensions, speed and weight.

The UGV we take for comparison sample is Packbot 510 [4], PIAP GRYF [5], and Mini-Caliber [6].

Table 1 UGV Benchmmarking

Parameters	Our UGV	PIAP GRYF	Packbot 510	Mini-Caliber	Unit
Speed	5	3.6	9.3	4	km/h
Height	155	450 (incl. manipulator)	178	240	mm
Width	520	590	406	400	mm
Length	680	690	686	600	mm
Weight	25	38 (incl. manipulator)	10.89	27 (incl. manipulator)	kg

Table 2 Design Requirements and Objectives

Dimension	680x520x155 mm
Weight	45 kg, fully loaded
	25 kg, Chassis Only
Environmental	IP65
Speed	5 km/hour (High)
	1.25 km/hour (Low)
Flipper Velocity	40 deg/s
Microcontroller	LPC4088FET208: Mid-range 32-bit Microcontroller based on ARM Cortex-M4 Core
Battery endurance	1.5 Hour. 2 battery depend on mission profile, up to 7.5 km
Communication	RF: Fully digital 2.4 GHz. up to 500 m range line of sight
Battery capacity	7.5 Ah
Climbing stairs	up to 35 degree depend on surface
Climbing slope	up to 40 degree depend on surface
Vertical obstacle	20 cm

B. Design, Requirement, and Objectives

Design requirement and objective of the UGV determined from benchmarking table (Table 1) and from survey and interview with UGV user.

III. OVERALL CONCEPT DESIGN

The general idea is to develop UGV with optimal maneuverability in multi-terrain and various conditions. So, it has to be able to get pass through various obstacles including stairs and doors.

To achieve that, our UGV design is equipped with belt track and flipper. Belt tracks can help the vehicle across the uneven terrain. Flipper is used to flip the vehicle. It helps vehicle ascending and descending stairs. Flipper also help vehicle to pass through the obstacles.

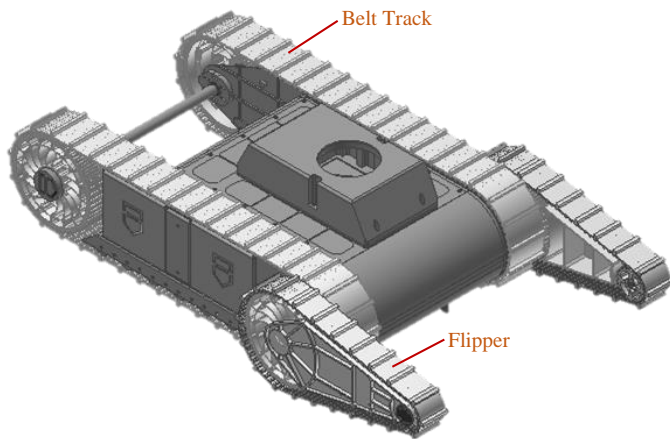


Figure 1 UGV Concept

The UGV also has to be light enough so it can be easily carried to the operation site.

In addition, to facilitate the UGV ascend and descend stairs, the Center of Gravity (CG) of the vehicle must be in front of the vehicle. If CG is located at the front of vehicle, the vehicle will be more stable ascending and descending the stairs. To achieve that, we put all the transmissions and electronic parts in front of vehicle so that center of gravity of the UGV is located in the front.

IV. ELECTRICAL CONCEPT DESIGN

To meet the design requirements and objectives, this UGV uses embedded system as main controller. This main controller is responsible in sending instruction data which control motors movement. Besides that, main controller will retrieve information about current and speed of motor. Moreover, main controller will retrieve commands from user directly through wireless communication.

Figure 2 shows LPC4088 as main controller. The LPC4088 is going to processing data from Operator Control Unit (OCU) into instruction data for motor. In mainboard, main controller will communicate with IMU sensor and power distribution board. The IMU is used for sensing altitude and direction of UGV movement. The power distribution board operates with divided level voltages to supplies power to the overall system.

Furthermore, data information about condition of batteries will be send to the main controller. At main board there is an external interface, which is used as additional communication with another microcontroller.

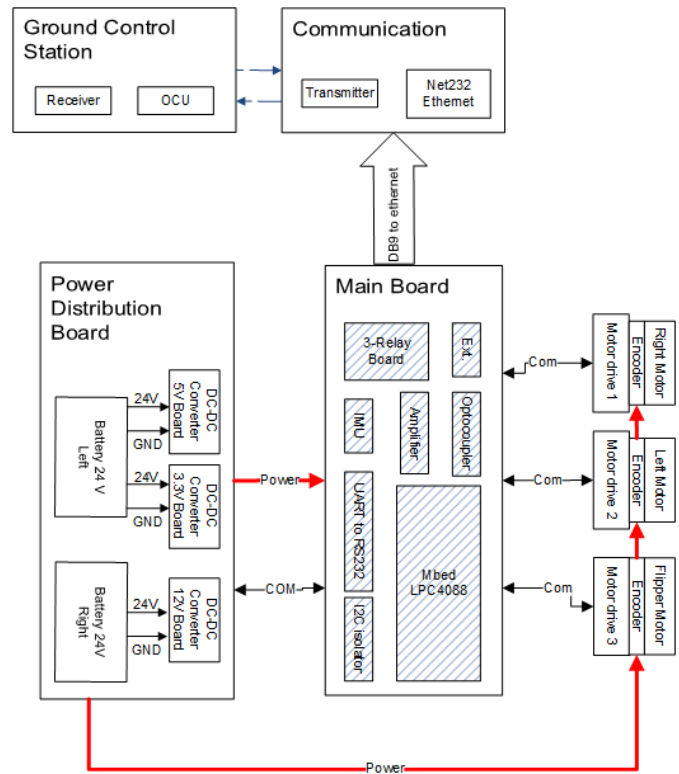


Figure 2 Electrical System of Unmanned Ground Vehicle

V. POWER TRANSMISSION DESIGN

A. Concept

All motor and power transmission placed at the front of vehicle in order to put its Center of Gravity (CG) to the front of chassis.

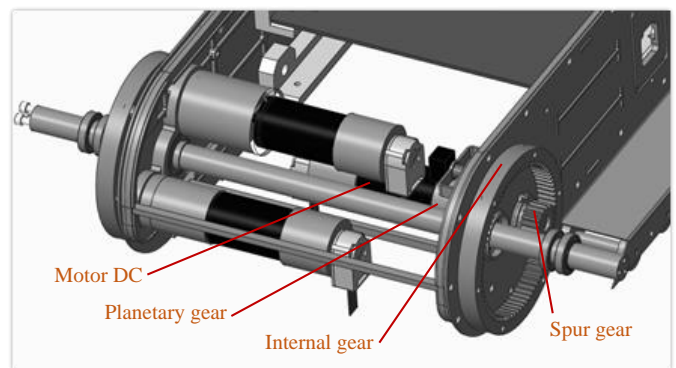


Figure 3 Drivetrain transmission Concept

Drivetrain transmission consists of two DC motors equipped with, planetary gears, to drive the vehicle. To control the mobility of the UGV, we use skid steering drive. Skid steering drive allows the UGV to turn and pivot the vehicle's direction.

Flipper transmission consists of a DC motor equipped with, planetary gear. We use a solid shaft to connect the left flipper and the right flipper.

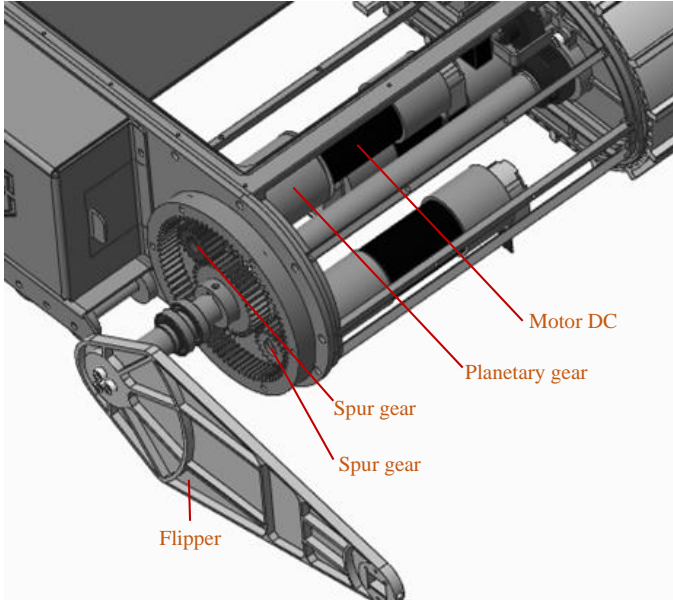


Figure 4 Flipper Transmission Concept

B. Motor and Gearbox Selection

Free body diagram analysis was calculated to determine some parameter according to design requirement. For a selection of drivetrain motors, the most extreme torque case is defined when the vehicle is climbing at an inclination of 45 degrees. For a selection of flipper motors, the most extreme torque case is defined when the flipper start to flip the vehicle. From the analysis, we determine transmission specification as shown on the Table 3 below:

Table 3 Transmission Specification Requirement

Drive Motor	
Nominal Torque	11 Nm
Maximum Torque	20 Nm
Nominal Speed	40 rpm
Flipper Motor	
Nominal Torque	75 Nm
Maximum Torque	147 Nm
Nominal Speed	6.67 rpm

Motors and gearboxes combined to meet the desired transmission specifications. We use MAXON motor RE40 to construct the transmission.

The drivetrain transmission consists of two motors to meet the design, torque and speed requirement. Table 4 shows the motor and gearbox selection for the drive transmission.

Table 4 Motor and Gearbox Selection for Drive Transmission

Motor DC	Planetary Gear Ratio	Internal Gear Ratio	Torque max	Minimum Speed
Maxon RE40	15:1	40:9	21.3 Nm	24 rpm

Similar to the drivetrain, the transmission on the flipper uses 2 stages of transmission. First stage use a planetary gear and second stage use spur gear. Table 5 shows the motor and gearbox selection for the flipper.

Table 5 Motor and Gearbox Selection for Flipper Transmission

Motor DC	Planetary Gear Ratio	Spur Gear Ratio	Torque max	Nominal Speed
Maxon RE40	353:1	2:1	150 Nm	7 rpm

C. Structural Analysis

To ensure the parts we design will not fail under a certain load, a structural analysis is performed. The software we use to perform the analysis is PTC Creo Simulate. Not all parts are analyzed, only the critical parts. There are three critical parts which we analyzed: turn table frame, front shaft, and rear shaft. These three parts we consider critical for they are directly subjected to a considerable amount of load. We consider a safety factor around 1.5.

1) Turn table frame

Figure 5 shows the turn table frame. The material of the frame is aluminum 6061 which yield strength is 278 MPa when the arm is lifting an object, this frame functions as the base for the arm, since the turn table is bolted to this frame.



Figure 5 The Turn Table Frame

There are two kind of loads exerted to the frame. The first is the arm's weight of 30 kg and the second is the moment when the arm is fully extended lifting the weight of 7 kg as shown in Figure 6.

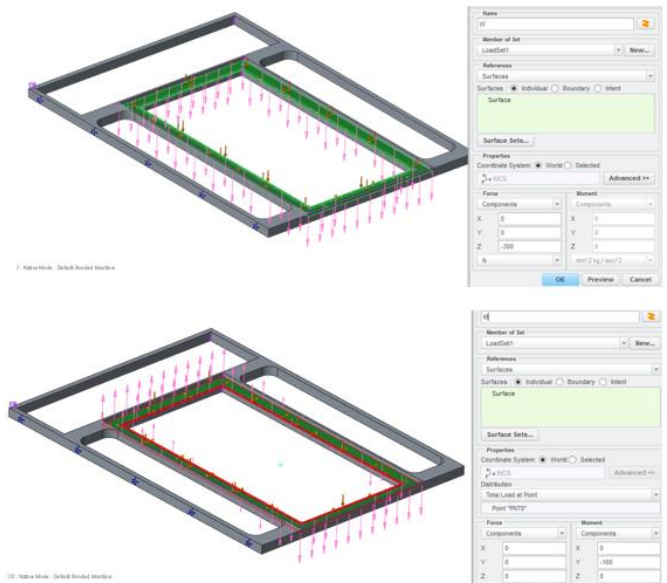


Figure 6 Two kind load exerted to the turn table frame

The frame is bolted along its side to the chassis of the UGV as shown on Figure 7.

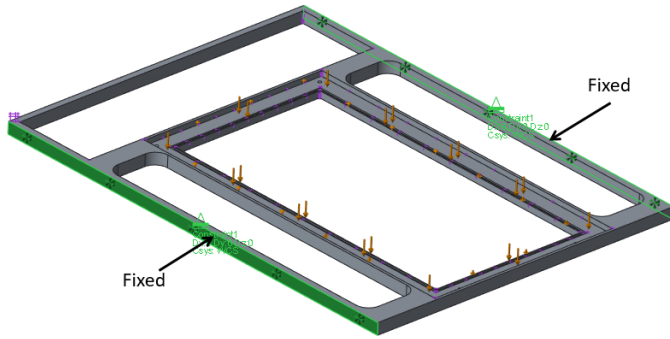


Figure 7 The fixed constraint for turn table frame

The boundary condition has been set using fixed constrain above. The simulation is then performed on the computer. Figure 8 displays the result of the von Mises stress calculation.

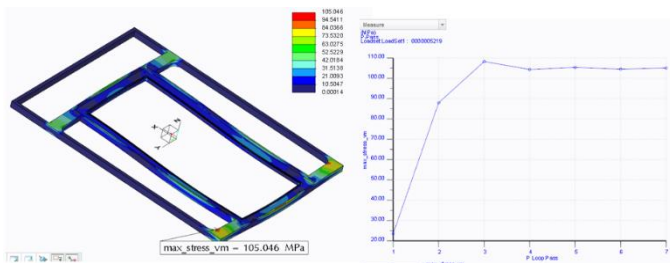


Figure 8 The result of the Von Misses stress

With convergence criterion under 1%, the von Mises stress yields 105.4 MPa. Thus, compared to the yield strength of the material, the safety factor is 2.67, which is safe.

2) Front Shaft

Beside the front wheels, both flippers are attached to the front shaft as well, so this shaft becomes critical when the flippers is used to support the UGV while the arm is lifting an object. All loads which the shaft has to endure are shown in Figure 9.

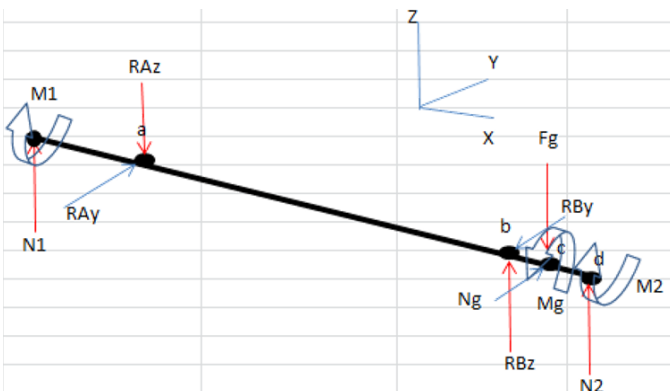


Figure 9 The load exerted to the front shaft

The shaft is supported by two ball bearing at a and b. N1 and N2 are normal force exerted by the flipper and has the value of 225 N each. A spur gear is used to rotate the flipper, it is located at c. So there are gear torsion Mg, gear tangential force Fg and gear normal force Ng, which value are 120 Nm, 4 kN, and 1456 N respectively. Figure 10 illustrates the constraint used for the shaft simulation.

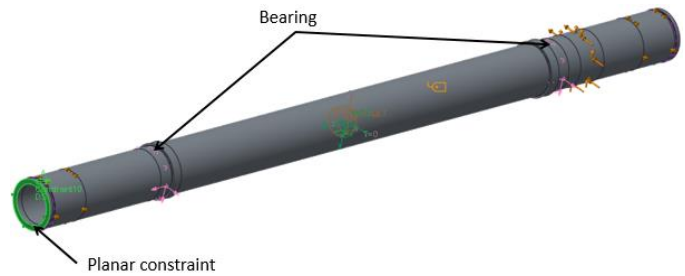


Figure 10 The constraint for front shaft simulation

Since there is no bearing constraint option in the software we used, in this simulation the bearing is modeled as a spring with large radial stiffness and zero torsional stiffness. To prevent the shaft from moving axially, a planar constraint is applied at the end surface of the shaft. The result of the simulation is shown in Figure 11.

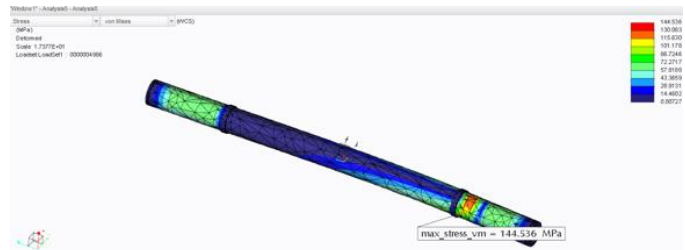


Figure 11 The result of the front shaft simulation

From the simulation, the maximum von Mises stress of 144.5 MPa is obtained. With the 304 stainless steel which has yield strength of 276 MPa is chosen as the material, this means that the safety factor is 1.9, which render the shaft safe.

3) Rear Axle

The last part we deem critical is the rear axle. The authors design the axle as lightweight as possible to minimize the weight of the whole chassis. Figure 12 shows this axle.

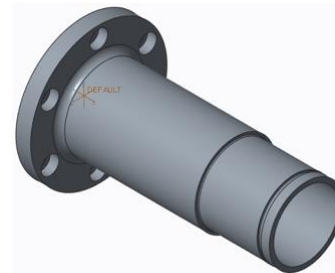


Figure 12 Design of the rear axle

The only part attached to the rear axle is the rear wheel with its corresponding belt. Thus, there are two load subjected to the axle. The first is the tension force of the belt and the second is the normal force from the ground. The value of these two forces are 122 N and 225 N respectively. To complete the boundary condition set, a fixed constraint is applied at a surface at the end of the axle. The load and constraint applied are shown in Figure 13. Figure 14 displays the result.

It turns out the maximum von Mises stress occurred in the axle is really small, around 19 MPa. With aluminum 6061 is used as the material, the safety factor is still quite large.

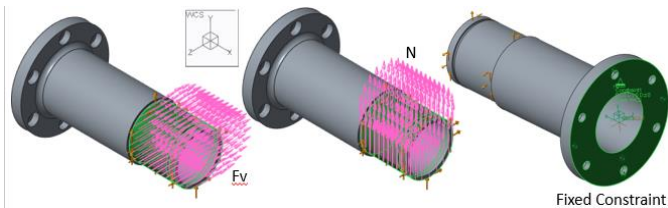


Figure 13 The fixed constraint of rear axle

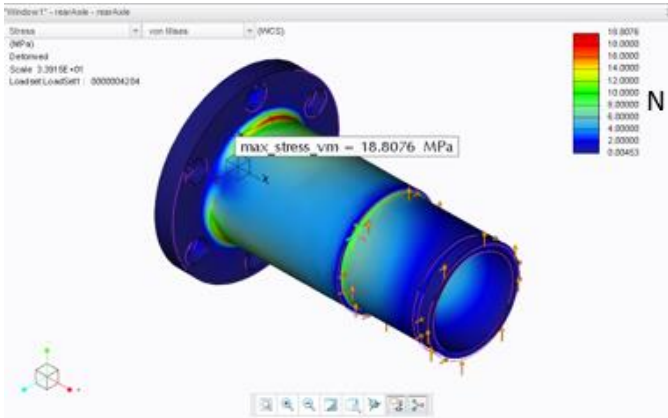


Figure 14 The result of the rear axle simulation

VI. MANUFACTURING AND TESTING

UGV has been manufactured using CNC milling and turning machine. Most part of the body manufactured from Aluminum 7075. We used bolt connection to assembly all part of the UGV.



Figure 15 Manufactured UGV

We have been testing our UGV through uneven terrain, obstacles and ascend-descend stairs and slopes. Testing result is below:

1. UGV can climb to 200 mm high obstacle.
2. UGV can ascend and descend slope up to 45 degree depend on slope surface
3. UGV can ascend and descend stairs up to 40 degree depend on surface
4. Stairs and slope surface affect the ability of the UGV. More slippery the slope and stairs more difficult UGV to ascend or descend.



Figure 16 Testing UGV

VII. CONCLUDING REMARKS

An unmanned ground vehicle (UGV) for field service operation has been designed and manufactured with off the market motor and gearbox selection, theory hand calculations, weight and balance calculations, production design, and finite element analysis. The UGV has been tested on various terrains and obstacles and shows that the UGV managed to move through those trajectories well.

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