CoMoRAT: A Configurable All Terrain Mobile Robot

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Abstract: - With the encouraging support coming from various funding agencies and increasing potential of mobile robot use in our daily lives, research in this field has been on the rise during last two decades. Areas of possible applications being vast, researchers feel the need for robots of different capabilities and size. Despite the wide spectrum of applications developed for mobile robots, mobile platforms available on the market for research purposes have been very few in number, and very limited in their capability for multi-purpose use. However, for many researchers, purchasing a new robot for different applications is not a realistic alternative. The research presented in this paper is driven with the urge of creating a modular mobile platform that is suitable for wide range of applications. Ease of installing new payload and ability to ride on wheels, tracks or both are the major design requirements. The developed robot is referred to as CoMoRAT (Configurable Mobile Robot for All Terrain Applications). The robot's design process and performance tests run on the manufactured platform are introduced in this paper.

Key-Words: - Mobile robot, design, terrain, configuration

1 Introduction

Demand for applications that makes use of mobile robots has significantly increased in the past couple of decades. The demand for consumer robots for various applications being on the rise [1], and the availability of various funds in addition to big stake competitions, both industry and academy have shown great interest in developing robotic hardware and applications. With the ultimate purpose of creating fully autonomous robots that can outsmart humans, wide range of applications have been developed for mobile platforms. Despite the rich spectrum of applications, mobile platforms available for research have been very few in number such as ATRV, Pioneer series robots [2, 5] and Packbot [7]. First of all these robots are not economically feasible, second, they are designed to operate on a specific environment, hence developing diverse applications that require installing additional hardware, and drive system manipulations cannot be done in these robots. Purchasing a new robot for every different application being developed is not feasible both in terms of money and time.

Mobile robot applications are one of the major interests of SPARC research group (http://www.me.metu.edu.tr/groups/sparc). A modular, easy to change, on and off road capable mobile robot has been designed and manufactured. The robot is referred to as CoMoRAT (Configurable Mobile Robot for All Terrain Applications).

Different applications require the mobile robots to operate on different environments. Some are designed to operate indoors, some outdoors. Robots operating outdoors may stay on the road or navigate off-road. For effective traversing diverse terrain, it is important to have a modular robot base which can easily be configured to suit the needs of navigation task at hand. Indoor environments are generally smooth and well structured, whereas outdoors, especially off-road sections are rough and pose challenges for wheeled robots.

Various types of locomotion methods are used for the mobile robots. For instance, Plunstech walking robot, which has been designed for the forest applications, provides automatic leg coordination while the operator selects a travel direction [3]. Six-wheeled mobile robot, Sojourner, was designed for the mission of exploring Mars surface [4]. Both of these robots have excellent rough terrain navigation capability, yet they are neither available to researchers nor versatile for diverse applications. Pioneer mobile robot is one of the mobile robot bases that are commonly used in research [5]. Magellan mobile robot is another platform preferred by researchers. It is designed for indoor operation and commonly used in indoor navigation applications. Being decorated with
various sensors, Magellan is not suitable for outdoor applications [6]. PackBot is a mobile robot platform used for applications of explosive ordnance disposal, search-and-rescue, bomb squad, SWAT teams, and other vital tasks [7]. It is a tough, light weight and quickly configurable platform. It also allows integrating flippers, a camera and a robotic arm on its structure. All the assembling and disassembling stages take only a short period of time. It can be adapted to a different environment and a mission very quickly. However, the price tag of this robot is quite a burden on a limited research budget. MR-5 is a remotely controlled mobile robot base. It is ideally suited for explosive ordnance disposal, SWAT, harmful material search, surveillance and other hazardous environment and material tasks. It has been designed for operating with wheel and/or tracks [8]. It has two motion modes. The first mode is moving with wheels. And another mode is moving with tracks that are placed on the wheels. By this special feature, the robot platform gives opportunity that it can be used for a variety of tasks and operational environments. Another well-known mobile robot platform which is commonly used by U.S. military is Talon. It has been designed for the missions ranging from exploration of the working environments to weapons delivery [9]. Even though integrating some equipment to its base can be done very easily and quickly, its driving system cannot be modified. It uses only tracks for the motion. The moving members cannot be configured with wheels. Besides its legendary success in military applications, Talon is not available for research and it is even more expensive than other platforms.

For academic research, developers often need to add and remove hardware when deploying new applications to a platform. Hence, physically adding new hardware to the robotic platform should be practical. CoMoRAT has been designed with the expectations that traction system can be easily changed (to be wheeled, tracked and wheeled + tracked) to suit a wide range of terrain, and allow additional hardware to be installed with minimal manufacturing and effort. In terms of size, it is aimed to create a robot that can be backpacked by a human if needed. In the remaining of the paper, the design procedure of CoMoRAT is presented followed by the simulations and experiments in order to evaluate the performance of the robot.

## 2 Design Procedure

This section describes the design and manufacture of CoMoRAT for traversing various terrains to accomplish missions successfully. A robot used for tasks in various terrains has different strict configurability requirements which have certain implications on how the robot body and the parts are designed. In order to meet the configurability requirements, the mobile robot platform has been designed for having three different configurations; wheeled, tracked and wheeled + tracked. This has been done by fastening wheels and pallets on a single robot. In this way, robot base gives opportunity that smooth surfaces can be traversed via wheels whereas pallets provide extra support when the surface becomes uneven. The nature of the design allows the user to choose the desired configuration which can be installed in a few minutes.

![Motion model of the mobile robot platform](image)

In order to design CoMoRAT's actuation system, the model given in Figure 1 has been constructed. Note that the model has been developed for an ideal flat surface condition in order to have an idea about the motion. In the mathematical model the forces coming from ground has been taken into account. The applied wheels' traction forces, which are needed to give the motion to the robot base, have been modeled as given Equations (1-3). The abbreviations used in Figure 1 and 5 are specified as: m denotes the mass of the platform. g denotes the gravitational acceleration. \( h_{\text{mg}} \) denotes height of the center of mass. \( F_{\text{Nr}} \) and \( F_{\text{Nf}} \) denote the normal forces acting on rear and front wheel, respectively. \( F_{\text{Tr}} \) and \( F_{\text{ Tf}} \) denote the total tractive effort for rear and front wheel, respectively. \( \gamma_l \) and \( \gamma_f \) equal 1 for the four wheel drive. \( \theta \) is the slope angle of the terrain. The details of the model are given in [11].

\[
\sum F_x = \mu_w \gamma_f F_{\text{Nr}} + \mu_w \gamma_f F_{\text{Nf}} - mg \sin \theta \\
\sum F_y = F_{\text{Nr}} + F_{\text{Nf}} - mg \cos \theta
\]
\[
\sum M = F_N L_w - mg(L_{cg} \cos \theta + h \sin \theta)
\] (3)

Figure 2 shows the 3D CAD model of three different configurations. The mathematical model of the mobile robot platform has been simulated in Matlab. In the design process, SolidWorks has been used. The dimensions of the parts have been optimized using the CosmosWorks finite element analysis (FEA) software. In the strength analysis of the components, it is aimed that the profiles of the frames should be reliable under the load that may come from a weight of a man having 70 kg. Frame of the mobile robot has been manufactured from 6061 series of Aluminum profiles. Two sliding slots have been manufactured inside the profile. As shown in Figure 3, the beams, which are fastened to the sliding slots, can be easily moved. By this way, internal space of the platform can be rearranged and used effectively whenever it is required. Linear sliding slots are designed at the outside of the base profile. In order to connect the motor mounting to the frame and to adjust the tightness of the pallets these slots can be used. Moreover, using these slots, the driving type can be rapidly configured within a few minutes.

The physical parameters of the mobile robot given in Figure 1 and 5 are \(D_{rw} = D_{fw} = 200\) mm, \(L_w = 347\) mm, \(L_{cg} = 173.5\) mm, \(h = h_{mg} = 100\) mm, \(\mu_w = 0.5\), \(\gamma_r = \gamma_f = 1\). DC motors which drive the mobile platform have an operating voltage range of 12 to 24V, maximum speed of 72 rpm (0.35 A) at no load and speed of 36 rpm with 54.6 kg.cm torque at maximum efficiency. The motors give 40 Watt output power at maximum efficiency. They draw 6 A current and produces 240 kg.cm torques at stall. The details of the model and the design parameters are given in [11].

As mentioned in this section, the mobile robot platform has been designed for flat, rough and uneven terrain applications. Three driving systems have been merged into one platform. By this way mobile robot can be used for different applications with proper configuration.

3 Experiments Conducted with CoMoRAT

CoMoRAT gives the opportunity for various applications performed in both indoor and outdoor environments. In order to show the usability of the platform, some experiments have been conducted and the results are presented in this section. These experiments are slope climbing, obstacle crossing over and power consumption. Moreover, tip over angles for the up and side motions have been obtained during the slope experiments. All the experiment outcomes have been compared with the simulation results.
3.1 Slope Climbing
Mobile platform with its three configurations has been tested in the mixed terrain that is composed of small size gravel and worn concrete. The surface on which experiments have been conducted has also incline. Experiment and simulation results have been figured out in Table 1 in order to make a comparison. Tipping over angles (up and side motion) of the configurations has been also obtained during those experiments. Wheeled configuration has been failed for climbing more than 19° of slope angle. The mobile platform with wheeled + tracked configuration has climbed through 28° of slope angle. This result gives a nearby result that has been obtained by the only tracked version. Hence a brief conclusion can be made for this experiment that wheeled configuration can be more powerful if it is combined with tracks. Wheeled + tracked version of the mobile platform has designated an advantage that it is more successful in climbing a slope than wheeled one. As a result of this test it can be concluded that tracked or tracked + wheeled mobile robots can be surely used in an environment having the features of mixed terrain and slope, rather than using wheeled robot.

Table 1. Experiments performed and simulation results for observing capability of slope climbing (T denotes tracked and W denotes wheeled mobile platform)

<table>
<thead>
<tr>
<th></th>
<th>Exp.</th>
<th>Sim.</th>
<th>Tip Over Angle (Up)</th>
<th>Tip Over Angle (Side)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>31°</td>
<td>34°</td>
<td>60°</td>
<td>70°</td>
</tr>
<tr>
<td>W</td>
<td>19°</td>
<td>20°</td>
<td>60°</td>
<td>70°</td>
</tr>
<tr>
<td>T+W</td>
<td>28°</td>
<td>31°</td>
<td>62°</td>
<td>72°</td>
</tr>
</tbody>
</table>

Mobile platform with its three configurations has been tested for velocity analysis. In order to show the performance of the configurations, no load speed of the mobile platform has been set to 1 m/s. Then, they have been tested on an indoor flat surface and on an outdoor surface composed of small size gravel and worn concrete. Configurations have been tested for a short path. While the mobile platform is traversing the path, the average velocity is obtained. The experimental results given in Table 2 show that the velocity of the tracked version of the mobile platform can be increased by adding wheels.

Table 2. Velocity of different mobile platform configurations

<table>
<thead>
<tr>
<th></th>
<th>Wheeled</th>
<th>Tracked</th>
<th>Tracked + Wheeled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indoor</td>
<td>0.8 m/s</td>
<td>0.6 m/s</td>
<td>0.7 m/s</td>
</tr>
<tr>
<td>Outdoor</td>
<td>0.7 m/s</td>
<td>0.5 m/s</td>
<td>0.6 m/s</td>
</tr>
</tbody>
</table>

3.2 Crossing Over an Obstacle
In order to analyze obstacle crossing over capabilities of CoMoRAT, a mathematical model is derived and a scenario is considered. In this scenario, robot makes an effort to cross over an obstacle that is placed just in front of it (Figure 5).

Normal forces and total tractive efforts required for crossing over an obstacle obtained from the contact points between wheel(s) and obstacle are specified in Figure 5. \( D_r \) and \( D_f \) denote the rear and front wheel diameter, respectively. \( \mu \) denotes the coefficient of friction between the wheel/track and obstacle. \( h \) denotes the height of center of mass about plane. \( h_{step} \) denotes the height of the obstacle. \( \Gamma_{rw} \) and \( \Gamma_{fw} \) indicate the required torques for rear and front wheel, respectively. \( \beta \) indicates the contact angle between the wheel/track and the obstacle. Normal and tractive forces are obtained for one wheel and two wheel blocked with an obstacle. Normal forces for the rear and front wheels in case of two wheel contact are given in Equation (4-5). The details of the mathematical model can be found in [11]. Note that the shape of the obstacles used in these experiments is rectangular.
\[
F_{N\theta} = \frac{2mg(L_{cg} + R \sin \beta)}{L_w + (D_{fw} / 2) \sin \beta} (4)
\]

\[
F_{N\theta} = \frac{2mgL_w - L_{cg}}{(L_w + (D_{fw} / 2) \sin \beta)(\cos \beta + \mu \gamma \sin \beta)} (5)
\]

CoMoRAT's different configurations have been tested with various obstacles having different heights. The experiment results are given in Table 3 (+ and - signs indicate successful and unsuccessful results about crossing over an obstacle respectively). Note that radiuses of the wheels and pulley wheels of the robot platform are 10 cm and 9 cm, respectively. Tracked configuration of the robot platform has been successful for the five different obstacles that heights are ranging from 6.4 cm to 13 cm. Tracked + wheeled configuration has managed to cross over all the obstacles except the last one having 13 cm height. Tracked and tracked + wheeled configurations of the platform give acceptable results. However, wheeled configuration is successful for only two obstacles having heights of 6.4 cm and 8 cm. From these experiments, tracked and tracked + wheeled versions have shown their dominancy about crossing over an obstacle.

**Table 3. Experiment results for crossing over obstacles**

<table>
<thead>
<tr>
<th>Height of Obstacle</th>
<th>6.4 cm</th>
<th>8 cm</th>
<th>9 cm</th>
<th>11 cm</th>
<th>13 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracked</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Wheeled</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tracked +</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Wheeled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the obstacle crossing over experiments, CoMoRAT has been tested with the obstacles in two cases. In the first case, one wheel of the platform has blocked with the obstacle. In the second case two wheels have blocked with the obstacle. Experiment and simulation results are given in Table 4.

### 3.3 Power Consumption

Three different configurations of CoMoRAT have been tested in indoor and outdoor environments for measuring the current drawn for a certain traversed distance. During tests the voltage of the motors is set to 24V and three different configurations have been tested for 10 m long straight path. The indoor test area is smooth flat surface. On the other hand, surface of the outdoor test area is composed of small size gravel and worn concrete. The results are listed in Table 5.

**Table 4. Experimental and simulation results for crossing over obstacle**

<table>
<thead>
<tr>
<th></th>
<th>One Wheel Contact</th>
<th>Two Wheel Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analytical Results</td>
<td>Exp. Results</td>
</tr>
<tr>
<td>T</td>
<td>9 cm</td>
<td>8 cm</td>
</tr>
<tr>
<td>W</td>
<td>18 cm</td>
<td>13 cm</td>
</tr>
<tr>
<td>T+ W</td>
<td>14 cm</td>
<td>11 cm</td>
</tr>
</tbody>
</table>

**Table 5. Power consumption experiments**

<table>
<thead>
<tr>
<th></th>
<th>Current drawn during motion (A)</th>
<th>Time traveled (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracked</td>
<td>Indoor 1.1-1.3</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>Outdoor 1.4-2.2</td>
<td>20</td>
</tr>
<tr>
<td>Wheeled</td>
<td>Indoor 0.9-1.1</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>Outdoor 1.1-1.5</td>
<td>14.5</td>
</tr>
<tr>
<td>Tracked +</td>
<td>Indoor 1.3-1.4</td>
<td>14.7</td>
</tr>
<tr>
<td>Wheeled</td>
<td>Outdoor 1.5-2.5</td>
<td>17</td>
</tr>
</tbody>
</table>

Power consumptions of three configurations can be evaluated using Table 5. Results indicate that wheeled configuration draws the lowest current and it has the highest speed.

### 4 Conclusion

While developing diverse applications for mobile robots, a researcher inevitably feels the need for a configurable robot that can efficiently operate both
indoors and outdoors, onto which various hardware can easily be installed and removed. CoMoRAT is developed with this perspective, to be a small size mobile robot suitable for academic research running on a limited budget. The traction system can be configured to use wheels, tracks or both. Body of the robot provides a closure for batteries, motor drivers and main computer. Additional hardware can easily be installed both inside and outside of the robot. Main frame is constructed from Aluminum profile which has groves to facilitate addition of hardware easily. Field tests conducted on the robot are in agreement with the simulations run prior to manufacturing the robot. As a result, a configurable robot platform is designed, manufactured and tested and CoMoRAT proved to meet the expectations as a versatile mobile robot platform to be used in academic research.

References: