Design and fabrication of multi utility unmanned robot

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Abstract. Humans have dreamed of mechanical devices to ease their chores and assist them in performing repetitive tasks for thousands of years. This project can be identified as a key tool for reducing the vulnerability of human lives when we deal with emergencies. The human presence is very much important in dealing with all emergencies. Even if it is a fire accident, disinfection activities or surveillance in places where the accessibility is very much limited. Each case the first responders’ lives are at risk. Their direct contact in the impact zones can put them in danger. This is where unmanned robots can be utilized. In this paper a multi utility unmanned robot equipped with a long range control system, nozzle system, camera for surveillance, and an all-terrain track to conquer different working environments was designed and fabricated. Thus the threat for first responder’s and health workers can be reduced.

1. Introduction
The human presence is very much important in dealing with all emergencies. Even if it is a fire accident, disinfection activities or surveillance in places where the accessibility is very much limited. The risk for first responders is very high during these incidents. Many of these accidents occur at hazardous and risky areas where humans cannot even engage directly for rescue operations. This causes huge damage to both human life and property. Due to the increased number of high raised buildings, accessing the situation in a fire outbreak or any other incident is critical. Currently, there are a lot of limitations faced by humans who are engaged in such situations due to their direct exposure to the fire. MUUR (Multi Utility Unmanned Robot) focuses on limiting these potentially life-threatening situations that can occur to a first responder unpredictably. Hence MUUR avoids the direct involvement of a human in dealing with these situations. Complete automation in this field can be really expensive, complicated and human decisions taken during these situations are of equal importance in saving lives. So we suggest a semi-autonomous MUUR to engage the situation so that human intervention can also be made possible.

2. Design of chassis and all terrain mechanism
MUUR is identified to be the priority for infrastructure support for any surveillance warning systems prevention and rescue in view of a pandemic situation as well as disasters like flood, fire incidents and other natural and unnatural calamities. Considering a pandemic situation, one of the topmost problems affecting is the process of cleaning and disinfecting the public places that could increase the risk of
getting affected by the exposed sites. MUUR with a long range control system will help humans to
tackle this situation from a safe distance into a wide area. Similarly in any other situation, human
safety will not be compromised. Figure.1 depicts the initial design of MUUR.

![Figure 1](image1.png)

Figure 1. (a) isometric view; (b) side view.

2.1. MUUR frame

The MUUR frame is the most fundamental part of the MUUR. A rectangular frame is the most
commonly used frame due to its simple structure. An inclination of 45 degrees is also provided in the
front of the frame for an advantage in terrain interactions. A pair of motors on each side opposite to
each other turn in the same directions. This configuration is selected based on the symmetry of the
frame. The frame is designed in Autodesk Fusion 360. The frame size depends on the total mass
including the payload that the MUUR has to carry. As the frame size increases, the inertia also
increases [1]. For the ease of manufacture and material availability mild steel was selected as frame
members. They also provide good material property. The payload will be the medical
supplies or goods that have to be transported across an affected region. In total, 200kg of kerb weight is calculated
for the MUUR.

![Figure 2](image2.png)

Figure 2. (a) Isometric view of the frame; (b) side view of the frame.

2.1.1. Analysis of frame members. MUUR frame has a hollow square pipe of the dimension 1 inch and
1.6mm thickness. Base member of the frame shown in figure 2, takes the maximum load in the
chassis. So the maximum load that the chassis can bear has to be determined [2]. Considering the for
fixed hollow beam, the total load capacity can be estimated using the equation (1):

\[ M = \frac{\sigma}{\text{per}} \frac{I}{y} \]

(1)

The term \( M \) denotes the bending moment, \( \sigma_{\text{per}} \) is the maximum permissible stress for the material
selected, \( I \) denote the area moment of inertia of the hollow beam and \( Y \) is the distance from the centre
of the hollow pipe to the outer edge. The values for \( I \) can be calculated by equation (2).

\[ I = \frac{BD^3}{12} - \frac{bd^3}{12} \]
Terms $B$ and $b$ gives the external and internal breadth of the section of the pipe and $D$ and $d$ gives the section height of the pipe. The maximum weight that can be loaded on the pipe for the length 360mm is calculated to be 238.32kg. Static stress analysis on the frame is shown in figure 3.

![Figure 3. (a) Stress analysis on chassis; (b) Deflection due to static load](image)

2.1.2. Analysis on the shaft of the road wheels. The strength of the shaft connecting the road wheels is a very important factor. The connecting rod arm for the rollers that are attached to the chassis is connected via a bearing to obtain a swing action for the suspension system. So the entire possible weight of the robot will be acting on the shaft connecting the rollers [3]. The minimum thickness of the required shaft can be calculated by equation (3):

$$M = \sigma_{per} Z$$  \hspace{1cm} (3)

The term $M$ denotes the bending moment of the shaft and $\sigma_{per}$ is the permissible stress for the selected material for the shaft. The section modulus $Z$ can be calculated for a solid cylindrical shaft by the equation (4) in which $r$ is the radius of the cylinder.

$$Z = \frac{\pi r^4}{4}$$  \hspace{1cm} (4)

2.2. Selection of chain and sprocket for drive. The MUUR uses two brushless dc motors for drive. Each motor is coupled to a chain drive system which will drive the all-terrain tracks. So calculating the required number of the chain links is essential to set the number of sprocket teeth required at each end. Considering a gear reduction ratio of 1:2 the sprocket that drives the tracks will have twice the number of teeth in comparison to the sprocket coupled with the motor. Setting the minimum distance between the sprockets is also important in deciding the chain length, pitch and the no. of chain links to avoid slippage [4].

The pitch of the chain link required can be calculated from the equation (5):

$$P \leq \left(\frac{66.67}{n_1}\right)^{\frac{2}{3}}$$  \hspace{1cm} (5)

Term $n_1$ is the rotations per second at the motor end. This value is obtained when the rpm of the drive motor is calculated. Using the above equation the pitch selected for chain drive is 12.70mm. Now selecting the sprockets for the chain can be done using the equation (6):

$$D = P \left(\sin \left(\frac{180}{Z}\right)\right)^{-1}$$  \hspace{1cm} (6)

The term $D$ is the pitch diameter of the sprocket, $P$ is the pitch of the chain and $Z$ is the number of teeth on the sprocket. Considering the running life of chain and sprocket, it is advised to have an even number of chain links if the number of sprocket teeth is odd or vice versa. For a drive without any slippage, the centre to centre distance of the sprockets has to be precise [5]. The total number of chain links required for a 150mm centre to centre distance of sprockets can be calculated by equation (7):
\( a \) is the assumed centre to centre distance and \( P \) is the pitch of the chain. The total number of chain links required is calculated to be 48. Now the centre to centre distance has to be corrected to avoid slip during the drive. This correction can be done using equation (8):

\[
L_n = \frac{a}{P} + \left( \frac{Z_1 + Z_2}{2} \right) + \left( \frac{Z_2 - Z_1}{2\pi} \right) \times \left( \frac{P}{a} \right) \tag{7}
\]

By following the equation (9) the centre to centre distance was corrected to 155.3mm. Chain and sprocket based on calculations sketched and shown in figure 4. For the required load that has to be driven with his chain, a single chain is only required based on the studies from different catalogues of different brands.

\[
F_r = \frac{1}{4} \left( \frac{Z_1 + Z_2}{2} \right) + \left( \frac{Z_2 - Z_1}{2\pi} \right) \times \left( \frac{P}{a} \right) \tag{8}
\]

By following the equation (9) the centre to centre distance was corrected to 155.3mm. Chain and sprocket based on calculations sketched and shown in figure 4. For the required load that has to be driven with his chain, a single chain is only required based on the studies from different catalogues of different brands.

2.3. Selection of bearings

MUUR is designed with 4 road wheels on each side to ensure an even distribution of pressure to the ground and also to help with tackling rough terrains by improving traction. Thus the load bearing capacity for the bearings is very important. A compromise in the working of rollers affects the terrain interactions of MUUR. In the above section (2.1.2), the diameter of the shaft for rollers was calculated to be 20mm. The centre bore diameter of the required bearing will remain the same. Both static load and Dynamic loads have to be considered for the selection.

On static conditions, the load will be resting on the road wheel so in the long term this could damage the hull of the bearing if this load is not considered. The dynamic load will be maximum when the MUUR will be taking a tight corner turn. The entire load of the MUUR will get transferred to the outer road wheels of the turn. This situation could trouble the bearing if it is not selected accordingly. Radial loaders are the loads that act on the bearing under static condition. This load can be easily calculated by considering the weight distribution of MUUR. Here it is considered a situation where the entire weight of the MUUR will be acting on a single road wheel for static load. For dynamic load, the centripetal force acting on a road wheel is also considered during a tight turn. The equivalent dynamic load on the bearings can be calculated by the equation (9):

\[
P_e = XF_r + YF_a \tag{9}
\]

\( P_e \) is the equivalent dynamic load, \( F_r \) and \( F_a \) are the radial and axial forces on the bearing and \( X \) and \( Y \) are the radial and thrust factors. By doing trial and error method for finding values of \( X \) and \( Y \) from the design catalogues of bearing the calculated value for \( P_e \) is 5317.47N. So the dynamic load capacity can be calculated from the equation (10):

\[
C = P_e \left( \frac{L}{n} \right)^{\frac{1}{2}} \tag{10}
\]

\[
C = P_e \left( \frac{L}{n} \right)^{\frac{1}{2}} \tag{10}
\]
In the above equation $L_{10}$ is the life of the selected bearing from the catalogue. For the design, it is decided to have the outer race of the bearing in rotation. Hence a race rotation factor 1.2 has to be included in the equation (10) for the radial force. From the above equations, the calculated dynamic load capacity of the bearing is 13829.96N.

2.4. Selection of spring for suspension

For the riding comfort through different terrain, MUUR requires a quality suspension that should not get compromised during the operation. The suspension cannot be very stiff nor very soft. Making a stiff suspension will make MUUR have sudden jerks when interacting with a sudden obstacle which could lose control of the system. Similarly, a very soft suspension system is also not adequate because of the load that has to be carried and the minimum ground clearance has to be maintained [6]. While designing the spring suspension system of MUUR, the width of the system was a major constraint. Since MUUR has to be driven through narrow paths the width has to be set minimum. This will help to steer in such narrow paths. So the length of the spring suspension was increased to reduce the width.

The load acting on the springs shall be considered as a fluctuating in nature. Therefore oil-hardened and tempered steel wire of SW grade is selected for this application. The spring index is assumed as $(C) \ 6$. The wohl factor $K$ can be calculated from the equation (11):

$$K = \frac{4C - 1}{4C - 4} + \frac{4.615}{C}$$ (11)

The induced shear stress that will be acting on the spring upon fluctuated loading can be calculated from the equation (12):

$$\tau = K \left( \frac{8P \cdot C}{\pi d^3} \right)$$ (12)

The term $P_1$ is the maximum load that can be acted upon the spring and $d$ is the wire diameter of the spring. The wire diameter is calculated by trial and error method by taking into account the maximum permissible shear stress ($\tau_d$) that can be acted on in the spring. Induced shear has to remain lesser than the permissible shear stress ($\tau < \tau_d$).

The permissible shear stress can be calculated from the equation (13):

$$\tau_d = 0.3 S_{ul}$$ (13)

$S_{ul}$ is the ultimate tensile strength of the material selected for spring. Hence after doing many iterations, the calculated value for wire diameter ($d$) is 6mm. The total deflection ($\delta$) of the spring upon static condition and the maximum compression is fixed as 40mm. The spring constant can be calculated for the fluctuating load with the equation (14):

$$k = \frac{P_{max} - P_{min}}{\delta}$$ (14)

Once the spring constant is calculated, then the number of coils required for the spring to function with the above mentioned constraints can be calculated by the equation (15):

$$N = \frac{GD^3}{8 \delta d L}$$ (15)

The term $G$ denotes the modulus of rigidity, $D$ is the outer diameter of the coil. For a spring with square and grounded ends, an additional 2 coils have to be added to the above calculated value. Hence the number of coils required is calculated and now total deflection under the full load condition can be calculated with the equation (16):

$$\delta_1 = \frac{8P_{max}D^3N}{GD^4}$$ (16)
The solid length of the spring can be calculated by taking simply the product of the number of coils and the wire diameter. Fixing a gap of 0.5mm between each coil the total free length of the coil spring for the above calculated constraints can be calculated [7] by the equation (17). Figure 5, figure 6 and figure 7, shows the designed shock absorber system for the MUUR.

\[
\text{Total free length} = \text{Solid length} + \text{Total deflection} + \text{Total axial gap} \quad (17)
\]

3. Analysis of MUUR power demand

Power requirement for the tracked robot is calculated by fixing primary constraints like the total load that has to be carried along the ride, maximum inclination that the robot should interact, acceleration and maximum velocity that it should travel with.

3.1. Power demand under general condition. The robot is driven by two brushless dc motors, the power requirement \( p \) in general can be calculated [8] by the following equation (18):

\[
p = \left( m g f \cos(\alpha) + m g \sin(\alpha) + \frac{C_d A}{21.15} u^2 + \delta n \frac{dH}{3.6dr} \right) \frac{\mu}{3600 \eta_T}
\]  

In equation (18), \( m \) denotes mass, \( f \) is the coefficient resistance of rolling resistance, \( g \) is the acceleration due to gravity, \( \alpha \) is road gradient, \( C_d \) is the coefficient of air resistance, \( A \) is the frontal area for the robot, \( u \) is the maximum velocity, \( \delta \) is the rotating mass conversion factor, \( \eta_T \) is the mechanical transmission efficiency. Since the robot is targeted to achieve a very low maximum speed the term considering the air resistance can be removed [9].

3.2. Power demand under a climbing condition. The power requirement will keep varying according to the slopes. The maximum slope that the robot is designed to climb is 30\(^\circ\). With this constraint the power requirement to climb the slope with the max velocity can be calculated by the equation (19):

\[
p = \left( m g f \cos(\alpha) + m g \sin(\alpha) + \delta n \frac{du}{3.6dr} \right) \frac{\mu}{3600 \eta_T}
\]  

3.3. Power demand for maximum velocity. When the robot is travelling on a normal flat surface the power requirement is less as compared to when the robot is climbing a slope. This power can be calculated by altering the general equation.

Eliminating the slope factors, the general equation can be rewritten as (20):
3.4. Calculating torque requirement. The maximum requirement of torque will occur when the robot is climbing a slope. MUUR is designed to travel a slope of 30°. So the torque required at the wheels plays an important part. This torque can be calculated by equation (21):

\[ T = \frac{F \cdot r}{i \cdot i_0 \cdot \eta_i} \]  

(21)

In equation (21), \( r \) is the radius of the drive wheel, \( i_g \) and \( i_0 \) are the transmission gear ratios of the powertrain. Two to three rechargeable batteries can be selected with respect to the total running time requirement of the robot. Rechargeable batteries will help the operators to quickly change them when the charge appears to be low. This will help them to overcome any delay caused due to charging in the midst of any operations. Motor driver can is an essential component in the powertrain. This will help the operator to control the robot more handy. The drivers can be installed with respect to the operator’s requirement that decides the total speed, torque and wireless control of the robot helps to face the challenges.

4. Cad drawing of MUUR

![Figure 7. CAD model of MUUR](image-url)
Figure 8. Rendered design of MUUR. (a) Isometric view from front; (b) Isometric view from rear.

Figure 7 shows the CAD model of MUUR and figure 8 shows the rendered design of MUUR. Thus design and fabrication of multi utility unmanned robot was completed.

5. Conclusion
Emergencies are always unpredicted and unexpected. Several casualties arise during one. The lives of the first responders and victims are equally important. MUUR with the suggested design the risk taken by the first responders can be minimized during such situations [10]. MUUR doesn’t compromise the presence of humans for such an operation. Wireless control will enable the rescuers to visually inspect, analyze and act according to the situation strategically. Considering the case of fire or sanitizing an area, human intervention can be minimized, and hence the risk taken by the rescuers is eliminated to a certain limit. The All-terrain track of the MUUR helps to travel through a wide range of soft and rough terrains under different conditions. Incorporating a firefighting nozzle will help the firefighting application of MUUR convenient as the total liquid carrying capacity mentioned is limited. Such an update will help the MUUR.

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