# Urban Search and Rescue Proposal: Buddy

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## I. Introduction

Carnegie Urban Rescue Force (CURF) has commissioned our group to develop a response vehicle for the purpose of locating victims trapped inside a collapsed building to facilitate rescue. In response to this commission, we have developed a proposal for a specialized urban search and rescue robot which can complete these objectives.

Our design proposal begins with our objectives for this robot, including the metrics we use to evaluate our robot. We present our design for the Urban Search and Rescue (USAR) robot, including a detailed sketch, a budget, and a benefit analysis which evaluates our design based on several metrics.

## II. Objectives

Our robot is designed to be evaluated according to several metrics: ground clearance, weight distribution, top speed, traction, and torque. We chose these metrics because of their importance in USAR.

Many obstacles will block the robot's path in a collapsed building. The robot must be able to navigate over or around this debris. Traction is an important factor in a robot's ability to overcome these obstacles. Higher traction will allow a robot to navigate over obstacles without slipping. This will be useful in situations with loose debris (like gravel). Without traction on such a surface, the robot could be left immobile or slide forward and possibly injure itself or worse, a victim.

These victims may be trapped anywhere in a collapsed building, including the upper levels. Because of this, the robot must be able to climb inclines like stairs or collapsed walls. A USAR robot must have sufficient torque to move the robot's weight up these obstacles. Higher torque will allow a robot to climb steeper inclines more effectively. Thus, a robot with a higher torque may be able to explore areas difficult to reach by a robot with less torque. Moreover, higher torque allows the robot to travel at lower speeds to aid in navigating tight spaces.

Ground clearance is also required for navigating over obstacles and debris. If the robot is too close the ground, it might hit an obstacle and become disabled or damaged. Weight distribution is also important in obstacle traversal. A skewed weight distribution will make a robot likely to fall over when tilting and traveling over an object.  If the robot has a symmetric weight distribution, one wheel being tilted at an odd angle will have less of an effect on the robot's balance.

It is important to reach victims trapped in a building within the first 48 hours of the collapse.  The speed with which a rescue robot moves will help determine how quickly the robot can reach the victims.  The faster this speed is, the more likely victims will be located and extracted alive.  A robot with a high top speed will be able to move through a collapsed building quickly.  This means that more time (battery life, daylight working hours, operator fatigue, etc.) can be spent searching for survivors, instead of wasted traveling to and from the search area.

## III. Design Alternatives

During our initial design phase for this project, we developed several alternate designs for both the chassis and the camera mount of our proposed USAR robot.  We have included descriptions and drawings of these alternative layouts, along with a brief discussion of why we rejected the design.

a) Base Design 1 - Our first design considered is a two-wheeled robot with a caster (see Figure 1).  Each back wheel is powered by a motor which combine to slide the robot forward on the caster.  This design was considered because it is a design we have great familiarity with, and is a good starting point for working out the differences the environment would cause on the design.  We initially thought we might be able to adapt this design to the USAR proposal. However, this design was eliminated because the castor easily gets stuck on obstacles or in soft ground.  In addition, since the robot is asymmetrical, it has difficultly climbing stairs or obstacles. The robot would be very prone to flipping over, especially with most of the weight in the front of the robot.

b) Base Design 2 – Our second design considered is a three-wheeled robot with only the front wheel driven by a motor (see Figure 2).  We designed this when trying to minimize the size and weight of the robot.  We thought that a three-wheeled robot might be smaller than a four-wheeled.  In addition, reducing the design to a single motor reduces the overall power requirements, and complexity of the design further reducing the size.  However, with only the front wheel being powered, the robot will have insufficient traction to travel loose or slippery surfaces. In addition, this robot has low reliability. If the front wheel is disabled or lodges in a depression, the robot will be unable to continue. Similar to Design 1, the weight distribution would be difficult on this robot, which might make prone to flipping upside down on inclines or traversing over obstacles.

c) Base Design 3 – Another design is a four wheeled robot with a tension belt wrapped around the wheels used as tank treads (see Figure 3).  This design was intended to allow the robot to travel over diverse terrains that may be difficult for a robot with wheels – such as gravel or a rocky debris field. The higher friction provided by the larger contact areas of the treads would also give more heft to the robot's drive train with a lower overall weight of the robot. However, this robot would require making tank treads using non-standard parts. Nonstandard parts could make this robot less reliable because of the possibility of problems with the interface between the robot and the treads. A common problem with tank tread style designs is getting debris caught in the tread/wheel interface, causing potentially disabling problems. Additionally, using tank treads would create heavy friction during turns. During these turns, the robot must slip and thus requires additional torque to compensate for the extra friction during these slips. This would make the robot difficult to control accurately during turns and would increase the robot's overall power consumption.

d) Camera Mount 1 – We designed a camera mount for a four wheeled robot which is attached to the front of the chassis (see Figure 4). The camera could pan using a motor and tilt using a servo. The advantage to this design is that the operator would have precise control of where the camera is pointing, and the servo could be used to have an auto-return to center when the robot is ready to move. However, we decided to use 5" wheels on our robot chassis for other design considerations. Thus, if the camera was mounted on the chassis in the front, the wheels would impede the cameras view on the left and the right.

e) Camera Mount 2 – Another design considered was a four bar linkage mechanism which would allow the camera to raise and lower – instead of tilting the camera (see Figure 5). This mount would be attached the front of the chassis as in Camera Mount 1, but the four bar linkage would be high enough so the camera view is over the wheels. The system would also have a motor for rotating the entire mechanism to pan the camera. This design would be useful for viewing the environment at different heights. However, four bar linkages are very complex and may fail more often than a simple design. Also, the four bar linkage would protrude from the body of the robot when rotating and affect our size constraints. The mechanism may get caught in protrusions from a collapsed building and disable the robot.

f) Camera Mount 3 – A final design considered was a mount powered by two servos; one for pan and one for tilt (see Figure 6). As with other servo designs, it would be very easy to have the servo return to center upon release of the operator's control, ensuring the camera was always pointing the direction of motion. In addition, if we included a gyro option, it would be possible to have the camera track a direction despite contrary movement of the mobile base. However, this would limit the camera to pan of only 180 degrees. We thought to position a rearview mirror on the front of the chassis with which the camera could view to see behind it. This design was considered because it would ameliorate the problem of the 180 degree rotation of the servos, without adding more technological complexity. In addition, a possible split view (half forward, half rearward) could be possible. However, if the camera is pointing at two wheels, the camera could either be oriented to the left or the right of the robot with few visible clues as to which is which. Also, because of the dim lighting on the camera, and the common problem of insufficient light in a rescue situation, it would be difficult to see anything of interest toward the rear of the robot.

## IV. Proposed Design

We propose a robot, **Buddy**, to explore a collapsed building and locate victims inside the building.

### Description

After much discussion and evolution of the design features we wished to incorporate, we propose Buddy as a four wheeled robot driven by remote control, with a centrally mounted camera that is able to pan and tilt. The wheels are 5" in diameter and have knobby protrusions for traction. Each wheel is driven independently by a motor, giving the robot 4-wheel drive. Buddy's approximate top speed is 30 ft/min. Buddy also has a camera mounted on the center of the chassis for surveillance. This camera uses a motor to pan 360 degrees and a servo to tilt the mount platform. We approximate Buddy's overall dimensions as 9" x 11" x 9" and the robot's weight as 6.5 pounds.

Buddy is controlled by a user-friendly intuitive remote control. The primary user interface is a joystick, allowing almost anyone to drive Buddy with typically little or no training. This remote control has a tether option for radio unfriendly environments, and a radio control mode for easier deployment in less harsh conditions, or where a tether is not possible. The remote control has six channels, four of which are used to drive the motors, and two are used to pass configuration options (such as when to drive a motor or the camera mounts). Buddy has a centrally mounted Vex microcontroller secured in the center of the robot. This microcontroller provides the interface between the remote control and the motors/servos. The microcontroller is powered by a battery attached the chassis.

For approximations on Buddy's specifications, see the *Specifications* section under the *Proposed Design* heading.

### Drawing

We have included a full drawing of our proposed robot design and drive train (see Figure 7 and 8). We have also attached a flow chart of the control and electrical connections of Buddy (see Figure 9 and 10).

### Theory of operation

When exploring a collapsed building, the proposed robot uses a tether to communicate back to its control center. The camera sends video data through the tether to a monitor back in the control center. The tether also provides a connection between the robot's microcontroller and its remote control. This remote control has control of the five motors and one servo on Buddy. The operator can use this controller to drive the robot, drive one wheel independently, or pan/tilt the camera. For more information about Buddy's control system, refer to the *Control architecture* section under the *Proposed Design* heading. Because the remote control delivers proportional analog commands, the operator will have precise steering of Buddy.

**Control architecture**

The robot will be controlled through a tether-able radio control transmitter. The radio control transmitter has six channels for use. The transmitter has two joysticks – which each consisting of two independent channels. The controller itself has several modes of operation, two of which control the mode of operation for the wheels. Mode 1 is called tank drive. In tank drive, the motors on either side are synchronous, with the left driving motors being controlled by the left joystick and the right driving motors are controlled by the right joystick. Mode 2 will allow the user to control each motor independently of the others. One individual channel of the remote control joystick will correspond to each motor. Mode 3 will allow the user to pan/tilt the camera. This will be done using two channels of the joysticks, with the drive motors disengaged during this mode. See Figure 10 for a flow chart of the control architecture.

**Analysis of objective metrics**

This section presents an analysis of Buddy with respect to the five metrics outlined under the *Objective* heading.

a) Ground clearance – Buddy will be designed to have two inches of ground clearance. This clearance will allow Buddy to travel over protruding objects without being damaged or disabled. However, a tradeoff exists between ground clearance and center of gravity. As ground clearance increases, the robot's center of gravity is higher. This higher center of gravity makes Buddy more susceptible to being flipped upside down when navigating over obstacles or inclines. In addition, since the robot's height is increased, it may not be able to fit into small areas.

b) Top speed – Since victims are often injured or trapped without food and water, it is important that Buddy find victims quickly. We approximate Buddy's top speed as 30 ft/min. At this speed, Buddy can quickly cover flat or open areas in the collapsed building searching for victims. The faster Buddy locates the victims, the faster the emergency teams can rescue the victims. However, if Buddy moves too quickly, the robot may miss something important. It is more difficult to stop quickly and accurately when moving quickly. If the operator is not careful, Buddy could potentially hit an obstacle or miss spotting a victim. While limiting Buddy to a lower speed would reduce the possibility of errors should the operator become careless, we felt that maintaining a higher maximum capability would give Buddy more flexibility for the trade-off of requiring more operator situational awareness. We highly recommend operator training expressly to cover this responsibility. With the joystick analog interface, Buddy does not have to be operated at full speed. A speed appropriate to the operation is under the operator's control at all times.

c) Traction - Buddy must be ready for any ground surface, including slippery ground and loose gravel. To travel forward Buddy must maintain a sufficient coefficient of friction on these surfaces. The necessary coefficient increases on inclines and during turns. The design goal for Buddy will be to travel up a 45 degree incline, and drive/turn on smooth surfaces and loose gravel without getting stuck. The one disadvantage to an increased traction in a four wheel independent drive system is that some slipping is required because the motors will not turn at exactly even speeds. Thus, the higher traction may make this required slipping more difficult for the robot.

d) Torque – Buddy's motors have a torque of approximately 190 oz/in per motor (accounting for losses and friction) – giving a designed level of 760 oz/in of torque. The design goal is for Buddy to negotiate a 2.5" vertical elevation change and travel up a 45 degree incline. The advantage of this high torque is that large obstacles will not stop Buddy. The problem with a high torque is a lower top speed. In addition, the motors draw more power the higher the torque. Therefore the robot's battery life decreases with an increase in torque.

e) Weight distribution – In order to compensate for our higher center of gravity, Buddy has a symmetric design to make the weight distribution even. We estimate Buddy's weight as 6.5 lbs. By distributing Buddy's weight over the four wheels, we try to make Buddy's center of gravity close to the x-y center of the robot. This will minimize the possibility of Buddy flipping over when navigating an incline or obstacle. A possible disadvantage is that our weight distribution cannot be used to leverage the robot over or off of obstacles.

**Potential pitfalls**

This section details potential problems we foresee with Buddy. We have tried to minimize any disadvantages in Buddy's design – however, as with all designs, we had to make trade-offs between Buddy's capabilities. For example, higher ground clearance means a higher center of gravity, which means the robot has a higher chance of tipping.

One potential problem is Buddy's width of 11". This might limit Buddy's mobility in exploring very small areas in the collapsed building. The size of Buddy's motors and wheels are the limiting factors. Because Buddy has four-wheel independent drive, this width cannot be minimized further without dramatically increasing the complexity (and hence lowering reliability) of the drive train linkage.

Our current design for Buddy's camera mount does not allow the camera to see underneath the robot. If Buddy becomes stuck on an obstacle underneath the chassis, the operator may have a difficult time discovering this.

Because we chose to design Buddy with a high ground clearance, the robot has a high center of gravity. This high centroid puts Buddy at risk for flipping upside down, especially when climbing steep inclines. To counteract this effect, we have managed Buddy's weight distribution to minimize flipping. However, we estimate that Buddy will only be able to climb high-friction inclines less than 30 to 35 degrees. In addition, Buddy will only be able to climb over obstacles under 2.5 inches high.

Another possible problem is Buddy's short battery life. Currently, we plan to design Buddy with a 60 minute battery life. Thus, Buddy will need to return to the control center to receive another battery approximately every hour – which could impede or interrupt Buddy's investigation of the building. Additionally, if Buddy is too far into the building, the robot may run out of batteries and be stuck inside the building until it could be pulled out by tether.

## Plan of Implementation

First, one Buddy will be constructed as a prototype. Pending CURF approval, Buddy will be constructed using Vex parts. The robot's chassis will be hand-assembled using metal brackets, screws and nuts. The motors and wheels will be attached to the chassis. The microcontroller will be countersunk into the chassis and the camera mount attached to the top of the chassis. All of Buddy's parts are commercially available. This is beneficial because if a part breaks, a replacement can be ordered quickly and cheaply.

## Requested Parts Budget

In our proposed design, we only require one additional component: a motor. The Vex Robotics Kit used to construct Buddy only includes four motors. These four motors will be used to independently power each wheel of the robot. The fifth motor is needed to pan the camera mount. We have included an approximate price below.

| Part | Vendor | Price |
|---|---|---|
| Vex motor | www.radioshack.com | $19.99 |
| | | |
| | TOTAL | $19.99 |

## Evaluation

To ensure that Buddy meets our proposed specifications, we will do extensive testing before delivery to CURF.

Scaife Hall was devastated by an earthquake last year. We will test our robot on the ruins of Scaife Hall. The robot should be able to successfully navigate all of Scaife Hall and locate any victims inside.

We will also create our own test field for Buddy. Buddy will need to pass our test field before being delivered to CURF. This test field will include the following (with approximate measurements):

1. Vertical ledge (2.5 inches) – climb and descend the ledge
2. Incline (30 degrees) – climb this incline at a 90 degree angle of attack indefinitely
3. Loose ground (0.5" diameter gravel) – navigate this without getting stuck
4. Continuous steps (1.5" steps) – climb or descend these indefinitely
5. Depression (2") – continue moving through the depression.
6. Sideways incline (45 degrees) – travel horizontally along this incline indefinitely
7. Sideways step (1") – traverse this step indefinitely with two wheels on the higher step and two wheels on the lower step.
8. Raised ledge (10.2") – traverse while executing turns and not falling off.

## Specifications

| Category | Approximate specifications |
|---|---|
| Size | 9" x 11" x 9" |
| Top speed | 30 ft/min |
| Turning radius | 0 – rotation about center axis |
| Ground clearance | 2" |
| Wheel diameter | 5" |
| Weight | 6.5 lbs |
| Torque | 190 oz/in per motor |

## Innovation

Buddy's design is innovative because of the solutions we have developed in response to the specific problem of urban search and rescue. The solutions include large wheels, independent four wheel drive, a rigid body construction and an intuitive user interface design.

First, the proposed wheels for Buddy are large (relative to Buddy's dimensions) all-terrain wheels. These wheels were chosen to provide Buddy with as much traction as possible on as many surfaces as possible – especially difficult terrain like gravel.  In addition, these wheels give Buddy increased climbing capabilities over obstacles.

Another unique feature of Buddy is the independent four wheel drive.  This drive serves two purposes in USAR.  One, if a wheel becomes stuck in a pit or depression, the operator can run one motor independently and free the wheel.  The second purpose is for redundancy.  If one motor is damaged and no longer works, Buddy will still be able to navigate the world and at the very least return to the operator for a replacement motor.

Buddy's chassis will be constructed as a rectangle (9" by 11").  The chassis will consist of metal brackets attached by screws, giving Buddy a rigid body.  Since Buddy's frame will be sturdy and square-like, Buddy will be able to resist torsional forces on the robot.  This will be useful for when Buddy is traversing uneven terrain or squeezed between obstacles.

Buddy is controlled through a highly intuitive use interface.  The remote control has two joysticks which can be used to steer the robot.  This remote control is very similar to remote controls used with cars or other toys.  This intuitive interface allows the operator to be watching the camera feed instead of trying to figure out how to move the robot.

## V. Conclusion

Buddy is a versatile, reliable robot design for use in locating victims in collapsed buildings.  We have illustrated Buddy's intended specifications and capabilities.  Solid construction, proven technological components and superior design techniques gives a robust product that will stand up to the demanding environments these robots operate in.

"It's 4am.  The roof just collapsed. Do you know where your Buddy is?"