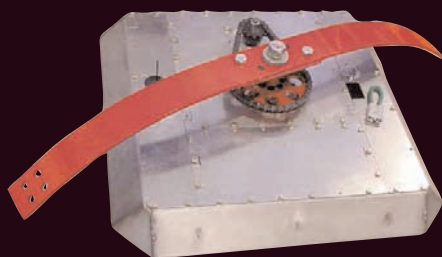


BUILDING BOTS

DESIGNING AND BUILDING ***WARRIOR ROBOTS***

WILLIAM GURSTELLE AUTHOR OF ***BACKYARD BALLISTICS***



BUILDING BOTS



BUILDING BOTS

**DESIGNING AND BUILDING
*WARRIOR ROBOTS***

WILLIAM GURSTELLE



Library of Congress Cataloging-in-Publication Data

Is available from the Library of Congress.

For more information, visit www.building-bots.com

Cover and interior design: Lindgren/Fuller Design

Cover photos, clockwise from top left: **Flexy Flyer**, courtesy Mike Konshak and Team Robot Dojo; **Stinger**, courtesy A. J. Klein Osowski; **Mad Cow**, courtesy Craig Lovold and Team Rabid Robotics; **Hammerbot**, courtesy Rand Whillock; **Propellerhead**, courtesy Mike Konshak and Team Robot Dojo; **Whytica**, courtesy Terry Ewert and Team Whyachi. Center photo courtesy **Robot Wars**. Frontispiece photo: courtesy **Robot Wars**.

©2003 by William Gurstelle

All rights reserved

First edition

Published by Chicago Review Press, Incorporated

814 North Franklin Street

Chicago, Illinois 60610

ISBN 1-55652-459-5

Printed in the United States of America

5 4 3 2 1

*To my sons, Ben and Andy.
They are why I consider myself very lucky.*

CONTENTS

Acknowledgments xi

Introduction xii

1. Safety 1

Basic Robot Safety Guidelines 2

2. How to Design a Robot 7

Brainstorming 7

Robot Fighting Styles 8

The Robot Design Process Explained 9

Setting Up a Team 11

Working Up the Design 13

A Look at Costs 15

Building a Very Small Robot 17

Basic Robot Design Guidelines 19

3. The Parts of a Fighting Robot 25

The Basic Building Blocks 25

4. Radio Control Systems 33

The Basics 33

AM and FM Radio 35

Pulse Position Modulation 37

Pulse Code Modulation 40

900 Megahertz Systems 41

5. Electric Motors 45

Motor Basics 46

How to Choose a Motor 50

Horsepower, Voltage, and Current 56

No Motor Data Sheet? 57

Wiring Basics 59

6. How to Choose a Fighting Robot Battery 63

- Voltage, Load Current, and Amp-Hour Rating 64
- Determining the Right Battery for Your Robot 66
- Connecting Batteries in Series and Parallel 70
- Cutoff Switch 71

7. Motor Speed Controllers 73

- Steering Systems 77
- Going Backward, Slowly 77
- Pulse Width Modulation 80

8. Gasoline Engines 89

- Internal Combustion Engine Speed Control 91
- Clutches 92
- Mounting a Weapon to a Motor Shaft 94

9. Drivetrains 97

- Setting Expectations 97
- Overview 98
- Shafts and Bearings 98
- Bearings 101
- Belts and Pulleys 105
- Wheels 109

10. Material Properties 113

- How to Choose Your Materials 114
- Properties 115

11. Building Materials 121

- Steel 121
- Aluminum 123
- Titanium 125
- Plastics 126
- Machining and Cutting Processes for
Robot Builders 126
- Machine Shop 101 127



Basic Machine Tools 129
Basic Metalworking Operations 132
Part Layout 133
Speeds, Feeds, and Other Important Data 134
Welding and Fasting 134

12. Robot Physics 141

Kinematics 142
Basic Kinematics Equations 143
Newton's Laws 146
Fighting Robot Physics Examples 150
Wrapping Up 153

13. Rotating Kinetic Energy Weapons 155

Designing a Spinner Robot 156

14. More Robot Weaponry 163

BMWs 164
Thwack-bots 165
Cutting Blade Robots 169
Lifters 170
Chameleon Robots 170



15. Fluid-Powered Weaponry: Flippers, Grippers, and Clamps 173

What Is Fluid Power? 175
Design a Pneumatically Powered
Flipper Weapon 176
Fluid Power Components 177
Design Examples 180

16. Game Day Strategy and Tactics 187

Before the Match 187
Specific Strategies 184
Game Plans 192
10 Tips for Building Battle-Worthy Robots 193

17. The Entrepreneur's Guide to Battling Bots 197

Getting a Sponsor 197

How to Organize Your Own Fighting

Robot Event 199

There's No Business Like Show Business 208

18. Getting Additional Information and Help 211

Robot Parts Suppliers 212

APPENDIX I: PARTS SUPPLIERS 219

General Parts Suppliers 219

Batteries 220

Computer Aided Design Services 221

Drivetrains 221

Electronic Speed Controllers 221

Fluid Power Supplies 222

Motors 222

Radio Control Equipment 224

Raw Materials 224

Specialized Parts 224

Tools 224

APPENDIX II: RADIO FREQUENCY CHART 225

**APPENDIX III: RULES FOR A TYPICAL ROBOT
TOURNAMENT** 227

Glossary 233

Index 237



ACKNOWLEDGMENTS

Scores of people assisted me in writing this book by providing information and photographs, by answering questions, and by pointing out better ways of doing things. To all who offered help and insight, please accept my thanks.

Robot builders are some of the smartest people in the world. Thanks to the many builders who were kind enough to spend time with me and provide me with their insight and advice. It is impossible to name all of these fine builders who graciously answered my questions and offered assistance, but I thank them all very sincerely.

Special thanks to the people who reviewed sections of the manuscript for accuracy and completeness. Their comments and ideas proved to me that engineers who know their stuff rank at the very top of society's food chain. They are: Ian Burt, Jason Dante Bardis, Dail deVilleneuve, and Stephen Felk. These folks are the heavyweights of the sport.

INTRODUCTION

When I first started to build a fighting robot, it was a frustrating experience, mostly because there were more than a hundred different Internet Web sites with information on how to build a warrior bot. Many of the sites were created by builders who wanted to relate their experiences as they built their own machines. Although parts of the sites were pretty good, trying to put all the information together so I could build a competitive robot was a tough task. It became apparent that new, midlevel, and even experienced builders need a book like this, designed to make building a bot easy and fun.

The popularity of combat robotics has been fueled by television shows such as *Robotica*, *Robot Wars*, and *Battlebots*. But this sport is not just about what you see on television. In fact, while television made it popular in a hurry, television alone won't keep it going. The sport will grow or wither depending on what happens at the grassroots level. If more and more people build their own bots and stage their own local tournaments, combat robotics could grow into another NASCAR. On the other hand, if it becomes a sport good only for filling up time on cable television channels, the audience will eventually tire of it and it will go the way of the XFL.

Personally, I think the outlook for the sport is promising. Many signs point to a surge in interest at the local level, where it should be. More and more local tournaments are sprouting up, giving builders a chance to compete without traveling cross-country.

So if you want to build a robot, start your own tournament, or just learn more about the sport, you've come to the right place. As far as I can tell, the only absolute requirement for building a fighting robot is interest.

If you check out the pit area—the back room at a warrior robot tournament where builders wire, weld, and fix their robots—you'll see all sorts of different people—young, technical professionals in their late 20s, teams of college students, fathers and sons, mothers and daughters, lone eccentrics, motor sports enthusiasts, retirees from the building trades, and many others. If you enjoy working with your hands and your mind simultaneously, you will find building a competitive warrior robot to be a lot of fun.

Unlike traditional sports such as football, basketball, or hockey, building warrior robots emphasizes intellect over brawn, craftsmanship over coordination, and innovation over physical strength. Here, mental toughness begets metal toughness, and style, creativity, and craftsmanship are as important as winning.

To many, building and competing warrior robots seems like a marriage of motor sports racing and professional wrestling. It is a raucous, young, loud, and action-packed sport requiring nothing but a few dollars (well, maybe more than a few) for equipment and the willingness to experiment and learn new things. I began building robots as a way to spend more time with my sons. Since then, we have both learned new skills, made many new friends, and developed a terrific feeling of pride in our respective abilities to fabricate and build things. Our latest machine is tougher than a prizefighter and more mobile than a gamecock. We're a long way from where we started.

A fighting robot, I think, says a lot about the person who makes it. Some robots are 300-pound metallic boxes on wheels—mean, hulking, indestructible, and free from any pretense to grace and agility. Some are beautiful, catlike creations, able to prowl about an arena like a steel cheetah. Others are hammers on wheels, a platform built to deliver a single deadly blow. All of these robots reflect the style and personality of their creators, so when they fight, their builders are fighting too, delivering the blows and feeling the pain.

That is what makes this sport so much fun. No one gets hurt—

the robots are just hunks of metal. Fighting robots appeal to many different types of people, and that's why I wrote this book: to help more people build their own robots and enjoy the sport of robotic combat.

Who Can Build a Fighting Robot?

You can.

Many people think that building a fighting robot takes an extreme level of technical knowledge and the sport must necessarily be the province of engineering grads and skilled machinists.

Not at all.

All sorts of people, some without any real technical backgrounds, have built good robots, sometimes even great robots. The only requirements are the desire to try new things and the ability to learn.

I wrote this book because I felt that there was no single source of knowledge that a nascent builder could reference in order to get started. To be sure, there are many sources of information available to the builder wannabe. But the information is spread out all over, in too many sources and in too many different places. Often the information in other books and on builder Web sites is too hard to understand and far too dense for the casual or beginning builder to use. Some of it is just plain wrong.

Faced with this, the novice builder's tremendous enthusiasm and excitement soon shrivel. Many new builders who encounter a multitude of motor data graphs, incomprehensible machine design formulas, and page upon page of dense, dry, and prosaic technical information may throw their hands up and decide not to build their bots after all.

Well, no longer, because this book is written for *you*. If you want to get started in the sport and build your first bot, this book will provide you with all the information you need. If you've experimented with robot building but want to reach the next level, this book will help you do so. Even if you have been building for a while and your current robot is made from water-jetted 2021-T6 aluminum, controlled by a self-designed electronic speed

controller, and operates a hydraulic lifter arm powered by a four bar linkage, you'll still pick up some new ideas here.

This is a book for all builders. It starts with the basics and breaks down each robotic concept into easy-to-understand chunks. It also explains the technology, in case you're interested, but if you don't care and just want to build your bot, this book will work on that level as well. It tells you how to go about designing your robot, selecting your components, and putting it all together. While the technical aspects can get complicated, they don't have to be. Competitive robots have been assembled in an afternoon from cordless electric drill motors and duct tape, and from modified radio-controlled race cars encased in charcoal grill covers.

Let me share a secret with you: there are only so many ways to build a fighting robot. Sure, all the robots on TV look different and have different types of components, but in actuality they generally follow the same rules and are built in a similar fashion. In this book I explain the way warrior robots are built, from the ground up.

Are you ready to build a fighting robot? Take this quiz and find out:

ROBOT BUILDERS APTITUDE TEST

I know how to drill holes using power tools.

Yes I can learn No

I like being part of a team and working with other people.

Yes No

I'm able to sketch out ideas on paper so other people can visualize them.

Yes I can learn No

I know how to solder electrical connections.

Yes I can learn No

I can use a joystick to control a video game or a radio-controlled car.

Yes I can learn No

I feel comfortable purchasing things over the Internet, from a trusted supplier.

Yes No

I am willing to spend money on my hobbies.

Yes No

If you answered either “Yes” or “I can learn” to these questions, you have the potential to build a competitive fighting robot. Answering “No” to any of these doesn’t necessarily mean you can’t be a builder, but you will likely need to find a partner who can supply the skills you don’t have.

No one—not me, not you, not the reigning world champion heavyweight robot builder—knows all there is to know about building fighting robots. Many aspects of this sport change frequently—new equipment becomes available, new methods of doing things come along, tournament rules change, and so forth—so the ability to learn and the willingness to try new things are most important. They’re more important than having a machining background or an engineering degree.

How to Use This Book

Chapter 1 is the safety chapter. Because robots can be strong and powerful, you need to make sure you build and compete safely. This chapter is extremely important. Please read it first, and carefully. **Chapter 2** explains the decisions you need to make before you start building. Who will be on your team? What kind of robot should you build? How much money will you need?

Chapter 3 is *very* important! This chapter tells you what is in a fighting robot. The text and diagrams provide the overall arrangement of and relationships among all the components that make up a fighting bot. It explains how a fighting robot is put together.

Chapters 4 through 9 describe the component parts of a robot. As stated earlier, there are only so many ways to build a robot, and almost all robots contain these items: radio control systems, motors, drivetrain parts, motor controllers, and batteries. Each component is explained. While some chapters go into considerable detail, you don’t really have to delve deep if you don’t want to.

Chapters 10 and 11 describe the materials used in bot frames and weapons. These chapters provide insight on how to choose between, for example, steel and aluminum for a specific part.

Chapter 12 teaches the physics of robot building. If you want to calculate, not guess, how big a motor to buy to reach a certain speed, or if you want to calculate how large a weapon to build to flip an opponent of a particular size, you can use basic physics to find the answers. But if you just want to build your bot, unfettered by theory and algebra, no one will look down upon you if you skip this chapter.

Chapters 13 and 14 reveal the secrets of the different types of weapons that builders put on their robots. Spinners, thwack-bots, wedges, and kinetic energy brutes like spinning disks and cutting blades are described.

Many builders will find **Chapter 15** extremely interesting. It gives builders information on how to incorporate fluid power into their robots. Fluid power refers to pressurized gas and liquid systems that can operate flipper arms, clamps, and hammers.

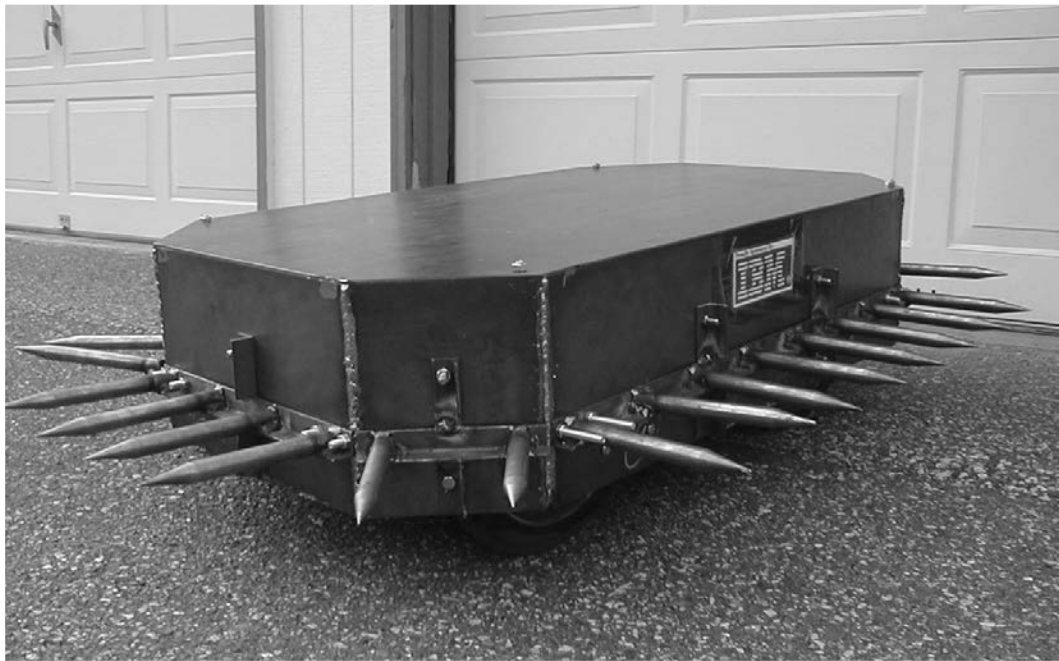
Chapter 16 provides information, tips, and ideas on how to compete most effectively on tournament day. **Chapter 17** is all about tournaments and competitions: how to compete, and how to put on your own competition. Putting on your own competition is fun and exciting, and easier than you think! **Chapter 18** lists additional resources and where to go for help.

Finally, you'll find a glossary and appendixes that list parts suppliers, a radio frequency chart, and a set of sample tournament rules.

So, if you want to build a robot, you've come to the right place.

Ready?

Good. Let's get started.



1. **SAFETY**

Given the amount of power and the number of dangerous items found on a typical fighting robot, it is almost inevitable that someday, something bad will happen. This chapter provides some basic, commonsense safety guidelines to get the new builder off on the right foot.

The largest fighting robots weigh over 300 pounds and are powered by large electric motors that have enough power to push a Ford truck uphill. These robots are outfitted with power saws spinning at ridiculous speeds, fast-moving hammers, and high-impact kinetic energy weapons. Many robots use high-pressure pneumatic systems that can burst through heavy pipe. Believe me, fighting robots can be as (or more) dangerous to the people in close proximity to them—the robot builders, the robot drivers, and spectators—than to other robots. The other robots are armored with quarter-inch steel plates. People are not.

I have seen high school kids with no training or education in high-pressure pneumatics attempt to compete with extremely suspect liquid CO₂-powered lifting arms. I have yelled at inexperienced builders to not adjust unguarded chain drives wearing long, dangling sleeves. I have heard of close calls when bot drivers attempted to destroy junk, just for fun, in front of spectators, without regard to the inevitable shrapnel produced.

Robot fighting can be very dangerous. If you participate, realize the dangers and heed the instructions

given here to mitigate them. Wearing safety glasses and gloves is not nearly enough. No list of safety rules is comprehensive enough to cover every situation.

The suggestions that follow are written to maximize safety. They are only guidelines. Every builder must make safety the number-one priority and accept responsibility to make the bot safe for everyone involved—the builder, the driver, and the spectators.

If you learn only one thing from this book, at least learn this: if you build a robot you do so at your own risk! If you build a robot, it is up to you to build it right and operate it safely. This book will help you. But in the end, all responsibility rests squarely on the shoulders of the builder.

If you are willing to take responsibility for your actions and are still interested in building a fighting robot, then heed these 10 rules. They do not guarantee your safety, but not following them practically guarantees a disaster.

Basic Robot Safety Guidelines

1. **Figure out what you're doing *before* you do it.** If you're going to build robots, don't be half-assed about it—go into it fully assed. Anything less is asking for trouble. If you don't know how to weld, learn how from someone who does. Never used a metal turning lathe? Read up on it. There's a right way and a wrong way to do everything. The wrong way may seem easier, but the right way is better and safer.
2. **Always wear safety glasses.** Almost every shop operation—cutting, welding, sanding, et cetera—involves the presence of flying metal, wood, or plastic chips. When necessary, wear personal protective equipment, such as welding gloves when welding, hearing protection when conducting noisy operations, and a face mask when using paints or solvents.
3. **Get a copy of the rules for any competition you are considering entering.** There is always a section on safety

rules. Read it for two reasons: (1) it provides guidance for building a robot safely, and (2) you won't waste time designing an illegal bot.

Every tournament has its own unique rules regarding safety. The rules pertain to both the construction requirements of the warrior robot and the procedures that must be followed during the tournament. Some tournaments are very particular about the type of radio controls allowed, and some are more concerned about restraints and tie-downs. Because competitions differ, every builder should obtain a copy of the event rules from the tournament organizer well before the actual event in order to make certain the robot is in strict compliance.

4. **Robots are remote-controlled vehicles and they are subject to radio "glitches."** This means they may turn on or off unexpectedly. Glitches occur frequently and come from a variety of sources. Besides a simple signal glitch, your robot may also be subject to radio interference from another contestant's radio transmitter, a commercial radio dispatch system, or even a garage door opener. Never place yourself in a situation where an unexpected radio transmission can activate your robot and hurt you or others.
5. **There must be an easy-to-reach, easy-to-activate main cutoff switch on the outside of your robot.** No matter where you compete, even if you just bang around your garage and scare neighborhood children, your robot must be fitted with a kill switch or removable link. This vitally important safety device is designed such that when it is deactivated or removed, no current flows from the battery to anything else. The drive motors, the weapon motors, the electronics—everything shuts down immediately. This safety device should be completely mechanical; that is, there cannot be any electrical components such as relays or sensors involved.

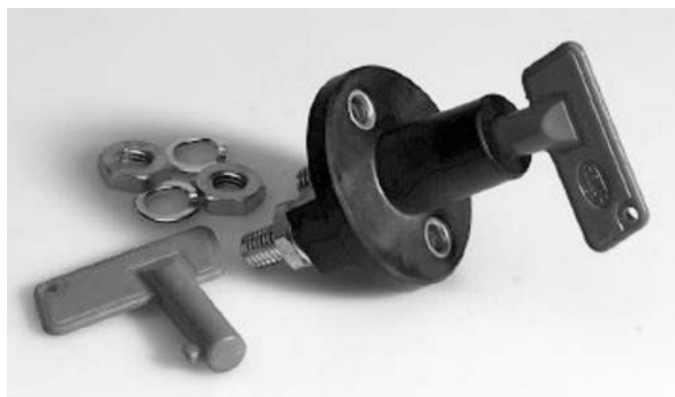
There are at least a couple of ways of doing this. The first way is to make or purchase a heavy-duty removable link that is easily inserted and extracted from its base. The link is positioned into the circuit in series with the batteries. Removal of the link stops all current flow. The trick is to make it foolproof and easy to pull



1.1 Removable link

out when needed, but not so easy as to allow it to be knocked loose by impact during a match.

The second way is to use a high amperage capacity (sometimes called a high ampacity) cutoff switch. These are available at auto part or marine stores that cater to the racing crowd. These switches often utilize a key or Allen wrench that must be inserted into the switch in order to turn it on or off. Automotive and marine supply stores often sell a variety of battery cutoff devices.



1.2 Cut-off switch

-
6. **Watch your fingers!** A robot drivetrain may consist of gears, belts, pulleys, shafts, roller chains, sprockets, and what not. These things will remove your finger if they catch it while moving. Be extra careful when working around your drivetrain, and put in guards whenever possible.
 7. **Many robots are extremely heavy — use proper lifting techniques.** Be certain your dollies and other carrying devices are rated to accept the weight placed upon them.
 8. **Always be attuned to the possibility of shrapnel.** Whenever your robot charges into something, robot parts, steel wreckage, concrete chunks, plastic shards, nuts and bolts, pointy things, sharp things, and heavy things come flying out at random trajectories and at high speed. If it happens in the arena behind Plexiglas, that's probably OK. If it happens in your driveway with the neighbor's kids watching nearby, that's real trouble.
 9. **Working with high-pressure fluids requires caution, an understanding of fluid power, and great attention to detail.** Many robot builders use fluid-powered lifting arms or poking devices to make great weapons. Become familiar with fluid power by reading Chapter 15 in this book, and talk to experienced builders or engineers to make sure you are proceeding in a safe and proper manner. There are plenty of other good weapons systems that are less complicated to construct.
 10. **Guards should be placed securely over all hazardous surfaces until the robot is in the battle area.** Many builders affix sharp, pointed weapons to their mechanical warriors. The guards should be fabricated from sturdy plastic or other suitable substance and held tightly using a bungee cord or other securing device.

- [Sales and Distribution in SAP ERP: Practical Guide here](#)
- [read online The Malayan Campaign 1948-60 \(Men-at-Arms, Volume 132\) pdf, azw \(kindle\), epub](#)
- [The Scientist \(April 2016\) pdf, azw \(kindle\), epub, doc, mobi](#)
- [Theoretical Philosophy after 1781 \(The Cambridge Edition of the Works of Immanuel Kant\) for free](#)
- [Forensic Reports and Testimony: A Guide to Effective Communication for Psychologists and Psychiatrists pdf, azw \(kindle\)](#)

- <http://musor.ruspb.info/?library/The-Bauhaus-and-America--First-Contacts--1919-1936.pdf>
- <http://musor.ruspb.info/?library/On-Being-Human--Why-Mind-Matters.pdf>
- <http://damianfoster.com/books/Encyclopedia-of-Assassinations--More-than-400-Infamous-Attacks-that-Changed-the-Course-of-History.pdf>
- <http://damianfoster.com/books/Blood-Ties--Castings--Book-1-.pdf>
- <http://anvilpr.com/library/The-Wise-Man-s-Fear--The-Kingkiller-Chronicles--Book-2-.pdf>