Improving Teleoperated Robot Speed Using Optimization Techniques

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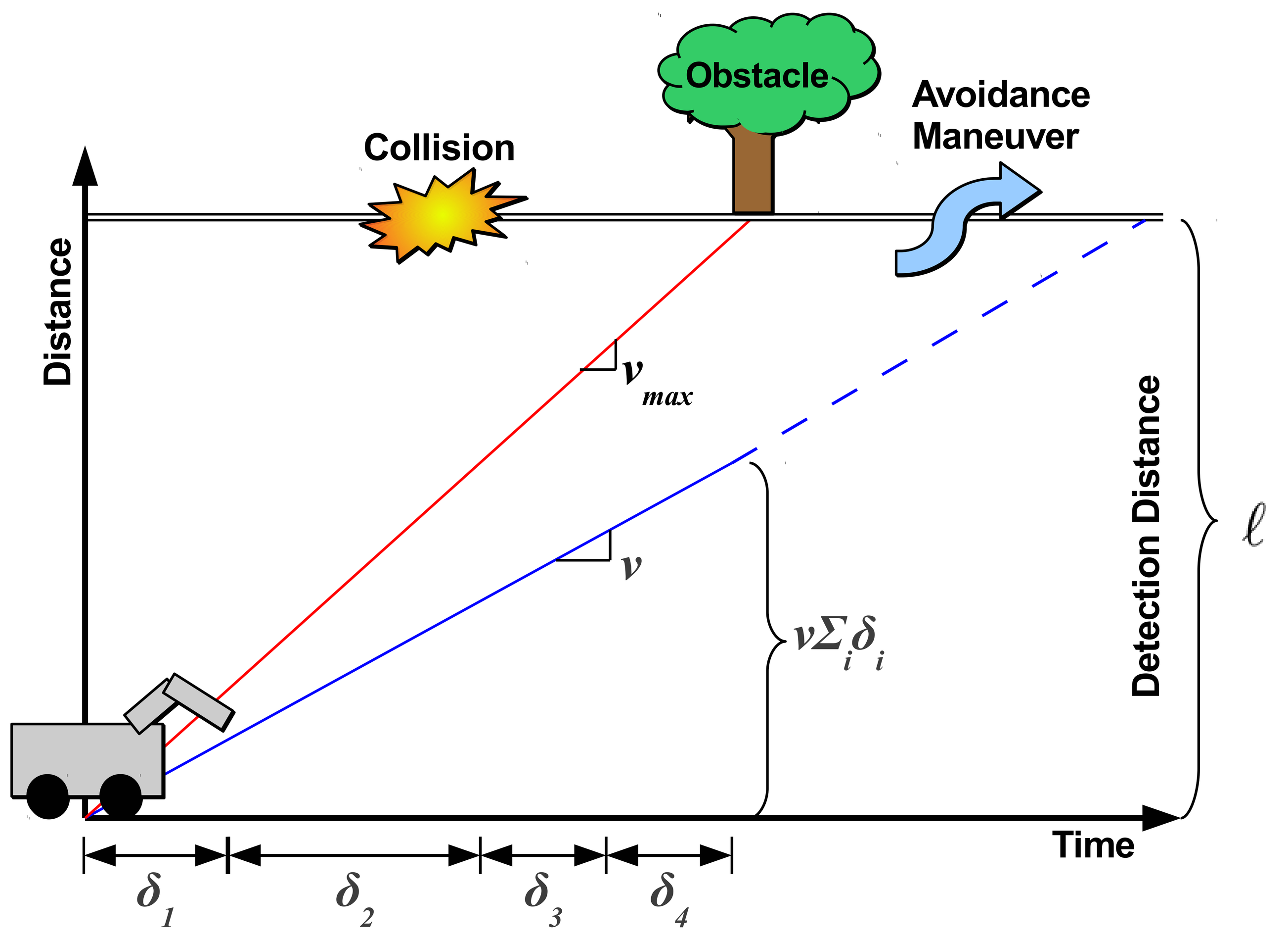
Project Overview

Current autonomous robots are not sophisticated enough to complete many mobile tasks, so human-in-the-loop control – including teleoperation – remains the only way to accomplish these tasks. However, **most teleoperated tasks cannot be performed at a reasonable speed.** When evaluating design choices, it is not always clear which designs will yield the greatest speed increase at the lowest cost. This project uses an **optimization-based approach for evaluating multiple design options** that weighs robot speed against costs such as component price and size. An example is presented to illustrate the methodology.

A Simple Teleoperation Scenario



The **maximum speed** that can be successfully achieved in this simple teleoperation scenario is a **function of the total time delay $\Sigma_i\delta_i$ and the detection distance ℓ.**

Optimization Steps

We use optimization to find a **compromise** between maximizing **robot speed** and minimizing properties such as such as system **price and weight**.

The steps of the process are:

1. Identify design objectives.
2. Enumerate possible design variables and options.
3. Model relationships between objective functions and design variables.
4. Assign trade-off weights and evaluate the optimization.

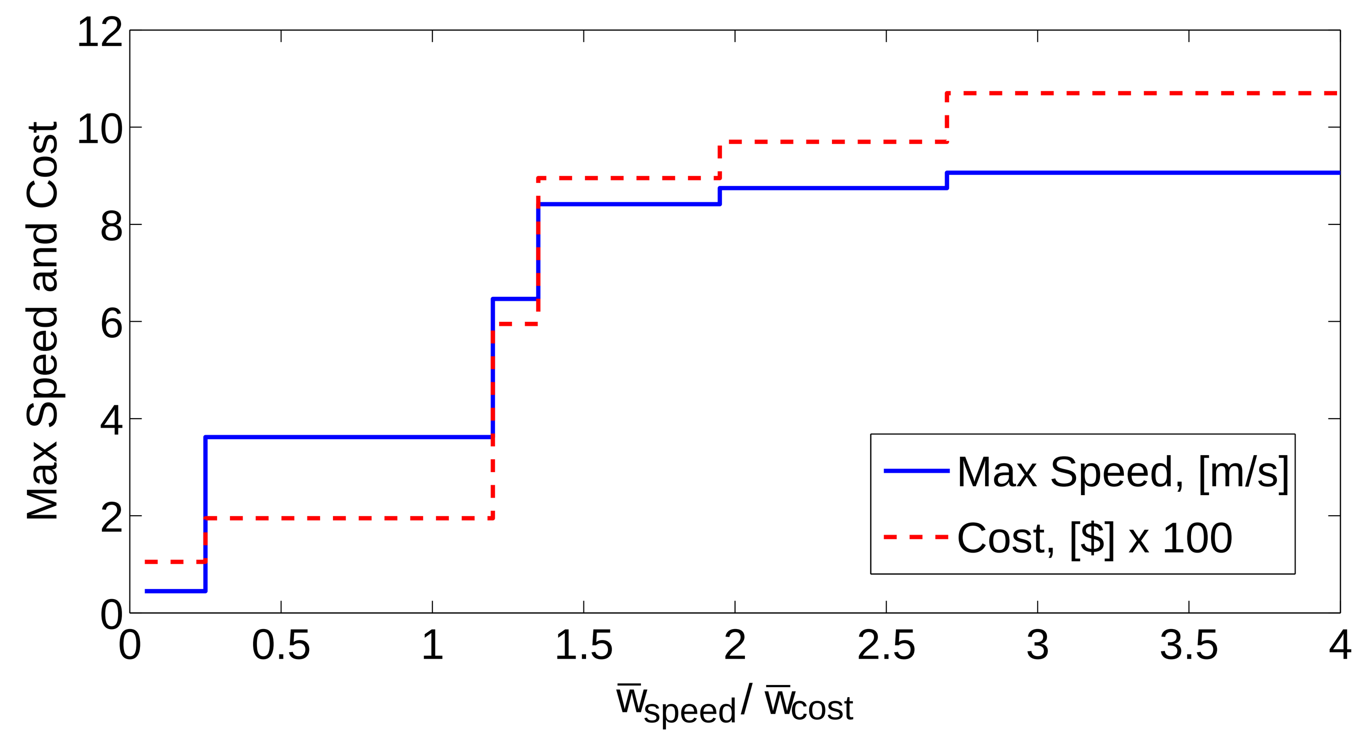
This framework **shifts the robot designer's job** from that of individual component selection **to the more holistic task** of understanding the design objectives and choosing appropriate objective function weights.

Example

The optimization approach is demonstrated by a simple example in which a robot designer has to **choose hardware from a set** of three cameras, three processors, and three network protocols, as well as two different UIs. We use models based on a **first-order estimate of system behavior** and we consider only the limiting factors of network delays (δ_N), computer processing delays (δ_P), operator delays (δ_O), and detection distance (ℓ). The objective function for speed is given by the maximum possible speed:

$$f_{speed}(x) = v_{max} = \frac{\ell}{\delta_P + 2\delta_N + \delta_O}$$

and the objective function for cost is simply the sum of the costs of the individual components.



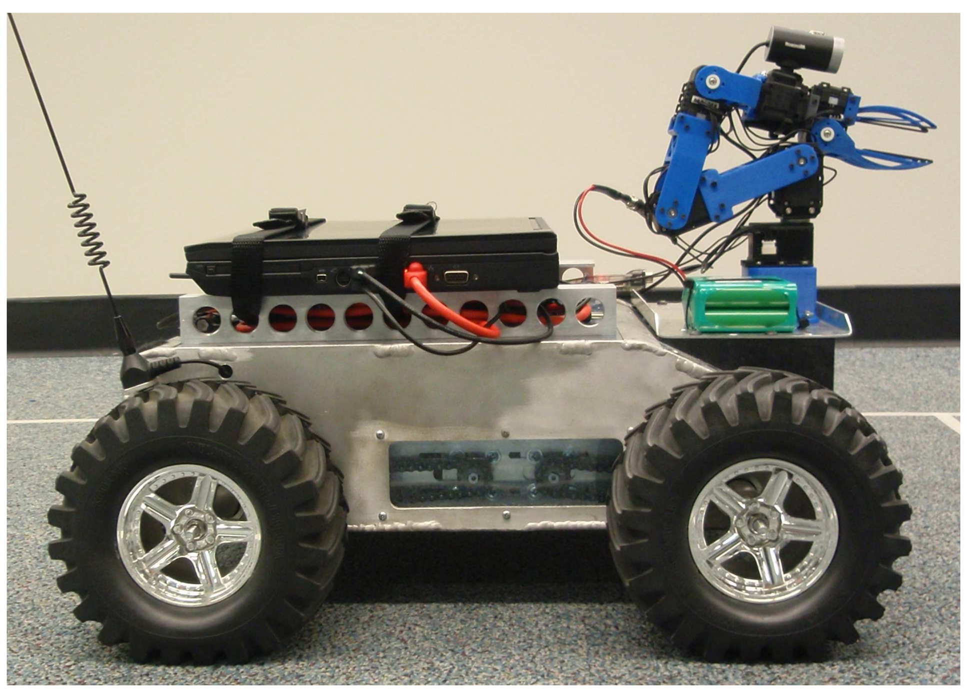
Plotting the **optimized system speeds and prices** as functions of the ratio between the weighting values $\overline{w}_{speed}$ and $\overline{w}_{cost}$ can show the **sensitivity of the optimization** to the choice of weights.

Optimal, fastest, and cheapest hardware options for weights of $\overline{w}_{cost} = 1$ and $\overline{w}_{speed} = 1.2$.

System Type	Camera	Processor	Network	UI	Video Size	Max Speed	Cost
Fastest	C_3	P_3	N_3	on	2073600px	9.1m/s	$1070
Cheapest	C_1	P_1	N_1	off	188509px	0.4m/s	$105
Nominal Compromise	C_2	P_2	N_2	on	921600px	3.0m/s	$550
Optimal	$\mathbf{C_3}$	$\mathbf{P_1}$	$\mathbf{N_3}$	**off**	**1989818px**	**6.5m/s**	**$595**

The optimized system is able to achieve a speed more than 15 times higher than the cheapest system and its **speed is more than double that of the compromise system**, while the **system cost was increased by less than 10%**. Also, we have shown that the cost of the UI relative to the speed increase was too high to justify its use.

Ongoing Work



We are currently investigating how to **combine experimental results and manufacturer specifications** to develop **more accurate models** for optimization so this approach can be applied more readily to real-world systems. We are also exploring how to optimize **more complicated systems** such as those involving mobile manipulation.

This optimization approach could be applied and used to:

- Help **design** new teleoperated robot systems
- Strategically **upgrade** existing robots that require humans in the loop
- Determine **safe operating limits** for fielded robots

References

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Acknowledgements

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