Autonomous Realization of Simple Machines

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Abstract. For robots to become integral parts of human daily experience, they need to be able to utilize the objects in their environment to accomplish any range of tasks. In this work, we focus particularly on physically challenging tasks that push the limits on the robot kinodynamic constraints such as joint limits, joint torques and etc. Previously, we demonstrated an autonomous planner that instructs a human collaborator where to place the available objects in the environment to form a simple machine such as a lever-fulcrum assembly. In this work, we report results on the autonomous realization of such a design by the humanoid robot Golem Krang, focusing on the challenges of autonomous perception, manipulation and control.

1 Introduction

The ability to use the available objects in the environment towards accomplishing goals is essential to thriving in challenging circumstances. Everyday examples of tool use include simple machines such as levers and pulleys. The challenge in autonomous design of such simple machines is the space of discrete choices for the component options and the related high-dimensional continuous configuration space of the chosen components.

In previous work [1, 2], we demonstrated the constraint satisfaction approach to assembly design, specifically for robotic manipulation and locomotion. The idea is to represent the constraints between the components of the design and on the robot kinodynamics as generic equality and inequality functions within an optimization framework and solve for the global minima. Operations research [3] and architecture [4] fields also use global optimization in design problems.

In this work, we take the next step towards full autonomy where the humanoid robot, Golem Krang, autonomously manipulates the objects in its environment to construct a simple machine. The robot perceives the available objects, specifically 15 kg cinder blocks and 10 kg wooden blocks (e.g. potential levers), relocates them to the desired configurations output by the constraint planner, and actuates them to flip a 50 kg load. Figure 1 demonstrates key scenes from this scenario such as (a) detection of a cinder block, (b) locomotion with a heavy load, (c) manipulating a lever while subject to multiple constraints and (d) application of force to the lever leading to a successful load motion.

Significant effort has been demonstrated by [5–7] to incorporate autonomous agents in human environments. Our work stands out in multiple aspects from the

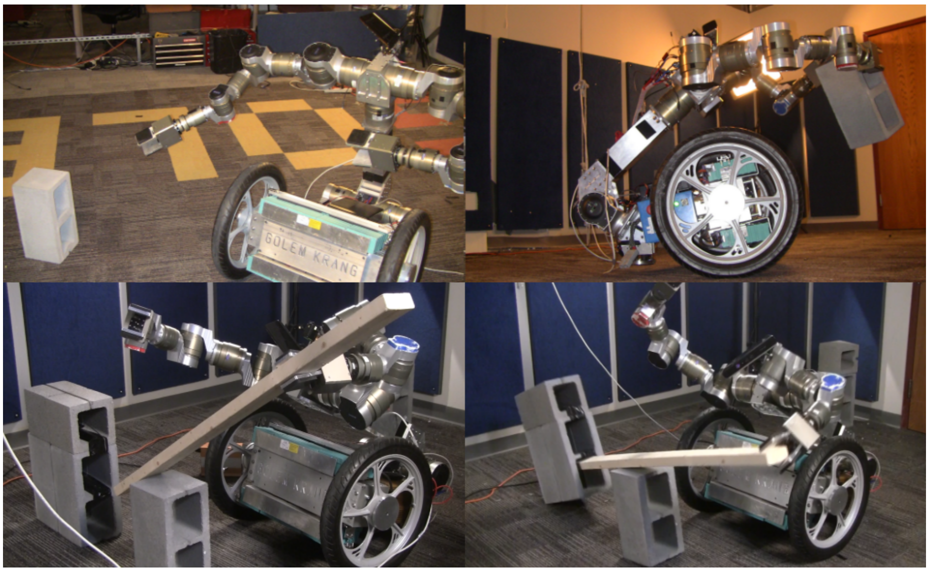

Fig. 1. The mechanical advantage in forces

established state of the art. First, Golem Krang is a two-wheeled balancing robot, similar to a segway with two 7-dof robotic arms installed. The challenge with such a platform is the dynamic stability constraint where the robot has to ensure its center of mass is close to the wheel axis at all times as opposed to legged or multi-wheeled platforms. Secondly, to the best of our knowledge, Golem Krang is the tallest and heaviest two-wheeled robot with 150 kg at 1.9 m, a unique property among similar designs [8]. At this scale, the weight can help with heavy-duty manipulation but also complicates the autonomous locomotion. Lastly, Golem Krang perceives its environment with an onboard RGBD sensor with two degrees of freedom that can be manipulated for gaze control. Autonomous perception and scene recognition has only recently started to gather interest in the humanoid robotics field [9, 10] as opposed to the established motion capture methods [11].

2 Experiments

Golem Krang is tasked with overturning a 50 kg load using a lever-fulcrum assembly with a limit of 300 Nm on the force it can apply to the environment. Given the dimensions of the available objects in the environment, the robot has to design a structure, locate the components, configure them into their positions and actuate the simple machine. In the following section, we describe a typical run, focusing on details of perception, locomotion and manipulation.

Placed in a random configuration in the room, Golem Krang begins by scanning the room for the available objects and finds the closest cinder block that would be used as a fulcrum (see Figure 2). The scanning process is composed of a set of atomic behaviors which move its arms out of its sight to avoid occlusions. Once the fulcrum is located, the robot approaches until it positions itself in a predetermined distance to grasp the object. Using the motion planning tools, such as RRTs and guarded moves, the robot grasps the cinder block at its top.

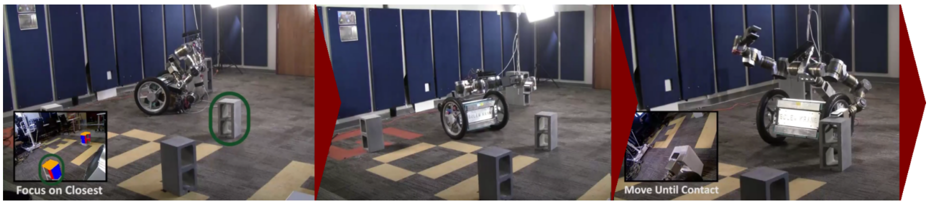

Fig. 2. Once Golem Krang detects the closest cinder block (left), it approaches (middle) and grasps the objects (right). Scene continues in Figure 3.

An interesting observation we expand on in Section 4 is about how the location of a manipulated object and the uneven distribution of its weight over the wheels affect the locomotion accuracy. To minimize such an artifact, in Figure 3, Golem Krang first moves the grasped cinder block to the middle of its torso before turning around and localizing the load object at 50 kg. Having detected the load, the final configuration of the fulcrum is deduced from the assembly design and the robot places it appropriately.

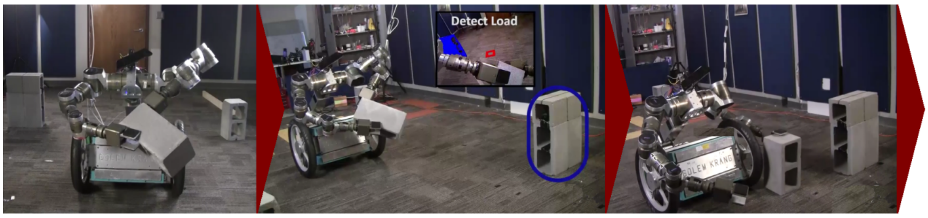

Fig. 3. Having grasped the fulcrum, the robot localizes the load and places the fulcrum in the initial design configuration. Scene continues in Figure 4.

In the third part of the experiment, Golem Krang needs to detect and localize a candidate lever object and grasp it, as shown in Figure 4. Given the size of the lever and the noisy perception data, we propose using the wheels to localize the lever object more accurately once the robot approaches it. Figure 4b displays the conformant behavior where the robot moves forward slowly to collide with the lever and have its localization error fixed. The left wheel first makes contact and the contact overcomes the input torque, while the right wheel keeps moving until the robot is parallel and directly in front of the lever.

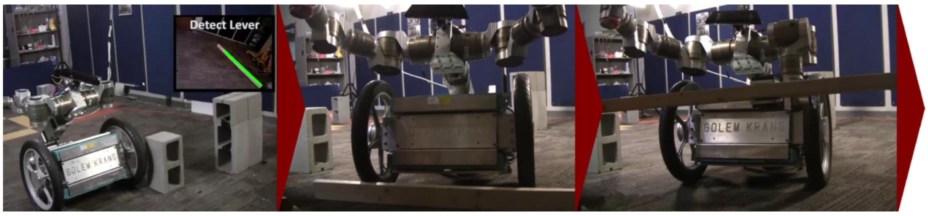

Fig. 4. The lever is picked up by first using vision and then running the wheels against the object to make physical contact before manipulation. Scene continues in Figure 5.

To simplify the locomotion, we have assumed collision-free paths and when Golem Krang carries the lever, we ensure that the lever is carried high enough that it does not collide with other objects (see Figure 5. Once the robot repositions itself in front of the robot, using guarded moves, the robot first pushes the lever against the load horizontal to ensure it is at the correct horizontal distance and then raises it until the design specification. Once at the correct height, the robot releases the lever and allows it to slide on the fulcrum into the load - one of the more practically challenging tasks. For addition tasks, we have used task-constraint manipulation with online perception to minimize the errors during this routine. Finally, in Figure 5c, the robot pushes the object at the desired contact point and overturns it.

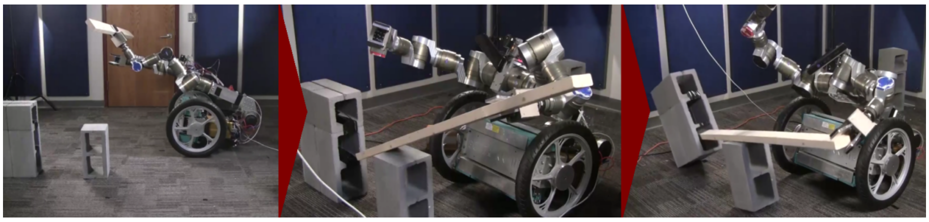

Fig. 5. Golem Krang places the lever in the planned pose and overturns the 50 kg load.

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