NYU Reactive Gripper: An Implementation

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Abstract

We consider the problem of grasping an unknown polygonal flat object using a parallel jaw gripper. Our design equips a standard gripper with several light-beam sensors (close to each jaw) and employs a control scheme based on a reactive grasping algorithm. This is done by probing the object to locate a good grasp position, and then grasping, without moving the object significantly. The goal is to do as little motion as possible to find a grasp. In this paper, we discuss an implementation of this device using NYU's MOSAIC robot, following a quick overview of the underlying reactivity principle.

1 What is a Reactive Algorithm?

By a reactive algorithm, we mean an algorithmic scheme where a robot's sensors determine directly the actions of the actuators. However, note that the actuators themselves may interact with the sensors (e.g., by moving them or occluding them, etc.) to close a feedback loop and thus causing further goal-driven as well as corrective actions.

In the simplest picture, a set of sensors determine a binary vector, where each bit of the vector may represent whether a sensor detects a signal or not ("on/off sensor"), whether the value detected by one signal is higher than another or a predetermined threshold, etc. Each possible value of the binary vector determines the movement of a single actuator immediately. The necessary actions for a given value of the vector are expressed in terms of a table with one entry per vector value. In a more complicated picture, we allow finitely many states with a table per state. In the table, in addition to the actuator moves, we also have an entry for state transitions.

Ideas similar to ours have also been studied by cyberneticists who built simple, reflex-based artificial animals to demonstrate the possibility of mechanical behavior and learning. For example Grey Walter's light-sensitive turtles and Braitenberg's "vehicles of desire." Another effort of similar nature is Rod Brook's [2] subsumption architecture and the insect species (e.g., Atilla the ant). Unlike these approaches, we view our problems as engineering problems and solve them without any inspiration or analogy from an anthropomorphic solution. Our endeavors are much closer to the ones in control theory (discrete event system

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and supervisory control) and theoretical computer science (computational geometry) than those in cybernetics, artificial life or intelligence.

2 Reactive Parallel Jaw Gripper

In order to demonstrate the feasibility of our methodology, we have designed and built a prototype NYU reactive gripper which can be described roughly as follows: We begin with a standard parallel jaw gripper and attach to each jaw two infrared emitting diodes (LEDs) and two infrared detectors as shown in figure 1. This allows us to have in fact four light beams which we can test for being interrupted or not by alternately illuminating the IR LEDs. The general scheme will be to close the gripper while constantly checking the status of the sensors, and performing actions according to that status in a table driven manner.

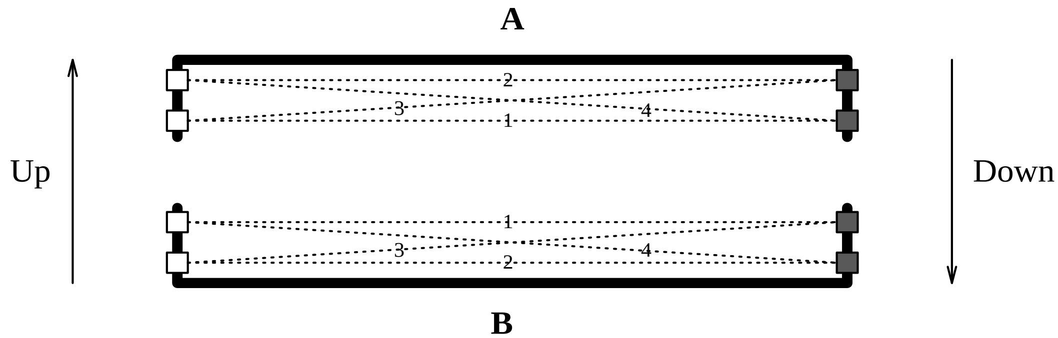


Figure 1: Parallel jaw gripper with sensors

The structure of the grasping algorithm can be easily understood by considering an angle θ and the diameter $d(\theta)$ of the object[2] to be grasped in the direction θ. Our gripper allows us to search for the local minima of the diameter function quickly and using the table shown as (Algorithm 1).

We assume that the initial orientation of the gripper is at angle 0 (with the x-axis, say), and that the gripper rotates around its center of symmetry. Let A_1 and A_2 be the state of the light beams on jaw A, and B_1 and B_2 be the same for jaw B. In the table, *up*-ward translation means translation perpendicular to the gripper jaws and towards jaw A, *down* is towards jaw B. This also defines naturally *left* and *right* translation. An '$\times$' in the sensor state indicates that the corresponding beam is interrupted. Also we have a *current direction*, which is clockwise initially, and the initial position is such that the object is somewhere between the gripper jaws.

For example, at the beginning we are in state 0 and the gripper closes until either state 1 or 2 is reached. Then a small translation occurs and immediately we are back in state 0 and the diameter function has decreased. An initial direction of rotation is chosen arbitrarily, which might be reversed in state 8. It is relatively straightforward to conclude that our reactive

[2]By definition, diameter function $d(\theta)$ is the length of the projection of the object on a line that forms an angle of θ with the x-axis. Antipodal points pairs correspond to local maxima, and local minima correspond to possible grasps.

Algorithm 1

State	A_2	A_1	B_1	B_2	*Action*
0	$\cdot$	$\cdot$	$\cdot$	$\cdot$	close the gripper
1	$\cdot$	$\times$	$\cdot$	$\cdot$	move up
2	$\cdot$	$\cdot$	$\times$	$\cdot$	move down
3	$\cdot$	$\times$	$\times$	$\cdot$	rotate in current direction
4	$\times$	$\times$	$\times$	$\cdot$	move up (parallel to jaw before previous rotation)
5	$\cdot$	$\times$	$\times$	$\times$	move down (parallel to jaw before previous rotation)
6	$\times$	$\times$	$\cdot$	$\cdot$	move up
7	$\cdot$	$\cdot$	$\times$	$\times$	move down
8	$\times$	$\times$	$\times$	$\times$	On first entry: reverse rotation direction, rotate Otherwise: stop

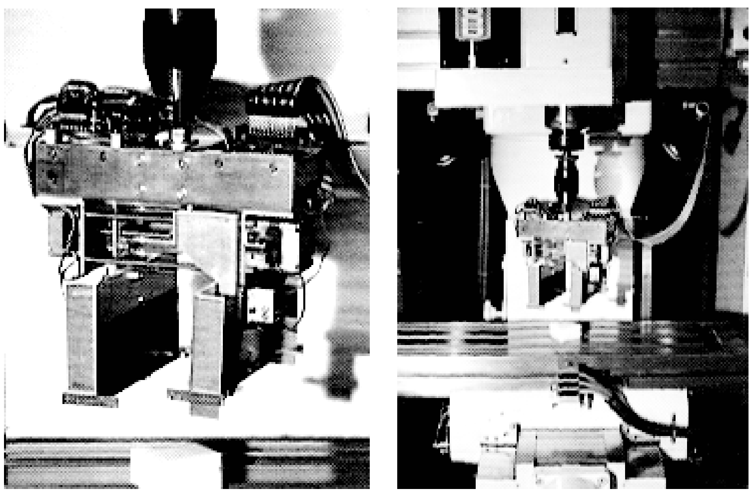


Figure 2: Reactive parallel jaw gripper.

gripper always terminates with a grasp at the contact points determined by the closest local minimum of the diameter function subject to a limit imposed by a small resolution error. More details can be found in our paper [12].

3 An Implementation

3.1 The Setup

We now describe the construction of a prototype of the parallel jaw gripper with sensors and an implementation of the reactive algorithm. The gripper was mounted in the chuck of a robotic milling machine, MOSAIC, developed at New York University [1]. A picture of the gripper alone and mounted on MOSAIC can be seen in Figure 2.

The MOSAIC machine is a three-axis, knee-type milling machine with pulse-width modulation motor drivers. It has a horizontal table which can move horizontally in two (xy) directions, and a spindle which can move up or down (in the z direction), and rotate around a vertical axis. Its motion controllers are installed in a VME chassis housing a 68020 CPU. The VxWorks real-time operating system runs on this CPU. The controllers can also servo the machine tool spindle. This is the special feature of MOSAIC which allows us to use it instead of a robot arm, since this particular application was of immediate interest independently. The only difference is that it is the table which moves, instead of the arm.

We augmented the existing software to contain an implementation of the algorithm explained earlier. The motion primitives which we used were only absolute and relative moves, for the table and for the spindle, and an *abort* command which stopped the currently executing move command.

3.1.1 The Reactive Gripper

Our gripper consists of three main components. A Motorola MC68332BCC single board micro-controller with 64Kb of memory and 'Time Processor Unit', a custom interface board between the micro-controller and the gripper hardware, and the gripper hardware itself. The micro-controller is connected through a 9600bps line to the VME computer.

The gripper itself consists of two platforms or 'jaws' which can move *independently*. Let us assume that the motion occurs in the xy-plane. This is in contrast with most existing grippers, and can be used to advantage to reduce the number of interactions between the gripper micro-controller and the robot. It also allows more precise control over jaw position relative to the object to be grasped. Figure 3 illustrates the design and shows some of the dimensions.

On each jaw a pair of infrared LED's (Motorola MLED 930) is mounted on one side, and a pair of infrared photo-transistors (Motorola MRD 300) is mounted on the other side, as depicted in Figure 4(a). This setup allows us to implement four light-beams, two parallel and two crossed, as depicted in Figure 1. We do this by turning on each LED in sequence and reading the level of infrared radiation arriving at the photo-transistors. In the current implementation, we do not use the crossed beams, however. The photo-transistors' output are read through an 8 channel, 12 bit, serial analog to digital (A/D) converter (Maxim MAX186) connected directly to a serial channel of the micro-controller. A patent for this gripper and the algorithm was applied for by NYU [14], and was allowed in January 1996.

The software running in the micro-controller, which we have written, reads the A/D outputs periodically, at a frequency of 2kHz in the background, using a periodic interrupt feature of the Time Processor Unit of the MC68332BCC. The use of an A/D converter allows us to measure "how much" a beam is broken. The distance along which this can be done is approximately 1.5mm. In other words, we can detect the presence of an opaque object between a LED/photo-transistor pair, and measure the distance of this object to an imaginary line connecting the centers of the LED and the photo-transistor, if this distance is less than about 0.75mm. The precision of the A/D converter allows us in effect to implement two (or more) parallel light beams, in the xy-plane. This is demonstrated by a simple experiment. Consider beam A1 fixed, and an opaque object is moving in a direction perpendicular to A1 and in the xy-plane. The axis of motion goes through the midpoint between the two sensors of A1. Figure 4(b) shows a graphs of A/D readings for beam A1, as a function of the distance traveled by the object. The region between 40 and 100 thousandths of an inch

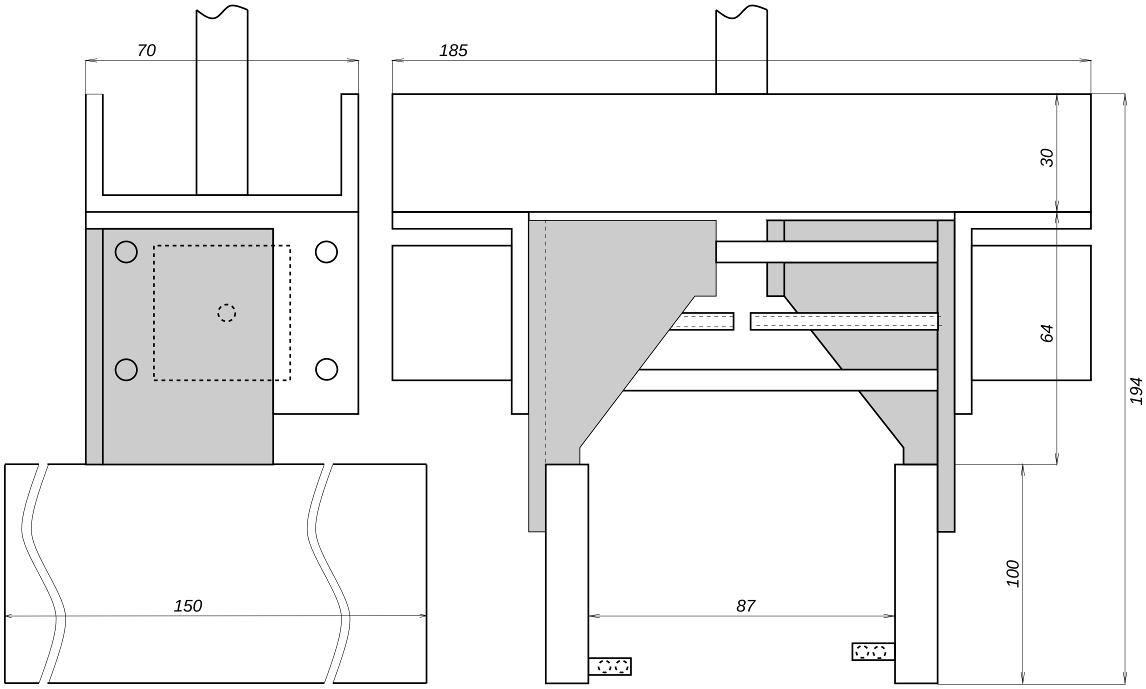
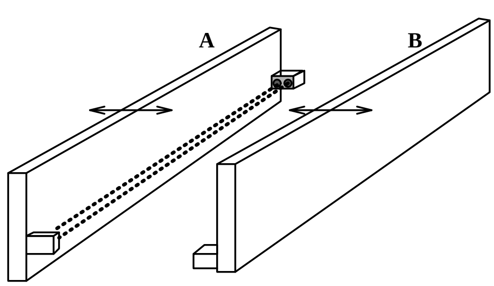
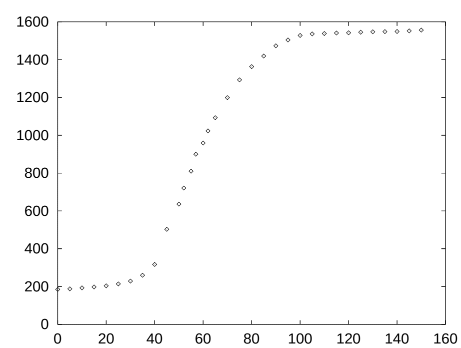


Figure 3: The reactive gripper.



(a) Light beam setup.



(b) A/D readings per distance traveled (10^{-3} inch).

Figure 4: Infrared light beams.

can be used for implementing the multiple beams.

The platforms are driven by two TEC type SPH-35B-12TBR stepper motors with a resolution of 1.8 deg/step. The stepper motor shaft is a threaded lead screw which drives the platforms. The combined axial travel of both fingers is 87mm. The interface to the stepper motors and to the A/D is mounted directly on the gripper. The micro-controller is sufficiently small to be also mounted on the gripper, which would permit a minimal interconnection between the gripper and the robot: a serial line and power. This is not currently done however.

The software running on the micro-controller monitors the status of the beams, and outputs through the serial line any change of status. It can also respond to queries about the status, and other commands such as *open* and *close* jaws, *follow object* (the light beams, hence the jaws, constantly track the object boundary), *initialize* (the jaws are opened until limit switches activate to zero position counters), and others. Another command is to close (or open) until a change in the beam status occurs. This is the command we use to implement the reactive algorithm. When the change occurs, the beam status is output on the serial line. The software on the VME computer monitors this information, and follows the table given in the preceding section. For example when a rotate state is entered, an appropriate rotate command is performed on MOSAIC. When the light beams change status, an abort is performed for the rotate command.

The *follow object* command can be used to obtain the shape of (the convex hull of) the object, since any change in the jaw position is reported. This information, along with the current position of the gripper can be combined in a trivial way to obtain an approximation of the shape. At present, we have not conducted experiments to determine the precision of the resulting polygon.

3.2 The Experiment

In this experiment, the distance between the two light beams on each jaw was quite large (0.8mm). The main difficulty encountered was a non-trivial amount of jitter in the spindle axis. This can be attributed to the fact that the controller for this axis is optimized for torque control and not position control. This caused the light beams to constantly change states, which is a problem only in state 8. Averaging successive readings and incorporating hysteresis solved the problem. We kept a log file which contained, for each state transition, the x, y coordinates (in inches in the coordinate system of the machine tool), as well as the orientation of the gripper (in revolutions), and a number indicating the width of the opening between the jaws (in the number of step-motor steps). Figure 5 shows graphs corresponding to the above parameters, as a function of the transition number, for one run of the algorithm. The first figure shows the initial position of the object with respect to the gripper. The initial direction of rotation was clockwise. We can see that there is an initial approach where the gripper (actually the table) is only translating (state 1)—this corresponds to the straight horizontal segment in the position graph. This phase is followed by a set of rotations with some translations, and then state 8 is entered for the first time and a reversal occurs, at transition number 159. Finally the gripper quickly reaches the other side of a valley in the diameter graph when the second transition (number 215) to state 8 occurs. We ran a number

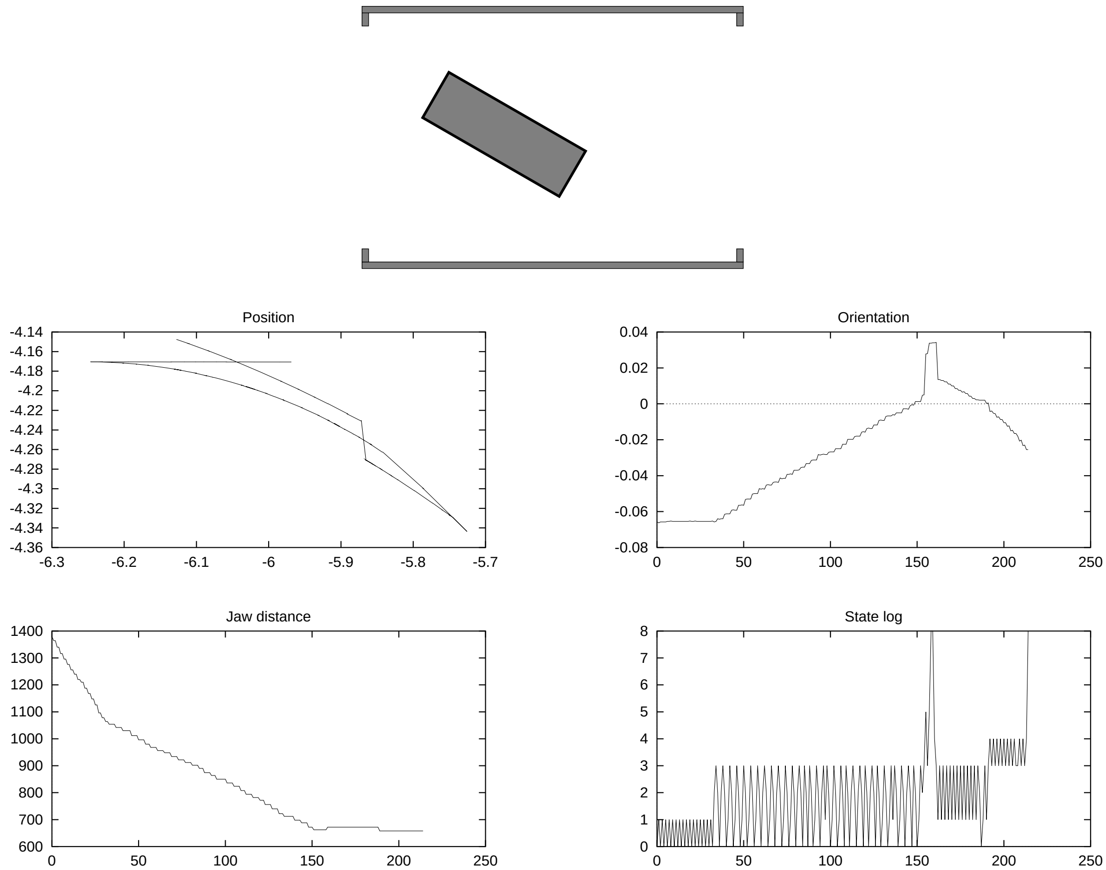


Figure 5: One run of the reactive algorithm.

of similarly successful experiments on differently shaped objects.

The *follow object* command also works well, as this requires much reduced interaction between the gripper and the machine.

4 Conclusion

We have presented simple algorithms for finding a grasp of a thick planar object using a modified parallel jaw gripper. These modifications are simple and obviate the need for complex vision systems. This is one of the first attempts at producing robot manipulators that know how to grasp by themselves, feeling the object first, but only to the extent it needs to grasp the object. We have constructed such a gripper, and the algorithms performed as expected.

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