Bin Picking with Proprioceptive Agile Robotic Gripper Chris Duncan, Kelly Kral, Nathan Rukavina

Introduction

Today's robots excel at limited tasks. Ever-changing products with shorter life cycles demand significant programming and mechanical engineering resources [1]. Typically, a robot gripper is engineered to handle only one, or a small handful, of parts. Almost all industrial robots use grippers based on a pneumatic actuator or vacuum cups. These components typically operate with two discrete states: "Gripped" and "Ungripped", which dramatically limits the variety of shapes they can grip. By contrast, humans can manipulate almost any small object with ease and they currently perform factory jobs that require a careful handling of parts in unstructured environments, such as bins or totes.

A variety of grippers have been created to meet the different needs of factories looking to capitalize on robotic gripper technology [2,3,4,5]. Unfortunately, many of these grippers are unsuitable for current use on a mass scale. Some grippers are large and intricate, and are therefore very susceptible to malfunction. All are expensive to repair. These factors deter many prospective companies from investing in this new, innovative technology.



Automation cost and complexity are reduced by simplifying human/machine interaction. Proprioception and many degrees of freedom enable randomly oriented parts to be bin picked after matching via 3d vision.



Typical bin picking use cases for proprioceptive gripper

Objectives

This project seeks to do for robot grippers what robotics did for material handling. That is, to provide a general purpose, field programmable mechanism to perform a wide variety of tasks. The primary objective of this project is to automate a gripper while keeping these standards in mind. This can be achieved through multiple implementable tasks:

- A direct feedback mechanism on each axis independent of the drive system through magnetic angle sensors
- A tensioning system that utilizes tendons to move finger joints and relay object weight information
- A user interface that allows for increased maneuverability and accuracy of the gripper

Approach

The gripper design used a system of tendons and stepper motors to rotate the finger joints. Stepper motors can spin freely and provide massive holding torque. The tendons are made from 0.46 mm diameter Nylon thread that has a 440N breaking strength. Tests conducted on the tendon material measured a strain of less than 3% (5mm / 1828mm).

Tendons are routed through grooves in the fingers to allow for opposing lateral movement. Each finger joint is powered by its own stepper motor. During testing it was discovered that the coefficient of friction for the 3d-printed material was too low, causing slippage of the tendon material. Special four-link inspired tensioners were added to increase the sling angle (α), thus increasing the friction.



The Capstan Equation provided inspiration for adding tensioners to each tendon that dramatically increase the torque realized at each finger joint by preventing slipping around the pulleys.

Hall effect sensors are used to directly measure the angle of each finger joint by sensing changes in the magnetic field from a stationary magnet. An Arduino microcontroller requests data from each sensor. The AccelStepper library in Arduino is used to provide acceleration, velocity, and speed control of multiple stepper motors. A C# application gives high-level commands to the Arduino (move to position) and provides a common interface for an operator to move any axis.

A 3-axis gantry was built to move the hand, as no robot was available for mounting. To allow for further experimentation, a laser line scanner was constructed on the gantry system. This uses the Halcon machine vision library, a line laser, and a machine vision camera to reconstruct a series of slices of the area under the hand. Halcon provides 3d matching capabilities that allow the system to guide the hand to parts placed under it and perform various manipulation tasks.



Sheet of Light 3d scanner.



Robotiq Adaptive Gripper, Barrett Hand, Schunk SDH Hand, Schunk S5FH, DLR Hand II



Test platform with gripper (a), 3d sensor (b), X, Y, and θ axes



Scan of a sample part using the Sheet of Light scanner.

Results and Discussion

Hall Effect sensors allowed for joint motion feedback that was both accurate and rapid enough enable closed-loop control of the stepper motors. Mechanical design iterations drastically lowered the coefficient of friction in each joint, making movements much smoother and more efficient. Routing the tendons and maintaining their tension proved far more difficult than expected, requiring additional tensioners and many iterations of pulley designs and tendon routing.

Incorporating a multi-axis gantry to simulate the movement of a robotic arm gave a realistic test and evaluation of the gripper design. The inclusion of a 3D scanning system increases the perception capabilities of the system to near that of a real industrial automation cell.



Gripper CAD model illustrates sensing at each joint (a) and drive system (b).

Conclusion

In order for a gripper to compete in an industrial market, actuation is essential. A system of routing tendons as a connection between joints and motors proved to be an inexpensive solution. However, the design brought about various issues concerning tension and friction. Addressing these issues required the development of new mechanisms that increased the complexity of the original concept.

Accuracy is also vital for a successful gripper. Magnetic angle sensors were found to be a reliable way of gathering accurate joint positioning. Problems in electrical noise variance required the implementation of a low pass filter that effectively cancelled out the variance. Fingers of the gripper were able to then effectively communicate positioning data to the Arduino to determine an object's positioning.

The last component of an advanced gripper is its "smarts." The proprioceptive nature and agile actuation of our design allowed for in depth analysis of its motion including the use case of scanning an unknown part to better determine how to approach manipulating it. When coupled with even a basic 3D scanner, this allowed for adept movement and control when presented with a variety of real world uses, namely semi-random picking and assembly operations.

While the current design represents a noteworthy attempt at automating bin picking, several problems remain to be solved:

- 1. A 3d-printed hand is not suitable for use in a factory. The design must be further ruggedized to survive in a hostile environment.
- 2. The tendons remain the most fragile and difficult part to get right. Future efforts should concentrate on simplifying the routing, tensioning, and fixing procedures / mechanisms.
- 3. A two-finger gripper can perform assembly operations or semi-ordered bin picking, but it is of limited use for truly random bin picking. Three fingers provide much more agility. Due to budgetary reasons, a three fingered gripper was not considered, but a good two finger design may be extended to three fingers by using higher quality (lighter) materials and components.

References

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