Concept for a precise academic Gripper

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Abstract. A new, precise, scalable multi-purpose gripper system for academic research purposes is proposed. The multi-purpose gripper is intended to be easily adapted to different tasks and object sizes. The gripper system is driven by two separate motor-gear-lead spindle units, operated by a small CNC control. Software running on the CNC unit is completely open source. A novelty for a gripper in this constellation is an interlock-line that may for example be used for a safety door, allowing to stop movement of the gripper fingers and thus being capable to avoid the bruise of an operator’s finger or arm part. This paper describes the steps mechanical parts were designed and simulated to allow a lightweight concept leaving some payload even for relatively small industrial robots used in academic research. Stability of the gripper fingers was tested by pressing the gripper finger towards each other by hand while “blocking” the movement with a finger showing no visible bending effect of the gripper parts.

To test the concept of the gripper system, a first prototype is under construction. Parts of the gripper system were simulated, 3D-printed with poly-lactic-acid (PLA) and mounted to a small laboratory robot. The CNC-gripping function will be furthermore optimized and tested at the prototype.

1. Introduction

Precise gripping of very different object sizes in different fields of automation becomes more and more essential. Existing parallel gripper designs allow either small objects to be gripped or large objects to be gripped. This situation leads to many time consuming tool changes, only to adapt to a different object size. When one piece manufacturing is intended, this could lead to time losses and as a result to a decrease of productivity [1].

Many designs still use air pressure activated mechanisms [13], which need a mechanical stop to be adjusted to the object size in order not to crush down objects which cannot withstand the full gripping force. Alternatively the air pressure is regulated. At low air pressures this can lead to the effect that the gripper barely starts moving due to the static friction of the air seals of the piston.

Common electric designs use one motor and allow current control to limit gripping forces. Position control is not available, which means that the gripper fingers move towards each other until the current limit of the motor is reached.

All these concepts have in common that they do not allow precise gripping over a wide range of different object sizes and weights.
2. Goals of the concept
Several goals were attempted to reach with this concept:

Main goal is to gain flexibility in usage and convenience in programming: The proposed concept allows moving each gripper finger independently and position controlled by using one CNC axis per gripper finger. This allows asymmetric gripping relative to the tool centre point as well as very small movements of the gripper fingers.

The second goal is to alleviate the drawback of existing electrically driven grippers to do always a full cycle. This is slow compared to pneumatic driven grippers. In combination with precise positioning of the gripper, this concept allows short cycle times since it is not mandatory to do a full open-close-cycle with every grip. A partial opening, just to fit the object to grip between the gripper fingers, is the intended method of operation.

The third goal is to allow scalability: The working principle can be adapted to much smaller robots e.g. for performing small parts assembly tasks or to much larger robots, e.g. for palletizing cardboard boxes of very different sizes. The size of the presented prototype was chosen to allow usage by a 1.2kg payload robot.

The last goal is to allow easy reproducibility. This is achieved by using 3D printed parts, which can be fused on any 3D printer large enough to fit the parts onto its build plate, as well as using standard parts.

3. Working principle of the gripper mechanics
High resolution linear drives have been realized in many different varieties: Direct belt drives are used widely in 3D printers, rack and pinion drives are used in scanners and small laboratory robots.

In this project we decided to use small geared stepper motors in combination with a lead spindle and nut mechanism. This kind of mechanism theoretically allows to reach high positioning resolution (1,8 µm per half-step) at reasonable force and low weight.

The gripper fingers are mounted on a single miniature rail (Type: MGN9).

The connecting parts between the spindle nut and the slide bar (MGN9H) of each gripper finger are specially designed and simulated parts which were also 3D printed.

The gripper fingers and connecting parts are screwed on top of each other onto the slide bars.

4. Conceptual approach
Figure 1 shows the basic mechanical concept of the gripper. At the time the pictures were taken, the linking parts were not mounted. In the outlook, a picture of the complete gripper system is shown.

5. Safety analysis
Regarding the construction of the gripper, the hazard of crushing the experimenter’s fingers is very unlikely since expected forces are worst case limited by the rigidity of the rail. In the unlikely case of
the motors not stalling and the force at the gripper finger getting too high, the rail will bend and render itself non-hazardous. In this case, no actions need be taken.

Although the gripper baseplate and motor brackets are 3D printed, sharp edges would lead easily to injuries (scratches) of the experimenter’s hands and forearms. As an avoiding measure of safety, edges of 3D printed parts were rounded wherever applicable.

6. The control

One of the major disadvantages of electronics is obsolescence and components are hard to replace.

The big advantage of the small stepper motors used is that they do not need large stepper amplifier stages. Combining the advantage with the disadvantage leads to an available and optimized solution: The Arduino CNC shield [3] with an Arduino Uno and a set of A4988 driver boards combined with the GRBL 0.9 software [2] is a readily available and a cost efficient solution for tiny CNC controls.

GRBL is widely in use by many non-commercial CNC mills and in a modified form also used as motion-control backbone of open source firmware for popular 3D printers.

The CNC G-Code control commands used for the gripper are M0 (move, fast approach position), M1 (move with working speed to position) and G92 (set axis to zero).

For controlled stop of the active cycle the GRBL specific feed hold command “!” and for continuing the cycle start/resume “~”-commands are used.

For setup, the $0 and $1 commands are necessary to define the x and y steps/mm.

7. Simulations

Before fusing the parts on a 3D printer, a simulation was performed to see if these parts can withstand the maximum foreseeable forces. For each part several optimizations steps including simulation, 3D printing and system integration tests were performed. All drawings and simulations were carried out using FreeCAD [5] and its integrated FEM workbench [6].

Figure 2 shows the van-Mises-stress result for a simulated force of 50N at each of the two small mounting holes of the flange (upper part of figure 2). The aim is to detect weak points under the assumption of a torque higher than the motors can exert. The forces around these holes are less critical than the forces at the mounting holes (coloured red in lower part of Figure 2) of the bracket to the baseplate. The inner surfaces of these two holes define fixed boundary values for the stress simulations.

Figure 3 shows the van-Mises stress simulation results for an assumed force of 100N at the outermost tip of a gripper finger. “Fixed points” boundary conditions were the inner surfaces of the four small mounting holes in oblong order in the upper area of the part. Simulated Material is PLA, using the properties provided by FreeCAD FEM workbench [6].
Figure 3. Van-Mises-stress simulation for a gripper finger

Figure 4. Van-Mises stress simulation results for both linking parts

Figure 4 shows the van-Mises stress simulation results for the linking parts between the brass nut and the gripper fingers. Gripper finger and linking part are screwed on top of each other onto the sliding part of the linear rail. The inside surfaces are assumed “fixed” for the simulation. A force of 100N is assumed as boundary condition to act in spindle direction to the side surface, where the brass nut is screwed to the linking parts.

8. Experimental results
Different experiments have been conducted to see if the mechanics work as intended:

Moving one gripper finger in small steps and measuring the distance of the move was compared to the expected distance. It turned out that the number of steps/mm calculated did not fit exactly. This was expected and corrected.

The mechanical resolution of the movement of the sliding brackets expected is 1.8µm/half step. The experimentally obtained resolution is 1.93µm in average over a 45mm move. This equals 518.067 half steps/mm instead of calculated 512 half steps/mm. [12].

It was observed, that near the end of the spindle the same number of steps resulted in a shorter movement than in the middle of the same spindle. It is not yet clear whether the spindle is the source
for this inaccuracy or whether mechanical friction and errors in parallelism between guide rail and spindle is responsible for the observed effect. This point needs further investigation, although it is a common scale error effect at the extremes of travel [11].

The measured backlash when changing the direction is approximately 0.5mm.

Depending on the gripping force, the springiness observed is in the range of ±0.3mm.

Moving one gripper finger to the other until the motor stalls requires a backward movement of 2.5mm to take out the pressure between the gripper fingers. For a maximum gripping force the gripper fingers can be closed approximately 2.5mm smaller than the size of the object without losing steps.

Moving both gripper fingers with a gripped object in one direction (off-centre) works as expected. The stepper motors move perfectly synchronous, the observed difference of the “gap” between the fingers is approximately 0.02mm, which is the range of the measurement resolution of the digital calliper gauge. The off-centering capability depends on the initial gripper opening width. Each gripper finger can be moved for approximately 25mm over the tool centre point and 45mm in opening direction.

This prototype is able to grip object sizes in the range from 0mm to 90mm.

9. Conclusions
   • The expected positioning resolution is within expected range and tolerance.
     • The absolute positioning exactness depends on the adjustment of the zero point. The nonlinearity of the linear motion in this use case is within the acceptable tolerance and does not significantly influence the functionality of the gripper.
     • Grippers can be built with 3d printed components up to certain rigidity. Therefore a simple but rigid fused filament printer is sufficient, but it must be adjusted very precisely.
     • The springiness deriving from the 3D printed parts in contrast to the use of classical metal parts is beneficial for the function in two ways: firstly it allows larger tolerances of the structure and secondly it enhances the function of gripping. With this springiness the “force steps” introduced by stepping motion are smoothed. This is very beneficial when handling sensitive parts, e.g. brittle parts or partially assembled conglomerates of parts.

10. Outlook
This gripper prototype represents a work in progress. The next steps in research are:
   • Integrating the cameras into the gripper control.
   • The introduction of functional safety [4] to avoid gripping human body parts, especially fingers by using the on-gripper-camera(s) and observing the picture(s) for skin-color as described in [7].
   • Camera controlled slip detection and appropriate counter action, not using extra sensors as e.g. in [8].
   • The automation of the gripping process by using cameras for multidimensional re-positioning of the gripper relative to an object, using a different approach than [10].
   • Supporting assembly tasks by using the on-gripper-cameras as shown in figure 5. In this figure cameras and gripper are slightly twisted to the viewer for better visibility. In “working position” the cameras’ view is perpendicular to the moving direction of the gripper fingers and the gripper with attached camera beam will be mounted to a robot.
   • The bending effect resulting from the springiness of the gripper fingers could be used for force measurement when calibrated and evaluated from the camera picture. Since springiness depends on the construction, an optimized gripper finger could be specifically designed for a task where this kind of measurement might be needed. E.g. to measure counter-reactions of parts when they get gripped and squeezed might be a possible quality control application.
   • Source of the observed nonlinearity of the spindle drive must be investigated.
**Figure 5.** Principle setup for further research. Source for red and green cubes [9]

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