

PNEUMATIC CONTACTLESS MICROFEEDER, DESIGN OPTIMISATION AND EXPERIMENTAL VALIDATION

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Abstract A novel contactless pneumatic microfeeder based on distributed manipulation is proposed. The part to be conveyed floats over an air cushion and is moved to the desired location with the desired orientation by means of the coordinated action of dynamically programmable microactuators. The design was optimised by CFD (Computer Fluid Dynamics) simulations. A proof of concept prototype was manufactured to obtain experimental indications that confirmed the soundness of the solution presented

1 Introduction

Highly integrated products such as those based on telecommunication technology or precision biomedical devices require the production and assembly of microparts. Though the need for such production has increased rapidly, the scale of manufacturing systems has not changed accordingly, thus becoming inadequate. In order to overcome this mismatch the concept of microfactory has been developed. The reduction in size of the manufacturing equipment leads to an improved space utilisation, lower energy requirements, and an overall cost reduction. Moreover microfactories are characterised by easier machinery replacement and dynamic reconfigurability that grants a prompter response to changing customer requirements [1]. For further progress of the microfactory concept, the introduction of a compact mode and mechanism to facilitate transfer of work between its components is necessary [2]. The presented microfeeder aims at filling this gap: it is designed not taking a specific object as reference. The only requirement is that the object is big enough to cover a few nozzles (each microactuator has a top surface of about $300 \mu\text{m}^2$). Such design grants the device with the much needed flexibility in part feeding which allows the introduction of new parts into the assembly system with minimal reconfiguration. Ultimate flexibility in feeding would require a device capable of accepting new parts without any or, at least, with a very short pause in the production [3].

The proposed microfeeder relies on distributed manipulation to carry out the conveying task: it is based on an array of microactuators each of which is made up of four nozzles. The nozzles are closed and opened by electrostatic forces giving the possibility to move objects in four different directions. Air is provided from the lower surface of the feeder so that the parts float over an air cushion and can be conveyed without any contact. A prototype, whose design is the outcome of an optimisation process by CFD simulations, is used to prove the concept on which the microfeeder is based.

2 Microfeeding – contactless manipulation

Feeders have the function of presenting parts that were previously randomly oriented to an assembly station at the same position, with the correct orientation and the correct speed. Distributed manipulation (Fig.1) is quite a common approach for conveying microparts.

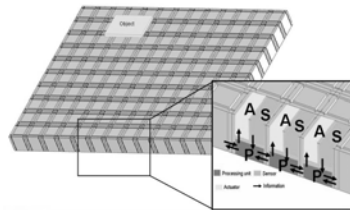


Fig. 1. Pneumatic contactless microfeeder

It is based on arrays of tiny actuators, each able to provide a simple motion. Even though the motion imparted by a single element is within a small range, it is possible to move objects over relatively long distances through the cooperation of a large number of microactuators.

Contactless manipulation is a feasible solution for microassembly because of the small size and light weight of the objects to be moved.

It is advantageous as [4]:

- Surface forces can be completely neglected
- It is suitable for handling fragile, freshly painted, sensitive micron-sized structured surfaces
- It allows the handling of non-rigid microparts
- There is no contamination of and from the end effector

3 Four directions microactuator

The microfeeder consists of an array of micronozzles. Air is used for keeping the parts suspended and moving them through the control of the micronozzles. A single microactuator is made up of four nozzles formed by a central electrode and four walls around it (Fig.2). The nozzles are opened or closed by electrostatic actuation. In neutral position the four nozzles are all open: the airflow, coming from the bottom of the microactuator, is equally divided among the four nozzles because of the symmetry of the structure (Fig.3). The outcoming airflows result in a force field that causes the micropart to hover above the microactuator (Fig.4).

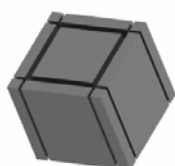


Fig.2. Electrostatic microactuator

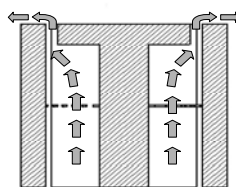


Fig.3. Microactuator - cross section

For moving the object, the central cursor is attracted towards one of the walls and the corresponding nozzle is closed. In Fig. 5 the upwards and downwards jets compensate each other hence there is a net force that pushes the micropart leftwards. A similar working principle was presented in [5]. The proposed design is advantageous because the single microactuator is more compact as it keeps the dimensions of the airflow channel constant. Moreover, movement in four orthogonal directions is achieved with a single microactuator whereas in [5] the same result is obtained combining four different microactuators capable of conveying objects in two directions only. This feature is of paramount importance as distributed manipulation becomes more effective if two conditions are satisfied: the microactuators have to be as small as possible, as their size directly affects the minimum size of the parts that can be moved, and the density of microactuators has to be high because this directly influences the position resolution that can be achieved. Hence, having smaller individual microactuators improves the performance of the microfeeder. Further details about the initial design and a sequence based on IC-compatible fabrication can be found in [6].

The performance of the microfeeder in directing the airflows when in neutral and active position was assessed by means of CFD simulations. The effect of geometry modifications on the issuing airflows was determined and the design consequently modified.

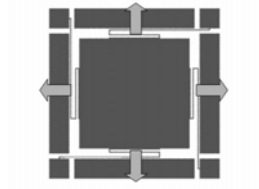


Fig. 4. Top view of the microactuator in neutral position

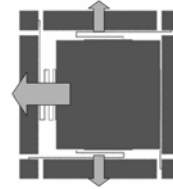


Fig. 5. Top view of the microactuator in active position

Further details can be found in [7]. The final outcome of this refinement process can be seen in Fig. 7 and Fig. 8.

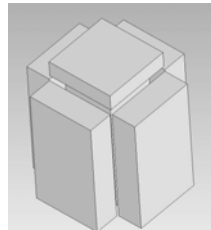


Fig. 7. Modified microfeeder design

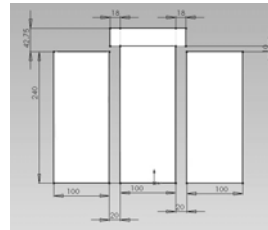


Fig. 8. Modified microfeeder - cross section

4 Experimental validation

A prototype based on the optimised design was built. The prototype is 50 times bigger than the original design and it was used to validate the theoretical approach and assess the influence the relevance of the weight and size of the part on the conveyance process.

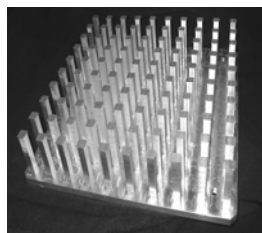


Fig.9. Prototype - central elements

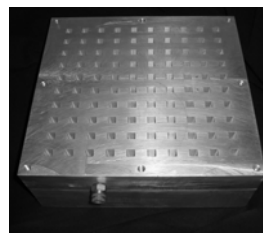


Fig.10. Prototype - side walls

As can be seen in Fig. 9 the prototype has a simplified structure in which all central elements of the actuators are connected together. Hence they move all at the same time whereas the original design requires all the microactuators to be individually addressable. The side walls which, together with the central elements, constitute the nozzles have been changed accordingly (Fig.10). In the prototype, the nozzles are 300 μm wide. The central elements are moved in two orthogonal directions by two PI M-110.2 closed loop micro-translation stages that have 0.0085 μm resolution and a maximum speed of 1.5 mm/s.



Fig. 11. Experimental testbed

Fig. 11 shows the experimental testbed. The sidewalls enclose the central elements and the motors thus creating a confined space that let the incoming air (which is provided from the sides) escape the device through the nozzles on top only. A Logitech Quickcam Pro 5000 completes the system and allows a performance evaluation of the device. For this reason, an algorithm was developed in a Matlab environment that processes the images acquired by the camera, identifies the center of mass of the part and follows its movement during the conveyance.

Because all the information about the part movement is obtained by image processing, it is expressed in numbers of pixel. For this reason it is necessary to determine the value of each pixel in the acquired image. The part conveyed is a flat dark (so that it stands out against the light background of the microfeeder surface) square component with an area of 0.001289 m^2 (measured with a Mitutoyo Absolute Digital vernier caliper). The same area expressed in pixels after the image processing is 2292 pixels². Hence the following relation stands:

$$1 \text{ pixel} = 750 \mu\text{m}$$

A certain level of approximation has to be taken into account considering that the camera is not perfectly perpendicular to the microfeeder surface and that there is a certain distortion in the image acquired. However these effects are negligible and

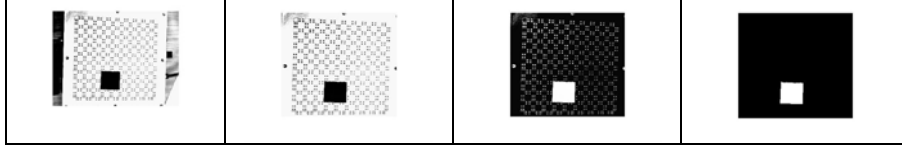


Fig.12. Image processing

the correct value is not too far from the one calculated. Fig. 12 shows the different stages in the image processing. The acquired image is cropped in order to remove the portions that do not belong to the microfeeder and therefore reduce the computational time.

This, together with other programming improvements, has reduced the computational time per loop to about 0.1 seconds. The part is then identified by creating a negative of the acquired image and by a thresholding operation that cuts out the connected areas whose value is below a certain figure which was experimentally determined.

To further assess the accuracy of the vision system a series of measurements were carried out leaving the part on the microfeeder surface without any air being supplied. Ideally the values of the coordinates of the centre of mass should remain constant throughout the whole measurement. In fact the values obtained from image processes are quite constant. The standard deviations s_x and s_y respectively for the x and y coordinate of the centre of mass were calculated as follows:

$$s_x \approx 60 \mu\text{m} \quad s_y \approx 70 \mu\text{m}$$

These values are low enough to consider the error coming from the vision system negligible.

Measurements were carried out with the central elements in neutral position (Fig. 4). The part behaves as expected: under the action of an equal number of forces pushing in opposite directions, it maintains its position. Fig. 13 shows the variation of the position of the centre of mass of the part in the case of a test in which the image processing loop was repeated 30 times. The origin of the axes is in the top left corner in order to match with the frame of reference associated with the acquired image. The variation along x is around 10 pixels corresponding to 7.5 mm whereas the variation along y is around 8 pixels corresponding to about 6 mm. These values are fully acceptable considering that at this stage the microfeeder is operated in open loop and the inevitable instability due to the transfer of shear stress from the impinging airflow to the part.

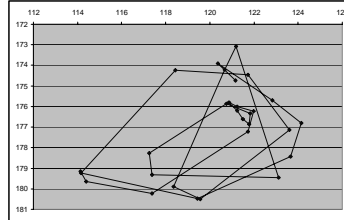


Fig. 13. Mapping of the variation of the position (expressed in number of pixels) of the part's centre of mass with central elements in neutral position

The following step was assessing the capability of the microfeeder transporting the part along a linear trajectory. Fig. 14 shows the results in a case similar to that shown in Fig. 5. The central elements are moved towards the right hand-side so that there is a resulting force that pushes the part towards the left. As expected the part moves towards the left along a linear trajectory.

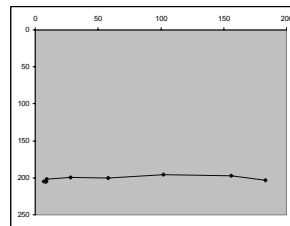


Fig. 14. Tracking of the position (expressed in number of pixels) of the part's centre of mass with central elements in active position

5 Conclusions

A new pneumatic microfeeder based on contactless distributed manipulation was presented. The initial design was refined by CFD simulations. A proof of concept prototype was built and used as a testbed to collect experimental results that confirmed the validity of the proposed solution. Future work will entail the use of closed loop control based on image processing to compensate for the instability that characterises the motion of the part due to the transfer of shear stress from the impinging airflows. The outcome of these further investigations will be reported in due course.

Acknowledgments

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