Automated robotic assembly of complex workpieces from tipped components forms

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Abstract. This paper deals with the automated robotic assembly of complex casting molds from components of regular shape. It addresses the issues of model decomposition and assembly sequence taking into account particularities of the gluing process and shape features. The decomposition parameters were determined by several approximation experiments. The obtained results validated via simulation and experimental study dealing with the assembly of particular workpieces with UR10e robot.

1. Introduction
Lean manufacturing progressively replace conventional materials by new ones that provide essential advantages from the point of view of mechanical properties of the final products and material re-use. One of such process is producing casting molds from model plastic instead of commonly used wood. Producing casting molds from the wood requires permanent presence of skilled an employee in the working zone while production process and that production can be hardly automated. Process automating is a common trend in industry given a possibility to decrease product manufacturing cost [1], which is very important for heavy metallurgy and engineering industry. This paper will be devoted to automation of casting mold production from re-usable model plastic.

Using robots in the casting mold production gives us a possibility to decrease production time and, consequently, product cost. Firstly, it is possible to use reusable material like special model plastic. Plastic will be a reasonable choice because manufacturers can melt shavings from milling, old casting molds and other plastic garbage into new forms. Secondly, an automated robotic complex is capable of building such molds independently without any employee present during the production process; the only requirement is providing enough material to the system. Also, the automated robotic complex may work faster because its performance can be much higher than a human’s one due to robot sustainability, hence their higher production accuracy. Thus, using reusable material and automated complex will optimize manufacturing, decrease production costs and increase production accuracy.

This paper deals with casting mold approximation with typical components and further assembly of complex workpieces [2], which will be subject to machining [3] at the final stage to get desired form. It propose an approach that relies of the automated control program design for industrial manipulator based on the specified technological task and sequence of motions.
2. Materials and research methods
There is one of the ways to create the automated robotic complex to solve the problem. The whole solution exploits regular shape components from the model plastic [4] with further milling processing [5].

This problem can be divided into several tasks:

- Scanning the shape of the complex workpiece;
- Determination components positions at the workpiece according to the shape and size of regular components. Obtained components should cover all workpiece;
- Determining assembly sequence according to the prepared model;
- Assembling workpieces by determined sequence. For the assembly, it is reasonable to use a manipulator and also we should determine the initial position of each regular component.
- Determining faces which should be covered with glue;
- Milling assembled model in order to obtain the final shape of the form.

There has been used industrial manipulator by Universal Robots [6]. Universal Robots UR10e is used as industrial manipulator. This is collaborative robot, hence it is user-friendly. Therefore humans might interact with robot with decreased risk. This manipulators can be simply accommodated with external control. They also move convenient to control from PC than KUKA or Fanuc and easy to integrate with ROS. After approximation is over robots stats manipulation typical components sequentially. Manipulation starts on their initial positions and end on the target places.

The kinect sensor was also used in work. It was desired to use because it combines camera and depth sensor. These sensors require to determine initial positions of the typical components. Camera is used as multi colour filter to remove external objects and also remove some noise. Depth sensor is used to determine typical components positions and the heights layer of them.

The robotic work-cell for assembly complex workpieces consists of industrial manipulator (UR10e manipulator), camera and depth sensor (Kinect) and laptop to control this system. Control system will select an appropriate algorithm taking into account current and final states of assembly.

To cover required tasks the system requires the following steps:
- Obtain target 3d model of complex workpiece (example is given in figure 1a). Target 3d model should be presented as stl file. There are no limitations to the form of the initial object, but there might be some limitations based on typical component shape. The shape of the typical component during described implementation will be a box.
- Approximate it with a set of typical components combined in a 3D binary array;
- Determine assembly sequence and specify the planes where the glue is required;
- Dynamically get positions of typical components in the stock by Kinect;
- Program manipulator according to the determined typical components position and assembly sequence. Figure 1 (b) presents final assembly for the example of workpiece given in figure 1 (a)
2.1. 3D object approximation

The 3D object approximation consists of several steps. First step requests stl file with an object shape (figure 2 (a)). The object shape is a mesh with consists of several triangles. For every triangle in the mesh there is a normal vector. This vector is used to determine internal and external surfaces.

Now we are able to approximate given model. Model commence slicing from bottom. It happens because higher layers should know base to determine glue. There are several layers \( Z \) of the approximated model:

\[
Z = \left\lfloor \frac{H}{h} \right\rfloor
\]

(1)

Where \( H \) — height of the 3D object, \( h \) — height of the typical component. For every layers there is several \( z \) slices. Several slices requested to reduce error of approximation. It allows us to detect some protrusions in one layer. Hence, the 3D object approximation will be have better quality.
There is an algorithm to make each slice. Firstly, we are going to determine the triangles (figure 2 (b)), which are intersects with horizontal plane at given height.

Next step is get intersection of the all picked triangles with horizontal plane. It may done by simple intersection two planes. After that, slice becomes a 2d body. This body consists of several lines (figure 3 (a)).

Based on the shape which is box and dimensions of the typical component there is a possibility to convert intersection. Intersection is going to be converted in to binary matrix, where point means that this is down left point of the square. The square is a projection of the typical component to the horizontal plane. The slice for given height is done.

Another operation is to combine z slices for one layer to get binary layer (figure 3 (b)). There is an “or” operation by elements during combining z slices.

After all layers are approximated there is a circumstance to combine them in to one 3D array (figure 4) which represents approximated 3D object. The 3D object approximation is finished.

Figure 3. One layer convertions.

Figure 4. Approximated 3D object.
Sequence generation

Sequence generation is necessary for getting information about typical components order. Based on the order it might be easily determined sided of the components which should be covered with glue.

In order to simplify realization we begin from bottom level, top left corner in the level. This approach provides us the simplest algorithm. The figure 5 demonstrates graphically described above algorithm.

![Figure 5. Building sequence direction.](image)

For the second and higher layer there is one more requirement: typical components should be installed firstly on the cubes which already installed. In other words, there is no possibility to install components in air, without any connections.

| x   | y   | z   | back | front | left | right | top | bottom |
|-----|-----|-----|------|-------|------|-------|-----|--------|
| 20  | 200 | 0   | False| False | False| False | False| True   |
| 30  | 200 | 0   | False| False | True | False | False| True   |
| 40  | 200 | 0   | False| False | True | False | False| True   |
| 50  | 200 | 0   | False| False | True | False | False| True   |
| 60  | 200 | 0   | False| False | True | False | False| True   |

According to the table 1, the coordinates \((x, y, z)\) demonstrates position of the center of the typical component in centimetres. The “back”, “front”, “left”, “right”, “top”, “bottom” demonstrates the faces of the component to get knowledge about glue.

### 3. Results and discussion

After loading model and setting all requested parameters, the approximation is stated. After this, robotic system starts implementing required model. This was done by using desired building sequence. Moreover, it demonstrates some shifting of the component. This shifting indicates that this is place to apply force. This force is used to achieve better adhesion which has been made with glue.

In this study there will not considered ”scanning the shape of the complex workpiece“ and ”milling assembled model in order to obtain the final shape of the form" items for general algorithm.

In order to implement and proof and algorithm typical components is presented as a cube. Therefore approximation algorithm is also has been simplified in term of rotation of the components is not necessary. It also do not affect to the anything.
Another simplifications were made for typical components detection. There is a requirement that Kinect should be installed horizontally and cube projection on the image should be parallel to the borders of image. These simplifications will be fixed during modifying initial positions determinations. It might be done as a cloud of points and adding the highest plane determination.

4. Conclusion
Over the work on this paper, an automated robotic assembly of complex workpieces from tiped components forms was developed. This robotic system included universal robot UR10e and Kinect. The main limitation is connected with typical component detection. It can be solved by using cloud of points and calculating planes dynamically. Another limitation is connected with gripper type. The possible improvement is modify gripped to neglect described problem.

References
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