Digital Human Modeling and Applied Optimization, Vol. 46, 2022, 120–127
https://doi.org/10.54941/ahfe1001908

Grasp Planning of Unknown Object for Digital Human Model

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ABSTRACT

This paper presents a grasp planner for unknown objects grasped by a Digital Human Model (DHM). This grasp planner considers the final DHM posture when choosing the preferred grasp. This is particularly useful to have plausible DHM posture. This grasp planner is part of the Smart Posturing Engine (SPE^{TM}) framework, which automatically places and posture DHM in a 3D environment, and focuses on grasping object in a virtual manufacturing context. This grasp planner is implemented in Dassault Systèmes/DELMIA "Ergonomic Workplace Design" application that helps manufacturing engineers design safe and efficient workplaces.

Keywords: Manufacturing, Digital human model, Grasp planning, Posture prediction

INTRODUCTION

Digital Human Model (DHM) offers the unique possibility to simulate worker task in a 3D environment. This is particularly useful in the manufacturing world, allowing to detect ergonomic problems before production lines are built. This does not replace traditional ergonomics, but can help detect problems in the virtual stage of the design phase to avoid costly changes on the production line in the real world.

Today, different DHM are available in commercial products: DELMIA Ergonomics (Dassault Systemes), Jack™ (Badler 1999), Santos® Pro (VSR 2004). (Zhou et al. 2009) explained that the biggest challenge in DHM applications is the low efficiency of the manikin positioning in 3D, due to manual posture creation, moving each joint separately, which is a very time-consuming process. Jack and IMMA proposed methods to automatically posture a manikin in a 3D environment (Cort 2019) (Hanson 2014). The posture prediction process is not fully automatic because the user must place the manikin close to the object manually before resolving the posture. However, this is a step forward to reduce the manikin posturing creation phase.

Dassault Systèmes released a new application called "Ergonomic Workplace Design" (EWD) that aims at helping manufacturing engineers to design safe and efficient workplace in 3D. The Smart Posture Engine (SPE^{TM}) technology was developed to reach that particular goal. The SPE is a framework that performs an autonomous posturing of a DHM based on minimal user inputs (Lemieux et al., 2016; Lemieux et al., 2017; Zeighami et al., 2019).

This paper focus on the grasp planning part of the automatic posture generation. (Bohg et al. 2013) divided the grasp problem depending on three objects categories: 1) known objects, 2) familiar objects and 3) unknown objects. Known objects are those for which grasps have already been defined. Familiar objects are new objects that can be grasped in a similar way as defined in first category. Finally, unknown objects are objects on which there is no prior grasp definition.

As mentioned by (Zhou et al., 2009), grasp planners usually try to find the best hand location on the object without considering the final digital human posture. This may end up in unrealistic final postures when reaching for the object.

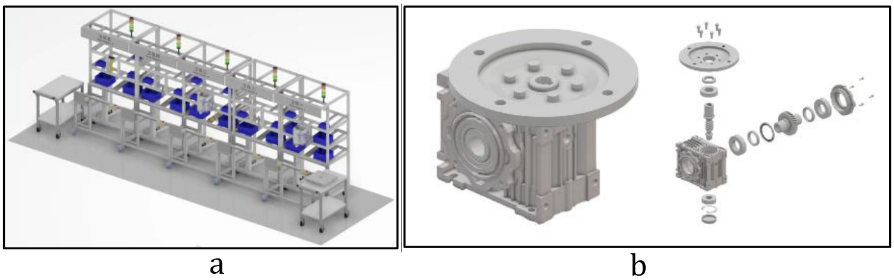
In a previous paper, a grasping algorithm has been developed to automatically grasp tools, which belongs to the first category of known objects (Bourret et al., 2019). The objective was to have a better DHM posture when grasping tools by allowing a range of motion to the hand on the object. An initial algorithm has been proposed to automatically find grasping cues on familiar tools, allowing the grasp planner to grasp familiar objects (Macloud et al., 2019; Macloud et al., 2021).

The present work introduces a complementary grasp planner for single-hand grasp on unknown objects, further referred as "part". Like for known and familiar object, this grasp planner considers different aspects of the DHM final posture when choosing the proper way to grasp the object. The objective is to propose visually plausible grasp on unknown objects in a manufacturing context.

METHODOLOGY

Virtual Environment Example

This paper proposes a methodology to grasp unknown objects in a manufacturing context. Unknown objects are parts that compose the product assembled on the production line. To explain and test the proposed grasp planning methodology, the following virtual production line and product will be used (Figures 1.a, 1.b).



a b

Figure 1: a - Virtual production line used to demonstrate the methodology. b - Virtual product (gearbox) assembled on the production line.

Inputs and Outputs

The inputs of this algorithm are: the 3D model of the object to grasp, the 3D model of the production line environment, an initial position of the DHM in the 3D environment and the hand to be used (right or left) see Figure 2.

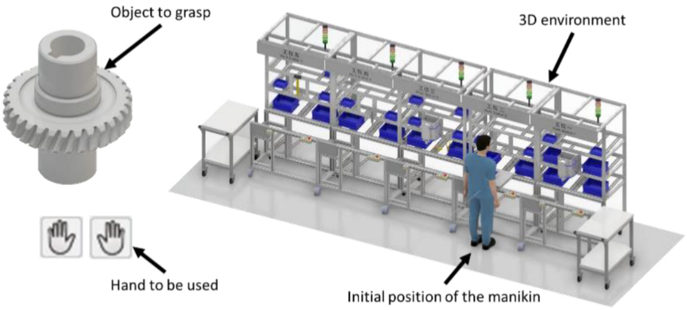


Figure 2: Inputs of the grasp planner.

The outputs given by the grasp planner are the grasp type to use and a grasp target, later explained. In solving the DHM posture, the SPE framework will use the grasp type to determine the position and orientation of the upper limb end effector, which is the hand. The end-effector will reach the target onto the object with the DHM using inverse kinematic algorithms.

The grasp planner is composed of five steps that will determine the grasp for an unknown object (Figure 3). Each step is further detailed below.

Grasp Planner

Figure 3: Steps of the grasp planner.

Bounding Box and Target Calculation

During the first step, the object is approximated by its minimum bounding box (Figure 4.a).

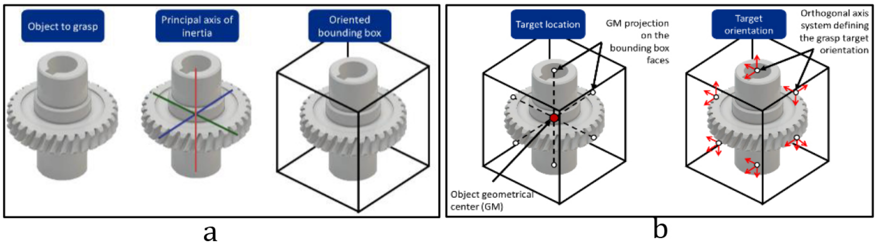


Figure 4: a - Object approximation by its minimum bounding box. b - Grasp potential targets position and orientation calculation.

To define the orientation of the bounding box, the principal axis of inertia of the object are used (Figure 4.a). A potential grasp target is then associated to each face of the bounding box. The geometrical center of the object is calculated. It is projected on each of the six faces of the bounding box. This gives the location of the grasp target. It follows heuristic that humans prefer to grasp an object close to its center of mass, probably to reduce the efforts on the joints (Bekey 1993). However, since the distribution of the mass is not available on the grasped objects, the geometrical center is used. The hand orientation for each target is defined by the orientation of the minimum bounding box.

Grasp Type Determination

(Feix et al., 2015) described a taxonomy of the different grasps that a human can do. In their work, a statistical analysis was performed for different grasp characteristics measuring the object size and weight, as well as grasp frequency for each grasp type. In the present grasp planner, three grasp types were chosen among the most used grasps to have a great coverage of the objects grasped in the manufacturing context (Figure 5.a).

For each grasp type, an open and close hand configuration are created (Figure 5.b) and are later used during the hand closure on the object.

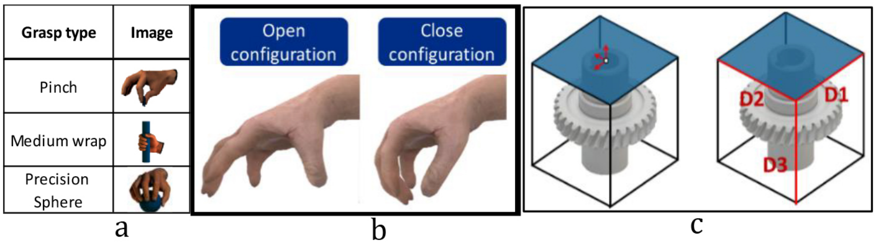


Figure 5: a – Grasp type considered in this grasp planner. b – Hand closure example for medium wrap grasp. c – Bounding box face characterization.

To determine which grasp type to choose, the dimensions of the bounding box faces are used. Figure 5.c shows that for each face of the bounding box, three dimensions can be found. First D1 and D2 are the dimensions of the face edges (D1 $\geq$ D2). Then D3 is the dimension of edge normal to the considered face.

Knowing the dimension for each face, it is possible to determine a rule defining the grasp type to use:

```
If D1 < 60mm And D2 < 35mm
    Grasp Type = Pinch
Else If D1 ≤ 90mm And D2 ≤ 90mm And D3 ≤ 50mm
    Grasp Type = Precision sphere
Else
    Grasp Type = Medium Wrap
```

To conclude, a small object will be grasped with a pinch grasp. A bigger object that has a small D3 dimension (flat object) will be grasped using a precision sphere grasp (using the tip of the fingers). Otherwise, a medium wrap grasp will be used.

Those values were initially chosen using (Feix et al., 2014) study and refined with empirical tests performed on different manufacturing parts.

Face Labeling

To be able to later rank the grasps and use heuristics, it is necessary to label the faces of the bounding box.

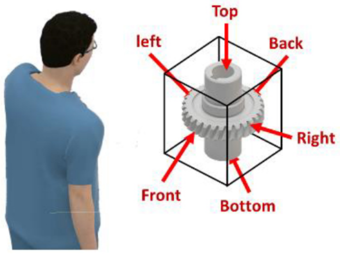


Figure 6: Object bounding box labeling regarding the manikin initial position.

Each face is labeled depending on its position relative to the manikin initial position. The six faces labels are: Front, back, left, right, top and bottom.

Graspable Faces

To determine which faces of the bounding box are graspable, two checks are performed.

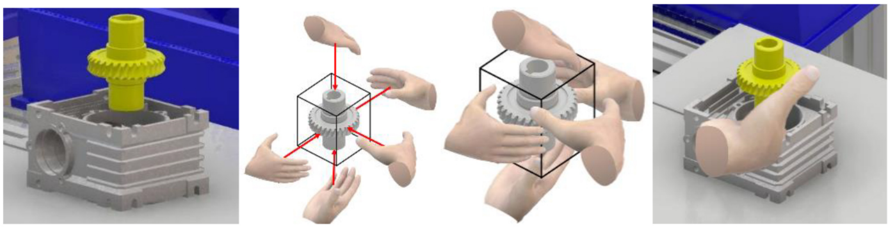


Figure 7: Collision check using isolated hand model to determine each faces accessibility.

First, the accessibility of each faces is validated. By positioning the isolated hand at the target's location in its open position, it is possible to check if the face of the bounding box is accessible. If a collision between the isolated hand and the environment around the object is detected, then the face is considered as not accessible and will be ignored at the final stage when choosing the final grasp. In the example of Figure 7, extreme right image, the bottom face is not accessible. All the other faces are still candidates for the final grasp.

The second check concerns the faces dimensions. For each of the accessible faces, if the dimension D2 > 100mm then the face is considered too big to be grasped. This limit value follows (Feix et al., 2014) observation regarding the limits dimension that a human can grasp.

Grasp Ranking

The final step consists of ranking the faces of the bounding box.

Table 1. Bounding box faces ranking.

Grasp Side	Top	Right/Left	Bottom	Front	Back
Rank	1	2	3	4	5

Table 1 shows the rank of the bounding box faces. Considering that the right hand has been chosen to grasp the object, the preferred face to grasp will be the top one. If it is not graspable (no free space or face too big), the next face will be checked for graspability until a graspable face is found (right, bottom, front, back). If no face is graspable, then the top face will be chosen.

If the left hand is used to grasp the object, then the second rank is the left side instead of the right side. In fact, when grasping an object with the right hand, the left side is considered as not graspable because it would end up in nonrealistic final DHM posture (the same is applied when grasping with the left hand).

Grasp Execution

Once the optimal face to grasp is determined, the target associated with the selected face is given to the inverse kinematic (IK) solver. The solver will match the upper limb end effector frame with the target frame (Figure 8.a). To have a more probable posture, three rotations degree of freedom are allowed along each direction of rotation of the end effector. The rotations about the Z axis was kept unlimited (Figure 8.b) while the X and Y axis were limited to some extent based on empirical tests (e.g. ±10 to ±30°). This gives the IK solver more room to find a visually plausible posture. Once the target has been reached, the hand closes on the object. The hand starts in its open configuration (Figure 8.b), then each finger is moved toward its closed configuration (Figure 8.c). When a collision is detected between the finger and the object to grasp, the closure ends for that finger. The closure continues until all fingers are in collision or until all fingers reach their closed configuration.

RESULTS

Figure 9 showcase grasps performed on a gearbox assembly line. The task consists of assembling the parts that compose the gearbox.

The examples show in Figure 9 provide a good representation of grasp that can be performed by the grasp planner with different grasp types and locations.

What is also interesting to see is the overall manikin posture. Thanks to the degree of freedom allowed to the upper limb end-effector, the IK solver has more room to find a visually plausible body posture.

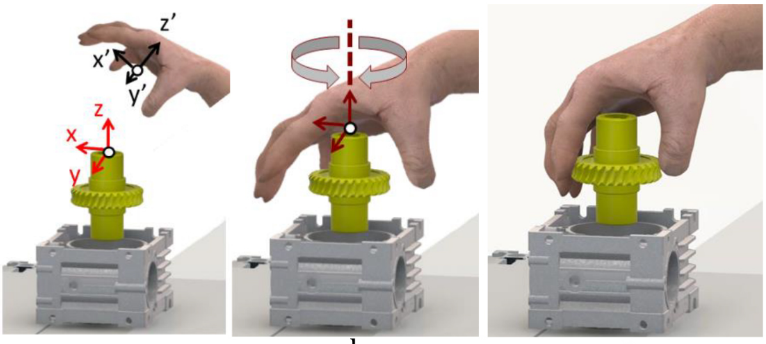


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Figure 8: Grasp execution steps: a. Target reach. b. Hand Degrees Of Freedom (DOF) on the object. c. Hand closure.

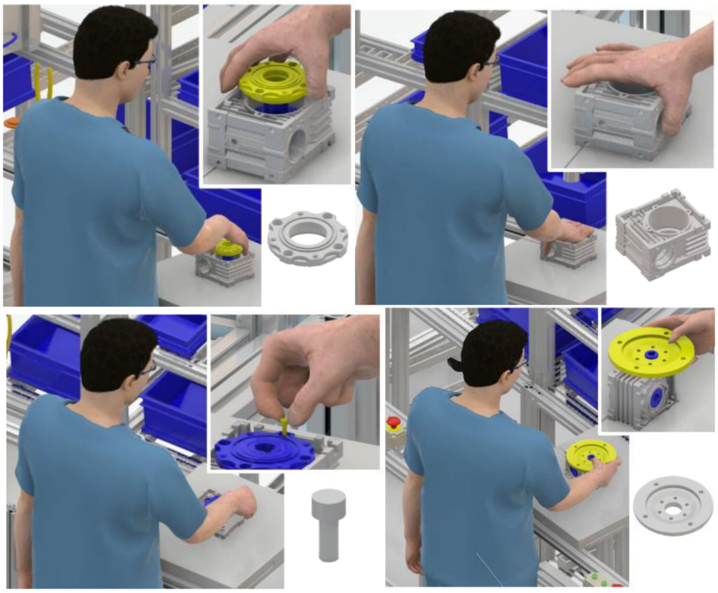

Figure 9: Examples of grasp results for different parts: a. Bearing cover. b. Housing. c. Screw. d. Flange.

DISCUSSION

The proposed grasp planner seems promising. In its current form, it is most suitable for small parts or bigger ones when they are well represented by their oriented bounding box. More complex and bigger parts may require further segmentation into multiple smaller subparts (Miller et al., 2003), allowing to perform the proposed checks at more specific locations on the object.

The present planner is used by the Smart Posture Engine (SPE) framework inside Dassault Systèmes application "Ergonomic Workplace Design". With the Ergo4All (Bourret et al., 2021) technology, the SPE allows to assess and minimize ergonomic risks involved in simulated workplaces.

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