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Porcine automation: Robotic abdomen cutting trajectory planning using machine vision techniques based on global optimization algorithm

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ABSTRACT

The purpose of this paper is to provide details on implementation of accurate and intelligent automation solution for porcine abdomen cutting while a pig is hung up by rear legs. The system developed utilized a 6-DOF industrial manipulators, customized tools, 2D camera and PC. Eye-to-hand calibrations built coordinate transformation relations of units in Cartesian space. The porcine abdomen curve was identified and fitted into quintic spline curve from image. Under cavum peritonaei constrains, optimal sectional trajectory was planned based on genetic algorithm (GA) by comparing several kinds of optimization algorithms. The results of experimental replications show that the system was successful both in following the varied position carcass and cutting open abdominal cavity without haslet damage. The system can enhance the quality, hygienic standard and efficiency of the process.

1. Introduction

FAOSTAT provided that pork has been the most commonly consumed meat worldwide and about half of the meat consumption in 2016. Due to this fact, safety, quality and hygienic standard of pork should be taken seriously. With an increasing demands from consumers for higher quality products, meat industry is always under considerable pressure to develop more efficient production systems, which can reduce production time and improve the quality of meat products (Dich-Jorgensen and et al., 2016). One way of meeting these challenges is automate processing operations. However, due to high variability of carcass size, harsh environments, and space constraints, automating processes on the meat cutting floor is very challenging. With the technical advance, meat product automation also evolves in adopting machine vision, robotics or computer technology and so on (He and et al., 2014; Miljkovic and et al., 2013; Zhan and Wang, 2012; Aviles-Vinas et al., 2016; Jiang and et al., 2015).

The porcine automation includes slaughtering, unhairing, carcass cutting etc. Abdomen cutting is pretreatment for removing male organs and guts of porcine carcass. The traditional manual process requires labor experience and consistency to guarantee haslet quality. Moreover, the contents of some organ have germs which may infect the labor (Schlink and et al., 2016; Zhang and et al., 2016). High degree of hygiene, quality and accuracy are demanded by mentioned process. Machine substitution is inevitable.

Singh provided a laser sensor measuring method in ovine brisket cutting (Singh et al., 2012). However, this cutting system didn't have adequate adaptability to variety of ovine size. Zhao provided a vision-based fruit harvesting robot which was similar to Mehta and Misimi (Zhao and et al., 2016; Misimi and et al., 2016; Mehta and Burks, 2014). They had tested and verified servo robot 3D-vision. However, they did not plan the trajectory of tool center point (TCP). Moreover, biosignature wasn't involved in their experiments. Bar developed a prototype concept system to explore robotic post-trimming of salmon fillets (Bar and et al., 2016). Although machine vision and biosignature were considered, the cutting path was planned based on characteristic points without optimization. Furthermore, machine vision has been applied in meat analysis, livestock identification and so on (Chmiel and Slowinski, 2013; Velez and et al., 2013; Xiang et al., 2014). Above-mentioned technologies have been applied on meat cutting successively but little can satisfy requirements both in quality, hygienic standard and efficiency. In order to solve the problem mentioned above, we propose a robotic cutting method using trajectory planning and machine vision techniques.

2. Materials and methods

2.1. Porcine carcasses cutting techniques

The porcine automation deals with unhaired carcass step by step. For cutting open procedure, starting point and longitudinal length are different according to the subsequent process. Cutting open procedure

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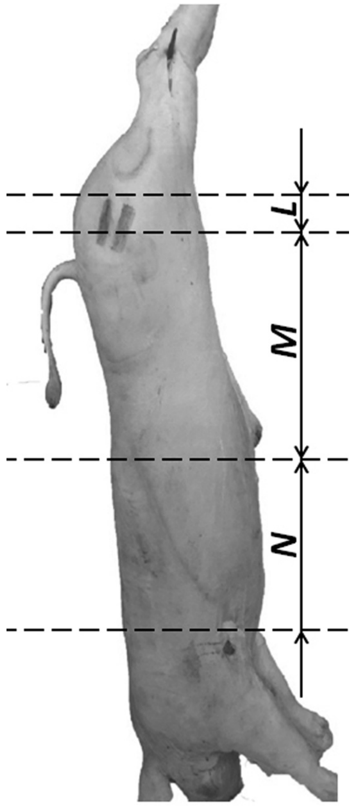

Fig. 1. Porcine abdomen cutting craftwork.

is carried out in median plane of carcass as shown in Fig. 1. Cutting *L* from anus to underbelly, this process is to dispose genital organ and urinary system. Cutting *M* from underbelly to chest, this process is to dispose tharm and other alimentary system. Cutting *N* from chest to neck, this process is to dispose viscera. The second step called abdomen cutting is selected to discuss.

2.2. Robot calibration

In order to ensure the accuracy of cutting, the robot tool coordinate system (TCS), user coordinate system (UCS) and Camera coordinate system (CCS) must be calibrated. The relationships of eye-to-hand in Cartesian space are shown in Fig. 2.

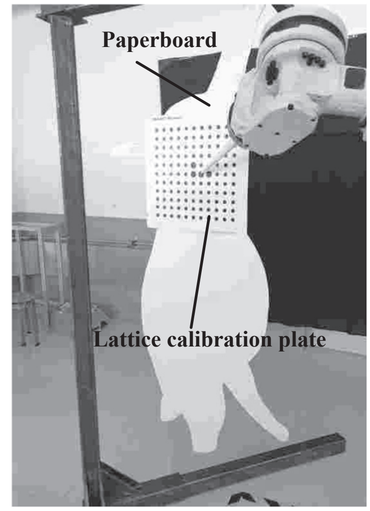

Fig. 3. User coordinate system calibration.

In Fig. 2, ${}^{t}\boldsymbol{C}$ is TCP coordinates and ${}^{e}\boldsymbol{C}$ is end-effector coordinates. ${}^{t}H_{e}$ is transform matrix between base coordinate system (BCS) and UCS. ${}^{t}H_{e}$ can be deduced from robot tool design drawing. Robot calibration establishes the relationship as:

$$ {}^{t}\boldsymbol{C} = {}^{t}\boldsymbol{H}_{e}\cdot{}^{e}\boldsymbol{C} \tag{1} $$

The median plane of carcass was set as *X-Y* plane of UCS. User frame calibration with the aid of lattice calibration plate and porcine paperboard is shown in Fig. 3. Paperboard is hung up in the plane where median plane of carcass will be.

Tool and user coordinates calibration should develop space relation between the robot and the carcass, so the hand is able to find the object. A photograph including lattice calibration plate was taken for identification. From known distances of observation points and focal distance of the camera, relation between target and camera can be established by points recognition (Fig. 4). Therefore, taking user coordinate calibration as the ligament, eye-to-hand space relations is built up.

Providing ${}^{u}\boldsymbol{C}$ is user coordinates. ${}^{t}\boldsymbol{H}_{u}$ is transform matrix between UCS and TCS. User frame calibration establishes the relationship with tool coordinates as:

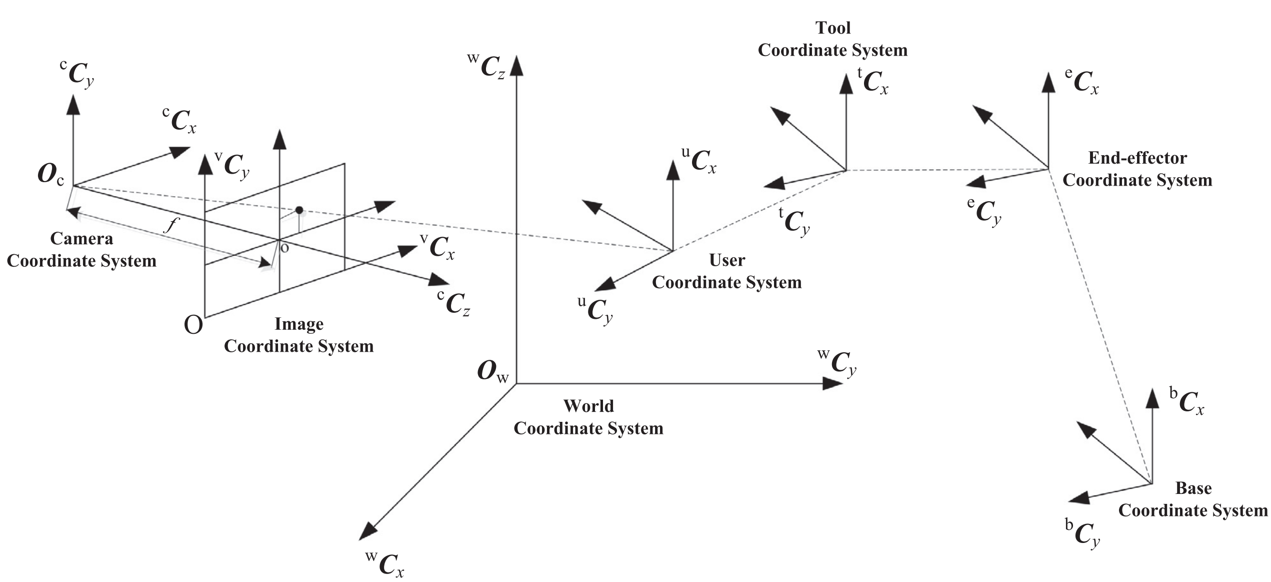

Fig. 2. The Cartesian space relationships of eye-to-hand.