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A 3D machine vision system for quality grading of Atlantic salmon

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ABSTRACT

Quality grading of Atlantic salmon (*Salmo salar*) is currently a task performed manually by human operators. To stay competitive in an increasingly global market, it becomes necessary to take advantage of technology to improve productivity and profitability. The Norwegian salmon industry sees the need to automate quality grading, in order to reduce tedious manual labor and to increase product consistency and production flexibility. A machine vision system for external 3D imaging in color, with a 360° scanning cross-section, has been developed for the purpose of quality grading of Atlantic salmon. The two primary causes of downgraded salmon are deformities and wounds. Two classifiers were developed, based on 3D geometric features and color information, to handle each of these primary causes of downgrading. These classifiers are able to detect deformities and wounds, with discrimination efficiencies of 86% and 89% respectively. This work shows that 3D machine vision can enable real-time automatic quality grading of Atlantic salmon. Many of the methods employed are general enough to translate to other species of fish or similar applications with minor modifications.

1. Introduction

One of the tasks performed manually in the Atlantic salmon aquaculture industry today, is that of quality grading. Each salmon that moves through the processing facility is separated into classes based on size, deformities and external blemishes, such as wounds. Processing these classes separately is necessary due to price differentiation and practical considerations along the processing line. Aquaculture has a great potential to grow, and will become an increasingly important resource in the future. Scaling up the production is challenging in itself, but also puts additional pressure on the processing facilities – especially the parts that involve manual labor. Automation of the quality grading of salmon will enable a greater potential for scaling up the production in aquaculture of the future.

We present a machine vision system for external 3D imaging in color, with a 360° scanning cross-section, for the purpose of quality grading of Atlantic salmon. The classes used to describe salmon are superior, ordinary and production. The superior grade is defined to be salmon of streamlined shape, and no external blemishes. The ordinary grade includes fish with minor defects such as asymmetrical shape or imperfections such a minor external blemishes. Production constitutes the class of all salmon that do not fall into the two previous categories, and is typically not used for human consumption. Approximately 90–97% of the salmon are typically classified as superior (Misimi et al., 2008). An automated quality grading system that separates out the superior salmon with a high accuracy, therefore enables a substantial reduction in the manual labor required. It also opens up the possibility of a more consistent grading than with human operators, even across separate facilities.

The cause of deformities cannot be attributed directly to a single factor. It has been shown that parasites, bacterial infections, malnutrition, incubation temperature, light conditions, water quality, pollution and genetics all can contribute toward the risk of developing such deformities in reared fish (Vågsholm and Djupvik, 1998; Boglione et al., 2014). Severe spinal deformities have various impacts on the resulting external shape of the salmon, giving rise to defects such as 'humpback' and 'short tail' (Witten et al., 2005, 2009; Fjelldal et al., 2007, 2012), which are major deformations that affect the shape or symmetry of the salmon. A salmon with visible external deformations is either placed in the ordinary or production class depending on the severity as consumers are vary of ill-formed products. Examples of superior salmon and downgraded ordinary salmon with deformations can be seen in Fig. 1.

A second defect is external blemishes, the primary cause being wounds. Wounds in salmon can appear in all sizes, and mainly occur on the sides. By the time a salmon reaches the processing stage, the wounds may have healed. This nonetheless causes a

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Fig. 1. Examples of a salmon (A) with no deformities, a salmon (B) with humpback deformity, and another salmon (C) with a short tail deformity.

downgrading of the quality due to the scarring that remains. The wounds themselves can start out as small scratches, which are then infected by bacteria, causing the wounds to expand. In waters of high salinity, such as seawater, the bacteria *Moritella viscosa* causes skin lesions (Løvoll et al., 2009). The outbreaks of that type of bacteria often occur during periods of cold water, and are for that reason called winter wounds or winter ulcers. All the wounds in the data set used in this paper can be seen in Fig. 2.

No commercial systems exist to perform a full quality grading automatically for Atlantic salmon. There are commercial systems that perform related tasks such as species identification using color and shape information from 2D imaging (White et al., 2006). Existing research use the silhouette from 2D-images to determine deformities, either using hand-crafted features extracted from the silhouette (Misimi et al., 2006, 2008) or Fourier-based outline analysis (Costa et al., 2013).

To the author's knowledge, 3D imaging has not been utilized with full 360° coverage for automatic quality control specifically, at least within the aquatic food industries. A similar solution has however been applied to automatically cut portions according to volume (Marelec Intelligent Portion Cutter, Marelec Food Technologies, Belgium). It can use multiple cameras to improve the volume estimate for round objects, but does not capture the underside of the object – thus limiting its use for color analysis in quality control. Previous automatic quality control research using 3D-imaging has been limited to one-sided analysis, using expensive commercial range-scanners with limited frame-rates (Mathiassen et al., 2006).

The 360° 3D technology presented in this work enables the quality control system not only to see what the human operators see today, but also the side of the fish that is normally obscured from view. The geometric and color information is used to detect deformities and wounds automatically. The custom camera system combines range information from three distinct high-speed cameras using a line-scanning technique to form a full 3D-image of the salmon as it travels across a conveyor belt. This approach has the benefit of making the full geometric information available for analysis, while also providing color information on both sides of the fish. The full geometric information gives the advantage of knowing the thickness of the salmon, which enables us to extract strong geometric descriptors and improve general robustness of shape analysis and deformity detection. The processing of the images acquired has been offloaded to a consumer-grade GPU, to accommodate real-time applications. Emphasis is placed on the robustness and correctness of the point cloud representation with respect to feature extraction, as well as applicability for future applications and improvements.

2. Materials and methods

2.1. Fish sampling

In April/May of 2015, 105 salmon were provided by Nova Sea AS in Lovund, Norway, and were transported in a chilled (on ice) condition using overnight freight transport. The imaging was performed at the premises of SINTEF Fisheries and Aquaculture AS in Trondheim, Norway. The salmon were gutted while fresh, and immediately frozen before transport. Of the 105 salmon, 45 were classified by Nova Sea to be of the superior class, while the remaining were downgraded. The downgraded salmon consisted of 16 salmon with wounds and 27 with deformities. The remainder of downgraded salmon had defects that were not considered in this work. The most notably defects not considered were abnormal

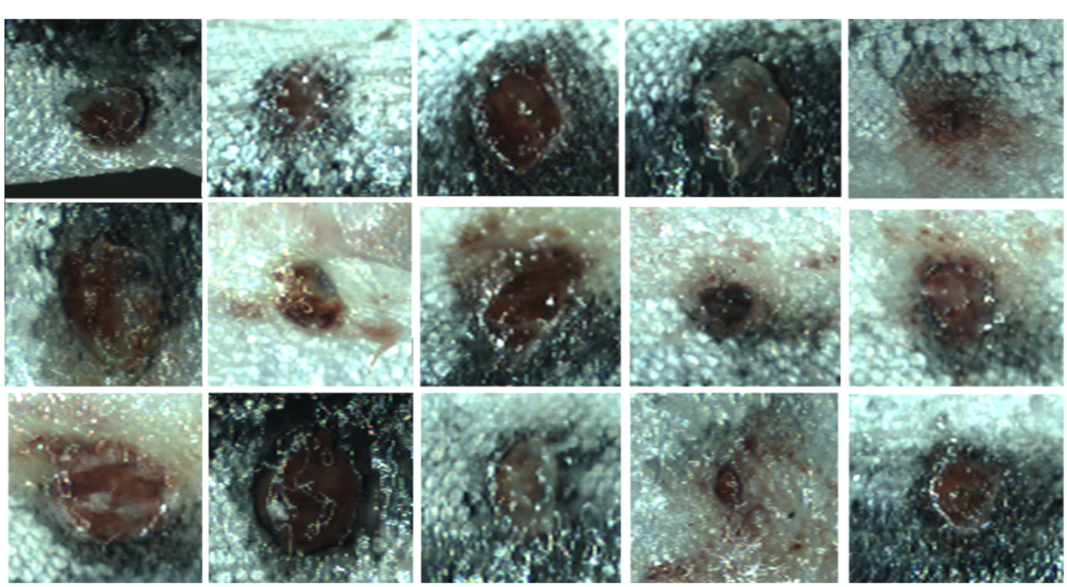

Fig. 2. Examples of wounds (winter ulcers) that result in a downgrading.