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Abstract of Thesis

Name （Prashant Kumar）	
Title	Robotic Food Handling for Automated Food Packaging （食品パッケージング作業の自動化のためのロボットによる食品ハンドリングの研究）

Food packaging is one of the most labor-intensive processes in modern industry. The growing demand for ready-to-eat meals and packaged food products has increased the need for automation capable of operating at industrial speeds while maintaining packaging accuracy, product quality, and food hygiene. However, unlike rigid industrial components, food items are delicate, deformable, and highly variable, making reliable robotic food packaging particularly challenging. More importantly, practical food packaging requires multiple sources of variability to be addressed simultaneously within a single task. Existing research often focuses on isolated challenges, whereas real-world packaging operations require robotic systems capable of handling diverse food properties, quantity constraints, and complex physical interactions concurrently.

In this thesis, food-handling variability is categorized into three fundamental groups: geometrical variability, quantity variability, and physical-behavior variability. Robotic approaches are then developed to address each of these challenges while simultaneously providing capabilities that extend beyond their primary objectives.

To address geometrical variability, a temperature-driven multi-modal soft actuator capable of bending, twisting, and extension is proposed. By utilizing multiple actuation modes within a single actuator, the system adapts to food items with diverse shapes, sizes, and stiffnesses.
To address quantity variability, a quantity-aware robotic packaging framework is developed for handling cluttered food items. Through vision-based segmentation, quantity estimation, and multi-action planning, the system efficiently picks target quantities required for packaging applications such as bento preparation. In addition to quantity control, the framework demonstrates robust manipulation of soft and irregular food items in cluttered environments.
To address physical-behavior variability, a modular bit-based gripper is proposed for handling challenging foods exhibiting granular, sticky, or entangled characteristics. By combining food-specific interchangeable manipulation bits with closed-loop weight feedback, the system enables accurate handling and dispensing of foods such as salmon roe and spaghetti. The proposed approach not only addresses complex food interaction behaviors but also provides precise weight control required in practical food packaging operations.

Although each contribution is motivated by a primary source of variability, the proposed solutions inherently address multiple challenges encountered in food packaging. The multi-modal actuator improves adaptability across diverse food geometries and stiffnesses, the quantity-aware framework combines quantity control with robust clutter handling, and the bit-based gripper integrates manipulation of difficult food materials with accurate weight-based dispensing. Together, these contributions establish a variability-centric framework for robotic food packaging and demonstrate how addressing multiple sources of variability can move robotic food packaging closer to practical deployment in real-world food manufacturing environments.

様式７

論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

食品パッケージング作業は現代産業において人手に頼る工程の一つであり、即食性食品や包装食品の需要増加に伴い、精度・品質・衛生を保ちながら高速に稼働できる自動化技術が求められている。しかし食品は剛体部品と異なり脆く変形しやすく多様性に富むため、信頼性の高いロボットによる食品ハンドリングの実現は容易ではない。本論文では、食品ハンドリングにおける多様性を幾何学的多様性、量的多様性、物理的挙動の多様性の三つに分類し、それぞれに対応するロボット手法を提案している。具体的には、温度駆動により曲げ・ねじり・伸長の複数動作モードを実現するソフトアクチュエータ、視覚に基づくセグメンテーションと数量推定を組み合わせた数量認識型ロボットパッキングフレームワーク、食品に応じて交換可能な把持ビットと重量フィードバックを備えたモジュール式グリッパーを開発し、多様な形状・数量・物理的挙動を持つ食品への対応を実現した。これらの成果は、食品パッケージングの実用化に向けた多様性中心の統合的枠組みを確立するものである。

主査、副査で論文の審査をおこなった結果、いくつかの疑問点が挙げられた。それらは主に、ソフトアクチュエータの限界、把持速度等によるソフトグリッパーの比較、食品分類チャートと各研究課題との対応関係、提案手法の産業応用可能性、トップダウン型手法以外への拡張可能性、生きた食品（活魚等）への対応などであった。審査の際に出た疑問点に関する議論を中心に最終審査をおこなった。最終審査ではKumar君は全ての疑問に明確に回答した。これにより、主査、副査全員一致で本論文は博士（工学）として価値があるものと認められた。