OFFICIAL

NORTHEAST REGIONAL RESEARCH PROJECT

PROJECT NUMBER: NE-179 (Revised)

TITLE: Technology and Principles for Assessing and Retaining Postharvest Quality of Fruits and Vegetables

DURATION: October 1, 1997 through September 30, 2002

STATEMENT OF THE PROBLEM:

The problem of assessing and maintaining the quality of fruits and vegetables limit the profitability and competitiveness of the United States fruits and vegetable producers and processors. Fruits and vegetables are subject to damage during harvesting, handling, and shipping if not handled properly. The ability to assess and quantify properties pertinent to damage is important in preventing and reducing damage and for selection of cultivars. Soft fruit is the most frequently reported physiological disorder on USDA receiving inspection forms. It is not totally clear which physical and biochemical properties affect firmness. A common approach to minimizing variability is to separate the produce into groups according to firmness. Various non-destructive firmness sensing methods have been proposed. However, they are still in the developmental stage and need further work before they can be employed commercially.

Significant progress has been made towards developing sensors to measure both the external and internal quality parameters. However, development of sensors into real time grading lines and inspection stations is the next challenge. Much of the previous work with sensors has been under static conditions and there is still more work that remains. The dynamic conditions of on-line systems introduce new conditions and speed requirements that are not inherent in the static tests. Integration of sensors into a practical, portable inspection station that can operate at the speed desired by the industry requires improvements and adaptations of modern technology.

Fruit and vegetable quality determination can be enhanced by employing modern sensing techniques. These techniques are different from classical sensing techniques in that the information is determined from signal patterns as opposed to a single signal value. Furthermore, information may be determined across multiple sensors as opposed to an isolated single sensor value. Multiple inputs entail the need for careful consideration of the signal processing step as an integral part of sensor system design. The advent of fuzzy logic approaches, the neural networks, and other advanced classifying techniques enable rapid and economical on-line implementation. The benefits of using multiple inputs are significant considering the economic premiums that are placed on consistent, superior quality in the marketplace.

JUSTIFICATION:

The fruit and vegetable industry in the United States generates over $6 billion in income annually. Domestic and foreign consumers crave and demand quality in both fresh and processed fruits and vegetables. The produce industry in the United States is competing in a world market that makes the industry vulnerable to high quality imports. Our foreign competitors have better quality control, marketing strategies, and lower labor costs that often allow them to deliver higher quality fruits and vegetables to the United States. We must develop and incorporate the best and most effective technology so the U.S. produce industry can compete globally and expand U.S. export markets especially to countries such as Japan.

Consumers are becoming more health-conscious and aware of the importance of fruits and vegetables in their diet for enhanced nutrition. Consumers are demanding consistency in maturity, textural quality, nutritional quality, food safety, freedom from bruises and damage, appearance, freshness in addition to an increasing variety of products. Unless high and consistent quality of fruits and vegetables is provided, consumers are less likely to purchase these products which would result in a loss in sales of fruits and vegetables and in nutritional quality for the consuming public.

Methods currently available for detecting quality are ineffective. Relationships between the quality attributes and the handling methods are not clearly understood. There is a fundamental lack of understanding of the underlying physical, chemical, and biological characteristics of fruits and vegetables that can be detected by existing and proposed sensors. Research is underway to gain an understand of the underlying phenomena influencing quality essential to the development of the sensors. Furthermore, research efforts must continue to determine the effect of different handling techniques on quality degradation.

A cooperative regional project is an excellent vehicle for the proposed research effort. Some of the instrumentation necessary to investigate the underlying phenomena influencing quality is sophisticated and expensive. It is not possible for one station to accumulate all the equipment and expertise necessary to carry out meaningful research. Fortunately, as a group, the cooperators in this project have access to most of the technology needed to assess quality. The cooperators will share equipment, experience, and ideas directed at common goal. Furthermore, there are cooperators that have similar equipment (machine vision and NMR) and can share data, software, and techniques. Lastly, some cooperators share commodities and all cooperators share an interest in developing qualitative measures of quality.

The proposed project is consistent with the national needs and priorities. 'Good diet: America's best health plan' is a priority listed under the heading of 'A safe, affordable, reliable, and nutritious food supply'. The availability of consistent and high quality fruits and vegetables to the consumers will enhance consumption and improve nutritional value of consumers' diet. Another national priority is to improve the competitiveness of the U.S. food and natural resource system. By consistently providing high quality fruits and vegetables the American growers would be more competitive in domestic as well as foreign markets.

RELATED CURRENT AND PREVIOUS WORK:

A significant portion of the current effort related to the three objectives of this project is being conducted by members affiliated with this project with a few exceptions. Only current work is briefly summarized here. Please refer to the Critical Review included in the Attachment for a more complete discussion of previous work.

Firmness and bruise susceptibility, as indicators of quality, continue to be a focus of current research. Several methods of measuring firmness are being investigated (Chen et al 1995, Hung and Prussia, 1995, Timm et al, 1996). These include response to static and dynamic forces including impact. Contact pressure that causes cell failure is being investigated as a possible indicator of firmness and bruise susceptibility (Chowdhury et al, 1995. Finite element modeling technique is being used to simulate bruising due to quasi-static loading and resonant vibration as affected by material properties (Chowdhury, 1995). Bruise susceptibility of apples, potatoes, peaches, and onions is being measured using the instrumented sphere (Schulte et al, 1994, Timm et al 1991). Studies are underway to understand what specific properties are measured when measuring "firmness". Another property being investigated is turgidity. Shock wave speed through tissue samples as a measure of relative turger is being investigated. Effect of factors such as orchard site conditions, production practices and environmental conditions on changes in fruit physiology and chemistry of cherries are being investigated.

The potential of X-ray technology for inspecting internal quality is being evaluated (Tollner et al, 1995). Insect damage, fresh bruises, corky tissues and void spaces are detectable based on X-ray absorption patterns associated with these features. Preliminary results show that pits in stone fruits such as peaches can also be detected. X-ray computed tomography (CT) is being utilized to detect changes in tissue absorption properties while in storage precipitated by initial impact bruise.

Techniques and technology are being tested to determine if potential exist to electronically detect bruising and skin cracks on dark sweet cherries. Bruise detection using NIR and visual reflectance from the apple surface is being investigated to optimize lighting, lens aperture, and camera sensitivity for greatest contrast between bruised and unbruised tissue (Upchurch et al, 1994, Upchurch et al, 1993, Throop et al, 1994). Combining NIR and green reflectance features from images of Golden Delicious apples show promise as a way of detecting bruise tissues (Throop et al, 1992). Internal water core damage has been detected using transmitted visible and NIR light (Upchurch and Throop, 1991). Fluorescence is being studied as an indicator of respiratory activity (maturity).

Nuclear Magnetic Resonance (NMR) is being used to perform constituent analysis of fruits and vegetables, particularly, soluble solids and oil contents and maturity (Cho et al, 1993, Stroshine et al, 1994). NMR is also being studied to detect internal defects such as pitted and unpitted cherries.

Efforts are under way to develop software to analyze visible and NIR images and other multidimensional sensory data from fruits and vegetables. Fourier analysis, texture analysis and computed tomography have been areas of intense interest (Tao et. al. 1995a). Algorithms have been developed to form a basis for a single pass quality feature inspection and grading. Image analysis algorithms are being developed to assess and quantify color, shape, and russet (Heinemann et.al 1995a and Tao et. Al. 1995b). Relative strengths and weaknesses of artificial neural networks versus traditional statistical classifiers are being addressed. Performance of the back propagation neural network and the Fischer discriminant function are being studied for machine vision inspection of greening, shape, and shatter bruise in potatoes.

A survey is being conducted of the apple industry (packers and processors) to evaluate their current satisfaction with automated sorting and their future needs and tolerance expectations for automated sorting. The objective is to help the apple industry understand the state of current technology and to bring the development of automated sorting systems in line with the needs of the apple industry.

A search of the USDA Research (CRIS) data base was conducted to identify any other related research. Many of the research projects retrieved used existing fruit and vegetable quality measures to quantify the effects of breeding, fertilization, chemicals, handling, storage, cultural practices, or marketing, but, do not in any way duplicate the efforts of NE-179. The vast majority of retrieved projects were associated with participating stations.

Florida, Texas, New Jersey, and Oklahoma are reporting recent or current projects that are related to the regional project in varying degrees. All of these stations have considered joining NE-179 and are aware of the goals of this regional project. In all cases NE-179 Regional project personnel are aware of, and do not duplicate, these efforts. TEX06500 is developing an adaptive sorting of carrots for size, shape, splits, and surface defects using commercially available optics. NJ08903 is and inactive (and recently expired) project that was actually developed under the NE-179 Regional Project. OKL02178 was looking at sonic and impact measures to non-destructively quantify peach firmness. FLA-AGE-03087 has recently concluded a project to "design, test, and evaluate various handling systems to reduce mechanical damage and improve quality maintenance of fresh produce.".

OBJECTIVES:

1. ***To identify, develop, and evaluate methodologies to assess the quality of fruits and vegetables.***

2. ***To develop sensor technology for quantitative measurement of fruit and vegetable properties indicative of quality.***

3. ***To develop methodologies for classification and sensor fusion which facilitate optimal fruit and vegetable quality discrimination.***

PROCEDURE:

Executive Summary:

The quality definition of fruits and vegetable depends of the product and the manner in which it is consumed. The quality parameters include but not limited to size, shape, weight, color, defects (external and internal), maturity, firmness, and bruise susceptibility. The three objectives describe a systematic approach for developing a system for on-line quality assessment and classification of fruits and vegetables. Under objective 1, attributes that may be used to define quality will be investigated as well as how these attribute can be measured. The on-line sensor development will be addressed under objective 2. Under objective 3 we will focus on the development of methodologies for sorting fruits and vegetables based on signals from multiple sensors that will utilize modern classification techniques such as neural network and fuzzy logic.

Objective 1: ***To identify, develop, and evaluate methodologies to assess the quality of fruits and vegetables.***

A. Evaluate impact properties (bruise threshold and bruise resistance) of fruits and vegetables related to bruise susceptibility - an important quality parameter.

Currently different methods (e.g. dropping test or pendulum impactor) and protocols for measuring those impact properties are being used. The researchers will work together to identify common methods and procedures for measuring impact properties of fruits and vegetables. The susceptibility of fruits and vegetables to damage will be studied on peaches, apples, cherries, potatoes, sweet onions, and wild blueberries using the common methodologies developed for assessing impacts and damages. Information collected will be related to maturity and cultivar. Specific recommendations on cultivar selection will be added to a common database and also made available to producers. (GA, ME, MI, ARS-MI, WA)

Cooperating stations (GA, ME, MI, ARS-MI, and WA on impact property; and GA, ME, MI, NC, ARS-MI on firmness) will develop standard procedures for quality evaluation, identify reference standards, and define what is being measured. Cross-correlation between different properties measured and quality will be conducted. A database encompassing all of the physical and chemical properties of all fruits and vegetables measured from this project will be established.

Cooperating stations (CA, GA, HI, MI, NY-C, PA, WA) will develop indices for basic product quality and quality consistency. Data from these stations will be compared to determine if the quality indices are applicable over a broad geographic region. Furthermore, this project provides an avenue for the cooperating stations to design future replicated experiments and compare the results.

B. Quantify fruit firmness, the most frequently reported physiological disorder recorded on USDA receiving inspection forms.

A common approach for minimizing variability and for marketing products with uniform firmness is to separate a batch of items into groups with similar firmness levels. There are a number of research projects, both completed and on-going, that have the objective of firmness sensing. Different firmness sensing methods such as Instron puncture, nondestructive force response, pressure sensing, and laser-puff will be compared. Firmness measurement will be made on fruit samples from a single source by researchers at different stations (CA, WA, GA, ARS-MI). Results will be compared and evaluated to determine the advantages and disadvantages of each system and ways to improve firmness measurements.

Fundamental research to identify which properties different devices are sensing, relative contributions of the skin and flesh to the readings, and how these readings relates to the firmness will be investigated. Design, fabrication and calibration plans of different firmness sensing methods will be shared among all cooperating stations. Results of these investigations will be used to form the basis for firmness sensing strategies for selected fruits (AR, GA, ME, MI, NC, ARS-MI). Several stations will emphasize the development of techniques to better predict maturity and shelf life of fruits and vegetables. Firmness is often used for estimating maturity of fruits and vegetables, however, non-destructive testing that compares well to current destructive test remains a challenge. Firmness measurements will be made on fruit samples from a single source by researchers at different stations (CA, WA, GA, ARS-MI). Results will be compared and evaluated to determine the advantages and disadvantages of each system and ways to improve firmness measurement.

Equipment for measuring impact properties and firmness will be shared among cooperating stations. Design, fabrication, and calibration plans of some firmness sensing methods will be shared among all the cooperating stations. More specifically, on impact property evaluation, GA, ME, MI, ARS-MI, and WA stations will be working together; and GA, ME, MI, NC, ARS-MI stations will be working together on firmness evaluation. ME will be using the volatile analysis device developed at ARS-MI for fruit maturity evaluation. These locations with specialized analytical equipment, facilities and/or experienced staff will continue to be available. Fruits and vegetables will be shipped to these facilities for analysis or other station members may perform experiments on site.

C. Evaluate selected chemical and viscoelastic properties that can be used as an indicator of fruit and vegetable quality.

Nondestructive apple quality assessment using chlorophyll fluorescence will be conducted. Measurements on chlorophyll fluorescence will be correlated with fruit maturity, flesh firmness, storability, and storage scald. A prototype device will be constructed using chlorophyll fluorescence for measuring quality of individual fruit on a commercial packing line application. Detection of flavor and pathogen volatiles can also be used to assess fruit and vegetable quality nondestructively. For this study, the volatile profile of whole and/or lightly processed vegetables and the volatile profiles of the three most important human pathogens (Listeria, Clostridium, Salmonella) and mold will be evaluated. These volatile profiles will be related to quality parameters including shelf life under retail and consumer storage conditions. Signature volatiles or volatile classes for rapid and efficient sorting of fresh fruits and vegetables will be identified (CA, ME, ARS-MI, NY-C). Rapid detection of flavor and pathogen volatiles to non-destructively assess quality of whole and/or lightly processed carrots, lettuce, broccoli and cabbage is a joint project of ARS-MI, MI and WA. NY-G will evaluate the suitability of using the intrinsic enzyme activity as an indicator of fruit and vegetable quality. For example, correlation between the firmness of apples and the levels of cellulase, xylanase, polygalacturonase, and possibly other enzymes will be established.

Shear-based viscoelastic properties of carefully prepared and selected skin and tissue of fruits (e.g., apple, peach, and pear) and vegetables (e.g., cabbage and tomato) will be determined (NY-G). The goal is to understand the role of different cultivars and, where applicable, storage conditions, as well as the influence of measurement temperature. Both small amplitude oscillatory and creep tests will be conducted in the linear viscoelastic range with a Carri-Med CSL2 controlled-stress rheometer. Parallel plate geometry with roughened surfaces to prevent slip at sample-plate interface will be used. The Peltier plate of the rheometer will be used to accurately control the temperature of the test samples.. Descriptive models will be developed for the properties at a fixed temperature and the influence of temperature on the properties.

D. Develop advanced electromagnetic methods for determining fruit and vegetable quality.

Considerable success has been shown in using X-Ray and nuclear magnetic resonance (NMR) as a nondestructive method for measuring fruit and vegetable quality. X-ray methods for detecting insects in mangoes will be evaluated (HI). In the early stages fruit that have been treated to kill any insects will be sent to Georgia for x-ray imaging. Since the treatments available for killing the insects are unacceptable in high quality markets further tests will be done with equipment available in Hawaii. Work is continuing regarding the X-ray properties of fruits in storage. Changes in tissue absorption properties while in storage which were precipitated by an initial impact bruise are being studied. These studies are using line scanning along with X-Ray CT. Plans are being formulated to investigate X-Ray energy levels less than 120KV (GA, NY-C).

An X-Ray CT scanner is available at GA and an NMR facility is available at CA. As a result of joint work on watercore in apples, changes in tissue absorption properties in apples while in storage will be studied using spectroscopy along with X-Ray CT. Characteristics of new and stored, bruised and unbruised tissue will be examined (GA, NY-C).

Measurement of 1^H-MR spin-lattice and spin-spin relaxation parameters requires that standardized sucrose solutions be available for calibration. Each station has distinctly different 1^H-MR equipment and standardization with these sucrose solutions will allow a comparison and evaluation of equipment performance. Sterilized sucrose solutions will be prepared (IN) and sent to the other stations for calibration and testing.

Proton magnetic resonance devices are also available (IN). The application of proton magnetic resonance (1^H-MR) will continue with investigations into non-destructive measurement of fruit and vegetable ripeness and quality. Changes in equipment and methods which will increase the precision of soluble solids measurements will be evaluated. Commodities to be evaluated will include apples and oranges. Applications of 1^H-MR to quality control processing of tomato products, and fruit and vegetable purees will also be studied (IN).

NMR will be used to determine if oil content of macadamia nuts can be determined when the nuts are moving through the magnets of the NMR equipment (HI, CA, IN). Researchers (CA) will continue to work with other researchers to investigate potential uses of NMR techniques for evaluating internal quality of selected fruits and vegetables. Equipment to singulate and transport macadamia nuts through the magnets of NMR equipment will be developed if oil content can be determined in moving nuts (HI).

1^H-MR sensing will be evaluated for detection of the maturity of unshelled peanuts and detection of maturity and quality of unshelled Macadamia nuts (HI, CA, IN).

The use of 1^H-MR for detection of soluble solids, water core, firmness, and other quality factors in apples will be evaluated. Apples will be provided (NY) with quality defects or variations in firmness. These apples will be shipped for testing in the 1^H-MR sensing laboratory (IN, NY-C).

E. Evaluate visible light and NIR as indicators of fruit and vegetable quality.

Stations with spectrophotometers (CA, ME, NY-C, GA) will provide facilities in which to do spectral analysis of fruits and vegetables on an available basis. It will be important to be able to do reflection, transmission and fluorescence spectroscopy in the ultraviolet, visible, and infrared parts of the spectrum. Cooperative projects will occur between centers of spectroscopy and those stations that have machine vision applications (AR, CA, HI, MI, NJ, NY-C, PA). Electronically controlled filters are available for the visible and near-infrared spectra.

Measurement of reflectance properties of fruit/vegetable samples with the variable electronic filters at the NY station will be critical. Samples may be sent to other locations, equipment may be sent to Michigan and/or respective researchers may travel to either the fruit or equipment location to conduct this cooperative research. It is also expected that cooperation will exist in sharing of results and data interpretation and ultimately in co-authorship of papers.

ARS-WV, ARS-MD and CA will cooperate in the development of NIR sensing techniques. Such cooperation, which may include sharing of sensor design techniques and cooperative system testing on actual commodities, will depend upon the restaffing and program re-directions currently being considered at ARS-WV and ARS-MD. Collaborative efforts will be undertaken (CA) to develop NIR sensing techniques for evaluating the quality of fruits and vegetables. These activities will include sharing of sensor design techniques and testing commodities across regions CA, ME).

F. Consider advanced technologies as possible indicators of fruit and vegetable quality.

Emerging technologies will allow the use of other types of energies - possibly electrical (EM fields, microwaves, etc.). There are no current plans in these areas but during the duration of the project other developing and appropriate technologies will be investigated. Biosensor technology will be investigated to detect biochemical constituents in low concentration for measurement of food quality and safety. Molecular recognition in the sensor will be achieved by immunoreaction between an antibody and the particular antigenic determinant, and signal transduction will be based on photometric sensing. Problems to be considered will be the on-line sensing of aromatic components from fruits (stone fruits and apples) and detection of molds and mycotoxins in fresh and processed foods (CA).

Objective 2: ***To develop sensor technology for quantitative measurement of fruit and vegetable properties indicative of quality.***

Preface:

Research will be conducted to develop new and evaluate improved sensing techniques which are suitable for ***high-speed*** determination of quality. Emphasis will be placed upon identifying and developing sensing technologies that have a level of sensitivity which will allow integration into high-speed handling systems currently used by industry. A number of different technologies will be investigated.

A. Electronic image processing technology.

Electronic image processing systems are available at each of the cooperating stations. Electronic images can be produced by all the appropriate energies. Therefore, common software techniques can be developed and shared for processing two-dimensional sensory images that are independent of the energy detected in generating the image. These generic techniques are useful in the initial investigations that determine the suitability of a sensor or sensory system. Software for pattern recognition, feature extraction, and on-line adaptive learning are techniques that have been shared and will continued to be used within the project. The development of integrated grading or inspection stations is a logical outcome of the development of sensors within this objective. There are sensory systems that have been developed in the previous project that are now being evaluated or used for on-line inspections.

The application of electronically tuned optical filters as spatial reflectance spectroscopes will be evaluated. Tunable filters in both the near infrared and visible spectra are available. Standard reflectance spectroscopy techniques, integrating spheres, and fiber optic/photodiode array spectrographic systems are available for comparison to tuned filters. These tools will be used to capture surface defects on a wide variety of apple cultivars. Surface defects will be identified by researchers including entomologists and plant pathologists. Image processing techniques will be applied to these data to enhance and distinguish the surface defects (NY-C).

Spectral properties will be studied and verified with electronically controlled variable filters. Machine vision and materials handling will be developed in an effort to proceed to a functional practical system and prototype development (NY-C, MI). Research will continue on identifying bruising and cracking defects on dark sweet cherries. We expect research in this area to expand with similar procedures to other commodities. Initial plans are being considered to study potato defects (MI).

Two dimensional human vision can be simulated with the availability of a true color camera and vision system. Grading of fruit and vegetables are often based on state and federal grade standards, which specify color. Color computer vision will be used for maturity, defect identification, and orientation determination for peaches, apples, potatoes, cherries and blueberries (AR, CA, MI, NY-C, PA, ME).

Cooperating stations (CA, MI, NJ, NY-C, PA) will jointly develop and exchange machine vision algorithms for processing computer images (see critical review). Although, individual projects may address different commodities and/or defects, the basic algorithms for enhancement, filtering, segmentation, representation, as well as analysis techniques will be very similar.

B. Adapt and innovate high-speed produce handling and sensing technologies.

Mechanical energies needed to transport the product also impart damage to fruits and vegetables during handling. Prevention of damage is as important as detection and proper presentation is important for inspection stations. Reduced damage due to handling and signulation of fruits and vegetable using a wave conveyor will be examined. The effect of wave pitch and diameter will be correlated to damage and the singulation produced by the conveyor (ARS-MI).

Integrated grading and inspection stations are being designed and will be evaluated. Inspection systems have been developed for pears with good success. Specialized pipeline processing techniques have been used in the process to produce the necessary processing speed. This inspection system will continue to be evaluated and applied to other fruits (CA).

Sensors developed under static conditions must be adapted for high speed on-line conditions. The system requires the integration of mechanical movement, the sensor and the device delivering energy to the fruit or vegetable. Detection of surface defects and bruises in on-line systems are being developed for apples and potatoes that use visible and near infrared sensors (AR, NY-C, PA). Fruit presentation to the camera (oriented versus non-oriented with stem/calyx identification), camera placement, and image capture for total surface coverage are all areas of concern for on-line systems (AR, CA, NY-C, PA).

At NY-C an inspection system for automatic sensing of apple defects at a rate of 6 - 10 apples/second is being developed. A commercial conveying line will be evaluated and modified under laboratory conditions. Image processing algorithms will be revised to match the processing requirements of on-line speeds and examination of images for bruises and common defects. The laboratory system will be evaluated with a large number of apples from many different cultivars. Final evaluation will take place in a grading shed of a major apple processor in the Northeast who is identified and has indicated an interest in cooperating. Statistical comparisons between the USDA inspections done at this site and the automatic inspection station will be completed. The final phase will include finding a manufacturer of apple handling equipment to build the automatic inspection system and to incorporate as much of the image processing in hardware as possible to reduce the time to process each apple (AR, NY-C).

NY-C will continue planning and sharing of equipment, ideas, and resources to accomplish the task of building an automatic inspection for apple defects. Without these combined efforts, resources, and ideas, the magnitude of design considerations and development cost for an automatic inspection station would be impossible in a reasonable time frame. PA and other stations will be invited to evaluate the completed air-puff firmness detection system developed at Georgia. Progress made by other stations will be used for the image analysis part of the detector (GA). Results of the contact pressure based firmness sensor being developed at Michigan will be compared with that developed in Georgia and North Carolina.

Work is continuing on the development of high-speed NMR techniques for sensing internal quality of fruits and vegetables while they are moving on a conveying belt (CA). The existing conveying belt will use different spectrometers to develop high-speed NMR techniques for determining soluble solid contents of selected fruits, and detecting internal tissue breakdown and presence of unwanted objects in fruits and vegetables.

The technique of using a puff of air to cause a deformation measured with a laser displacement sensor has been developed into a firmness detector. Work will include research needed for the design and testing of an automated system firmness detector suitable for off line users such as quality control inspectors, USDA inspectors, warehouse managers, and retail store clerks. A three axis positioning stage will be built to align the fruit with the center of the air nozzle. Fruit centerline will be determined by making a line scan with the laser displacement sensor or through image analysis from two cameras at 90 degree angles. Geometric configuration improvements to the detector head will be investigated (GA).

Objective 3: ***To develop methodologies for classification and sensor fusion which facilitate optimal fruit and vegetable quality discrimination.***

A. *Develop common data sets which can be shared among laboratories equipped to evaluate advanced sensing system approaches.*

Laboratories exist among project members which contain highly specialized equipment such as visible light (VL), near infrared (NIR) transmittance or reflectance, magnetic resonance (MR), x-ray evaluation or acoustical evaluation for measuring quality attributes. Other laboratories are well equipped to perform detailed physical property evaluation of fruit and vegetable quality. A chief limitation within some of these laboratories is the lack of equipment and perhaps expertise in performing the accepted standard tests for fruit and vegetable quality determination. Another limitation is the inability, due to lack of knowledge, to properly combine inputs from multiple sensing approaches. Equipment for measuring impact properties and firmness will be shared among cooperating stations. Design, fabrication and calibration plans of some firmness sensing methods will be shared among all the cooperating stations. More specifically, on impact property evaluation, GA, ME, MI, USDA-MI, and WA stations will be working together; and GA, ME, MI, NC, USDA-MI stations will be working together on firmness evaluation. Development of shared data sets will enable appropriate sensor fusion coupled with excellent physical property evaluation and accepted evaluations with respect to various grade standards.

B. *To evaluate a suite of techniques such as neural net, fuzzy logic, canonical correlation, principle components analyses,*

discriminant analyses, regression analyses, pattern recognition approaches and hierarchial classification (e.g. CART) for efficacy in signal processing in selected quality determination applications.

Several of the above techniques are suited to understanding relations between and among multiple outputs from a single sensor type as related to multiple outputs from a detailed physical property evaluation (e.g. fuzzy logic, canonical correlation, principle components). Such approaches will be used to better understand existing x-ray, NMR and mechanical evaluation methods by relating them to detailed physical property evaluation results. Shared data will enable these evaluations.

Techniques noted above exemplify methods which accommodate multiple inputs. Depending on the nature of the input (e.g. continuous or discrete), the correlation which may or may not be present with multiple inputs, and possibly other as yet unidentified factors, the optimal technique will probably change with specific application. Not all laboratories are equally proficient in making each evaluation. Especially with neural nets and other pattern recognition approaches, architecture possibilities are quite diverse and coordinated testing in multiple laboratories would enable a more complete evaluation. Data will be shared among cooperating laboratories enabling each method to be evaluated in a coordinated fashion. Cooperating stations (CA, MI, NJ, NY-C, PA, USDA-WV) will jointly develop and exchange machine vision algorithms for processing computer images. Although, individual projects may address different commodities and/or defects, the basic algorithms for enhancement, filtering, segmentation, representation, as well as analysis techniques will be very similar.

C. *To develop criteria and evaluate selected sensor fusions enabling integration of existing sensor technologies into efficacious quality sensing systems.*

Approaches and shared data of Objective 2 would be extended to multiple sensing platforms. Initial evaluations would be made combining sample weight with optical properties because both are very common. Visible light-based results may then be fused with x-ray based data in cases where x-ray is currently used (e.g. potato hollow heart evaluation). Mechanical firmness outputs may then be fused with visible light data in selected applications. Practicality and economic feasibility considerations would be considered along with likely benefit when selecting candidate sensing approaches for sensor fusion studies.

Fuzzy logic, discriminant analyses and neural networks provide convenient approaches for fusing or melding results from multiple sensor types and consequently will receive the most attention. From the knowledge base developed in this objective, criteria development for selecting and fusing sensing system approaches would be attempted. Knowledge learned would be integrated into packing line equipment.

EXPECTED OUTCOMES

The development of integrated grading or inspection stations is an overall outcome of this project. The following are the specific outcomes:

The project will develop a standardized impact properties measurement method for fruits and vegetables. With a standardized method to quantify impact properties, a database of impact susceptibility of different fruits and vegetables can then be established. This information would be useful in selecting and handling different varieties of fruits and vegetables thereby reducing damage during sorting and handling.

Nondestructive firmness sensor for fresh fruits and vegetables will be developed. Firmness is considered an indicator of the storability and eating quality of fruits and vegetables. This will improve the overall quality of fruits and vegetables on the market and value to the products. Firmness information will help the packinghouse managers in deciding where to market their products.

Sensors to measure parameters such as maturity, color, shape, size, surface and internal defects for the dynamic environment for on-line, accurate, high-speed grading and inspection will be developed. These sensors will have similar benefits as discussed above under firmness.

Another outcome of the project will be classification methods based on techniques such as neural network, fuzzy logic, canonical correlations discriminant analysis and or pattern recognition. Optimum sensory system based on sensor fusion would enable more accurate sorting decisions.

New sensor technology may make it possible to sort for quality not currently defined. For example, along with optical weight data, modalities such as NIR and X-ray linescan may be used to detect watercore in apples. It is expected that as a result of this project, the overall quality of fruits and vegetables in the market would increase which would make the U.S. growers more competitive in the domestic and foreign markets. Having higher quality products in the market, the consumption of fruits and vegetables will increase thereby improving nutritional intake.

ORGANIZATION:

The Regional research project organization has been established in accordance with the format suggested in the "Manual for Cooperative Regional Research". One person at each participating agency is designated, with approval of the agency director, as a voting member of the Technical Committee. Other persons at agencies are encouraged to participate as non-voting members of the Technical Committee.

An Executive Committee, consisting of the Chairman, Secretary, Industry Liaison, Member-at-Large, and Administrative Advisor will conduct the activities of the regional project between annual Technical Committee meetings. Additional duties of the Executive Committee are as outlined in the Manual for Cooperative Regional Research. Membership on the Executive Committee is not limited to the official voting representatives. The Executive Committee is elected annually by voting members of the Technical Committee with the exception of the Industry Liaison. The Industry Liaison will be elected for a three year term, and will be responsible for informing industry representatives about yearly committee activities. Normally, a succession of offices from Member-at-Large to Secretary to Chairman is desirable, but is not established pro-forma. All members of the Executive Committee will be elected each year. No member shall hold the same office in consecutive years.

NE-179
Technology and Principles for Assessing and Retaining Postharvest Quality of Fruits and Vegetables

SIGNATURES:

Roger P. Rohrbach May 1, 1997
Chairman, NE-179 Project Outline Revision Committee Date

M A Mount June 10, 1997
Administrative Advisor Date

for the Association 8/13/97
Chairman, Regional Association of Directors Date

8/25/97
Chairman, Cooperative State Research Service Date

REFERENCE:

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ATTACHMENTS:

PROJECT LEADERS
REGIONAL PROJECT No. NE-179
Technology and Principles for Assessing and Retaining Quality of Fruits and Vegetables
(Oct. 1, 1997 - Sept. 30, 2002)

STATION	PROJECT LEADERS [1]	AREA OF SPECIALIZATION.
AR	Tao, Y. -PI	Automated Inspection/Machine Vision
	Walker, J. -CoPI	Machine Systems
ARS-East Lansing MI	Marshall, Dale - PI	Fruit/Vegetable Hand.
	Timm, Edward	Postharvest Technology
	Beaudry, Randy	Postharvest Physiology
California	Chen, P. - CoPI	Physical Properties
	Delwiche, M. - PI	Sensor Development
	Slaughter, D.C.	Machine Vision
Georgia	Prussia, S. - PI	Postharvest Systems
	Hung, Y. - CoPI	Quality Evaluation
	Tollner, E. - CoPI	Sensor Development
Hawaii	Gautz, L.-PI	Fruit Handling Systems
	Liang, T.	Fruit Handling Systems
	Paquin, D.	Fruit Handling Systems
Maine	Donahoe, Darrell-PI	Fruit/Veg. Production/Postharvest

Technical Committee voting members are designated by PI for each station

Michigan	Srivastava, A.-PI Guyer, D.	Phys Prop/Sensor Fusion Automated Inspection/Machine Vision
New York-C	Aneshansley,D.- PI Throop, J.A.	Automated Inspection/Machine Vision Automated Inspection/Machine Vision
New York-G	Hang, Y.D.-PI Rao, A	Food Enzymology Food Engineer
North Carolina	Rohrbach, R.-PI	Machine Systems / Auto. Inspection
Pennsylvania	Heinemann, P.-PI	Automated Inspection
Indiana	Stroshine, R.L.- PI	Physical Properties, Proton Magnetic Resonance Sensing
Washington State	Hyde, G.-PI Pitts, M. Davis, D. Patterson Cavalieri, R.	Process Automation Instrumentation Physical Properties Quality Evaluation Postharvest Systems

RESOURCES:

REGIONAL PROJECT No. NE-179
Technology and Principles for Assessing and Retaining Quality of Fruits and Vegetables
(Oct. 1, 1997 - Sept. 30, 2002)

STATION	NAME	TITLE	SCI SY	PROF PY	TECH TY
Arkansas	Tao, Y. - PI	Asst Prof.	0.50		
	Walker, J.	Prof.	0.10		
		Research Assistants		0.80	
		Technical Assistant			.25
ARS - E. Lansing MI	Marshall, D.	Agricultural Engineer	0.80		
	Timm, E.	Research Specialist	0.80		
	Beaudry, Randy	Assoc. Prof./Hort.	0.10		
California	Delwiche, M.-PI	Prof./Ag. Engineer	0.20		
	Chen, P. - CoPI	Prof./Ag. Engineer	0.55		
	Slaughter, D.	Assoc. Prof/Ag. Eng.	0.30		
		Research Assistant			0.50
		Research Assistant			0.50
		Development Engineer		0.50	
Georgia	Prussia, S. -PI	Prof/Bio and Ag Engr.	0.70		
	Hung, Y.-CoPI	Assoc. Prof/Food Sce.	0.50		
	Tollner, E.- CoPI	Prof/Bio and Ag Engr	0.20		
		Postdoc		1.00	
	Research Technician				0.70
	Engineering Technician			1.00	
Hawaii	Gautz, L. - PI	Assoc. Prof./Ag. Eng.	0.30		
	Liang, T.	Prof/Ag. Eng.	0.10		
	Paquin, D.	Mechanical Engineer		0.20	

Maine	Donahue, D. - PI	Asst Prof	0.20		
		Grad Res Asst		0.25	
Michigan	Srivastava, A.-PI	Prof/Ag.Eng.	0.20		
	Guyer, D.	Assoc. Prof/Ag.Eng.	0.10		
		Research Assistant		0.50	
New York-C	Aneshansley D.-PI	Assoc Prof/ABEN	0.10		
	Throop, J.	Res. Asst. in ABEN			0.50
New York-G	Hang, Y.D.-PI	Professor/Food Sci.	0.20		
	Rao, A	Food Engineer	0.15		
		Res. Tech.			0.30
North Carolina	Rohrbach, R. - PI	Prof./Ag. Eng.	0.30		
	Harris, D.	Project Engineer			0.40
		Grad. Research Assistant		0.50	
Penn	Heinemann,P.-PI	Assoc. Prof./Ag.Eng.	0.30		
		Grad. Asst./Ag. Eng.		1.00	
Indiana	Stroshine, R.L.-PI	Professor	0.20		
		Grad Asst.ABE		0.25	
Washington State	Hyde, G.-PI	Prof./Ag. Eng.	0.25		
	Pitts, M.	Assoc. Prof./Ag. Eng.	0.25		
	Davis, D.	Prof./Ag. Eng.	0.10		
	Fellman, J	Assoc. Prof/Scientist	0.20		
	Himsi, V.	Computer Main. Eng.			0.20
	Dewitt, W.	Eng. Res. Technician			0.20
	Cavalieri, R.	Asst. Prof./Ag. Eng.	0.25		
		TOTALS:	7.95	6.00	3.55