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Introduction

Assessing meat yield and quality in carcasses is important for exporting meat and for the domestic consumer. The U.S. livestock and meat industries depend heavily on USDA to provide the rating of their meat for marketing. There is also a trend in the U.S. meat industry to process meat closer to the site of slaughter because of increasing transportation and energy costs. Only the edible portion of the carcass will leave the slaughter plant. These trends will increase the volume and demand for more consistent, equitable, and timely methods for grading meat.

Since the USDA meat grading system was first put into use in 1927, meat has been graded by human graders. Because grading is subjective in nature, it is very difficult (if not impossible) to achieve consistency and equity. The development of instruments to assist the human grader in evaluating grade factors has been strongly recommended.

Current developments in the expert systems and natural languages make it possible to devise systems to assist meat graders. At MARC we have initiated a project with an immediate objective of developing systems to assist graders in grading meat, and an ultimate objective of automating the meat grading process through applications of image processing, natural languages, pattern recognition, and expert systems technologies.

This paper describes a knowledge-based expert system which has been developed to assist meat graders in deciding beef carcass yield and quality grades.

System Configuration

Figure 1 is a block diagram of the voice-input, knowledge-based expert system for grading carcass beef.

This consists of voice recognition and knowledge-based subsystems. When the meat grading system is first started, the knowledge-based subsystem is invoked and it is ready for the inputs of the characteristics of the first carcass. The meat grader inputs the characteristics by talking into a microphone headset while examining the carcass. Upon the reception of the characteristics of the first carcass, the computer program reasons through the production rules of the expert system to reach the quality and yield grades and prints out the results. After the results are printed out, the computer is ready for the inputs of the characteristics of the next carcass from the meat grader. This is continued until all the carcasses are graded. Both subsystems reside in a COMPAQ DESKPRO 386 computer (two megabytes of memory).

Voice Recognition Subsystem

The VoiceScribe-1000 Speech Recognition System developed by Dragon System, Inc. of Newton, MA, which is a discrete utterance, speaker dependent, recognition system (up to a 1,000 word vocabulary), was used. Table 1 lists the vocabulary of the voice input subsystem. This vocabulary matches the parameters used in production rules of the knowledge-based subsystem and consists of descriptive words and phrases taken from the Official U.S. Standards For Grades of Carcass Beef.

Since the voice recognition system is speaker dependent, a grader must "train" the system to his or her voice for each word or phrase in the vocabulary. The voice patterns of these training words are saved on computer hard disk for routine usage.

After all the patterns are formed, recognition can then be activated. Once in the recognition mode, a pattern is formed for the incoming utterance and is compared to all the reference patterns in the active vocabulary. The word or phrase that matches the incoming pattern with the highest correlation score is considered the "winning" word or phrase. If the score exceeds the reject threshold, the speech driver outputs the results to the computer as if they were typed in through the keyboard.
Knowledge-based subsystem

Personal Consultant Plus Expert System Shell from Texas Instruments (PC+) was used to develop the knowledge-based subsystem. The knowledge-based subsystem reads the files of beef characteristics input verbally by the meat grader and determines the quality and yield grades of beef carcasses.

The production rules of the knowledge-based subsystem are based on the meat grading knowledge described in the Official U.S. Standards For Grades Of Carcass Beef. Bulls and veal calves are not graded for their carcass quality. Cows will not qualify for prime quality, and bullocks cannot be older than ‘A’ maturity.

1) Yield grade. The yield grade of the carcass is determined based on the values of the carcass weight; the backfat thickness on the exposed ribeye; the percent kidney, pelvic, and heart (KPH) fat; and the area of the ribeye. If an accurate estimate of the KPH fat cannot be made or the area of the ribeye cannot be measured, subjective estimates can be entered. The knowledge-based system is capable of determining default values for these parameters. This default area of the ribeye is computed by a linear equation developed from the table of carcass weights and ribeye areas given in the Meat Evaluation Handbook, published by the National Livestock and Meat Board.

The default value is further adjusted according to the subjective estimates entered by the grader. The subjective estimates of VERY-LARGE-RIB-EYE, LARGE-RIB-EYE, NORMAL-RIB-EYE, and VERY-SMALL-RIB-EYE change the yield grade by -0.6, -0.3, no change, +0.3, and +0.6, respectively.

If a numeric estimate of percent KPH fat is not given, the default percent KPH fat value is set to be 3.5. A subjective estimate of VERY-HEAVY-FAT, HEAVY-FAT, NORMAL-FAT, LITTLE-FAT, or VERY-LITTLE-FAT, further changes the yield grade by +0.4, +0.2, no change, -0.2, or -0.4, respectively.

The final YIELD-GRADE is obtained by dropping the fractional portion of the value of PRELIM-YIELD-GRADE after it is adjusted for subjective estimates of the ribeye size and any excess fat. The parameter RIB-EYE-SIZE is traced only if the area of the ribeye is not found in the voice inputs.

2) Quality Grade. The quality grade is determined, based on the degree of marbling and firmness as observed on the cut surface of the ribeye, in relation to the maturity of the carcass. The meat grader inputs the degree of marbling on the exposed ribeye. If the firmness of the lean tissue and the color of the ribeye area have an effect on the quality grade, they should also be given.
Otherwise, the knowledge-based subsystem assumes that the firmness of the lean tissue is comparably developed with the degree of marbling, and the quality will be determined on maturity and marbling alone.

Maturity can be entered three different ways. First, the stage of maturity can be entered with a letter stage such as A, B, C, D, or E. However, the grader has the second option to input skeletal characteristics, such as condition of the vertebrae, rib bones, chine bones, and color and texture of the meat. This is particularly necessary when the grader cannot decide on a letter stage of maturity for the carcass because the stage of maturity is on the borderline between two stages. The third option is that using the default value of ‘A’ for the stage of maturity if no letter maturity or skeletal characteristics are given. If the skeletal characteristics are given, they have a higher priority than the letter indication and will be used to determine the stage of maturity. Based on the skeletal characteristics, the knowledge-based system will determine the stage of maturity of that carcass.

For all beef carcasses having ‘A’ maturity, degree of maturity within ‘A’ is not used to determine the quality grade. However, for other maturity groups, an increase in the degree of marbling is required to compensate for the progressive increase in maturity in each grade. To accommodate this feature, the grader should include a numeric value for the degree of marbling and stage of maturity inputs to the knowledge-based system. Rule040 is an example of a very young carcass:

**Rule040**

**IF:** CHINE-BONE = RED-POROUS AND THORACIC-VER = NO-EVIDENCE-OSS OR THORACIC-VER = SOME-EVIDENCE-OSS AND RIB-BONES = SLIGHTLY-ROUNDED OR RIB-BONES = NOT-FOUND AND LUMBAR-VER = LUMBAR-SOME-OSS OR LUMBAR-Ver = NOT-FOUND

**THEN:** STAGE-MATURITY = A
AND PERCENT-MATURITY = 20

In this rule, if the conditions of RIB-BONES and LUMBAR-VER are not given (NOT-FOUND) because they are not in disagreement with the overall carcass maturity while other parameter values meet the conditions, the rule still will conclude that STAGE-MATURITY = ‘A’ with a percent maturity of 20. However, if RIB-BONES or LUMBAR-VER is given, this rule will be concluded only if they also match the conditions of RIB-BONES or LUMBAR-VER as required by the rule.

The rules to determine the maturity of the carcasses with a PERCENT-MATURITY of 100 (carcasses at the juncture between two maturity groups) are coded directly according to the Standards. For carcasses which are not at the juncture between two stages of maturity, other rules having comparable percent of maturity are searched and matched. When skeletal characteristics are used, emphasis is placed on the conditions of the CHINE-BONE, followed by the THORACIC-VER, and less on the RIB-BONES, LUMBAR-VER, SACRAL-VER, MEAT-COLOR, and MEAT-TEXTURE. The latter parameters are used mostly to decide different percentages of the same stage of maturity.

Once the stage of maturity has been determined and the degree of marbling has been entered, the quality grade is determined according to Figure 1, page 11 of the Standards. If maturity is greater than ‘A’, then the rules try to determine the percentage of that stage. If no percentage is in the file, the system assumes it is 100.

**Rule002** demonstrates an ‘A’ maturity carcass:

**IF:** STAGE-MATURITY = A
AND DEGREE-MARBLE = ABUNDANT
OR DEGREE-MARBLE = SLIGHTLY-ABUNDANT
AND FIRMNESS = MOD-FIRM
OR FIRMNESS = FIRM
OR FIRMNESS = NOT-FOUND
AND SUB-CLASS ! = COW

**THEN:** QUALITY-GRADE = PRIME

Rule002 also indicates that the cow cannot qualify for PRIME grade. The following Rule009 demonstrates the effect of PERCENT-MATURITY and PERCENT-MARBLE on the QUALITY-GRADE of a ‘B’ maturity carcass:

**Rule009**

**IF:** STAGE-MATURITY = B
AND DEGREE-MARBLE = SMALL
AND FIRMNESS = SLIGHTLY-FIRM
OR FIRMNESS = MOD-FIRM
OR FIRMNESS = FIRM
OR FIRMNESS = NOT-FOUND
AND VALUE PERCENT-MATURITY
VALUE PERCENT-MARBLE

**THEN:** QUALITY-GRADE = SELECT

In Rule009, the QUALITY-GRADE = SELECT is true because the PERCENT-MATURITY increased greater than the PERCENT-MARBLE.

**3) Decision-making Process.** QUALITY-GRADE and YIELD-GRADE are the two goals which this knowledge-based system tries to find. For example, to find QUALITY-GRADE, the program looks at all the rules that have QUALITY-GRADE in the THEN portion of the rule. The inference engine then tries these rules to find one that is TRUE. If a parameter such as ‘CHINE-BONE’ is used in the rule being tried and has no present value, the program stops processing the original search for the value of QUALITY-GRADE and searches for the value of CHINE-BONE. If CHINE-BONE is NOTKNOW, a function call is made to find the value of CHINE-BONE in the input characteristics.

Once the program has determined the value of CHINE-BONE, it goes back to the rule it was trying and continues where it left off. If the reasoning process requires the value of THORACIC-VER, and no value was assigned to it, the program will then use a function call to search for the characteristics of the thoracic vertebrae. Once all the parameter values in the IF portion are KNOWN and If the rule is TRUE, the THEN portion of the rule is processed. If the rule is FALSE, then the search continues with the rules that have the current goal in the THEN portion. This continues until a rule which has current goal in the THEN portion and the IF portion is TRUE. In this way, the inference engine processes only those rules that may supply the goal value, and searches only for the unknown parameter values that are necessary to conclude those rules. This is called backward-chaining process.

The program will stop processing when the goals of the program have been concluded.
Program Output

When the data have been processed, the results and the accompanying characteristics will be stored in a permanent file with the identification number of that carcass as the file name and the same data will be sent to the printer. Following is an example of the resulting printout for Carcass no. 1001:

(CARCASS-DATA-FILE-FOR CARCASS-NO 1001)
(QUALITY-GRADE-IS MED-CHOICE)
(YIELD-GRADE-IS 2)
(MODERATE 60 TINGED-RED PARTIALLY-OSS SLIGHTLY-WIDE-FLAT MOD-FINE MOD-LIGHT-RED CARCASS-WEIGHT 605 BACK-FAT 0.4 RIB-EYE-AREA 12.3 KID-PELVIC-HEART-FAT 3 ( ) ( ) ( )

After the output is given, the grader has the option of saying CONTINUE to continue for the next carcass or, if the grader is interested in knowing how the system reasoned to reach the result, the grader may select the option 'HOW' and the specific parameters he or she is interested in.

Discussion

This system has been tested extensively with a wide variety of carcass characteristics, and the results are consistent with the Standards. It requires about 20 sec for a meat grader, with one-half day's experience with the system, to vocally input the characteristics of a carcass. With the development system, the computer requires about 8 sec to reach the conclusions and print out the grades of each carcass. The time required to grade a carcass will be greatly reduced as the grader acquires experience and becomes more familiar with the system.

With this system, the grader needs to be only a trained carcass characteristic inspector and the computer will do the grading. This will relieve the grader from the intensive mental work of assigning grades to the carcasses. Since the computer is doing the reasoning, the process would not deteriorate after long hours of continuous work.

Also, since the rules are based on specifications of the official meat grading rules, the resulting grades should always be equally or more consistent than those assigned by the human meat grader. However, the consistency of the final yield and quality grade is dependent on the consistency of the meat characteristics observed by the meat graders. The rules are easily changed or upgraded to implement new standards. Also, the meat characteristics and yield and quality grades are permanently recorded, and the processes of decision-making can be easily reviewed. This system can be used not only on the industrial kill floor, but is also very useful as a training tool for future meat graders and a good research tool when meat quality and yield are important parameters.

Summary

This paper describes a knowledge-based, voice-input system being developed to assist meat graders in deciding carcass yield and quality grades. By talking into a microphone headset while examining the beef carcass, the meat grader inputs the meat characteristics into the computer via a voice recognition system, and the computer, based on the meat characteristics, reasons through the production rules to reach the quality and yield grades of the carcass. This system also records the characteristics of each carcass and allows the meat grader to review how the final yield and quality grades have been determined by the program.