From HGP to HGS: Towards Objective, Economic Meat Grading by Computer-Integrated, Programmable Robotic Systems

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SUMMARY

With the overall objective of arriving at better and standardized meat grading procedures, evaluation tests concentrate on the HGP, KSA/FOM and SKG instruments. These tests are briefly surveyed, and developments with the HGP (Hennessy Grading Probe) since the first FDI/HGP survey paper of 1981 (Vienna/Zagreb) are described. With parallel developments in robotics in manufacturing industry, progress towards a total, computer-automated system using a grading robot is presented. The objectivity, economics and performance of such HGP technology make it internationally attractive to researchers, the meat industry, and to classification authorities.

1. INTRODUCTION

Developments aimed at the creation and acceptance of a completely objective, yet economical meat grading method are continuing. The three systems on which scientific interest and experiments presently focus are the HGP (Hennessy Grading Probe, New Zealand), the KSA/FOM (Kød-spaek-Automatic/Fat-o-meat'er, Denmark), and the SKG (Schlachtkoerper-Klassifizierungs-Geraet, Federal Republic of Germany). A common, and indeed necessary feature of all these instruments is their computer-compatibility, enabling their integration into overall computerized evaluation systems.

A very comprehensive comparative survey of the above and some other instruments has recently been published /1/. The accuracy, efficiency, speed and cost situation of the FOM, HGP and SKG show these systems to be of interest for classifying pork sides. Earlier papers/e.g. 2/ also consider the KSA and SKG for this purpose. The first papers concentrating particularly on the FDI (Fat Depth Indicator, NZ), and HGP also surveyed test results for, and showed their applicability to, other carcasses (beef, lamb) /3,4,5/. With the other systems well covered in the literature, the present paper concentrates on developments with the HGP since /3/.

Extensive tests with the improved HGP were first performed in Sweden /6,7/, aiding in the development of a new classification system for pigs and involving 200,000 carcasses. Over 800,000 pig carcasses have now been graded commercially with HGPs in Sweden, with farmers' payment based directly on HGP results. The instrument has been officially approved for classification of pigs in Swedish abattoirs, and operates with a keyboard terminal also connected to other equipment /8/. Another test series on 224 pig carcasses has been performed in Canada /9,10/. The HGP and FOM resulted in similar accuracies of measurement and lean yield prediction, with the choice of instrument depending more on their durability and performance under commercial conditions, for which the HGP gets full credit in the above Swedish tests. - Developments based on HGP performance and technology are also used to develop "dedicated" probes, e.g. for lamb (TDI: Total Depth Indicator) in New Zealand, and beef /11,3,4/. The NZ tests show the TDI as satisfactory for M5 measurement on lamb carcasses. The various HGP developments, leading to completely integrated HGS (Hennessy Grading System) configurations, are receiving increasing recognition in New Zealand /12/ and elsewhere, and are now presented with emphasis on instrument characteristics, classification aspects, and completely objective, robot-assisted grading.

2. THE HGP INSTRUMENT

Development of a Grading Probe started in the last quarter of 1980. The design brief was for an instrument to provide full carcass evaluation and to complement the shortcomings of the FDI for automatic computerized measurement. The instrument had to be portable, self contained and easily adapted to the various Grading Systems in use around the world. This requirement was met by the use of a microprocessor. Initial prototype instruments (model GP1) measured only the fat thickness, muscle thickness, intrafat, carcass depth, and distance probed. This instrument could then be coupled to a host computer and keyboard to produce a lean meat percentage /3/. Early trials of the instrument (Sweden, May 1981) showed the need to speed up the limit testing of the measured parameters which, together with the calculation of lean meat percentage, was hence brought/performed in the HGP. This new instrument (called GP2) was now a complete portable grading tool which could be used from a battery pack. Testing of prototype GP2s started in Kristianstad, Sweden in July 1981. Improvements in the design and function of the instrument were greatly enhanced by these tests. With the prototype development stage now concluded, serial production of the "production model" HGP is now proceeding. Its main features are: range 0-140 mm; resolution 0.4 mm; accuracy ± 0.2 mm (2 mm-140 mm); speed 1 reading per second; power 12 volts DC; weight 1450 g; length x width 460 x 75 mm; modular electronics; optional data entry via keyboard; dual microprocessor control; standardized computer interface, 8-digit alphanumeric display (function change without hardware change as in other displays). Further details are available elsewhere /13/.

3. MEAT CLASSIFICATION ASPECTS, GRADING EQUATIONS

The generalized grading equations advanced by Arndt /3,5/ may be used as basic mathematical models, especially for computerized meat grading. With grade G, lean meat %L, limit interval ΔL, constants A,a, fat and muscle readings f, m, intramuscular fat Δf, monetary yield \$, weight W, veterinary V and other cost data C and case-specific variables-X, they are:

$$G_i = \phi[\%L, \Delta L_i] \quad ...(1), \quad \%L_{HGP} = A - \Sigma a_{1j} f_j + \Sigma a_{2j} m_j \pm \Sigma a_{3j} f_j m_j \pm \Sigma a_{4j} f_j f_k + \Sigma a_{5j} m_j m_k - a_{6j} \Sigma \Delta f_i \quad ...(2),$$

$$\$_i = \phi(W, \%L, V, C, Xi_j) \quad ...(3), \quad \%L_{prac} = A - a_1 f_1 - a_2 f_2 - a_3 f_3 + a_4 m \pm C_j \quad ...(4),$$

where the simpler version (4) of eq. (2), with subscripts referring to different probing sites, is generally used in practice.

A comparison of the equations used in the main computer-assisted instruments is now possible, largely as a result of the work of Sack /1,2/, and based on eq. (4). Table 1 lists the corresponding multiplication constants, and shows the number of readings required (not necessarily at corresponding sites), for the KSA, HGP, FOM, and SKG, for pig classification. Obviously the optical, TV-based SKG system must use largely different parameters to the hand-held probes. The latter are better suited for research purposes in establishing appropriate multi-

plication factors, on which, as Table 1 shows no consensus has yet been reached. Since the HGP interface is compatible with most of today's small computers, it can, via its power supply, be connected directly to any such computer for research and data acquisition purposes. An important consideration is grading speed. To attain high speeds it is obviously desirable to use as few sites/readings as possible. Sack /1/ has shown that the omission of a_2 and/or a_3, via adjusted regression coefficients, only leads to minor loss of accuracy in the multiple correlation, but to a considerable time saving. Apart from this it is questionable whether constants with up to 6 significant figures are really necessary to satisfactorily describe the correlation. It is suggested that this be based on simple factors, such as used in the HGP.

Instrument \ Factor	A	a_1 (fat)	a_2 (fat)	a_3 (fat)	a_4 (meat)	C_j*	Country
KSA ('79)	-	0.2369	0.2263	0.2037	0.1781	0.1766W	DK
HGP ('83)	59.25	0.260	0.440	-	0.120	-	S
FOM ('82)	54.7292	0.18768	0.1112	0.32247	0.18097	-	DK
SKG ('82)	-	0.5281	-	-	-	0.01606W 1.3524STQ $-0.2130\alpha_s$	FRG

Table 1: Comparison of Grading Equations (W = carcass weight, STQ = SKG ham/loin width ratio, α_s = SKG ham angle)

Tests using the HGP have diverged into two basic schools of thought: single site instruments, or dual site instruments. The dual site instruments (currently under evaluation in Sweden, Finland, Norway, England and Germany) all measure the fat thickness over the centre of the m. long. dorsi on the last rib, and the fat and muscle thickness between the 3rd and 4th rib, 60 mm from the spine (11th/10th rib if counted from the head). This results in a lean meat percentage equation of the form:

$\%L_{HGP} = A - a_1 f_1 - a_2 f_2 + a_4 m$, ...(5), with constants as shown in Table 1.

Carcass dissection and analysis for commercial value is currently being performed to arrive at any modification which may be required to the equation. For the single site trials (proceeding in Canada '83), a single measurement is made at the 3/4 rib using the "single site" HGP equation, $\%L_{HGP(1)} = 59.25 - 0.65 f_1 + 0.12$ m. This system may however be discarded in favour of a measurement at the last rib, which is easier to find. Problems with pushing an optical probe right through the carcass at the last rib may be overcome by only measuring the fat thickness and using an equation of the form, $\%L = \phi(f, W)$, which is then compatible with the existing classification system, thereby facilitating the introduction of new technology. Trials in New Zealand on lamb /11/ show that a carcass thickness measurement between the 11th/12th ribs, 110 mm from the spine, is proving successful.

The need to have a unified carcass grading system from the smallest abattoir to large automated systems cannot be over-emphasised. The HGP is seen to meet this requirement best, by providing a portable, self-contained instrument for the small abattoir, with sufficient speed and performance to allow exactly the same instrument to be used in the largest works. Such equipment standardization is in the interests of all.

4. HGP-EXTENSIONS TO COMPUTER-AUTOMATED TOTAL GRADING SYSTEMS

4.1 Computerized Total Grading with Manual HGP

In many works it will be advantageous to connect the grading probe to a host computer system (commonly called 'terminal', and in general another microprocessor), as is the case with most probes presently under evaluation. A variety of such terminals exists (e.g. Flintab, Avery, STC, AWA). A typical configuration for the total grading by such a (still 'manual') system is shown in Figure 1 (also c.f. /3/).

The terminal provides a means for entering and changing the slaughter number, race, farmer number, veterinary information, date and operator. The information collected from the transducers (weight, fat thickness) and on the keyboard is collated and sent to the carcass identification equipment, printer and host accounting system. The interface of the HGP allows the probe to be used with almost any terminal (in constrast to the design philosophy for the FOM, which must always be used with a specific terminal (Selectric)). When connected into an accounting system, the use of a terminal will be inevitable to provide data entry and matching of protocols.

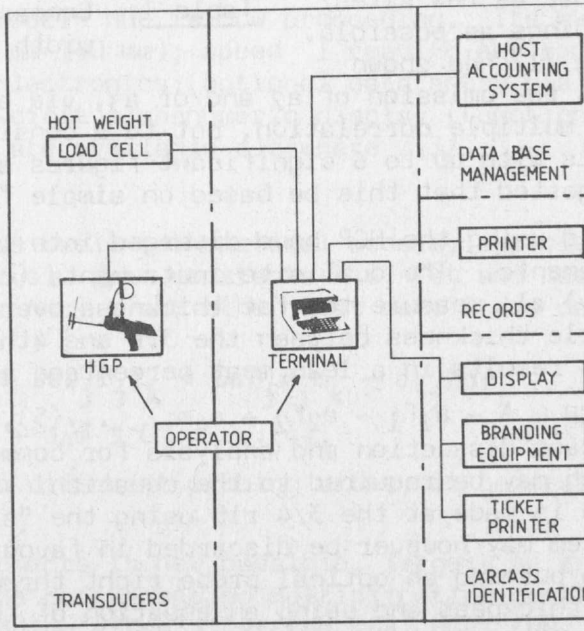

Figure 1: Total grading system with hand-held HGP and computer terminal.

4.2 Objectivity and Cost of Grading Systems

Apart from operational reliability, accuracy and speed, the two basic factors determining the acceptability and viability of a meat grading system are objectivity and cost. 100% objective readings can only be guaranteed in completely automatic systems. The SKG-system approaches this ideal, but at relatively high cost. With hand-held probes the opposite applies: although relatively cheap, they are prone to subjective manipulation, though this problem may be decreased somewhat by the use of probe alignment and positioning gauges. It is suggested that the solution lies in operating a 'manual' probe by means of a robot. - Only by means of such completely objective systems will standardization be achieved. The need for extensive and costly government or state control authorities, whose function it is to monitor and interrelate test results from the various accepted, but nevertheless subjective, grading probes, would also be obviated thereby.

4.3 Automatic Carcass Grading Using a Grading Robot

*As already indicated 2 years ago /3/ robot technology exists, mainly in manufacturing engineering applications, which may also be used beneficially in the meat industry. One of the ingredients presently revolutionizing manufacturing industry is the 'industrial robot', now firmly established in most industrialized countries /e.g. 14, 15/. However, the application of robotics to agriculture has started, as witnessed for example by the development of a sheep-shearing robot in Australia /16-19/. This is shown in Figure 2. It removes 90% of the wool yield of one sheep in 120 seconds, thereby indicating at what speed computer-programmable, sensor-equipped robots can handle very complex manipulative tasks today, and suggesting the technical feasibility of a grading robot. Other examples are the use of remote electronic sensing devices for animal identification and monitoring /20,21/. As a design brief, a robotic system for carcass grading must be able to accommodate different carcass types, shapes and sizes - a basic design philosophy also of the FDI/HGP /e.g. 22/. It should be able to operate at the highest abattoir chain speeds, and be technically, economically and environmentally compatible and viable. Grading speeds of up to 450 carcasses/hour have already been achieved with the manually-held HGP, the limits being set by the human operator, not the instrument. With a robot-guided single probe, speeds of up to 600 c/hr should be possible (6 seconds/carcass) for single site-probing. For multiple-site probing it may be feasible for one robot to hold and insert two or more grading probes simultaneously, resulting in similar speeds. Even higher speeds are possible by branched lines, i.e. robots working in parallel. The limits are determined by the speed at which current sensor technology, in which rapid advances are currently being made, can reliably operate.

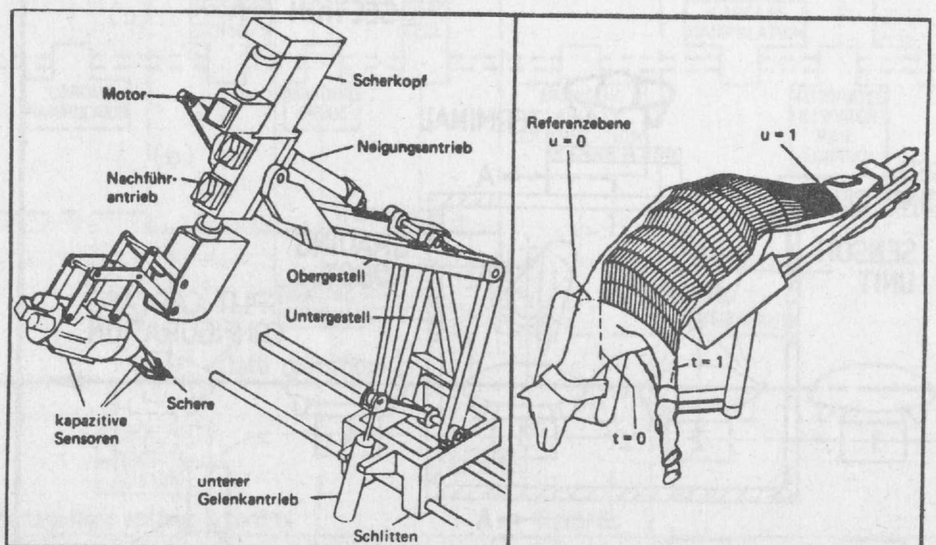

Figure 2: Sheep-shearing robot application (Uni. of West Australia, /17/)

A possible solution concept of a robotic grading station satisfying the above requirements is presented in Figure 3.

Figures 3a and b show the geometrical requirements of a grading robot for probing different carcasses. With beef as generally the largest in size, the robot must be able to present the probe(s) perpendicular to any surface point (situated on approximately concentric circles) contained within the volume of the 'front' half of the body of revolution shown. The carcass surfaces may be described in cartesian or cylindrical coordinates, and are established by sensors. The normals at any pre-defined probing site may then be computed, and the robot'hand' guided accordingly. Figure 3c then shows a side-elevation (View AA in Figure 3d) of a typical industrial robot installation fulfilling the geometric constraints of Figures 3a and b. Quite a variety of robots considered suitable for this task is available today. Positive lo-

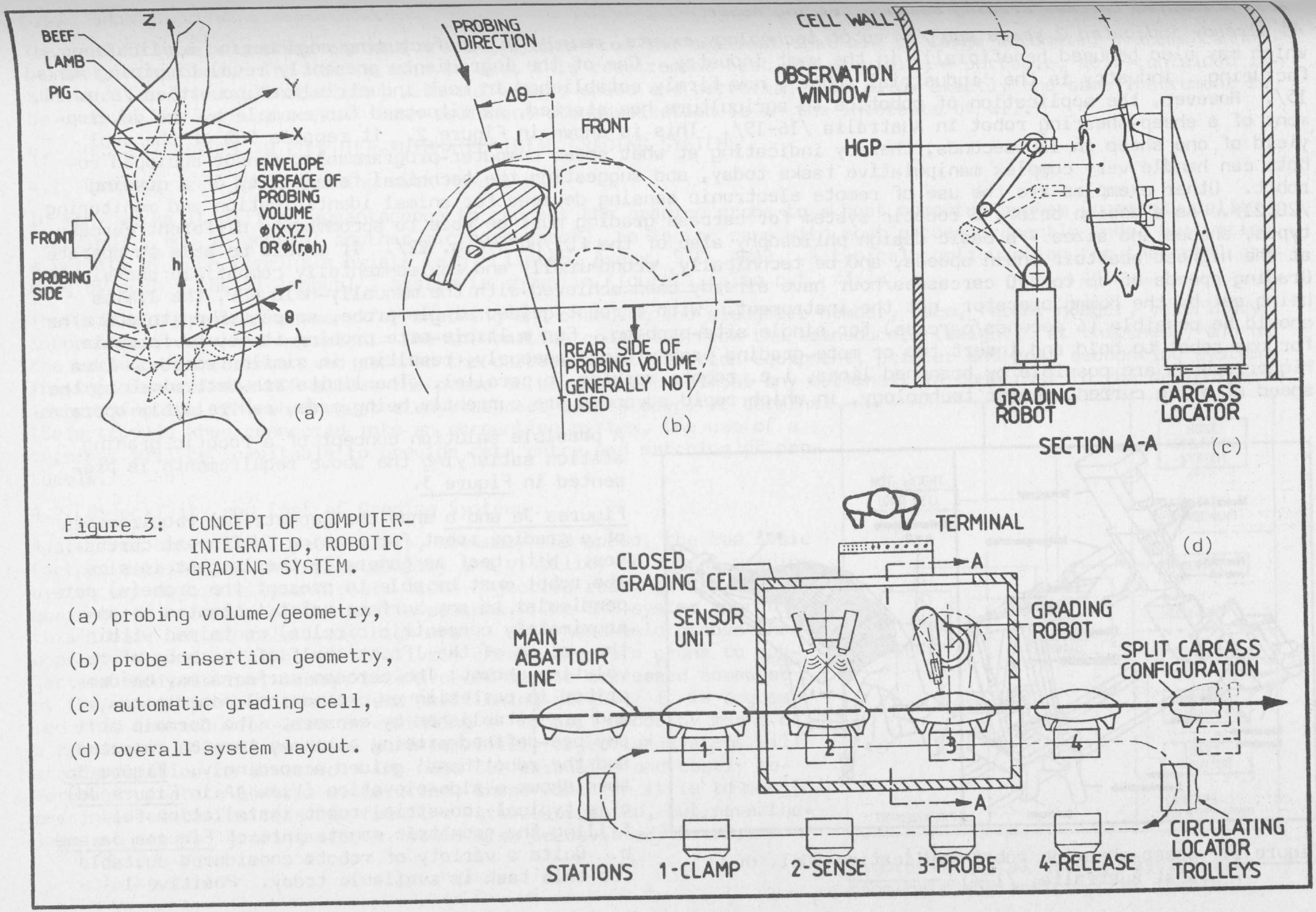

Figure 3: CONCEPT OF COMPUTER-INTEGRATED, ROBOTIC GRADING SYSTEM.

(a) probing volume/geometry,

(b) probe insertion geometry,

(c) automatic grading cell,

(d) overall system layout.

cation/clamping of the carcass is essential to facilitate sensing and ensure accurate probe insertion. One possible solution of this problem is shown in the overall system configuration of Figure 3d. The sensing and probing functions are separated into two stations for ease of operation and increase in output speed. The grading system, located on the abattoir chain, encompasses 4 stations (clamp-sense-probe-release), interconnected at fixed-pitch distances by a location track on which synchronized carcass support/location trollies circulate.

Carcass clamping/unclamping may be manual or automatic. Sensing (e.g. ultrasonic, tactile,optical, x-ray) and probing (standard HGP held by robot, such that it can also be removed and used manually, if necessary) take place in the closed-off, "intelligent" grading cell, with external data entry/keyboard access, and no manual interference: the operator merely supervises the process.

The control configuration for such a robotic grading cell system, integrated with the other relevant inputs, is shown in Figure 4, as one example of a truly objective, yet flexible total carcass grading and processing system. Industrial robots generally have a payback period of 1 to 3 years, depending on shift work. It is estimated that this should also apply to the system here described, so that the performance characteristics, cost, flexibility and compatibility of such a system would make it an economic proposition for the meat industry. The latter, together with robot manufacturers and perhaps other institutions, should be encouraged to support research and feasibility studies into robotic grading systems of the kind described, in the interests of higher efficiency and objectivity in meat grading. Preliminary work is in progress.

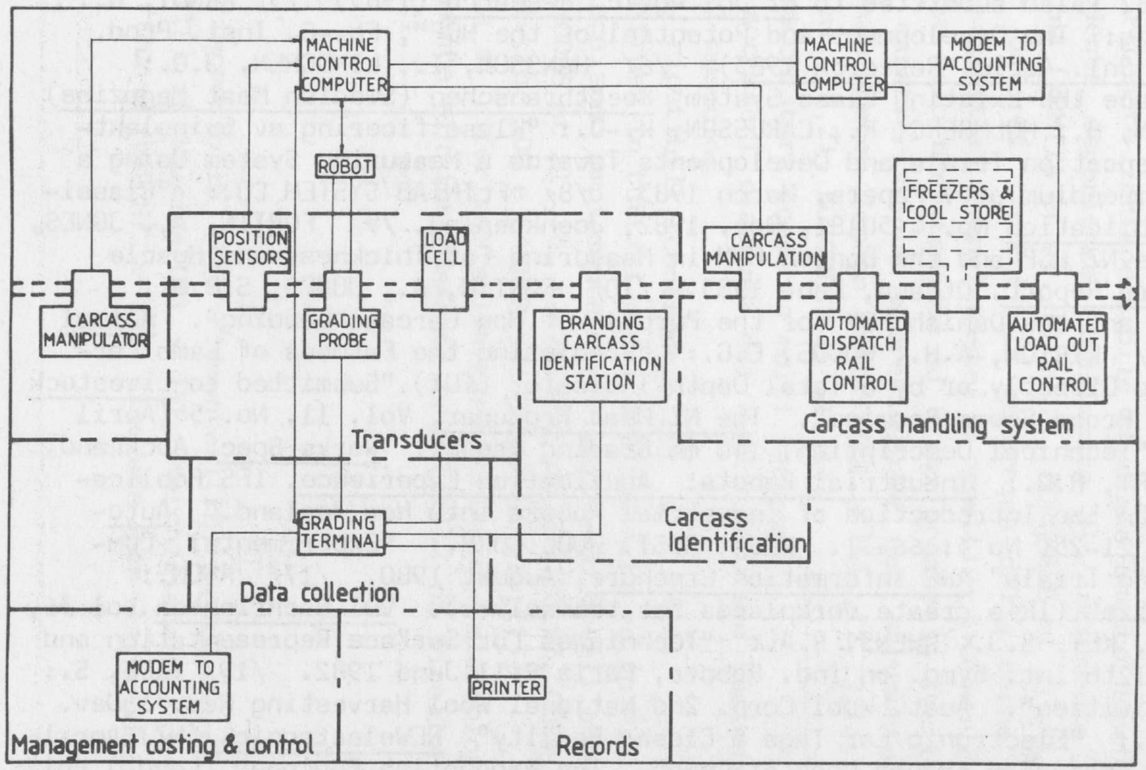

Figure 4: Control configuration for computer-integrated total carcass processing system including intelligent, robot-automated grading cell.

5. CONCLUSION

Based on developments and application tests over the past 3-4 years, and as initially conceived, the Hennessy Grading Probe (HGP) is suitable as the basic building block in any carcass grading system, ranging from the simple hand-held version for small meat works, to the completely computer-automated robotic version for large-scale high-speed abattoir chains. Combined with a standard industrial robot it can lead to a completely objective, economic meat grading system suitable for any carcass. A possible solution concept has been presented, and shows great promise. It is suggested, however, that the overriding merit of the HGP is its superior performance as a universal, basic aid towards achieving uniform, objective grading procedures on an international basis.

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