3 June 1991

Automatic Grading and Packing of Prawns
- FIRDC Project 90/92 -
Final Report

1. Overview. This is the final report of research under FIRDC Project 90/92 to develop technology for automatic grading and packing of prawns. We have demonstrated the technical feasibility, and indicated the economic feasibility, of automatically producing single-layer 'consumer' tray packs of prawns so that, in every tray, each prawn has approximately the same mass, faces the same direction and is approximately straight.

The technology we have developed requires that prawns of mixed grade and haphazard orientation arrive on a conveyor in such a way that adjacent prawns generally do not touch each other. We understand from industry sources that existing technology is available to satisfy this input requirement.

Our developments include a specially programmed machine vision system and a novel prawn gripper mechanism attachable to a robot arm. The machine vision system embraces one or more cameras. These scan a designated area of the conveyor and supply imagery that is analysed immediately by a special-purpose computer. 'Downstream' from this vision system are one or more robots (the number depends upon peak processing requirements for the installation). Each robot is equipped with a prawn gripper mechanism.

The machine vision system is programmed to determine, for each arriving prawn, its location, its orientation (i.e., on which sides are the prawn's head, tail, and legs), its amount of curl, and its approximate mass (calculated on the basis of the prawn's silhouette area). In addition, the software calculates the co-ordinates of three points on the surface of each arriving prawn. These points, which we call 'pick-up points', are located on the prawn's carapace, on its middle abdomen and near its tail.

The gripper mechanism, attached to a robot arm, is programmed to orientate itself to acquire, by vacuum, a designated prawn at its three pick-up points. After the prawn is lifted off the conveyor, the mechanism's motors move so that the acquired prawn is straightened, removing the curl determined by the machine vision system. At the same time, the robot arm transports the gripper mechanism so that the prawn is moved just above the next available 'slot' of one of several adjacent trays. Then the prawn is deposited into this 'slot'. When full, all prawns in this tray will be approximately the same size and will have the same head-direction and orientation as the current prawn.

This novel technology has the potential to be installed in on-shore processing facilities or on trawlers. It can be utilised with sea-caught or aquaculture prawns. When used on a trawler, the technology could reduce to one the number of times that prawns are frozen between the time of catch and the time they are cooked and eaten. This should considerably improve the gastronomic quality of these prawns and should confer a significant marketing advantage to the product.

Producing consumer packs of prawns in Australia also allows one or more 'brand-name' identities to be created for Australian prawns. A brand-name identity should enable the product to command premium prices in overseas markets where Australian prawns compete with those from other countries.

Automation of this process also has the potential to repatriate an operation that now often is done overseas. And by automating what is presently a very labour-intensive and repetitive task that requires no human creativity, the technology increases quality control of the grading and packing process in addition to saving labour costs.

The novel technology can process deheaded as well as head-on prawns. In the former case, where there is no carapace, only two pick-up points are utilised: the part of the gripper mechanism that would make contact with the carapace is automatically moved out of the way.

An occasional pair of entangled or overlapping prawns that arrive on the conveyor should not cause a processing problem, as the machine-vision or gripper systems should be able to detect this as an anomaly to be diverted from the conveyor for subsequent human examination.

It is envisaged, at least in the short-term future, that one person will scan the conveyor in advance of the machine vision system and will manually remove any by-catch, foreign matter or damaged or otherwise defective product observed there.

2. *Machine Vision.* This part of our research and development utilised hardware facilities installed at the CSIRO Division of Manufacturing Technology in Melbourne. These facilities include an Australian-designed 'Area Parameter Accelerator' machine-vision electronics board which

analyses multiple nontouching silhouettes in a scene as fast as a camera acquires an image of that scene. This machine-vision system can calculate information about prawn images such as the areas of their silhouettes at speeds of about 25 nontouching prawns per second, which is faster than current production speeds.

The following algorithms were developed in the present project:

¶ An automatic method—which appears to work reliably all the time—for identifying the head end and the tail end of head-on prawns. This algorithm utilises information about image curvature and the comparative thickness of the carapace to distinguish the head from the tail.

¶ An automatic method, based upon image curvature, for determining on which side of the image the prawn's legs are to be found. This algorithm also appears to work all the time, and takes advantage of the circumstance that a prawn's physiology limits the shapes it can assume.

¶ An automatic method for estimating prawn mass on the basis of prawn silhouette data. The algorithm developed in this project utilises a particular threshold level to screen out some thin portions (e.g., parts of prawns' legs) of the silhouette image. Then the algorithm estimates a prawn's mass to be a correlate of the area of the remaining silhouette.

With assistance from the CSIRO Division of Fisheries and Newfishing Australia Pty Limited, more than 200 prawns were processed through the machine vision system, utilising specially developed software that implements the above algorithms. The prawns were of several species, but primarily banana *(Penaeus merguiensis)*, tiger *(Penaeus semisulcatus)* and endeavour *(Metapenaeus endeavouri)*. Both head-on and deheaded prawns were used in these trials.

Experiments were undertaken to determine the reliability of the mass-estimation algorithm. *Figure 1* appended to this report is a graph showing the relationship between silhouette area (in square millimetres, as calculated by this algorithm) and mass (in grams, as weighed on an electronic balance) of 214 prawns. The dashed line is the "least-squares" fit line.

Analysis of the data establishes that, for this set of 214 prawns, the correlation of calculated silhouette area to weighed mass was about 87%. Let us explain more precisely what this means.

Prawns are presently sold commercially in mass-related grades.

Examples of these grades are: under 22 prawns per kg, 22–33 prawns/kg, 34–44 prawns/kg, 45–55 prawns/kg, ..., and 133–154 prawns/kg. Ideally each prawn in each of these grades therefore should weigh >45 g, 30–45g, 23–29g, ..., and 6g respectively.

The machine-vision algorithm calculated silhouette areas for each of the 214 prawns. These areas then were sorted in ascending numerical order. It then proved possible to set thresholds (e.g., assign prawns with silhouette area below 3230 mm^2 to the category 29g or less; assign prawns with silhouette area above 3230 mm^2 to the category 30g or more) so that 186 of the 214 prawns (or 87%) were automatically assigned to the correct grade. Generally the remaining 28 prawns were automatically assigned to the next larger or next smaller grade.

We think this is an excellent outcome, for the following commercial reasons:

¶ Previous research by this company established that the percentage of prawns correctly classified by experienced prawn packers in one processing facility was considerably lower than 87%.[1] The lighter the prawn, the more likely it was to be misclassified, as even experienced human graders are unable to make 2 g distinctions reliably without constant reference to an electronic balance.

¶ Grade information is anticipated to be used by the industry in one of two ways:

§ to assign prawns to single-layer "consumer packs" on the basis of their approximate size. These packs will be sold on the basis of their count—e.g., ten large tiger prawns—rather than on the basis of their weight. The current machine-vision methods clearly can select ten prawns having approximately identical silhouette area. Of course, the net weight of each packed tray of ten prawns can subsequently be calculated if it is desired that the price the consumer pays for the entire pack reflects a unit price per kilogram of prawn. A major goal of the present R&D project has been to demonstrate the feasibility of packing such consumer packs by automatic means.

§ to assign prawns to bulk (e.g., 2 kg or 3 kg) packs. For

1. In the mid-range of prawns, say between 34 and 55 prawns per kilogram, experienced prawn packers produced 2 kg export packs in which only 70% of the prawns were correctly sized. See M. Kassler, "Robotics and Prawn-Handling", *Robotica*, vol. 8 part 4 (October-December 1990), pp. 299–301.

the foreseeable future, we believe that bulk packs will continue to be packed manually, as we see no cost-effective method of automating the packing process to produce packs of nestled prawns that meet the aesthetic presentation standards required by the Japanese market. Therefore, we envisage that the machine-vision silhouette data could be utilised to select (say) 80% of the contents of a bulk pack. After this quantity is packed by hand, the pack would be weighed. Then prawns of the appropriate size (also set aside by the machine-vision system) would be manually added or subtracted until the pack had the exact desired net weight within an acceptable tolerance.

In any case, 100% correlation between mass and silhouette area is impossible to achieve because the silhouette data lacks all volumetric information. It may be possible to get some small improvement to the 87% correlation experimentally achieved in the present project. However, while this may have some relevance to biological studies of prawns, such an improvement does not appear, for the reasons indicated, to have commercial signficance.

Analysis of the data for the 214 prawns showed that a quadratic model had no greater predictive power than the linear, least-squares model utilised to estimate mass from silhouette area.

3. *Mechanical Gripping and Straightening of Prawns.* After the machine-vision system, utilising the techniques described in the previous section, determines (say) that prawns no. 3, 9, 17, 18, 24, etc. arriving on the conveyor are to be put into the same single-layer consumer pack, each of these prawns must be automatically removed from the conveyor. Once such a prawn is reliably picked up by an appropriate gripper mechanism, it must be uncurled (if it is not already approximately straight) and it must be orientated so that (say) its head is North, its legs are West and its tail points South.

Then the straight, correctly orientated prawn must be placed in an appropriate tray adjacent to the conveyor and put in the next available compartment or space in that tray. Finally, the gripper mechanism must deposit the prawn without alterting its orientation and then must return to the conveyor to acquire the next prawn.

It is essential that this process does not damage, blemish or mark the prawn in any discernible way. As cycle time is crucial, it is appropriate that the orientating and straightening of each prawn be done 'on the fly', i.e., while the prawn is being transported from the conveyor to the tray.

Also it is essential that the gripper mechanism be hosable down to maintain food-quality standards and to eliminate the possibility of contamination.

Certain aspects of this process can take advantage of prior established technology. For example, machine-vision technology is commercially available to track manufactured components travelling on a conveyor so that a robot arm 'downstream' of the camera can pick up the desired part. Computer technology also is available to calculate where the next item in a series of items should be positioned in a tray. Accordingly, it has not been necessary to develop or to demonstrate these tracking and positioning capabilities as part of the current R&D project.

The novel mechanical technology that was required to be developed and demonstrated is the technology specific to prawn-handling. This comprises methods for gripping/releasing and for straightening/orientating prawns.

Experiments carried out in the present project demonstrated that suction is a reliable method of acquiring, gripping and releasing prawns. In contrast to other conceivable gripping methods, such as mechanical 'fingers' or pins, vacuum gripping has the important advantage of not puncturing or compressing the prawn surface. Also, it should leave no visible mark on the surface when the prawn is released. Moreover, in contrast to some other conceivable gripping technologies such as adhesives, vacuum gripper mechanisms can be manufactured to satisfy food-quality standards.

Tests have been conducted to establish and confirm the suitability of vacuum gripping of prawns in a variety of environmental conditions, including wet and dry prawn surfaces and circumstances where the vacuum provides only partial coverage of the prawn surface. This can happen if part of the vacuum cup extends beyond the edge of the prawn body or includes contact with prawn legs which have intermediate gaps.

Tests have shown that an acquisition time of approximately 0.3 seconds is sufficient for a vacuum cup to grip a prawn. Relevant vacuum parameters, such as resistance to slip, and vacuum performance under different vacuum intensities, have been measured.

Experiments also showed that a linked 'hand' comprising three independently controllable vacuum gripper mechanisms should be adequate to straighten curled prawns to the desired extent. The concept—see *Figure*

2—is that one of these gripper mechanisms will make contact with the carapace of the prawn, another with a portion of the prawn body near the tail, and the third with a portion of the prawn body on the middle abdomen between the carapace and the tail.

(In the case of deheaded prawns, the gripper mechanism normally assigned to the carapace will be controlled so that it makes no contact with the prawn surface. The acquisition and straightening of a deheaded prawn then will be accomplished by the action of the remaining two gripper mechanisms.)

Examination of the 1989 Catch Composition Report for the Northern Prawn Fishery[2] indicated that a mechanism comprising three links, connected at two hinge points—see *Figure 3*—, should be adequate to handle virtually all prawns, from the smallest to the largest, which are caught in that fishery for commercial sale. Therefore it is unnecessary to utilise different sizes of gripper mechanism for different sizes of prawn.

This circumstance obviously simplifies the resulting system as it avoids having to change or to adjust the system mechanically from one batch of prawns to the next.

A mechanism based upon this design, incorporating three vacuum grippers, was built. It has been manually tested on both small and large prawns within the size range of prawns caught in the Northern Prawn Fishery.

This prototype mechanism utilised stepper motors to rotate two of the three links to the extent necessary to grip a prawn in its initial curled state. A production version of this mechanism probably would utilise DC motors.

After a prawn was acquired by the mechanism, the stepper motors were manually controlled to rotate the two links to uncurl the prawn. Once uncurled, the prawn was placed down in the appropriate place on the consumer-pack tray.

In a production version, the angles and direction of the prawn's initial rotation will be calculated by the machine-vision system at the same time as it calculates the prawn's silhouette area. As explained above, the machine vision system also will calculate the three 'pick-up points' (two in the case of deheaded prawns) where the suction cups on the mechanism are to make

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2. Somers, Ian and Brian Taylor, *1989 Catch Composition Report.* Cleveland, Queensland, CSIRO Marine Laboratories, 14 February 1990.

contact with the prawn.

4. Economic Considerations. The cost–effectiveness of introducing into a particular installation the novel technology we have developed depends upon the processing requirements of that installation. Here we provide some general indications of circumstances in which the new technology is likely to prove cost–effective.

We do not take into account the considerable additional economic advantages that should accrue from utilising the new technology for value–added processing in Australia, such as the establishment of brand–name tray packs of prawns, as insufficient data are available for us to indicate the likely benefit of this change in dollar terms. Accordingly, the analysis that follows is likely to *underestimate* the true economic benefits of exploiting this technology.

A revised version of the Australian machine–vision electronics board is currently under development by an Adelaide company, Atlantek Microsystems Pty Limited. Besides having lower cost, the new board is expected to offer three times the processing capacity and speed. It is anticipated to be commercially available in about a year. Amongst other advantages, this additional capacity will enable all candidate 'pick–up points', such as the centroid of the carapace, to be calculated at the same time as the other information required from the machine vision system.

First, we consider the costs and benefits of utilising the machine vision technology for grading only, with packing continuing to be done by the present manual methods. As a rough estimate, a production machine–vision system, including cameras and lenses, lighting, a conveyor, the new machine–vision electronics board and other electronics hardware, and a power supply, is expected to cost about $50,000. A ruggedised version of this suitable for use on board a trawler is expected to cost an additional $10,000.

These costs do not take into account the additional software that must be written and tested, and the 'system integration' that must be undertaken to convert the present research system into a robust system suitable for reliable use in a production environment. At commercial rates, this additional work—involving essentially the construction and testing of an initial prototype system which, after all the problems have been sorted out, can subsequently be duplicated—is expected to cost an additional $60,000, making the cost to develop the initial system $110,000.

Prawn grading is presently done by two different mechanical methods. The Danish firm Kronborg Maskinfabrik A/S is one of several companies that manufactures a shrimp grading machine with adjustable grading pipes. The prawns are vibrated and the mechanically adjustable distance between adjacent pipes determines the grade into which the prawns fall.

A standard Kronberg machine, the Panda 2004, accommodates three or four grades. Its capacity is stated as 1,200 kg/hour or 20 kg/minute or 333 g/sec. If a prawn weighs, on average, 25 g, this machine should be able to process 13 prawns/sec on average into three or four grades. Its price in Denmark is stated by the manufacturer to be about $A 36,000. The manufacturer does not specify the accuracy of this system. In practice, the grading accomplished by such a machine usually is refined by human packers to achieve the accuracies that are commercially required.

Check–weighing is an alternative existing technology. The Taiwan firm Mirle Automation Corporation manufactures a shrimp grader based upon check–weighing each prawn. A 'dynamic weighing accuracy' of ±1 g is claimed for this machine. Its maximum capacity is 14,400 prawns/hour or 4 prawns/sec. (This limit is a function of the minimum settling time of about ½ sec required for a load cell to calculate the mass of a prawn.) Its price in Taiwan is stated by the manufacturer to be about $A 51,000.

The novel machine–vision method developed in this project determines prawn mass less accurately than check–weighing. However, to process 24 prawns/sec would require an expenditure of about $300,000 if four Mirle Automation Corporation machines were used. Allowing for the cost of diverters (to remove individual prawns from the conveyor) and for marketing costs and profitability, it appears that machine vision will have an increasing competitive advantage over check–weighing technology as the number of prawns processed per second increases.

The Kronborg machine offers high processing speeds but is limited in the number of grades into which it can sort at a time. If only three or four grades are required, the mechanical–pipe technology exemplified in that machine appears to be cheaper. However, machine vision would appear to have a competitive advantage where it is desirable to sort prawns into, say, eight or more grades at a time. It is clearly advantageous to sort prawns once rather than more than once, as multiple handling increases the risk of damage to the product as well as the processing costs.

A production version of the novel prawn gripper mechanism, satisfying food–quality standards, is expected to cost about $10,000. (Once again, there would be further development costs of about $25,000 to develop and test the initial production version, to produce engineering drawings for manufacture of the gripper, etc.) For budgetary purposes, a cost of about $50,000 per robot arm can be assumed—there is a range of available robots having different costs, speeds and other relevant parameters.

Accordingly, the basic costs of *subsequent* systems (after the initial prototype system has been built, thoroughly tested in a production environment, and modified in the light of that experience) comprising a machine vision system, a conveyor, and robotic straightening and packing of prawns would be:

- $110,000 for a 1-robot system
- $170,000 for a 2-robot system
- $230,000 for a 3-robot system

It must be emphasised that these figures do *not* include the costs of associated equipment for automatic presentation, handling, wrapping and labelling of trays, nor have they been 'marked up' to cover marketing expenses, delivery and installation expenses, training expenses, etc.

If, on average, the cycle time for a robot to acquire, straighten and pack a prawn and then to return to the conveyor for the next prawn is 2½ seconds, which appears to be a good estimate, then a single robot would pack 24 prawns per minute or 1440 prawns per hour. Therefore such a robot would pack 11,520 prawns in 8 hours, 17,280 prawns in 12 hours or 23,040 prawns in 16 hours.

Statistics obtained from one Australian on-shore prawn processing facility suggest that a human packer can straighten, orientate and pack (into bulk packs) about 250 kg or 10,000 prawns per day (assuming an average mass of 25 g per prawn). Thus, on a two-shift basis, one robot would do the work now done by 2.3 people.

A two-robot system therefore would do work now done by 4.6 people. If each packer costs $25,000 (including on-costs), and a two-year payback is desired, a company should be prepared to pay $25,000 × 2 × 4.6 = $230,000 for an automated system. This is more than the nominal $170,000 cost of such a system.

Although these costs need to be further refined, this preliminary analysis indicates that a reasonable payback period should be achievable for a system including two or more robots that operates for two or more shifts.

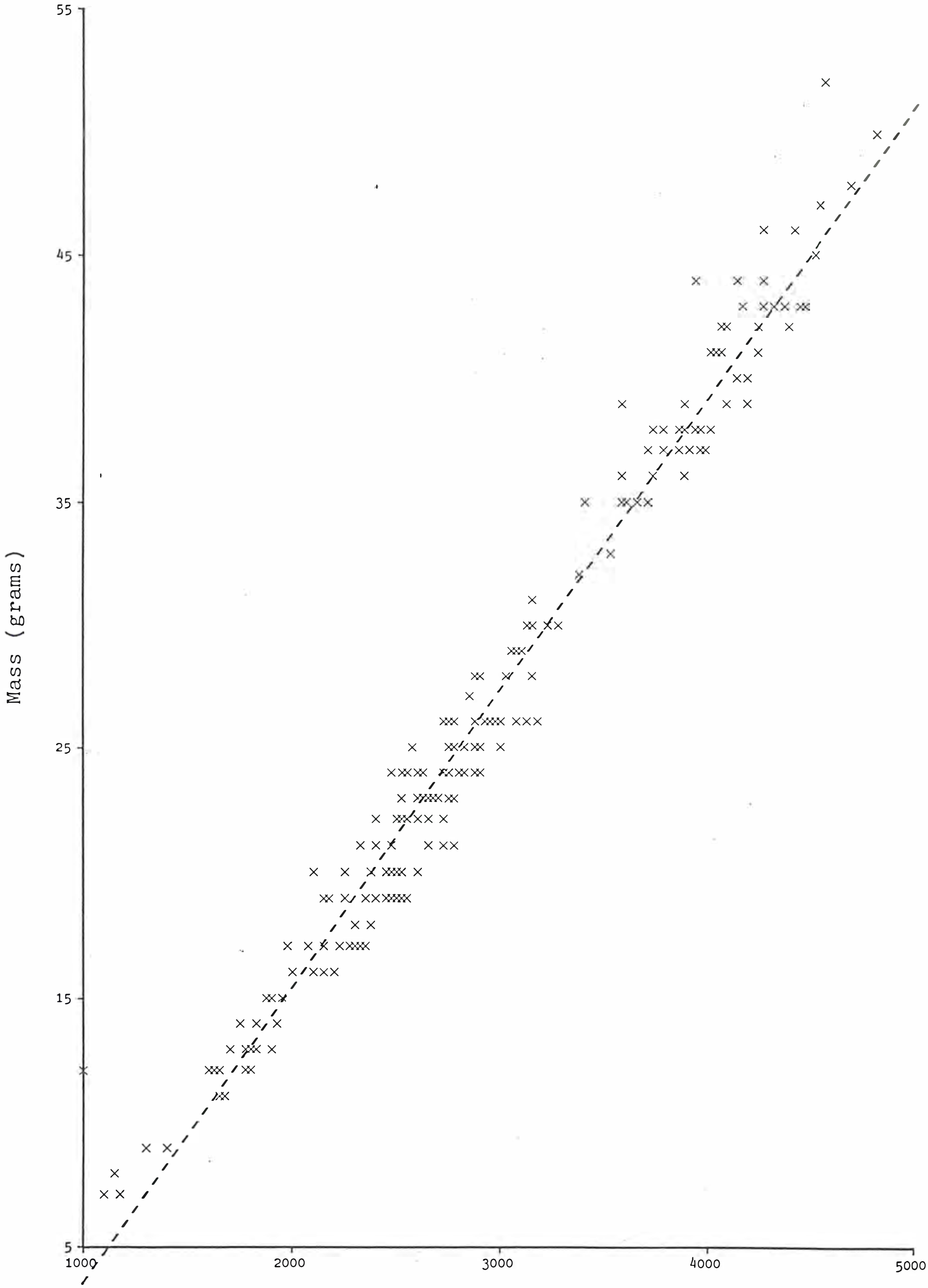
As mentioned, to reach that stage, further investment is necessary to enable an initial system to be built and thoroughly tested. We have had discussions with representatives of the Australian fishing industry on this subject. However, at time of writing, we are unable to report that such investment is likely to be forthcoming.

5. Dissemination of Project Results. Scientific papers reporting on the results of this research have been accepted for presentation to the International Advanced Robotics Programme workshop on "Robotics in Agriculture and the Food Industry" to be held in Genoa, Italy, in June 1991 and to the 22nd International Symposium on Industrial Robots to be held in Detroit, U.S.A. in October 1991. An interim report on this project was presented to the Northern Prawn Fishery pre-season workshop in Cairns in February 1991.

Non-technical articles on the project have appeared in *The Australian*. A further report is expected to appear shortly in *Australian Fisheries*.

A video and slides illustrating the machine-vision and gripper mechanism developments have been provided to the Executive Officer of FIRDC.

6. Annexe. We annexe to this report a memorandum entitled "Machine Vision for Prawn Grading and Robotic Grip Site Determination". This memorandum, prepared by Peter Corke of the CSIRO Division of Manufacturing Technology, describes in greater detail the work accomplished by CSIRO as a subcontractor to this firm on the current project.



Silhouette Area (sq. mm.) of 214 Mixed-Species Head-On & Deheaded Prawns

Figure 1

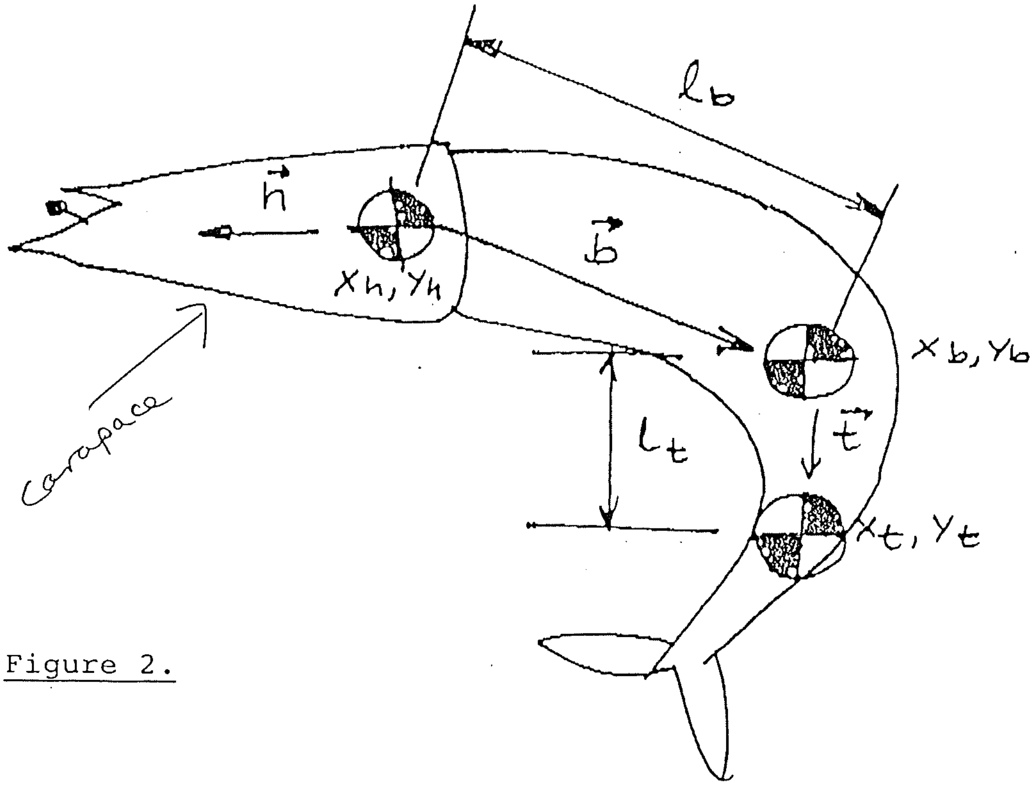


Figure 2.

STRUCTURE OF GRIPPER MECHANICS

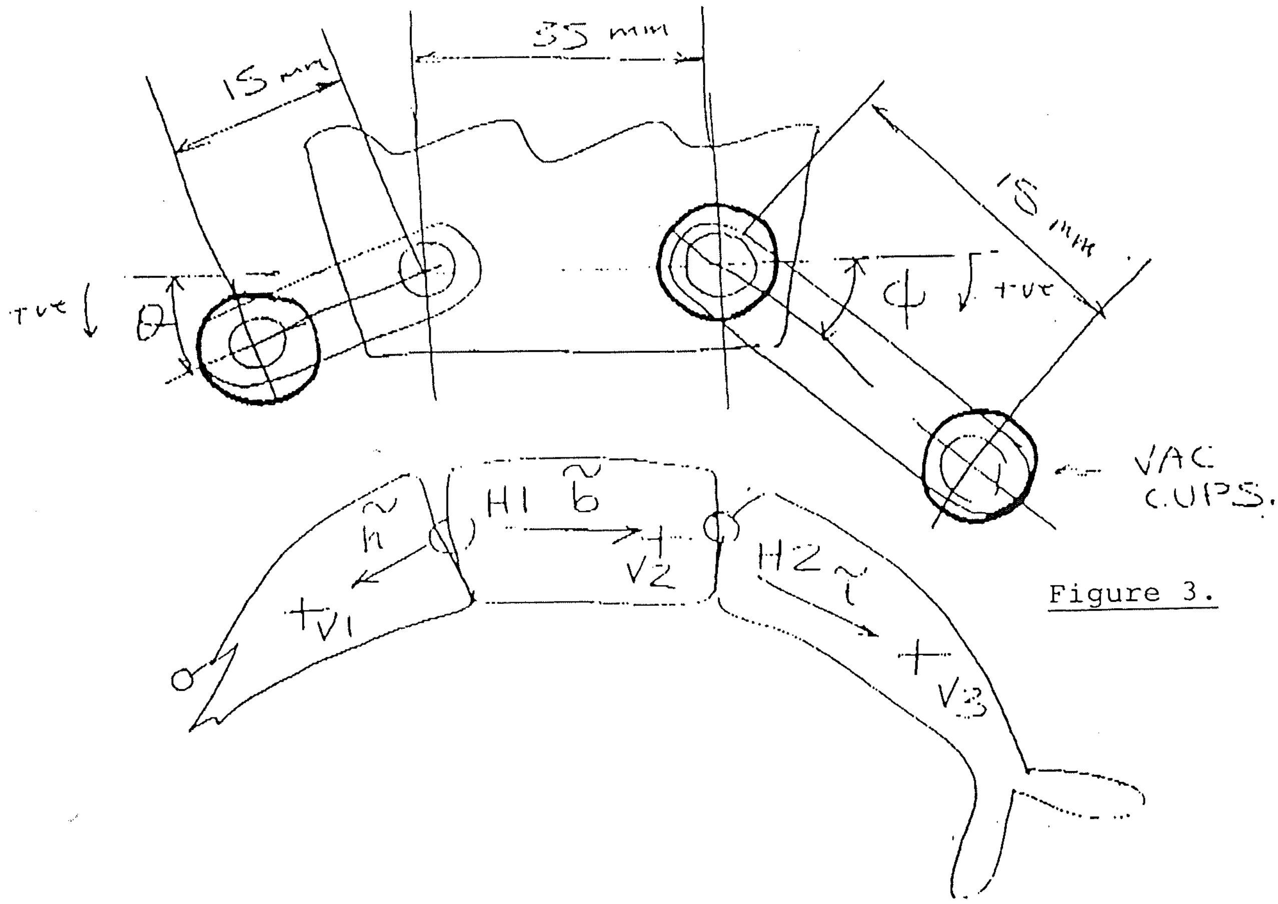


Figure 3.

MODEL PRAWN

HINGE POINTS: H_1, H_2; VACUUM ENGAGEMENT: V_1, V_2, V_3

The mechanical hand will manipulate H_1 and vector b (which are fixed with respect to the hand) into position, and drive vectors h and t to match the initial shape of

13/2/91

Machine Vision for Prawn Grading and Robotic Grip Site Determination

Report to Michael Kassler and Associates.

Peter I. Corke
CSIRO Division of Manufacturing Technology.

1 Introduction

This document summarizes the algorithms developed under contract to Michael Kassler and Associates on the use of machine vision for prawn grading and robotic grip site determination. The term APA is used as a generic term for both the existing APA-512, and the APA-2 currently under development.

2 Area measurement

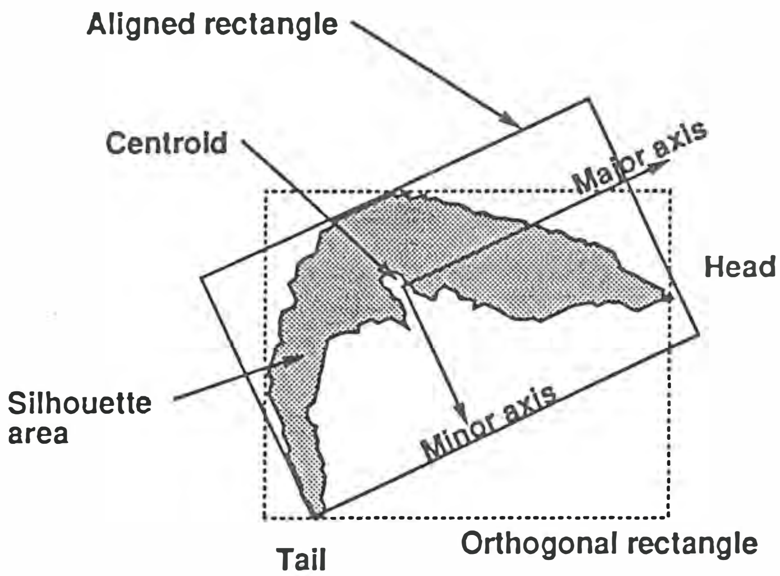


Figure 1: Basic APA derived features

Area is simply the silhouette area of the backlit prawns observed with an overhead CCD camera. Number of pixels per region is obtained directly by the APA, and is simply scaled to obtain area.

As prawns progress across the viewing area they change in apparent size, by as much as 10%. Possibe contributing factors are;

- Uneven backlighting in conjunction with the relatively 'soft' edges of the prawn image and a fixed threshold. A simple fix for this would be an improved lightbox, possibly deeper than the current one, in which the light source is further away from the diffuser screen.

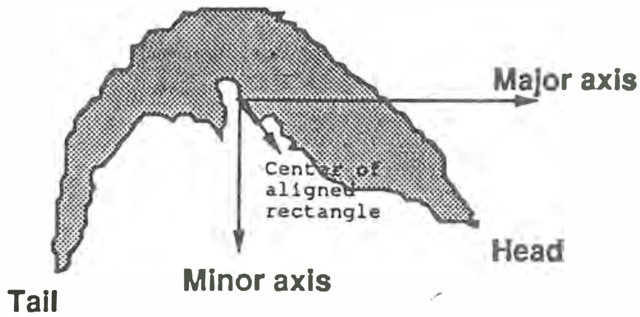


Figure 2: Head/tail pointing vector

This may have some impact on conveyor design requiring greater separation between the top and return belts.

Another option is to take an image of the lightbox and belt with no prawns, and subtract this 'background' from future images. This would involve an extra framestore to hold the background image, and a simple pixel ALU board to perform subtraction.

- Apparent change in area when the prawn is viewed from an oblique angle.
- Possible lens distortion effects towards the periphery of the viewing area.

These effects could be diminished by always recording the area measurement when the prawn is closest to the center of the image.

3 Orientation measurement

Orientation of the prawn is obtained cheaply (in computational terms) from the moment parameters computed by the APA per region. The angle of the major axis with respect to the X axis is given modulo 180 degrees.

The vector from the centroid towards the center of the aligned rectangle is observed to point towards the head and the leg side of the prawn. This has been well verified in experiment.

The aligned rectangle has its sides aligned with the major and minor axes of the object, and is computed by software traversing the perimeter of the region, from a starting edge point determined by the APA.

In the case where there is no significant component along the major axis (SRI parameter *x3sign*) the head/tail ambiguity is resolved by investigating the average intensity of the original grey scale image along the positive and negative sections of the major axis. Because of the greater density of the prawn's carapace section, the average intensity is lowest along the positive part of the major axis.

The component along the minor axis (SRI parameter *y3sign*) is always significant except in the case of a highly curled prawn, one in which the tail tip almost touches the head.

The SRI parameter *axratio* is the ratio of minor axis length to major axis length. A value less than 0.35 indicates a 'straight' prawn, and greater than 0.60 a 'curled' prawn.

4 Grip site identification

The attached figures 4a,b,c show outlines of three different prawns that have been classed as straight, normal and curled respectively. Each has been rotated so that the major axis is horizontal and positive to the right. The grid is scaled in terms of major axis length. The

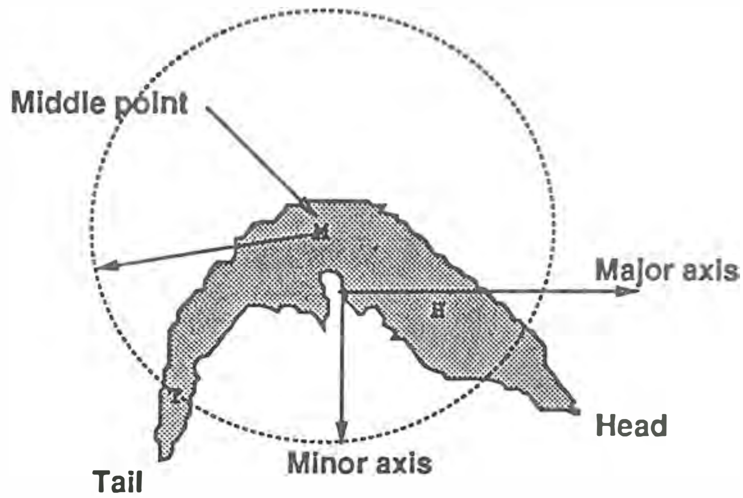


Figure 3: Grip site determination

minor axis is shown as a vertical solid line through the origin. The middle of the prawn is taken as a fixed point with respect to this normalized coordinate system, typically $(-0.2, -0.5 * minor/major)$. The head point is adequately described by the fixed coordinate $(0.4, 0.0)$.

The tail point is much more problematic, and as the figures show, a tail point does not lie at a constant point on the normalized coordinate frame. One option is to determine a number of points appropriate to the 'shape', but this may not be robust.

Since the gripping mechanism is hinged, and the suction cups are a fixed distance apart, it seems better to search for the tail along a circular path about the middle point. The radius of the circle is the distance between the middle and tail suction grippers l_t[1]. The head could also be found using another circular search path of radius l_b about the middle point. Knowledge of prawn geometry would allow the searches to be restricted to two arc segments.

5 Performance issues

As prawns enter the scene the APA will determine moments and area parameters with relatively little burden on the host CPU. However searches to resolve indeterminate head/tail orientation, aligned rectangle computation, and grip site searchs may be too costly to perform for every prawn in the frame whilst maintaining continuous frame processing. A better solution would be to perform the time consuming seaches only when a new prawn enters the scene, its orientation and grip site positions relative to the centroid remaining unchanged through the scene.

The computational strategy may be something like;

- on the first occurence of a prawn in the scene
  - traverse the perimeter to compute the aligned rectangle used for head/leg pointing vector.
  - if the head/tail direction is indeterminate scan the major axis to determine the average intensities.
  - search two circular arcs to determine the grip sites.
- for each prawn in the scene compute centroid and area. If the prawn is near the center of the scene, record this area as the 'proper area' for mass determination. Update grip site

[1]As described in the fax of 27/12/90 from Michael Kassler and Associates

coordinates with respect to changed centroid. Prawns may be matched between frames on the basis of shape and knowledge of conveyor motion with respect to the image frame. Prawns should travel from top to bottom of the video frame so as to allow maximum overlap of the APA and the host CPU processing, and give one complete frametime (40ms) for the CPU to perform all required search operations.

The computational strategy outlined should allow continuous frame processing, but final performance figures will depend on CPU, and the maximum number of prawns entering the scene per frame.

Normal

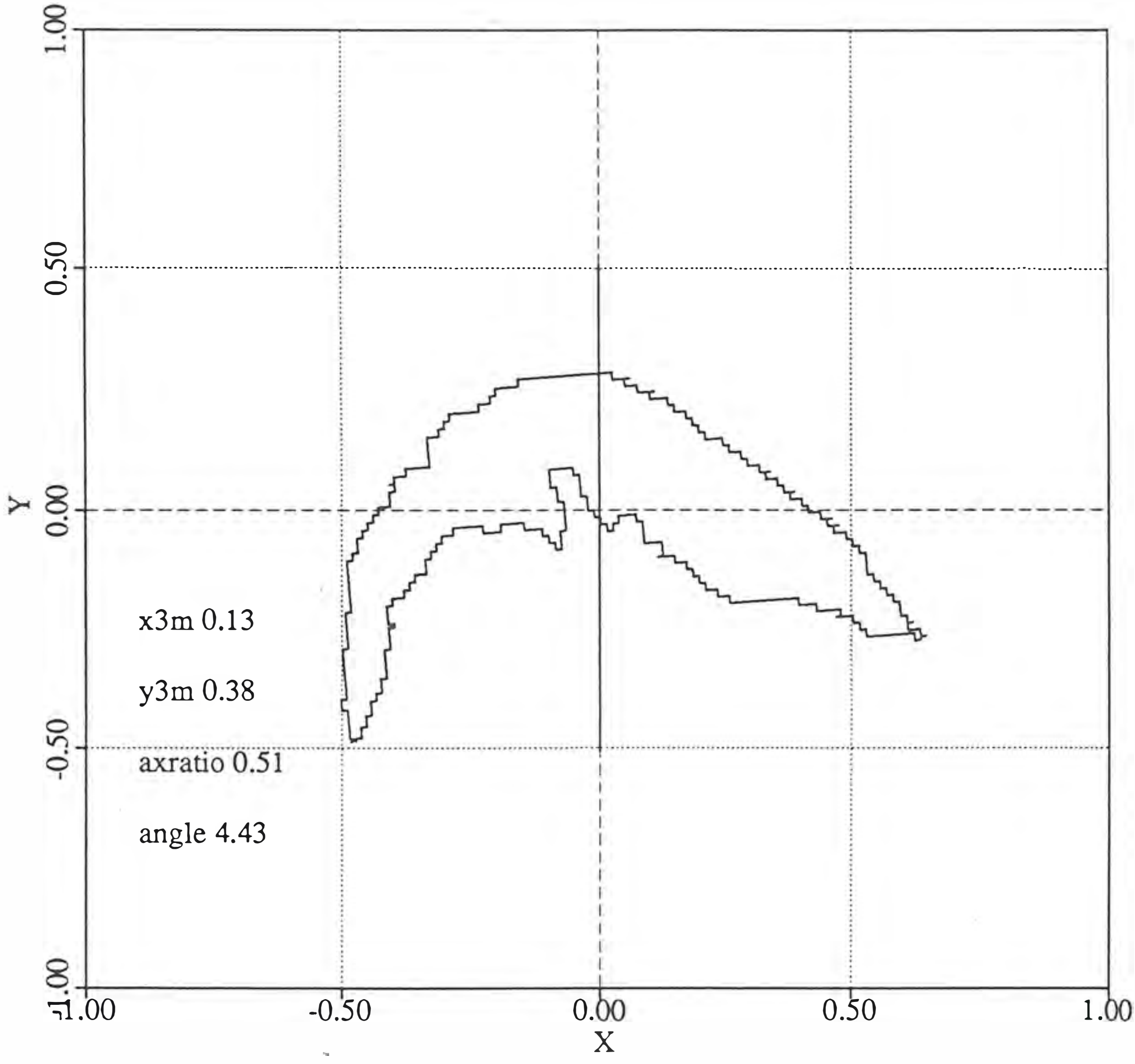


Fig 4(b)

Straight

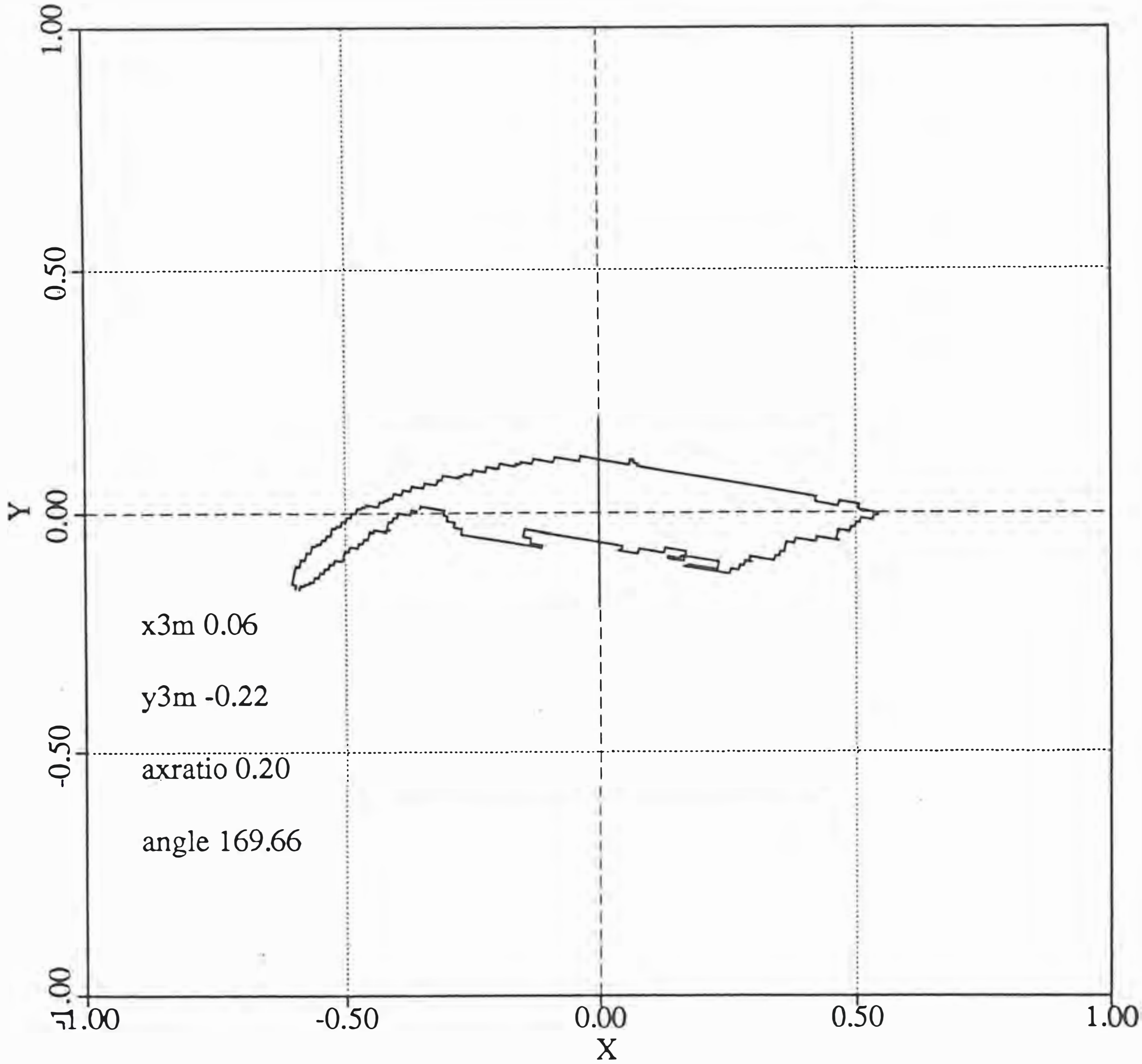


Fig 4(a)

Curled

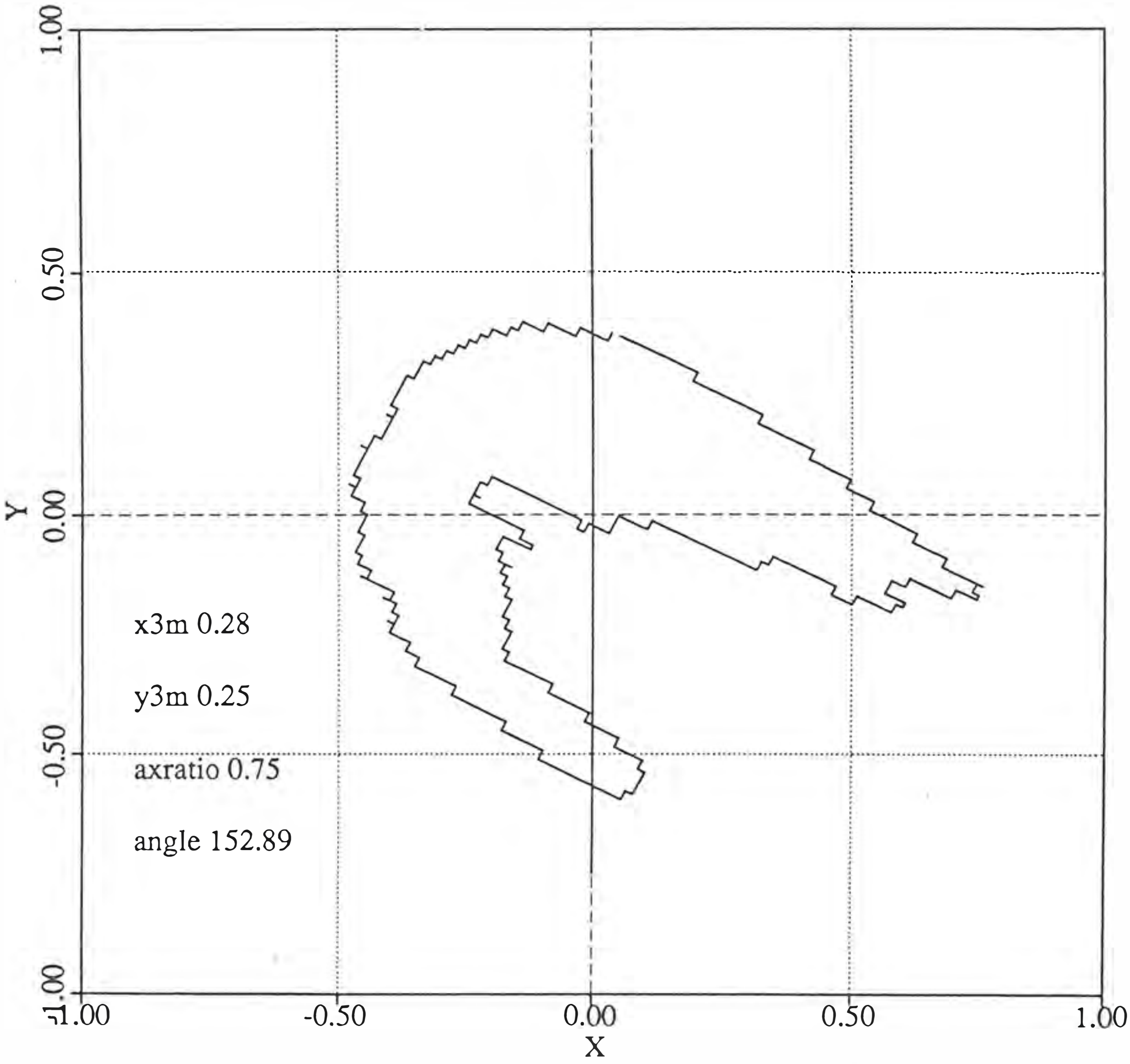


Fig 4(c)