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Automation of Packing Cell in Fresh Fish Facilities

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***Abstract*—**The problem discussed in this paper involves packing fresh fish fileet of the northern Cod into a standard square container. The fish is first cleaned and split and then collected on a belt ready to be stacked in a container. The aim of our work is to pack the fish into the container with constraints on the amount of overlap allowed for the fileets. The current focus is to design a packing cell that can be real-time and of practical use, while finding the optimal solution to the degree of overlap and minimise the unused space of the container.

***Keywords*—**Facilities Planning and Management, Intelligent Systems, Manufacturing Systems, Operations Research, Production Planning and Control.

I. Background and Introduction

ONE of the leading factors for high production is the ability to automate parts or sub-part of the production line. Furthermore, the financial crisis have been an catalysator for the focus on automated production. It is not necessarily evident that by replacing human resources with autonom robots the overall costs goes down, but its more for the sake of using human resources differently. The Norwegian fish industry has a high reputation internationally and traditions that go back many hundred years. Unfortunately, because of high work cost they are facing difficult economical times. This constantly drives the industry to look for more efficient ways to produce and drawn more and more to automation. The strongest objectors claim that replacing human resources with machines for the fish industry would alter the taste characteristics and in exceedingly consequence interfere with their market share holdings. They believe that there is an underlying technique and charisma which the workers possess and which is inherited. In dialog with the fish industry (the producers) and the main objectors we have been able to setle a few cells of the productions line which can be subject to automation. One of the cells which has been quite sensitive and can be regarded as the turing point is the packing cell of the fresh fish. The main objectors claim that their way (human) of packing the fish is crucial and further state that if the fish is faced up or down is would alter the taste characteristics. On the other hand, the producers would like to minimise the unused space in the container to ensure maximal profit. The producers also look at the human costs. Today, ususally two employers are packing the fresh fish into a container, in addition there is one taking care of transportation of the filled/empty container. There is a possibility in reducing costs and thus be able to give the employees tasks which have less physical stress (i.e. supervising the process).

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The current layout that will be discussed in this paper has a conveyor belt delivering 25 fresh fish fileets per minute to the packing area. The human fishpackers are manually throwing the fish into the container and tries to obtain no overlap within each layer. Although, they stress that the fish should not have overlap, by throwing the fish we have found (by empirical studies) that the best fish packers have around 8 % overlapp within a layer. After each filled layer there is added salt. Our goal is to replace the two human resources with one industrial robot and still maintain the packing rate. The timeslot the robot has is 2.4 seconds for each fish, both to run the packing algorithm and to pick and place the fish. The gripper should be able to adjust dynamically to the fish sizes and also to pick and place without damaging the fish. There has been different proposal for the gripper, but due to patent processes we cannot elaborate on the gripper in this paper. As for the matter of the fish size, empirical studies has shown that for a batch of Northern Cod fish has length variations ranging from 30cm to 70cm including the tale. The container which is used for packing and transportation has an international standard measuring (LxWxH) 120x120x100 cm. The packing problem in the container would imply three dimentional packing domain, which belongs to the class of non-polynominal hard (NP-hard) problems which are unsolvable in polynomial time. In order to be able to solve the packing problem we have to make some critical trade-offs in order to maintain the timeframe of 2.4 seconds. As for the key merits for evaluating different packings solutions neither the producers nor the packers have established figures for measuring the packing in terms of volume, quality or amount. Today the producer evaluate the effectiveness of the packing as the distance from the height of the last layer and to the ceiling of the container, while there exists no measure for quality. They also have severe lack of data and information overview about the containers content (i.e. the amount of fish packed, sizevariations, overlap and so fourth).

Literature review gives many algorithms and heuristics of packing. Generally, the pallet loading problem has had much of the attention. Moreover, there are two ways to approach the loading problem: (i) “Manufacturert’s Pallet Packing Problem” [1] representing identical items to be stacked, so that the task is effectively reduced to the calculation of 2-D domain. (ii) “Distributort’s Pallet Packing Problem” [2] representing non-identical items to be stacked. This fish packing is almost a combination of both approaches, the fish fileets are non-identical and we would pack in a 2-D domain. The 3-D packing domain [3]–[6] is more viewed as a generalisation of a 1-D and 2-D packing problem and is found to be NP-hard [7]. Unlike many packing problems [8]–[10] our container packing has a fixed height and the walls provides lateral support for

the packages (fish). Most studies have considered the practical aspects of loading the container with developing heuristic solution for filling out the container with boxes organised in layers [8], [9], [11]–[13]. These heuristics are online packing algorithms, which pack boxes one-by-one in a given order. The algorithm therefore only has the information of where the previously boxed are packed and once a box is packed, that box cannot be moved or altered. Since the pallet packing problem has such a large solution space it is the outmost difficult to prove a solution to be the global optimum. In the absence of exact mathematical formulations, empirical testing forms the basis of comparing algorithms and heuristics.

In this paper we intend to build a reference model that producers and packer can agree on. Throughout the work we have tried to make the model as simple as possible in order to maintain a high degree of robustness and speed of the algorithm. We have simplified the problem domain to be a triangle packing in a square without any pre-sorted incoming list. The outline of this paper is as follows; in section II we give a presentation of the methodology and elaborate on the choices and point of views. In section III we present the straight forward industrial algorithm development, while in section IV a more adaptive algorithm is presented. Finally, the paper concludes with the benchmarks and pinpoint possible adjustments of the algorithm and the packing cell.

II. Methodology

In the case of a facility planning and management as well as in production plan and control, we like to display the different steps and cells in each subsection. The production line would give an overview of the whole line from the delivery of the fish to the factory and to the shipping out to the stores. Within the production line there are several cells, one of them are the packing cell which we will dedicate an subsection. The fish and the robot is also given an subsection, while in the last subsection we present some key figures for building a reference model and the key elements as well.

A. Production Line

The fish is delivered from the fishing ships in large containers. The fish are then put on a convoyer belt (cell A) to be cleaned and weighted. The convoyer belt ends in a machine (cell B) which cut the fish open. It is then cleaned (cell C) and sent over to be packed (cell D) in containers with salt and sent to stores.

B. Packing Cell

The fish arrives on a convoyer belt and there can be up to 25 fish per minute. The container is (LxWxH) 120x120x100 cm and the fish is put in the container with the skin down. The packing is carried out by sucsessfully filling a horizontal layer of fish, without overlapping each other. Then there is added salt to cover the whole layer. Then packing of the next layer is carried out on the same manner. This is done until there is no more space vertically in the container. The container is then driven to a cool storage ready to be shipped out. Further in this paper we will present different design of the packing cell.

C. The Fish

When the fish is cut open it resembles a triangle in outline. The fish be delievered to the packing cell either skin-down og skin-up depending on the production line design. Since the fish is fresh, there has to be added salt in between the layers when the fish is packed into the container. If the fish skin is laid upon a fillet, the fillet would have a change in taste and at worst case be destroyed.

D. The Robot

Although, there exist no robots in the fish industry for packing fresh fish fillet, we will in the following present a solution. In first order it is simply to compare it to the human packers. They take out one fish at the time and throws it into the container in a suitable place. Empirical stydies show that an average fish packer have a rigth above 10% overlap in each layer. We will show a robot solution that is capable of pick and place the fish within the given timeslot (i.e. 2.4 seconds for each fish). Most importantly is the way the griper tool is design. Unfortunately, due to patent pending process we cannot elaborate on the gripper tool in this paper. Further in this paper we will present different solution to the placement of the robot in order to be able to pack and have good range for placing the fish.

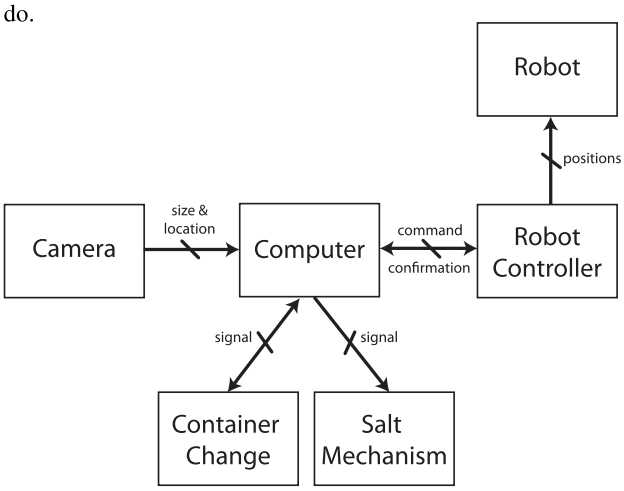
E. Reference Model

In this paper we have concentrated on building up a reference model that can be used to compare future models, algorithms or heuristics. Although, the industry has its own figures of merits, we believe that there is of great importance to build new criteria. Each fish producer has its own tradition and it is crucial that the packing of the fish in container does not interfere with their claimed taste characteristics. The key mesures which is introduced in this paper is the overlap degree, filling degree, worst-case senarios as well as debating a key formula for the quality.

III. Modelling - Facility Planning

In the heart of the automation proposal a computer is performing the overall controll and signal distribution. For our prototype we have used a MAC mini. The communication paths and the technical layout is illustrated in Fig. 1. The first part of the automation is to have a sensor device, in this perticular case cameras to detect the fish size is sufficient. The cameras should be able to detect both the placement of the fish and the height. Our test has shown that it is sufficient to use two cameras with egde dectection filter overlay in order to obtain high detection speed. The cameras feed the computer with inputs while the computer is running the adaptive algorithm. The computer is sending commands and signals to the robot controller, salting mechanism and to the truck driver to change/renew the container. Our testing has

Fig. 1 The technical layout of the packing cell. The communication between the different parts are also specified. As for the case of the computer, we have used a MAC mini. The specification of the computer is to have ethernet and USB connection. We have found that there is no need for a ultra high CPU processor. A standard off-the-shelf computer will do.



show that the bottleneck is the communication with the robot controller. The inherent delay makes the process to slow down. The communication between the computer and robot controller is both ways. The controller resonds first with a acknowledge and then a confirmation signal. Furthermore, there is an overall timeslot which the whole process has to been halted. That is when the container is full and needs to be changed.

The packing cell layout is depicted in Fig. 2. Our proposal is to use one robotarm and one container. The robotarm should be placed on the side at the end of the conveyor belt, while the container is placed with a small distance at the end of the belt. In this position the robotarm would have the whole container area in range. Although we are not discussing the gripper tool, it is worth mentioning that the position (specially

Fig. 2 The proposed fish packing cell layout using one robotarm and one container. The fish are located and measured in the camera unit. The roobt pick and place the fish from the belt and into the container.

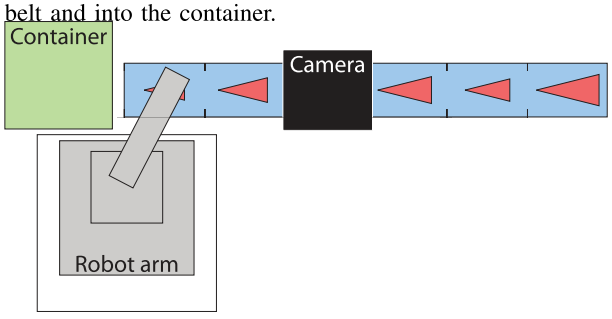
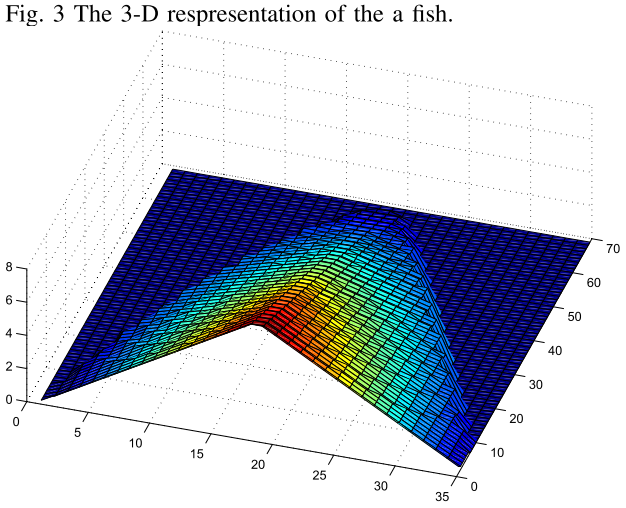


Fig. 3 The 3-D respresentation of the a fish.



the height) the fish is released is crucial. That is due to the fact that the fish is slippery and would from glide away from its intented position if released from high altitude. Furthermore, when choosing a robotarm it is wise to trade off the force and lift ability for speed, due to the low weight of the fish.

IV. Modelling - Software

Firstly, we start by stating that the empirical studies have shown a clear propotional relation between the lenght, width and the height of the fillets. We model the fish as a isosceles triangle and as a special case of a tetrahedron, as illustrated in Fig. 3. We have build a simulator which can provide us with results that can be used to compare different packing algorithms. We have choosen to model the software with a few key measure. The first key measure is the overlap degree in each layer, given in percent and calculated by:

$$OD = \frac{\sum A_{overlap}}{A_{layer}} \quad (1)$$

where $A_{overlap}$ is the amount of fish area that has overlap and not the specific area in the container. The overlap can be translated to amount of damaged fish. Table I illustrates the range of accepted average overlap and expectations for each layer in a batch. The filling degree for each layer in each container is given by:

$$FD = \frac{\sum A_{fish}}{A_{layer}} \quad (2)$$

TABLE I The goal and the expectations for the average amount of overlap for each layer during a batch of fish.

Goal	overlap < 2%
Over expectation	2% < overlap < 4%
Expectation	4% < overlap < 6%
Under expectation	6% < overlap < 9%
Unacceptable	overla

TABLE II The average amount of filling degree for each layer during a batch of fish. Note that the empirical stydies from the human packing has been around 70% .

Goal	Filling > 80%
Over expectation	75% < Filling < 80%
Expectation	70% < Filling < 75%
Under expectation	60% < Filling < 70%
Unacceptable	Filling < 60%

TABLE III The overall quality of packing fish.

Goal	Quality > 40
Over expectation	40 < Quality < 25
Expectation	25 < Quality < 14
Under expectation	14 < Quality < 8
Unacceptable	Quality < 8

It is important to stress that the layer is considered to be a two dimensional area, which does not give the volume of the packing in each layer. The range of satisfying filling degree is listed up in Table II. The key figure for quality of the packing is given by the formula below and its respective goals are listed in Table III.

$$Q = \frac{FD}{OD} \tag{3}$$

In addition, we need to have some reference of the worst-case scenarios. Worst-case scenarios are (1) the lowest fish area in one layer and (2) the maximum overlap in one layer. There are also practical aspects which need some attentions; (a) fish rate, (b) gripping tool, (c) pick and place delay and (d) tool range. All these factors must be discussed for each new model, algorithm or heuristic.

V. First Order Adaptive Algorithm

The simulation environment has been conducted with a batch of 500.000 fish. Even though, real data over the fish length does not exist, we have built up an random generator which feeds the simulator with fish data. The random generator chooses within a normal deviation with a set of fish data. We have based the data on the length of the fish and simulated a batch (i.e. 500.000 fish) for each fish length between 30 to 70 cm.

The first order adaptive algorithm is much like first fit strategy of bin packing. The algorithm is placing the next fish as close to the previous fish as possible without any overlap. The algorithm always keeps track of the layer area and empty places. The algorithm is using levelling based on the longest fish to deploy a new row, but this levelling factor is also able to be adaptive. The levelling factor can based on the results, self-configure in order to obtain a better packing ability. The leveling is an abstract line which in practical view divides the container. At the top-level of the algorithm, a variable controlling the overlap has been declared and is used to assert how many percentage overlap is accepted. This is of use to actually place the fish as close as possible. The pseudo-code above gives an overview of the main core of the packing algorithm. In order to better grasp the pseudo-code, two different situations are illustrated in Fig. 4.

Algorithm 1 Packing Algorithm

```
while (there is fish) AND (enough empty space in row) do
  pick a fish
  if (the previous fish is tale up) then
    Rotate current fish
    Place the fish at point P_U {start point ← Upper point}
  else
    Place the fish at point P_L {start point ← Lower point}
  end if
  this.level ← find best suited level for this fish
  if (global.level < this.level) then
    global.level ← this.level
  end if
end while
```

Table IV presents the simulation data obtained for the adaptive algorithm, while Fig. 5 visualizes the data. Note that the leveling has been manually programmed to divide the container based on the longest fish in the row. It is evident that the filling and overlap degree have quite small variation and interestingly there is a maximum peak for the quality measure at fish length 60cm. The actual filling degree has a maximum at fish length 52cm. Not surprisingly the average overlap is maintained almost stable below 2%. Extracting the data for the average fish, we find the simulated fish area to be 72.49% and the filling degree at 68.56%. The overlap degree on average is 1.16%, while the overall quality measure is 62.49. Furthermore, the worst-case layer for the average fish has 27.40% and 7.60% for the fish area and overlap degree, respectively. For the fish length interval, L = [30-70], the overall worst packing concerning the filling degree, shown in Fig. 6 is found to be at fish length 40cm with 23.96% of the layer. For the case of overlap degree, Fig. 7 shows the overall worst-case layer, currently fish length 34 cm with an overlap of 8.81%.

VI. Improvements and Future Work

The presented algorithm is at an early stage and the focus has been to develop an algorithm that is able to perform in

Fig. 4 This figure shows two different situations which can be obtained during packing given the variations in fish sizes. The situations corresponds to the pseudo code shown in Algorithm

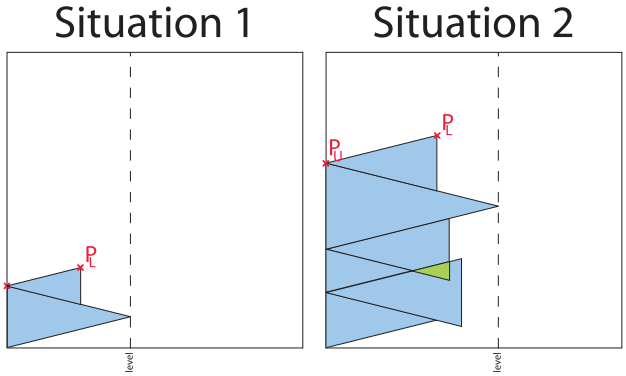


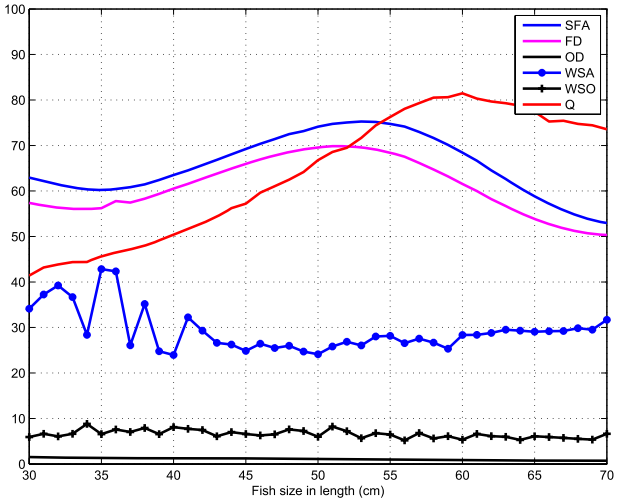
TABLE IV The table shows the data obtained from simulation results for the adaptive algorithm. The headline info is as follows: Fish length (L), simulated fish area (SFA), filling degree (FD), overlap degree (OD), worst-case fish area (WSA), worst-case overlap degree (WSO) and the quality (Q).

L	SFA	FD	OD	WSA	WSO	Q
30	62.95	57.38	1.52	34.13	5.93	41.41
31	62.20	56.81	1.44	37.24	6.63	43.19
32	61.41	56.34	1.40	39.24	6.07	43.86
33	60.78	56.05	1.37	36.68	6.65	44.36
34	60.39	56.07	1.36	28.37	8.81	44.40
35	60.22	56.23	1.32	42.82	6.57	45.62
36	60.43	57.78	1.30	42.33	7.58	46.48
37	60.83	57.46	1.29	26.09	7.03	47.16
38	61.46	58.31	1.28	35.16	7.91	48.02
39	62.42	59.37	1.27	24.77	6.57	49.15
40	63.51	60.52	1.26	23.96	8.11	50.40
41	64.52	61.57	1.25	32.22	7.72	51.62
42	65.69	62.71	1.24	29.31	7.47	52.98
43	66.85	63.81	1.23	26.62	6.08	54.35
44	68.04	64.91	1.21	26.25	7.01	56.23
45	69.24	65.96	1.21	24.86	6.60	57.22
46	70.36	66.93	1.18	26.43	6.28	59.63
47	71.42	67.77	1.17	25.50	6.52	61.04
48	72.49	68.56	1.16	25.99	7.60	62.49
49	73.15	69.15	1.14	24.71	7.25	64.17
50	74.13	69.55	1.11	24.11	5.99	66.78
51	74.75	69.84	1.09	25.82	8.22	68.58
52	75.06	69.78	1.08	26.87	7.20	69.50
53	75.26	69.60	1.05	26.07	5.67	71.68
54	75.16	69.12	1.01	28.03	6.78	74.42
55	74.74	68.39	0.98	28.17	6.48	76.27
56	74.16	67.53	0.95	26.55	5.20	78.06
57	72.96	66.15	0.92	27.55	6.81	79.30
58	71.65	64.71	0.89	26.68	5.62	80.51
59	70.14	63.19	0.87	25.33	6.10	80.62
60	68.43	61.54	0.84	28.36	5.34	81.46
61	66.65	59.98	0.83	28.39	6.62	80.30
62	64.53	58.21	0.81	28.80	6.11	79.67
63	62.64	56.69	0.79	29.51	5.98	79.29
64	60.63	55.18	0.77	29.30	5.28	78.74
65	58.84	53.86	0.76	29.06	6.10	77.42
66	57.20	52.72	0.76	29.18	5.92	75.26
67	55.81	51.82	0.74	29.24	5.74	75.42
68	54.56	51.10	0.73	29.85	5.52	74.74
69	53.59	50.57	0.72	29.51	5.37	74.43
70	52.96	50.32	0.72	31.69	6.63	73.56

practice and to a high level of stability. Therefore, there are many improvements possible ad in the following we will try to give an guideline for the most beneficial improvements.

One of the measures that have not been fully elaborated on is the height of the packing and the number of layers. Actually, the fish industry has a set of “unwritten” rules about packing. One of them is their way to measure the height and the effectiveness of the packing includes the average distance difference from the last fish layer and to the ceiling of the container. Although this is quite difficult to measure, they still use it. In order to minimize the distance, the algorithm can be improved to handle height for each fish. This would dramatically increase the complexity of the algorithm and may bring it to a 3D problem. One immediately short cut in order to prevent a 3D-problem is to have a fixed proportional factor for the height as a function of the fish length. Finding the best model for the fish would help to simplify the problem

Fig. 5 Visualization of the data obtained in Table IV. As the results show the optimal point, i.e. quality, is around fish length 60. Furthermore, the results indicate that the first fit heuristic is best suited for large fish sizes.



space. Secondly, if the algorithm handles the height factor, it can pack the fish in such a manner that the final/top layer has as low topological variation. A suggestion for an improvement here is to rotate the container 180° and 90° successive after each filled layer. It is also worth mentioning that in case this rotation actually are able to reduce height difference by 10%, then an additional layer can be inserted in each container, thus leading to an higher filling degree for the container. The aspect of the response time and performance time of the rotation of the containers must be examined. It may be more advisable to

Fig. 6 A layer view of the worst overall filling degree for the adaptive algorithm. This particular layer is from fish length 40cm and has a occupation of 23.96% of the layer area.

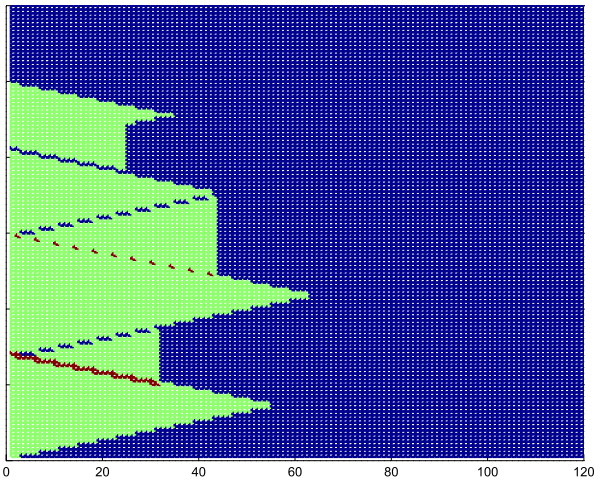
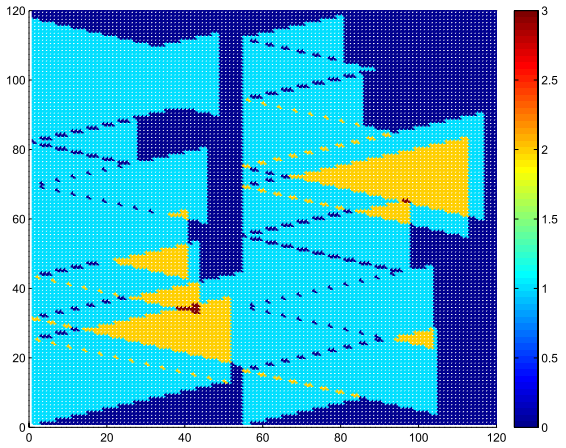


Fig. 7 A layer view of the worst overall overlap degree for the adaptive algorithm. This particular layer is from fish length 34cm and has an overlap of total 8.81%.



implement this rotation in the software of the robot.

Concerning the improvements for the packing in the layer, there are a few topics that may be tested out. Firstly, have a combination of static divided container and an adaptive. By this we mean that at the start of the packing, the container can have an pre-divided area for small, medium and large fish. In this way the respective fish sizes are in a way sorted out and placed, this improvement can give a few higher filling degree. Another suggestion is to exploit the "side-pockets" of the layer. By "side-pockets" we referre to the open area between the container wall and the first and last fish in a column. That area can fit a very small fish without any overlap and hence increase the filling degree.

One other improvement is to have two containers, which are simultaneously being packed. But this system design must be evaluated upon the costs and area outline. Having two containers immediately imply an increase in the effectiveness of the packing, while on the other hand the algorithm becomes more complex and time consuming. Futhermore, the area consumption usually has a assosiated cost factor. Moreover, there is also the aspect of having both containers in range of the arm. Our preliminary prototype tests has shown that in the arm base can be tilted a few degrees, then the robot arm will be able to reach both container. Our cell design in this perticular case is proposing the containers to be on the opposite side of the robot, leading the conveyor belt in between.

VII. Conclusion

This paper we have presented a solution to automate the packing cell of a product line in a fish production. The proposed solution have both the aspect of facility planning as well as the software and algorithm development. The simulation results obtained demonstrates the strength and the challenges of the adaptive algorithm. For concluding this paper we would like to extract the potential of sorting the incomming fish in an descending size order. Referring back to the results we find the overall algorithm to perform best for larger fish sizes. Thus, the sorting would imply high quality in packing, regards to the quality measure is more optimal for the upper fish sizes. Furthermore, the adaptive leveling can take further advantage of the sorting by dividing the container is a complex heuristic.

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