SeaScope Fisheries Research
Independent Marine Consultants

Final Report- Development of a prototypic PIT tag scanner

Sustainable Fisheries Interactions and Conservation of Elasmobranchs in Scottish Seas

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Project Aim

Develop an automated system suitable for deployment on fishing vessels that will detect the capture of previously discarded and tagged elasmobranchs, show feasibility of geographically and temporally tagging the ID of the individual and transmission of that data to a shore reception system.

Background

Not all elasmobranch species are prohibited catch, with many of the smaller, more abundant species being managed via quota assignment. To prevent these limits from being reached quickly, effectively choking a fishery under the Common Fisheries Policy (CFP) Landings obligation, there is an exemption for species displaying high discard survival rates: Article 15, paragraph 2(b), of the CFP states “species for which scientific evidence demonstrates high survival rates, taking into account the characteristics of the gear, of the fishing practices and of the ecosystem, are exempt”.

While there is a general assumption of high survivability in elasmobranchs, there are gaps in the evidence to support this. This project will develop prototypic technology suitable for deployment on multiple fishing vessels which will be capable of detecting Passive Integrated Transponder (PIT) tags in previously tagged and discarded specimens. Each tag carries a unique identification code which would be detected by an automated scanning device linked to an on-board data collection system which would provide a spatial (GNSS) reference and date and time for the scanned tag. These data will then be automatically transmitted to a land-based server providing much needed data on discard survival levels, as well as informing us on the movement of multiple species between tagging and recapture positions. Ideally the system will have minimal or zero impact on the workflow of the crew during catch processing. Time constraints for the delivery of this project suggest that development of the prototypic, proof of concept system and preliminary testing will be possible. Further development would be required to fully operationalise the proposed system.

Preliminary Research-Stage 1

In order to deliver the main aim of the project, a focus on the type of technologies available, along with the physical environment the equipment will be working in and the need for autonomous tag reading (no additional catch handling requirements placed upon vessels crew), was required.

Tag types

Early tagging experiments relied on simple tags attached externally to specimens of interest. These tags would have information recorded on them (a unique ID, and contact details normally), such that when tags were recovered in the field, information on the time, location and status of the tagged specimen could be relayed to the relevant researcher/research organisation.

It is widely accepted that external tags have a lower recovery rate (33%, pers. comms, James Thorburn, 19/12/2019) than internally implanted PIT tags. This could be due to a number of factors, including natural shedding, fouling, removal by fishers and anglers without any follow-up reporting.

PIT tags however, when deployed internally (there are various options for tagging locations either subcutaneously into musculature or into the gut cavity) tend to show much higher recovery rates (64%, pers. comms., James Thorburn, 19/12/2019) in general. As a result of the improved recovery rates, the use of PIT tags in tag-recapture work has become widespread.

In conducting this brief review of PIT tagging and in discussion with the University of St Andrews (USTAN, the customer), it was decided that internal glass encapsulated PIT tags were the preferred option due to the higher recovery rate associated with internal tags compared to external tags. However, using this type of tag can create a number of hazards/risks that an organisation considering a widespread tagging programme should take under consideration before initiating any tagging programmes. A good summary document outlining potential risks to various stakeholders and consumers has been produced by the New Zealand Ministry of Primary Industries (Middleton *et al*, 2018), a summary of which is reproduced in Table 1. Whilst this table summarises risk in a specific fishery, one in which the majority of the catch is exported whole (ungutted), the majority of hazards identified would be relevant to any tagging programme utilising glass encapsulated PIT tags.

Table 1: Risks associated with the use of glass encapsulated PIT tags in the SNA1 (Snapper 1 fisheries management area) tagging programme (Middleton et al, 2018)

Classification	Hazard	Person(s) exposed	Potential harm
Governance	Evidence of food safety suitability	Processing company	Legal proceedings and reputational damage
	Acceptability of implantation site	Processing company	Legal proceedings and reputational damage
Process	Tag reaches plate and is identified	Processing company	Reputational damage
	Tag reaches plate and is not identified	Consumer	Adverse health effects from tag (see hazards below)
	Tag implantation into muscle rather than gut cavity	Consumer	Increased risk of tag remaining in food
	Implantation of undetectable tags	Consumer	Increased risk of tag remaining in food
	Tag breaks during commercial processing	Consumer	Decreased tag detection, increased potential for harm
	Tag breaks during food preparation	Consumer	Decreased tag detection, increased potential for harm
	Tag reaches consumer via a species other than snapper	Consumer	Decreased tag detection, increased potential for harm
Physical	Choking	Consumer	Injury or death
	Biting tag	Consumer	Dental damage
	Swallowing tag whole	Consumer	Internal injury
	Swallowing broken tag	Consumer	Internal injury
Biological	Toxins released by tag into food	Consumer	Injury or death

Prospective PIT tag technologies

There are 2 main types of technology available when considering small glass encapsulated PIT tags, they are;

HDX (half-duplex)

FDX (full duplex)

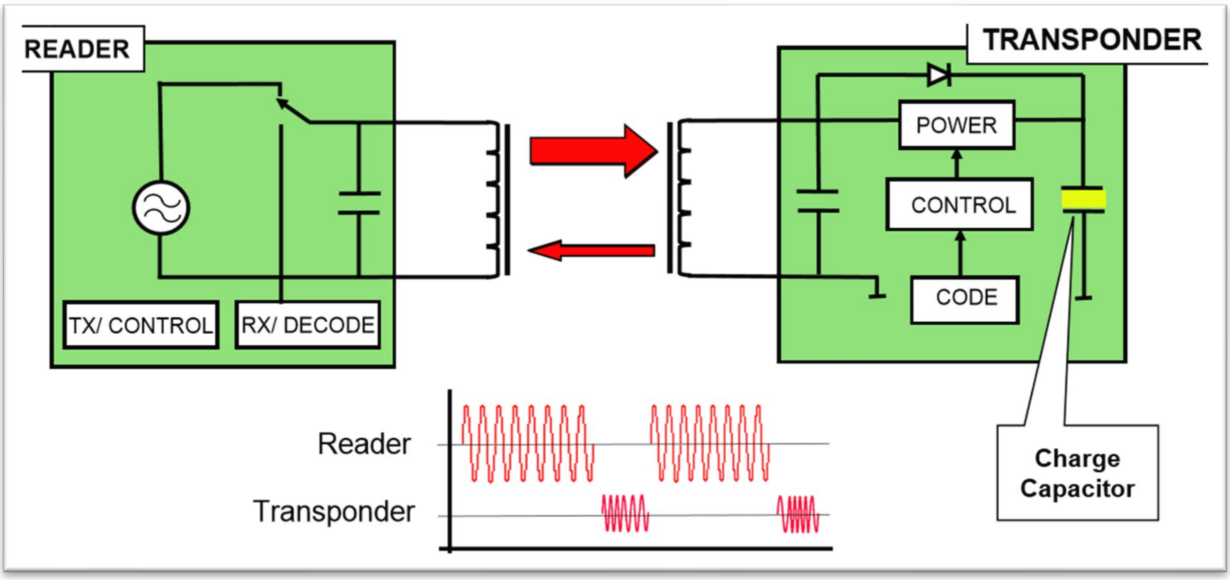


Figure 1: Schematic diagram outlining componentry and transmission principle of HDX systems. From Texas Instruments 2008.

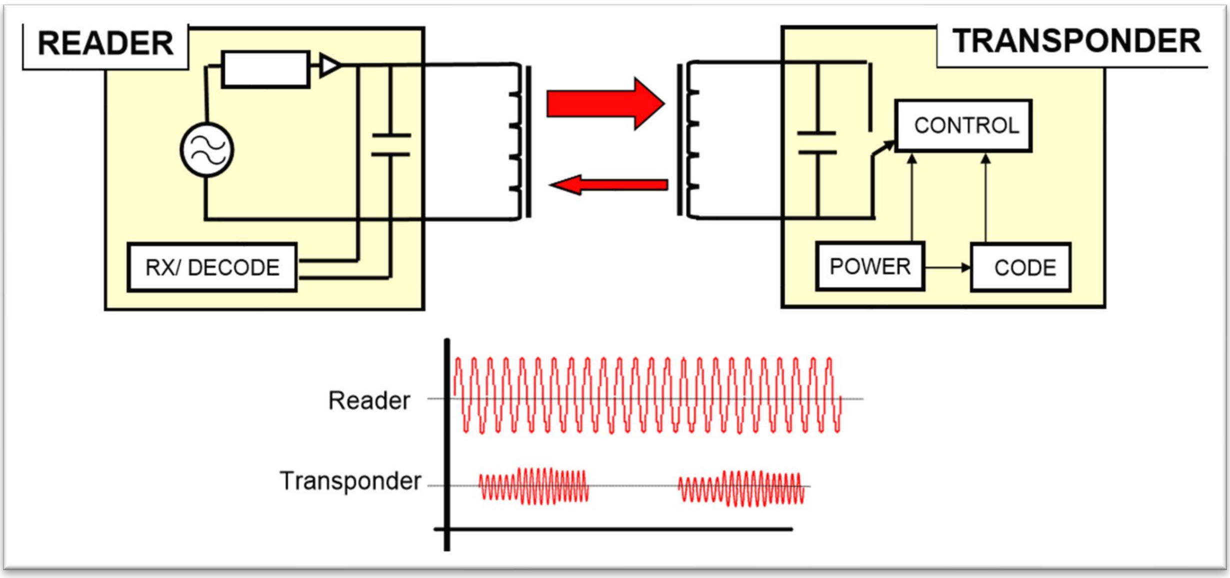


Figure 2: Schematic diagram outlining componentry and transmission principle of FDX system. From Texas Instruments 2008.

The main operational differences between the two systems, as shown in Figures 1 and 2 above, relate to how the systems energise the PIT tags and subsequently transmit that data back to the tag reader. HDX tags are constructed with an additional capacitor which, when energised by the read antennae, is able to store enough charge until such a time as the antennae stops emitting. At this time, the capacitor within the HDX tag releases the stored charge, which enables the tag to transmit its unique ID parameters back to the reader.

In an FDX system, the antennae are permanently energised, and as PIT tags pass within range of the antennae, the tags are energised and transmit their unique ID parameters back to the reader. This in turn leads to a requirement for more complicated electronics being required to isolate and interpret the transmission signal from the constant output signal of the FDX reader/antennae.

Whilst HDX is considered to be older technology by some, as compared to FDX, the one over-riding factor that encouraged us to use this technology is that HDX technology is well-known to deliver superior read-ranges compared to the FDX equivalent. When considering a fully automated system, deployed on a commercial fishing vessel it made sense that optimising read-ranges had to be one of, if not the most important factor when considering the system design. A similar rationale for selecting HDX technology for tagging trials of southern bluefin tuna (*Thunnus maccoyii*) in New Zealand was used by Harley *et al*, 2008.

Power requirements

Most fishing vessels are equipped with a suite of electronics, both for locating fish, navigation and communications. Therefore, it is important to consider the power supply to the proposed equipment and the power consumption of these additional electronics, with a recommendation to seek a technological solution with minimal power consumption. When comparing power requirements between HDX and FDX systems, literature suggests that greater read ranges will be achieved with lower excitation power requirements with HDX technology when compared to FDX power requirements (Texas Instruments, 2008).

Read ranges

HDX systems typically provide greater read ranges than a comparable FDX system, and readability is in part a function of physical tag size. For this reason, a number of tag samples were obtained to assess this characteristic. HDX tag (134.2Khz) sizes, from HID Global, tested include: -

- 3 x 15mm
- 3.85 x 22.5mm
- 3.85 x 32mm

Early testing of these tags in an 'open air' environment produced read ranges of up to 1 metre with the physically larger HDX tags. Whilst there was an expectation that these ranges may be reduced in the presence of the fish handling 'chute', due to it being made of metal (as would also be the case for the FDX tags), these results were initially encouraging.

Figure 3: Example of glass encapsulated tags selected for project.

Should read distances be deemed unsatisfactory once initial testing is conducted on the simulated catch handling chute, we plan to look at some external type tags (UHF-ultra high frequency), which purportedly have very high read ranges, as an alternative.

Tag orientation

When considering the brief for the project, it is worth noting that for a fully autonomous PIT scanning system fitted to a commercial fishing vessel, that orientation of the tags relative to the reader antennae can have a big impact on tag readability. Whilst we will endeavour to test and document results with tag orientation in mind, it is worth noting that tag orientation relative to antenna orientation will largely be out with our, or programme managers control, in a real-world scenario.

Design and Build-Stage 2

After initial research suggested that HDX was the most appropriate technology to deliver the desired outcomes, a system utilising HDX technology was constructed. Figure 4 shows the enclosure housing the antenna tuner, tag reader and logging components.

Figure 4: Purpose built PIT tag scanner hardware (excluding antennae).

The HDX system comprises an antenna tuner and a main microcontroller module with an LCD screen. The system has an RS232 output which is used to transmit the tag ID to external logging devices. The internal componentry, including equipment for receiving and logging of tag data are shown in Figure 5.

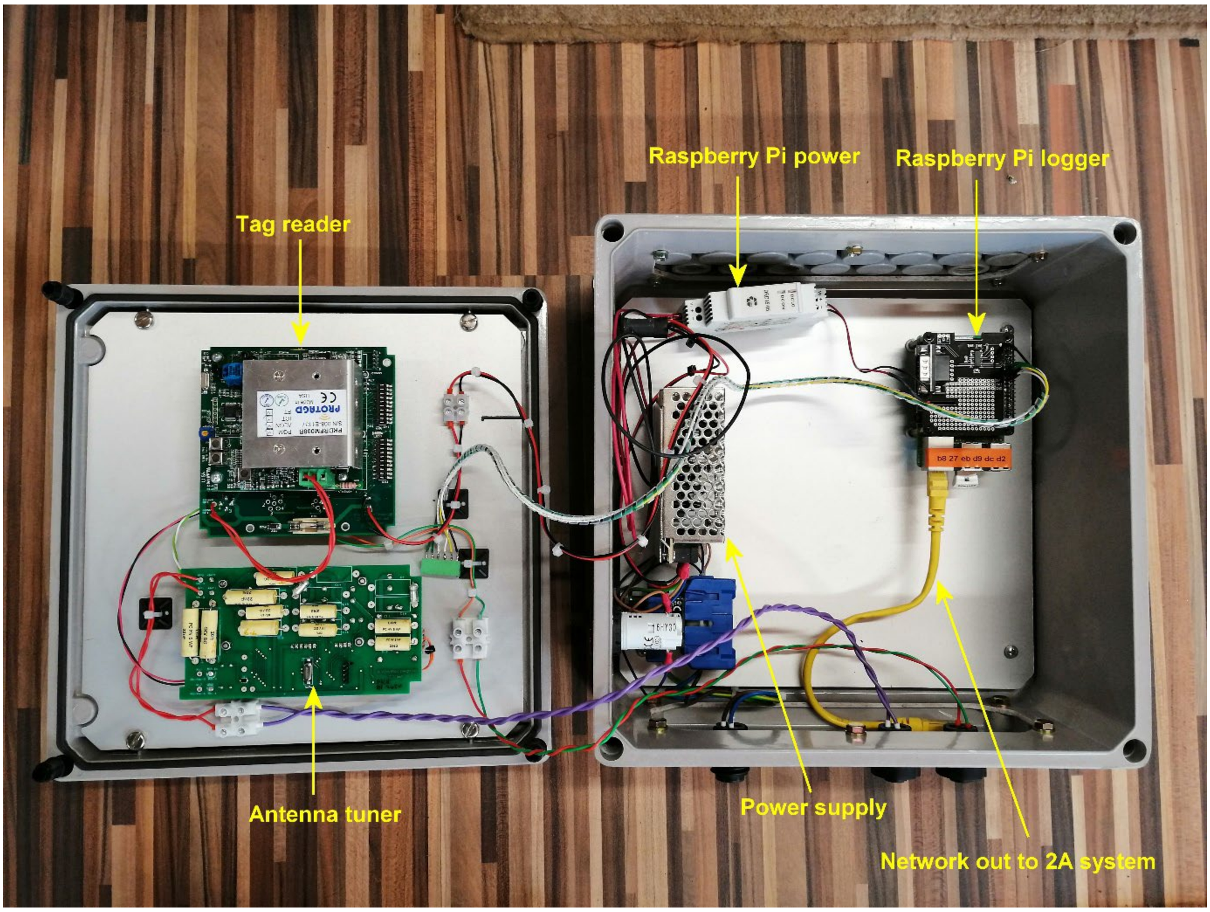


Figure 5: Internal components of the prototype PIT scanning system with the additional logging package.

The tag reader component consists of a main controller and a power driver/decoder module. The main controller module communicates with the antenna power driver/decoder module, it is this module that sends and receives the radio frequency (RF) data. The microcontroller module displays the number of tags read and the last tag ID. There is a green LED on the enclosure that flashes each time a tag is read. This was the main feedback that was used in the testing as it is easily seen whilst carrying out the test procedures.

When a tag is in range it can transmit up-to ten reads per second, a DIP (dual in-line package) switch on the controller can be used to filter the results so that only a single output is generated whilst the tag is within the field.

To maximise the RF field the system needs to be tuned to the antenna, this is done by adding capacitors to tune the circuit. One of the issues is that the tuning changes based on whether the antenna is close to metalwork or in free air. There may also be locations where the equipment or other metallic hardware is moved around, and the antenna needs to be retuned for best results. Thus, the antenna has to be tuned in situ. This would be a very tedious process however we have included another module which is an auto antenna tuner. When the system is powered up, the antenna tuner automatically switches in and out a binary weighted set of capacitors until the best matched tuning is achieved. This process takes approximately 90 seconds when the system first boots up but can save hours of configuration if tuning was to be completed manually. We have built all these modules into one enclosure to provide a single installable unit.

To emulate the type of catch handling environment that may be encountered on a range of commercial fishing vessels, we had a 1.2mm thick stainless steel chute manufactured in 2 sections

(Figure 6). The dimensions of the 2 individual sections were 1000mm(L) x 700mm(W) x 200mm(H) and were constructed to allow a pass-through (letterbox style) antennae to be inserted between the 2 sections.

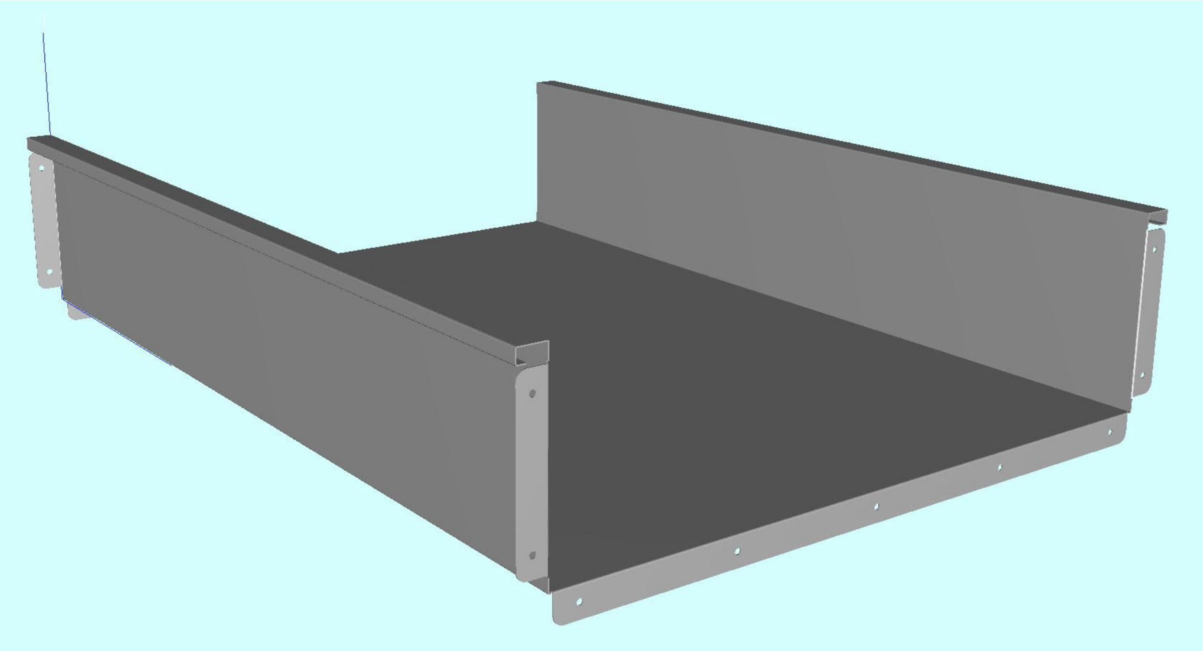


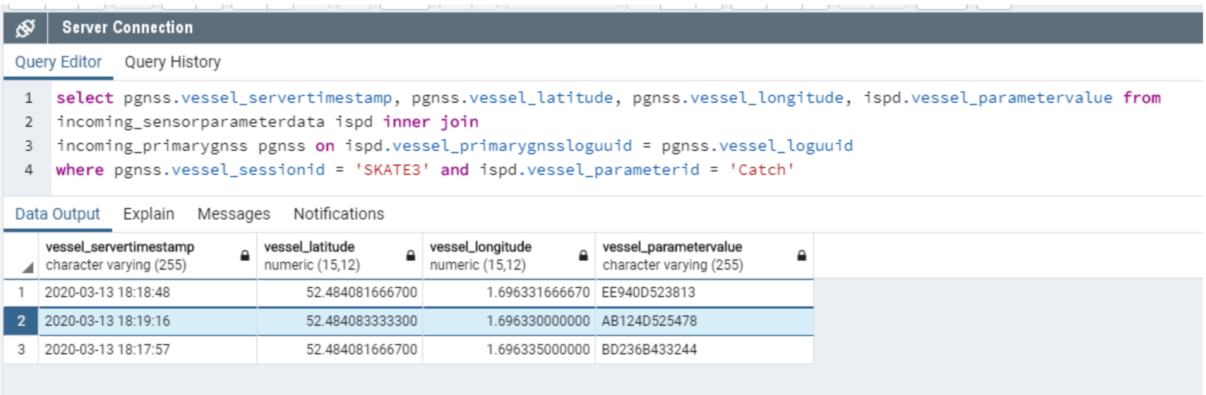
Figure 6: Schematic diagram showing general outline of 1 of the simulated catch-handling chutes (in the design phase).

Logging and transmitting the data

A key part of the project was not only to develop and test a PIT scanner system, capable of reading tags in various orientations from suitable distances that would not impinge on typical catch handling, but also to prove it is feasible to tag successful tag reads both temporally and spatially and transmit this tagged data ashore. This was accomplished by interfacing the newly developed scanning equipment with a previously developed system that was constructed and trialled during the University of St Andrews "Scottish Inshore Fisheries Integrated Data System" (SIFIDS) project (Ayers *et al*, 2019). This system was called the OnBoard Central Data Collection System (OBCDCS), it provides geospatial and temporal data linked to the tag data, alongside data storage and communication functionality.

The antenna unit cannot communicate directly with the OBCDCS as it only provides an RS232(serial) data feed; the OBCDCS system is designed to accept XML formatted data packages via a network connection. To read the serial output from the antenna unit and package it into a form suitable for transmission to the OBCDCS a Raspberry Pi (Pi) running a Python program was used. The Pi was fitted with a set of LEDs to provide simple status for the logger (Operating, Error, Tag logged). The python program was set to start automatically when the Pi booted and listen for data on the serial port, when data was received it was packaged and sent to the OBCDS and logged locally onto the Pi. The locally logged data was time-stamped and grouped within a file for each run of the program.

During the testing process, the PIT tag scanner system was coupled with a functioning OBCDCS system using the Pi system described above, this produced the geo-tagged tag reads on the SeaScope cloud database as expected, example data is shown in Figure 7.




```
select pgnss.vessel_servertimestamp, pgnss.vessel_latitude, pgnss.vessel_longitude, ispd.vessel_parametervalue from
incoming_sensorparameterdata ispd inner join
incoming_primarygnss pgnss on ispd.vessel_primarygnssloguuid = pgnss.vessel_loguuid
where pgnss.vessel_sessionid = 'SKATE3' and ispd.vessel_parameterid = 'Catch'
```

	vessel_servertimestamp character varying (255)	vessel_latitude numeric (15,12)	vessel_longitude numeric (15,12)	vessel_parametervalue character varying (255)
1	2020-03-13 18:18:48	52.484081666700	1.696331666670	EE940D523813
2	2020-03-13 18:19:16	52.484083333300	1.696330000000	AB124D525478
3	2020-03-13 18:17:57	52.484081666700	1.696335000000	BD236B433244

Figure 77: Example of basic output from the coupled OBCDCS/PIT scanner system.

Power requirements

At the outset, the project team identified that, in order for the proposed device to be acceptable to vessel crews, it would have to be designed to consume as little power as possible. This is because most commercial fishing vessels tend to be fitted with a wide array of electric/electronic devices, meaning access to adequate power supplies can sometimes be problematic.

With this is mind the design team specifically looked for suitable components and system design strategies to minimise the systems power requirements. The final PIT tag scanner prototype draws a minimal 1 amp at 12VDC (approx. 15 watts), which, on most commercial vessels should not cause any undue loading of available power supplies. We estimate a total power of < 2 amps at 12 volts DC will be required to incorporate the required components for geo tagging and transmission of data.

Worthy of note is that whilst the system has been specifically developed to run aboard commercial vessels with a low to modest power consumption, certain parts of the circuitry can and do operate at voltages much higher than the supply voltage. In particular, the antenna driver when tuned at resonance can generate voltages well over 300V peak to peak. Under no circumstances should anyone ever make connections to live antennas or touch live connectors. Always switch the power off at the mains if connecting or disconnecting an antenna. Similarly, if and when these systems are installed on vessels, due care and attention to cabling, connections, cable protection and suitably rated enclosures must be observed.

Antennae design and 'dry' testing

A number of antennae configurations were initially considered for testing. These included pass-through (letterbox), pass-over and pass-under options. However, once the chute was constructed and delivered, mock-ups of these various antennae scenarios showed that pass-under options would more than likely intrude too much upon crew working at the sorting area. The mock-up pass-under antennae proved to be both a visual (obscuring parts of the chute) and a physical (not allowing all catch items to be retrieved from certain positions on the chute) intrusion and for these reasons were not taken forward to the testing phase.

For the purposes of testing read-ranges for the various tags and antennae configurations, the chute was essentially divided into 9 cross-sectional areas (top left, top middle, top right (as shown in Tables 2-5)) and tags were run through each of these areas 3 times to determine an average read range. This was done for each tag size (and with the tags in 3 different orientations) relative to the antennae. The results of this 'dry testing' are presented in Tables 2-5.

To note, the orientations described by X, Y and Z are;

- X: Tag orientated lengthways along the chute and parallel with the base of the chute
- Y: Tag orientated widthways across the chute and parallel with the base of the chute
- Z: Tag 'standing' straight up, perpendicular to the base of the chute

Measurements as recorded in the individual cells of the results tables are an average value of a minimum of 3 length measurements. The measurements are derived from noting distance from a set datum line when a tag is first read. The datum lines are shown in red for each antenna configuration in Figures 8 – 11 below.

Letterbox configuration

As expected, the pass-through 'letterbox' antennae configuration worked well (Figure 8). The system read all tags, regardless of both orientation and size, although better read ranges were achieved with the larger tags orientated in the X direction (Table 2). Whilst this performance was encouraging, it is worth noting that this antennae configuration may be quite challenging in terms of installing aboard commercial fishing vessels and may require a custom-built antenna for each vessel.

Table 2: Read-range results for letterbox antennae

LetterBox

Tag orientation	Chute	HID_3x15			HID_3.85x22.5mm			HID_3.85x32mm		
		Left	Middle	Right	Left	Middle	Right	Left	Middle	Right
X	Top	42	52	48	76	88	86	101	101	101
X	Middle	48	53	49	87	91	90	101	101	101
X	Bottom	51	51	52	93	101	96	101	101	101
Y	Top	34	5	27	47	14	48	62	27	60
Y	Middle	17	7	17	34	23	27	47	39	43
Y	Bottom	12	3	5	30	14	10	27	36	25
Z	Top	43	32	41	64	54	66	74	69	73
Z	Middle	33	22	34	56	49	61	65	62	71
Z	Bottom	8	10	9	17	19	25	24	34	29

Figure 8: Letterbox (pass-through) configuration antennae, attached to 1 segment of chute. The red line depicts the datum line from which tag read ranges were measured.

Flatbed (rectangular) configuration

After several design prototypes of rectangular pass-over type antenna were constructed, the design that appeared to give the best results was a rectangular antenna that has two offset windings (Figure 9). The 2 winding concept was done to eliminate an apparent blank spot around the centre of the chute. By making this dead zone at an angle to the x axis we were able to detect tags that would have previously slipped through the central strip of initial designs. That said several zero readings or dead zones still occurred (Table 3).

Table 3: Read-range results for pass-over antennae (flatbed, rectangular). antennae

Flatbed										
Tag orientation	HID_3x15			HID_3.85x22.5mm			HID_3.85x32mm			Chute
	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right	Chute
X	0	0	0	24	26	0	28	27	28	Top
X	25	23	7	29	29	26	31	29	28	Middle
X	32	33	31	35	37	36	36	39	37	Bottom
Y	0	0	0	20	0	0	19	0	24	Top
Y	23	18	22	25	19	26	31	26	30	Middle
Y	25	25	26	28	28	28	29	28	31	Bottom
Z	0	0	0	22	0	0	19	12	18	Top
Z	17	30	5	21	35	27	39	42	40	Middle
Z	29	29	29	34	30	31	37	36	34	Bottom

Figure 9: Flatbed (rectangular) pass-over antennae configuration. The red line depicts the datum line from which read-ranges were measured.

Quad configuration

We spent a considerable amount of time trying to develop a solution that would span the 700mm wide chute and give good reads in both X and Y tag orientations. Pursuit of this design was mainly motivated by the relative ease with which this antennae configuration could be installed on the majority of vessels. The initial design utilised two antennas positioned directly opposite each other and located at the sides of the chute. These were originally wired in phase and gave excellent reads with the tags in the Y orientation, which was to be expected (Table 4). However, the read in the X orientation was very poor in comparison. By modifying the antennas to be out of phase (creating opposing fields), there was a marked improvement to tag reads in the X orientation. The final solution was to use two pairs of antennas. As seen in Figure 10, the final design included the front set of antennae wired out of phase to give good X reads, whilst the rear set remained wired in phase to give good Y reads. Both pairs of antennas were wired in parallel. The pairs were then wired in series and driven from the one antennae supply. The antennas had to be ‘stood off’ (approx. 20mm) from the sides of the chute in order to operate effectively. If these were manufactured in volume this could be designed as a complete GRP side panel with tapered lead in edges to allow fish to flow freely in front of the antennae. In some applications where multiple antennas are used, a multiplexer is used to drive the antennas independently. This approach eliminated the need for a more complex multiplexing solution.

Table 4: Read range results from quad antennae configuration

	Quad									
Tag orientation	HID_3x15			HID_3.85x22.5mm			HID_3.85x32mm			Chute
X	68	0	68	69	0	70	71	76	72	Top
	68	0	70	71	65	71	71	79	71	Middle
	66	0	67	69	75	68	71	78	70	Bottom
Y	71	0	71	76	6	77	81	19	80	Top
	70	0	71	76	14	77	83	23	81	Middle
	71	0	71	77	10	76	80	17	79	Bottom
Z	64	0	65	67	0	68	69	64	68	Top
	64	0	66	67	0	62	70	0	67	Middle
	62	0	64	67	0	67	66	0	68	Bottom
	Left	Middle	Right	Left	Middle	Right	Left	Middle	Right	Chute

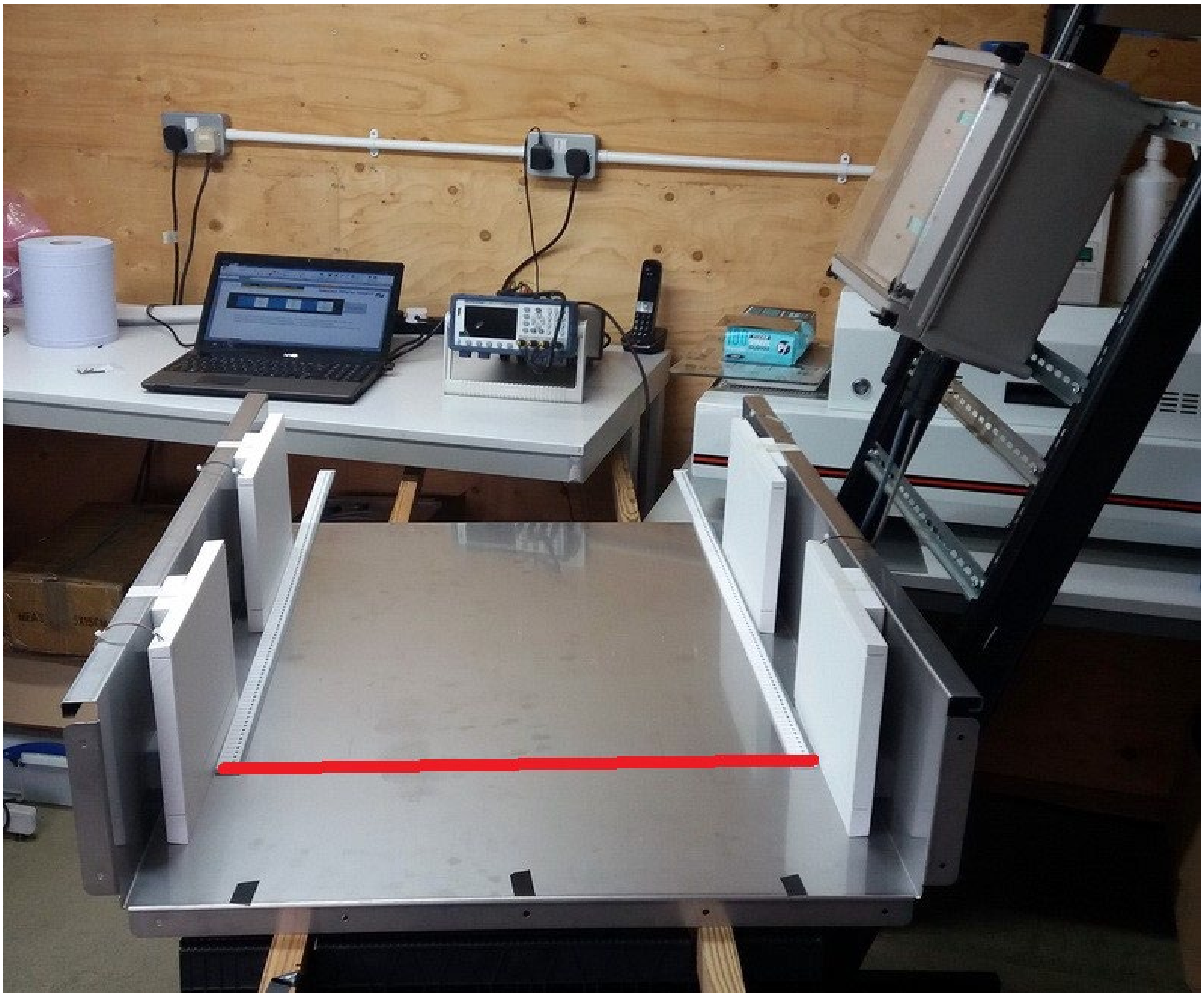


Figure 10: Quad antennae configuration. The red line depicts the datum line from which read-ranges were measured.

Flatbed (Round) configuration

During testing of various antenna designs (with varying success) it was decided to try out a basic round antenna design which is used in many applications. However, it is usually best suited when the tags are orientated to point into the centre of the antenna, much like a dart into a dartboard. The only practical way to fit this within the chute system was to use it in the base of the chute in a pass-over configuration. This meant the optimal tag orientation was in the Z orientation which would probably never be encountered in real world use. Having carried out free air tests we were pleased to find this configuration also achieved very good X and Y orientation reads in situ (Table 5). The decision was made to modify the chute by cutting a 600mm diameter hole in the centre of the chute to create a cut out section that housed the antennae (Figure 11). The X datum point was the far centre point of the cut out.

Table 5: Read range results for pass-over (flatbed, round) antennae configuration.

Flatbed Round

Tag orientation	HID_3x15			HID_3.85x22.5mm			HID_3.85x32mm			Chute
	Left	Centre	Right	Left	Centre	Right	Left	Centre	Right	
X	0	61	0	54	66	49	57	67	59	Top
X	42	61	40	69	80	76	81	83	82	Middle
X	65	80	65	80	81	80	82	81	81	Bottom
Y	39	0	46	52	37	53	61	58	55	Top
Y	50	49	46	54	59	50	58	62	57	Middle
Y	57	63	59	65	65	64	76	68	66	Bottom
Z	0	54	0	72	74	72	79	81	78	Top
Z	62	72	61	72	76	70	77	77	76	Middle
Z	53	65	53	61	69	60	71	84	64	Bottom

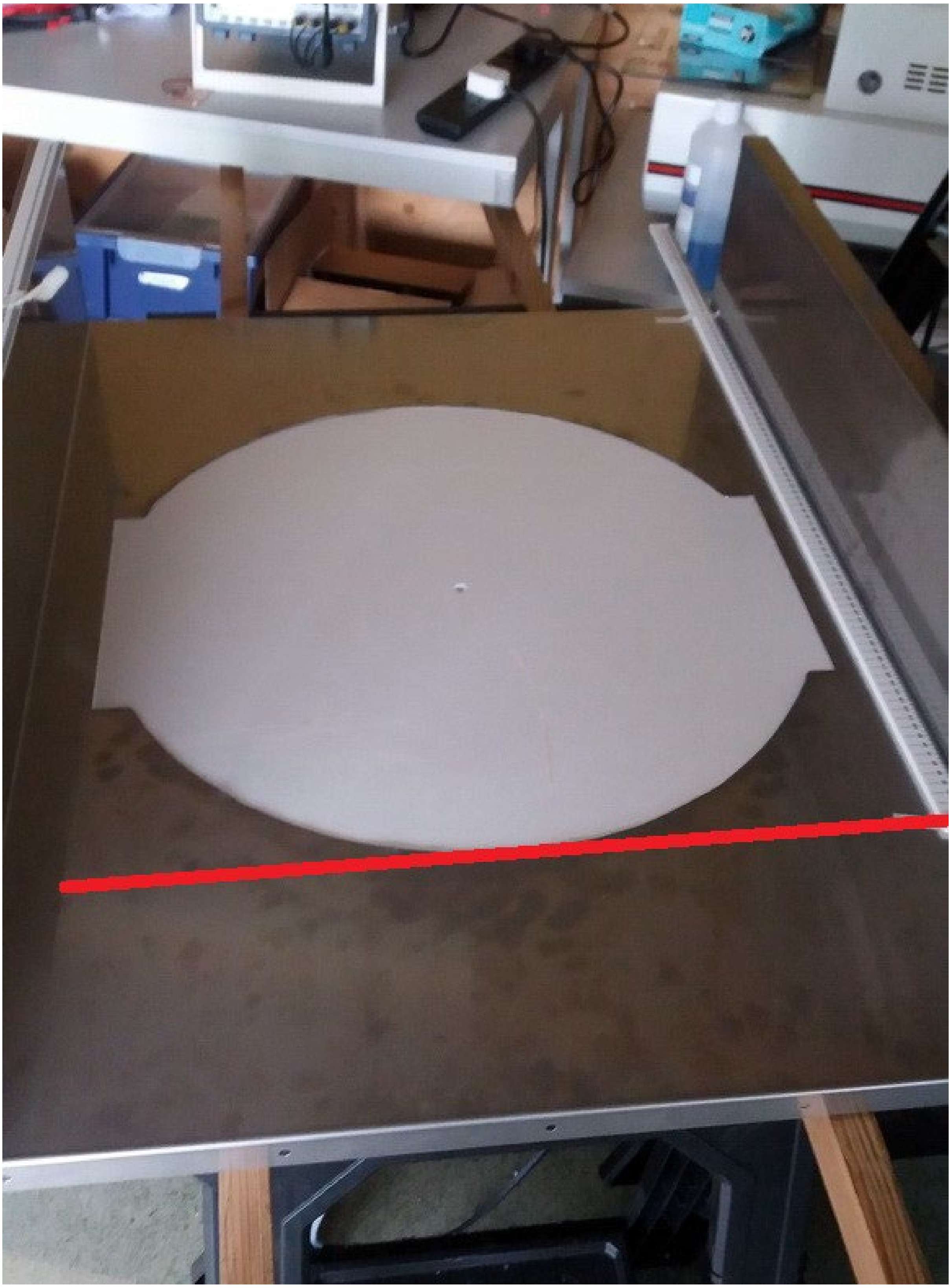


Figure 81: Flatbed (round) antennae configuration. The red line depicts the datum line from which tag detection ranges were measured.

Of the 4 configurations tested above, both the flatbed (rectangular) and quad configurations showed weaknesses. For the flatbed (rectangular) set-up, the system tended to fail to read tags in the upper third (top section) of the chute, although this improved as tag size increased. The quad configuration on the other hand showed weaknesses in readability through the central region of the chute (dead zone) and even with the largest tags, struggled to read them reliably when they were presented in the Z orientation.

Conversely, both the letterbox and flatbed (round) configurations were able to read almost all tags presented (exception was 15mm tags with the flatbed (round) configuration), regardless of size or orientation, with the letterbox configuration the only one that successfully read all tags.

Wet testing

The 2 most effective antenna configurations, those being pass-through (letterbox) and pass-over (round), along with pass-by (quad) were tested further. These were chosen either because they were the most effective during dry testing or because they provided good results coupled with easy installation. Each size of HID tag (15 x 3 mm, 22.5 x 3.85 mm and 32 x 3.85 mm) were implanted in blonde ray (*Raja brachyura*), tope (*Galeorhinus galeus*) and cod (*Gadus morhua*). For the ray specimens, 3 implantation sites were used; intramuscular in the left hand cheek (following guidance from Marine Scotland for the tagging of flapper skate (*Dipturus intermedia*), supplied via pers. comms, James Thorburn, 19/12/2019); at the base of the tail (Figure 12); and inside the gut cavity. For the tope and cod specimens, a single intramuscular site at the rear of the dorsal fin was used, along with a gut cavity insertion (see note below regarding gut cavity tags). With this being a relatively small proof of concept study, rather than purchasing a tag application gun, tags were inserted manually. A small incision relative to tag size was made with a No. 11 scalpel, then the tag was manually inserted into the incision and pushed into place. All specimens used for testing were commercially caught and processed (gutted) excluding the tope. For all intents and purposes, we believe the tags were sitting in a similar location/orientation as they would if live animals were tagged in the gut cavity, as is normal practice on a wide range of tagging programmes. Similarly, as the specimen animals used in this study were not living, investigations into tag rejection/migration or fish survival rates, were not possible. Obviously, should a widespread tagging programme be considered, animal welfare issues, sterility of tags and associated equipment, use of anaesthetics would all need careful consideration. Where good results were achieved with the smallest tag, the amount of testing was reduced for the larger tags as they are already known to perform significantly better than the smaller options.

Figure 92: Blonde ray, showing locations of intra-muscular tagging sites (red rectangles).at base of tail and in the left cheek. The 3 sizes of PIT tags tested are shown resting on the rays dorsal surface, from left to right; 15mm x 3mm, 22.5mm x 3.85mm and 32mm x 3.85mm.

The antenna arrays were mounted on a test rig, as described earlier, designed to emulate a sorting table/conveyor catch-handling system. The rig consisted of 2 stainless steel trough sections measuring 700mm (w) x 1000mm (l) with 200mm (h) side panels with a turned top edge (Figure 13).

Figure 103: Testing rig with quad antennas fitted. Note PIT tag scanner control box/enclosure on frame to left.

The specimens were passed through or past the antenna array both singly and as a tagged individual within a bulk of untagged fish consisting of the other test specimens plus additional haddock (*Melanogrammus aeglefinus*) and mackerel (*Scomber scombrus*). The mackerel were included in the bulk to examine whether fish with a high oil content would have an effect on the signal strength. When tested as single specimens, the individuals were, where possible, passed through in different orientations.

The results include not only the performance of tag detection but also comments on the applicability/practicality of the design with regard to installation and operation in a live environment.

Wet tag test results

The results of the "wet" testing of the equipment i.e. testing of the various antenna configurations with the three sizes of tags implanted into actual fish specimens, are shown in Table 6.

Table 6: Wet testing results

RAY									
Antenna Type	**Letterbox**			**Round Pass Over**			**Quad Pass By**		
Tag Size	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Intramuscular cheek	Y	Y	Y	Y	Y	Y	N	I	Y
Intramuscular base tail	Y	Y	Y	Y	Y	Y	I	I	Y
Gut Cavity	Y	Y	Y	Y	Y	Y	N	I	Y
TOPE									
Antenna Type	**Letterbox**			**Round Pass Over**			**Quad Pass By**		
Tag Size	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Intramuscular dorsal fin base	I	Y	Y	Y	Y	Y	I	Y	Y
Gut Cavity	Y	Y	Y	Y	Y	Y	N	I	Y
COD									
Antenna Type	**Letterbox**			**Round Pass Over**			**Quad Pass By**		
Tag Size	**S**	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
Intramuscular dorsal fin base	I	Y	Y	Y	Y	Y	I	Y	Y
Gut Cavity	Y	Y	Y	Y	Y	Y	N	Y	Y

(Tag Size: S = 3 x 15mm, M = 3.85 x 22.5mm, L = 3.85 x 32mm; Results: Y = read successfully on all occasions, N = could not be read on all occasions, I = Intermittent results of read and unread)

There was very little difference in detection of the tags between the different implantation sites within each species tested on the letterbox and Round Pass-over designs. The only small difference was during the testing of the Letterbox design where the smallest tag (3x15mm) was read intermittently when implanted at the base of the dorsal fin for both cod and tope. The Quad Pass-by was less reliable and had several incidents of inconsistent (intermediate) tag reading results.

The quantity of fish being moved past or through the 3 antennae configurations tested did not affect their performance and no difference in detection of the tags between single fish or tagged fish within a bulk of other fish, including the high oil content fish species, was detected.

When pass-over antennae were tested with non-metallic surroundings (36mm of plywood sheets) directly over the Round Pass-over antenna, there was no detectable difference in read-ranges as recorded in dry-testing. This indicates that the plywood had no detrimental effect on the read range.

Quad antenna

The quad antenna struggled with the smallest tag size but provided good detection rates for the largest size of tag. The medium sized tag had mixed inconsistent results and so was marked as "intermediate".. During this wet testing, this configuration also showed a noticeable dead zone for approximately 5mm from the base of the simulated sorting table. This did not cause issues for the tope and cod as the nature of the implantation sites meant that the tag was naturally held outside the low level dead zone. However, for the ray it was possible to push the fish flat enough for tag detection to fail with both the gut cavity and cheek implantation sites. This lower "dead zone" was not detected during the dry testing results (Table 4, which only showed a central "dead zone"), suggesting that the quad configuration, at least at this scale, may allow tagged individuals to pass through the tag read area undetected. It is conceivable that the central dead zone could be eliminated on narrower fish sorting conveyors and tables, and similarly, the dead zone at the bottom of the chute could be eliminated by adding a layer (approx. 5mm) of non-ferrous material to the base. In its favour, this antenna configuration perhaps offers the easiest of installation options. The quad antenna array could be custom manufactured as a single glass reinforced plastic (GRP) section each containing 2 windings, that could be bonded directly into the exiting chute/table/conveyor on vessels, or as a set of 2 plates. However, the largest possible tags would need to be used to ensure consistent tag read capture.

Pass-through (Letterbox) antenna

This antenna design was second best in overall wet test performance. Its detection range and tag-orientation insensitivity were excellent for the larger 2 tag sizes tested and it very nearly detected all of the smaller 15mm tags, with only the tags placed in the intramuscular dorsal fin area on cod and tope, becoming less consistent. These failures to read the 15mm tags are a function of the lower read-ranges of these tags (Table 2) , in conjunction with how fast they were passing through the letterbox antenna during wet testing. The antenna was fixed at the end of the chute, so once the majority of the fish passed through the antenna, gravity took over causing a rapid increase in speed

However, due to its nature and the fact that it needs to surround the entire sorting/catch handling system (conveyor/table/chute) on all four sides, finding an appropriate installation location for such an antenna could be problematic. This antenna design is ideally suited to installation either around an exit or entry opening on a fish handling system, or where the catch handling equipment changes (e.g. transition point where conveyor ends and drops contents into a chute), or even surrounding the scupper where fish are discarded from the vessel, with the antenna sized to suit the opening. As noted above, the locating and installation of the antenna should be done with consideration of how fast the fish are likely to be moving at any particular point of the catch handling system.

Pass-over, flat bed (round) antenna

The round pass-over antenna design was the only configuration that provided 100% detection rates on all the tag sizes and orientations tested. Its detection range and tag-orientation insensitivity were excellent for all tag sizes tested. The potential downside to this antenna is the installation. It would require a large hole to be cut in the base of any metallic sorting table or tray to provide a non-metallic aperture for the detection field to be projected through. Alternatively, it may be able to be installed on the underside of a non-metallic sorting table or conveyor system. As with the quad antenna, a chamfered high-performance plastic plate could be affixed over a section of the trough to provide a snag-free path for the fish whilst still protecting the antenna.

Discussion

The best design of PIT tag antenna that we trialled was the round pass-over antenna configuration as it was able to detect all tags, irrespective of the size of tag or where the tag was located on the fish sample. We would however recommend the largest possible tags (subject to the size of the fish being tagged) as these appear to be less susceptible to orientation issues, and bearing in mind that the testing regime utilised only tested in 3 test orientations (X, Y and Z but nothing in between). The reality of an onboard processing line on a commercial fishing vessel is that the orientation of tags within tagged fish will be a factor that is unlikely to be controlled in any way and so the antennae design chosen needs to be able to detect tags in any orientation. We would envisage that these antennae would also be easier to both manufacture and install than other designs and may not require bespoke designs for different vessels.

The other antenna configuration that gave good results was the pass-through letterbox design, which was able to detect all of the medium and large PIT tags, as well as all the small PIT tags embedded in the ray. It only had inconsistent detection rates on the small tags when they were inserted into the musculature around the dorsal fin of the cod and tope. This apparent anomaly between dry and wet testing is most likely due to the speed at which the tags (within the fish) were approaching and passing through the antenna, rather than the type of fish tagged. Again, increased tag size seemed to negate any potential tag orientation issues in this system, as well as the failure to read the smallest tags due to the speed at which they passed through the antenna. Whilst the letterbox antenna performed exceptionally well, it would most likely require a custom build for specific vessels due to the different points within the catch processing system that it could be installed. This may lead to it being difficult to install and depending on the vessel layout, getting a reliable unobtrusive power source to the reader may also be complicated..

It is worth noting that all testing completed was done with assumption that part or all of the catch handling system would be constructed in a metallic material (marine grade stainless steel or aluminium being the most common). That being said, many older and smaller vessels have been observed to be fitted with simple plywood tables/chutes. In this type of environment, our trials would suggest that relatively simple Passover antennas could be easily fitted directly underneath such sorting platforms without the need for any cut-outs, greatly reducing any potential installation costs.

Our trials also indicated that tag implant location (i.e. where the tag is inserted into a fish), had no effect on the readability of the tags when optimal antenna and tag size combinations were used. That said, due consideration of the potential risks of glass encapsulated PIT tags should be a major consideration when considering a wider tagging project. Our trials showed that the prototypic systems ability to read tags was not affected by the location of those tags. However, whilst outside the scope of this trial, tag implantation location could have serious implications regarding fish welfare and survival rates. Our initial recommendation would be for tags to be inserted into the gut cavities of tagged fish, as, if these fish are subsequently caught and processed, in most cases the tag would be removed during the gutting process, minimising the risk of them entering the food chain.

The prototype system used a Raspberry Pi to communicate with a SIFIDS OBCDCS system to provide the geo and spatial tagging, data storage and onward transmission to a shore-based system. Although the OBCDCS provides all the functionality necessary to achieve the goal it could be considered over-kill; It provides 1Tb of storage, redundant GNSS positioning modules and network capability. It would be possible to incorporate the essential elements into the tag reader unit reducing space, power and cabling requirements along with a likely reduction in overall cost. The onward transmission of data using the OBCDCS or an integral system adds to both the capital cost of implementing the system and the ongoing costs involved with cellular data and hosting and managing the reception database; if manual data collection is an acceptable route then system cost and complexity can be reduced by removing this functionality.

As a one-off build, the prototype PIT scanning system, without integrated positional logging and transmission capabilities cost £4000 to construct. This assumes that a "standardised" antennae configuration might be possible. Should a custom antenna be required for all vessels, the cost would likely have to increase. In an ideal world, the componentry required to geo-tag and transmit the tag ID data would be incorporated into an all-in-one unit. We estimate an additional £300 to engineer this functionality into the scanner system developed. The tags used in this trial are generally only available to purchase in quantities of 10,000. However, our technology partner, who has worked extensively with HID Global in the past has the ability to purchase in lesser quantities (minimum 2,000 units). Costs for individual tags are £1.59 and £1.75 respectively for the 22.5mm x 3.85mm and 32mm x 3.85mm tags. Our technology partner could also provide these tags, individually bagged and with 2 unique white polyester labels for approximately £2.75/tag if required. The above cost estimates do not include the cost of installing and commissioning the equipment aboard vessels and these will vary depending on the boat layout and installation preferences.

The system constructed for this project appears to meet all the major targets outlined in the initial brief. Trials of the constructed HDX system showed that 100% of tags could be detected when used with the most effective antennae arrangement (in this case the round pass-over, closely followed by the pass-through letterbox design), irrespective of tag orientation and location in the fish. Resultant tag ID data were then able to be transmitted along with the linked temporal and spatial information gathered by the OBCDCS system.

Next Steps

If a larger scale tagging project is considered where this technology might be required aboard fishing vessels, a survey of likely vessels should be undertaken to better understand the type and dimensions of the catch handling systems, to identify the most suitable antennae arrangement for the vessel. This should also include a detailed look at the most common conveyor systems used by the fleet to determine whether, for example, antennae could be fitted between rollers, or if a universal type pass over antenna would be possible for the majority of vessels. These vessel surveys should also consider the possibility of the potential to fit letterbox antenna either inside the vessel at a suitable transition point in the catch handling system, or externally at the point discarded fish and fish by-products exit the vessel. A similar design of letterbox type antennae has been successfully constructed and used (in this example it is an FDX system) at locations within Borland lift fish pass (Figure 14) systems to monitor the passage of migrating freshwater species. If sufficient clearance is available on the outside of vessels this type of design would likely be the easiest in terms of installation of letterbox type antennae.

Figure 11: An FDX letterbox type antenna fitted to a Borland lift fish pass. Image courtesy of Anglian Electronics.

We believe further testing and development of the quad antennae configuration is warranted. If field strength can be improved to a point where dead-spots (both central and near the base of the sorting table/chute) can be eliminated, this antennae configuration will likely be the easiest design to fit to vessels.

At present, the system is able to scan, record and transmit the unique ID of individual PIT tags. The system is unable to determine whether this tag is within a live animal that has been caught and subsequently released (discarded) or a tag that has been removed from a previously tagged individual during catch processing (as part of the discarded guts). There is potential to build upon the current system, whereby a successful tag read could initiate further actions, such as triggering a still image from a digital camera to be captured, integrated within the current system.

As outlined in the project brief, larger specimens (especially larger specimens of Flapper skate) will not physically fit on a lot of vessels catch handling systems, and if accidentally by-caught, are generally removed manually either directly from the net or from the vessels pounds or hoppers through the use of ropes and winches. These animals, if tagged, would obviously not be able to be scanned by the prototypic system in its current form. As such, an alternate means of scanning these individuals (and perhaps different tagging methodologies) should be considered for larger individuals. There is potential that a hand-held portable scanner may be able to be used and integrated into the system.

We would also recommend that the system be comprehensively tested aboard a working fishing vessel to test assumptions around metallic catch handling equipment etc. and to expose the equipment to the harsh environment it would be required to operate within. This includes operating the system alongside the other electronic and electrical devices commonly found on commercial fishing vessels to assess whether such equipment might alter or interfere with the systems operation and vice versa.

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