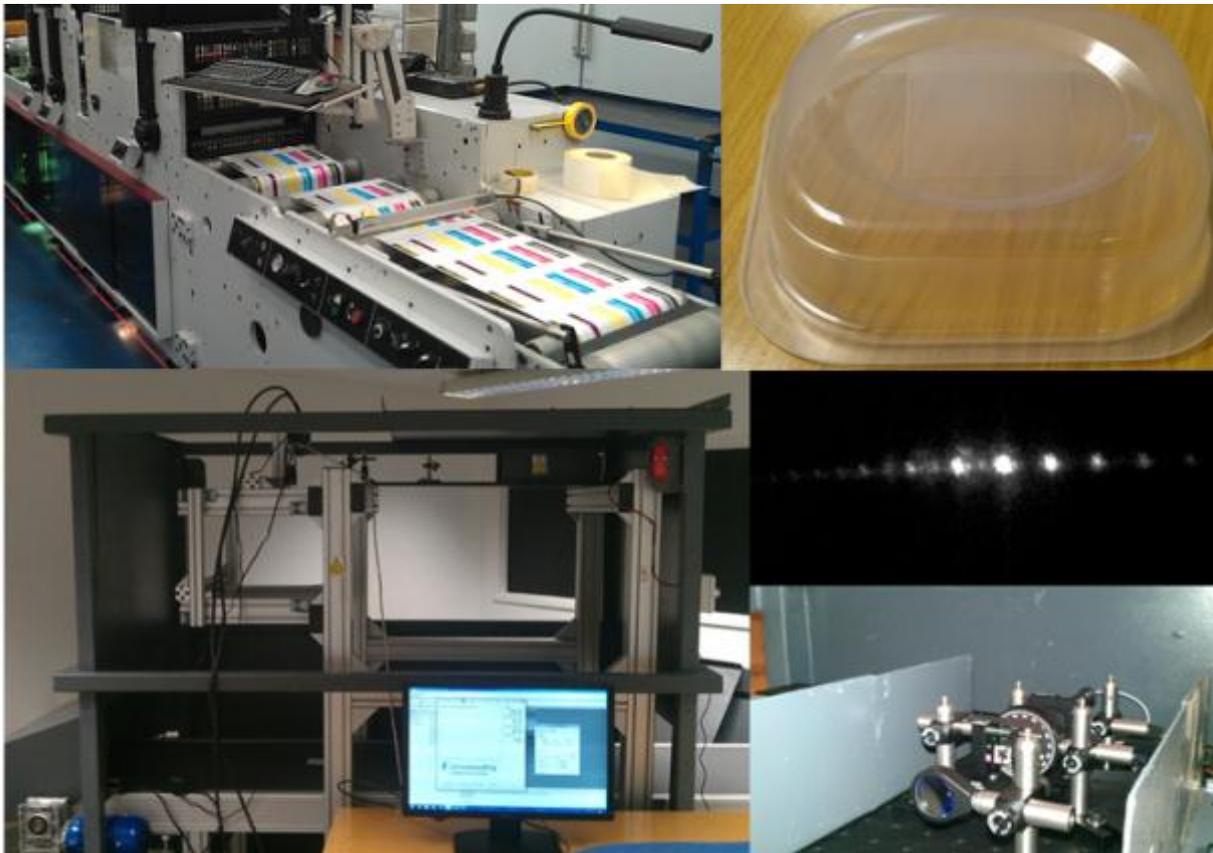

Summary report

Diffraction gratings for food contact packaging identification



A study into the potential of diffraction gratings as a technique to identify and sort food contact plastic packaging.

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where resources are used sustainably.

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communities to help them reap the
benefits of reducing waste, developing
sustainable products and using resources
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Written by: Richard M^cKinlay, Liz Morrish and Richard Williams



Front cover photography: Production of printed gratings at Systems Labelling, thermoformed PP tray with impression moulded grating, demonstration unit diffraction pattern and laser optics within the unit.

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Executive summary

WRAP commissioned Axion Consulting to assess the suitability of using diffraction gratings as a technique to identify and sort food contact plastic packaging, allowing this type of packaging to be separated and recycled in food packaging applications. The technique has been identified as one with potential for identifying food contact packaging through previous work conducted by Axion on behalf of WRAP. This project focuses on polypropylene (PP) packaging as there is currently no automated way to produce a PP food contact stream able to be recycled back into food packaging applications, but the diffraction grating technique is also potentially applicable to other polymers such as high density polyethylene (HDPE) and polyethylene terephthalate (PET).

Currently there is no automated process to identify and sort food contact PP from non-food contact PP and therefore recycled PP cannot be used in food grade applications, as accepted EFSA (European Food Safety Authority) guidelines suggest food grade PP must be made from 99% food contact material. To enable the production of recycled, food grade PP in the future, the food contact packaging must be sorted and then purified and extruded. This project focuses on the identification and sorting of food contact PP and parallel work has been carried out by WRAP to develop a food grade extrusion method for PP.

A diffraction grating is a structure consisting of a series of equally spaced lines which 'diffracts' (splits) incident light into multiple directions producing a unique pattern of diffracted beams when light is shone onto it. This pattern is characteristic of a diffraction grating and is unlikely to be produced accidentally by light hitting other structures. Therefore if diffraction gratings are applied to food contact packaging the items can be 'interrogated' by a beam of laser light in the recycling plant and if the characteristic diffraction pattern is observed, it can be concluded that that item of packaging is food contact and may then be recycled into food contact applications.

The project required a specialised demonstration unit to be designed and built, along with the development of image processing software to identify diffraction gratings on food packaging.

The following five methods for applying diffraction gratings to packaging items were investigated:

- Injection moulding a grating on the packaging surface;
- Impression moulding a grating on the packaging surface;
- Printing a grating on a packaging label;
- Holographic film containing a grating, applied to a packaging label; and
- Laser engraving a grating on the packaging surface.

In order to produce the samples of packaging with diffraction gratings applied to them in the above ways, a number of industrial partners participated in the project, including label manufacturers and packaging manufacturers.

A trial programme was developed to test the samples produced for the project. The trial programme was designed to assess ease of identification for samples in six different states, in order to come to an informed conclusion on the suitability of diffraction gratings for this application:

- Static samples aligned to give the best possible chance of detection. This allowed for a baseline comparison between the different types of sample;
- Samples travelling at speeds of 0.1 m/s;

- Samples where the gratings were contaminated with various foodstuffs;
- Samples where the gratings were damaged;
- Samples which were deformed i.e. crushed and crumpled; and
- Samples travelling at speeds of 1 m/s and analysed with a scanning laser to demonstrate the identification and sorting could be achieved at commercial scale.

These trials were successfully carried out, along with an economic assessment of the cost of applying gratings using the different methods and the economic benefit to a recycler to produce a food contact PP product.

The trials showed that it should be possible to apply diffraction gratings to mass market packaging at a cost low enough to be commercially viable and also to automatically identify the gratings at speeds comparable to existing optical sorting machines that are used in the recycling sector. The software was able to correctly identify images of diffraction gratings and separate these from images of noise showing no gratings. The data obtained gives strong evidence that sorting could be done reliably at commercial speeds with further optimisation of the grating designs and detection hardware and software.

All grating production methods generated samples that could be detected by the demonstration unit. Although preliminary samples of the printed gratings could be identified, production samples could not, probably due to differences in ink viscosity leading to the structure of the printed grating not forming correctly. Holographic film gave the highest quality diffraction patterns, with injection moulded, impression moulded and laser engraved gratings all being of similar, reasonable quality.

Studies showed contamination of gratings through the waste collection and sorting process may prevent detection. This depends on the level of contamination present on the grating, which may not be as heavy in a real life scenario as was tested during the trials, and further investigation is required into how actual levels of contamination would affect the ability to read gratings.

Table 1 shows estimates for the cost of applying gratings to packaging. It is estimated that impression moulding, injection moulding and holographic film would all cost around 0.2 pence per item of packaging or less. Printed gratings would have a negligible cost to produce but require High Definition (HD) printing technology which is not currently widely used and would require significant investment in the printing industry. Laser engraved gratings are likely to be of a much higher cost, and would probably cost more than the item of packaging itself.

Table 1 Estimated costs of applying diffraction gratings to items of packaging

Production method	Estimated cost to apply grating per item (pence)
Injection moulded grating	0.17
Impression moulded grating	0.06 – 0.18
Printed label grating	Negligible once investment in High Definition printing technology made
Holographic film grating	0.1
Laser engraved (surface) grating	18.57
Laser engraved (sub-surface) grating	22.86

The benefit to a plastics recycler producing a baled PP food contact packaging product was also estimated using an economic model. It was found that investing about £1 million in sorting equipment (two sorting units) and employing a final manual sorter to 'polish' the material would give a payback period of 3.4 years and a Net Present Value (NPV) of £0.8 million with a 10% discount rate. This payback period and NPV should represent a good investment opportunity for a Plastics Recovery Facility (PRF) operator or a potential food grade reprocessor processing bales of sorted PP packaging.

Overall it appears that diffraction gratings can potentially be used to identify food contact packaging effectively and economically; however, they are not yet ready for use commercially until a full industry-wide solution has been developed and commercialised. To further validate the findings of this study a programme of additional work should be undertaken. Recommendations for further work are:

- Optimise the different diffraction grating application methods to give higher quality gratings and allow for detection at commercial sorting speeds;
- More work on printed gratings to improve the detection performance for high speed printed labels;
- Further work on holographic film to determine if film could be placed on In Mould Label (IML) packaging;
- A study on the types of PP packaging in the municipal waste stream focusing on which grating application methods would be most viable to the different types of packaging, the areas of packaging that could be marked and the associated cost;
- A study into actual levels and types of contamination that would be present on PP packaging in the waste stream. This could involve a large scale trial in which marked packaging with diffraction gratings is traced through the waste collection and sorting system and analysed to determine the impact of the contamination, and any damage caused to the packaging, in identifying the diffraction grating;
- Design and manufacture a prototype sorting unit with more sophisticated optics to overcome issues of crushed packaging and allow for the detection of diffraction gratings at commercial sorting speeds; and
- Develop further uses and markets for a diffraction grating sorting unit. This may include the use of diffraction gratings to sort HDPE milk bottles. This could help to encourage the sorting unit manufacturers to invest the necessary development time and resources into this technology by increasing the likely number of machines that would be required and potentially sold.

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Glossary

EFSA	European Food Safety Authority
FPS	Frames per second
HD	High Definition
HDPE	High Density Polyethylene
HRI	High Refractive Index
IML	In Mould Label
Injection moulding	The process in which molten polymer is injected into a mould and allowed to solidify to take on the shape of the packaging
MRF	Materials Recovery Facility
MP	Mega Pixels
NIR	Near Infra-red
NPV	Net Present Value
PA	Packaging Automation
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PRF	Plastics Recovery Facility
Thermoforming	The process in which a sheet of polymer is heated and then stretched over a mould under a vacuum to produce the shape of the packaging
WRAP	Waste & Resources Action Programme

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- University of Bradford: assistance in the manufacture of the production impression moulded samples, provision of expertise in polymer processing and equipment to manufacture the samples;
- Fianium: production of laser engraved samples as well as engraving the moulds for the impression and injection moulded samples;
- OpSec Security: involvement in the manufacture of the holographic film samples;
- Packaging Automation: provision of feedback on the technical aspects of applying impression moulded gratings using their expertise in the manufacturing of heat sealing equipment for the food and beverage industry. Also production of the preliminary impression moulded samples;
- RPC Containers: supply of packaging to make impression moulded samples and also production of samples of injection moulded gratings as well as assistance with the economic assessment;
- Systems Labelling: provision of advice on printed gratings as well as production of a wide range of labels with printed gratings;
- GJ Creative: input into diffraction grating label design; and
- The Co-operative Food: feedback from a retailer's point of view along with supplying data used in the economic assessment and the use of label designs.

1.0 Introduction

1.1 Background

It is estimated that approximately 180,000 tonnes of PP is placed on the UK household market each year, of which more than 60% is food contact packaging such as ice cream tubs, soup pots and microwave meal trays¹. The remaining 40% of packaging consists of non-food applications such as cleaning products or cosmetics. Without further separation this recycled PP cannot be incorporated into food contact packaging applications, as the European Food Safety Authority (EFSA) suggests that 99% of the recycled polymer must only have ever been used in food contact applications. This has become widely accepted within the recycling sector as a requirement in the production of recycled polymers for food grade applications. At this time there is no automated way to separate food contact PP from non-food contact PP packaging.

The effect of this is that PP food packaging cannot currently contain recycled content, and must be made from 100% virgin polymer. With growing consumer awareness and a desire for packaging with a recycled content from brand owners and retailers aiming to reduce the carbon footprint of their products and packaging, there is strong interest from the supply chain to develop an automated sorting technique and enable the production of a recycled, food grade PP as has been seen with Polyethylene Terephthalate (PET) and High Density Polyethylene (HDPE). In some cases packaging users are specifying more expensive PET in preference to PP, purely because PET with recycled content is available².

Previous work done for WRAP³ investigated various techniques which could be used to identify food contact PP; allowing it to be separated at a Materials Recovery Facility (MRF) or Plastics Recovery Facility (PRF). There are several requirements for an identification technique to be successful:

- Cost effective: it must be cost effective to apply a marking to the packaging and also to identify and sort the packaging at a recycling facility;
- Adoptable by the supply chain: the method must not be overly complicated or require highly specialist equipment;
- Can be used on a variety of polymer types and packaging types; and
- Destructible in the recycling process: the identification must be destroyed during the recycling process, prior to the material being incorporated into a new product. The recycled polymer may be used in a non-food application in future uses; if this is the case and the marker is not destroyed then once it was recycled again the item would be wrongly sorted as food grade material even though it had been previously used in a non-food application.

Diffraction gratings were identified as the technique with the greatest potential for fulfilling the above criteria.

A diffraction grating produces a unique pattern of diffracted beams when light is shone onto it. This pattern is characteristic of a diffraction grating and is unlikely to be produced accidentally by light hitting other structures. Therefore if diffraction gratings are applied to food contact packaging the items can be 'interrogated' by a beam of laser light in the

¹ WRAP, 2012, 'UK market composition data of polypropylene packaging' (Axion Consulting), <http://www.wrap.org.uk/sites/files/wrap/Phase%203%20Food%20Grade%20PP%20Market%20Final%20Report.pdf>

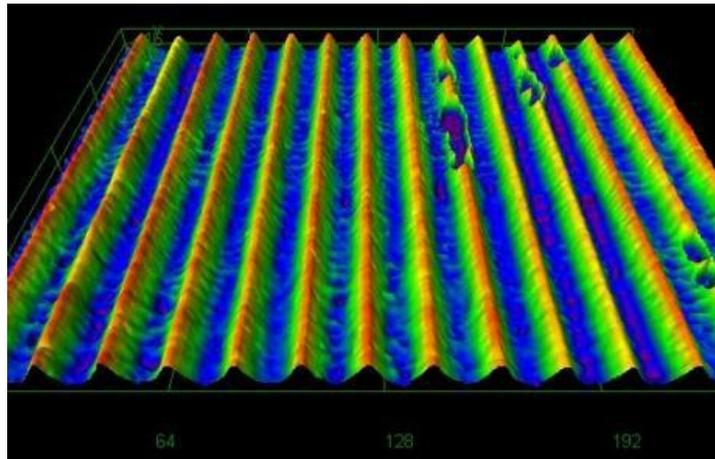
² Confidential communication to Axion Consulting from a thermoformed packaging converter

³ WRAP, 2012 'Sorting plastic for food use' (Axion Consulting)

recycling plant and if the characteristic diffraction pattern is observed, it can be concluded that that item of packaging is food contact and may then be recycled into food contact applications.

A diffraction grating is a structure consisting of a series of equally spaced lines which 'diffracts' (splits) incident light into multiple directions. **Figure 1** shows a magnified surface profile of a diffraction grating. The actual distance between the peaks on the surface is 20µm.

Figure 1 Magnified surface profile of a diffraction grating in a steel impression mould



1.2 Project aims

The aims of this project were to:

- Identify a number of methods of applying diffraction gratings to packaging items;
- Determine the suitability of each application method in terms of the proportion of the item of packaging able to be marked and potential for interference with retailer/product branding;
- Design and build a demonstration unit for identifying diffraction gratings on packaging items;
- Determine how easily diffraction patterns can be identified for different samples when stationary and in motion;
- Analyse the effect of contamination, destruction and deformation of the gratings applied to items of packaging;
- Conduct a preliminary economic analysis to estimate the cost per item for applying gratings and the benefit/cost to a plastics recycler for separating food contact packaging; and
- Provide an overall conclusion on the potential of diffraction grating as a technique for identifying and sorting food contact packaging and recommendations for further work.

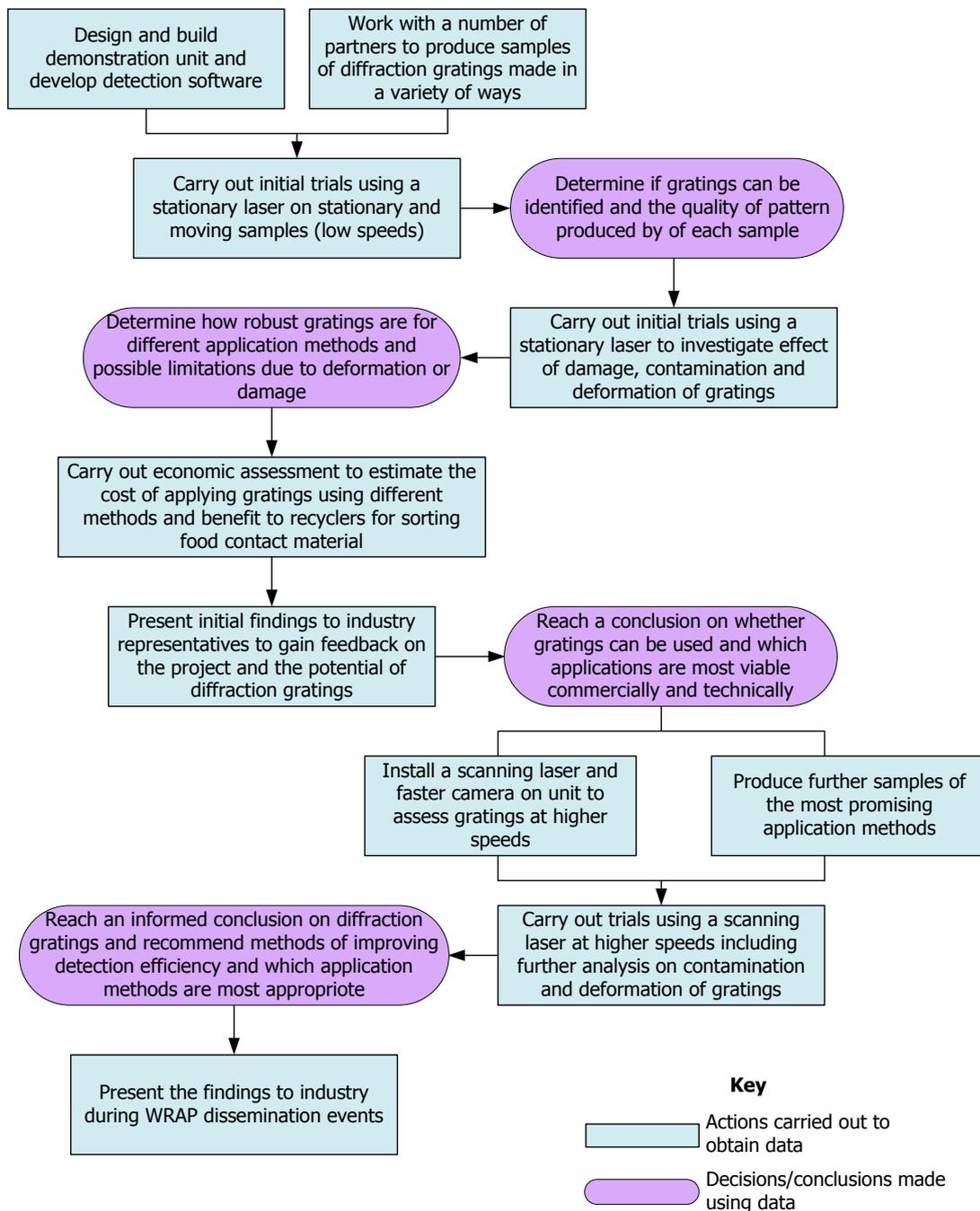
The focus of this project has been PP packaging as there is a need to automatically sort food contact PP from non-food contact PP packaging in order to enable a stream of packaging to be utilised in the production of food contact PP packaging with a recycled content. The diffraction grating technique is also potentially applicable to other types of polymer, in particular HDPE and PET packaging.

This summary report focuses on the key results and conclusions from the project.

1.3 Project methodology

In order to deliver the project aims, the work was carried out as shown in **Figure 2**. The aim was to reach an informed decision on how suitable diffraction gratings are as an identification method, the costs associated with marking and sorting and the possible limitations to different application methods and the technique as a whole. It will also be possible to recommend ways in which a detection unit and gratings could be improved to give higher sorting efficiencies.

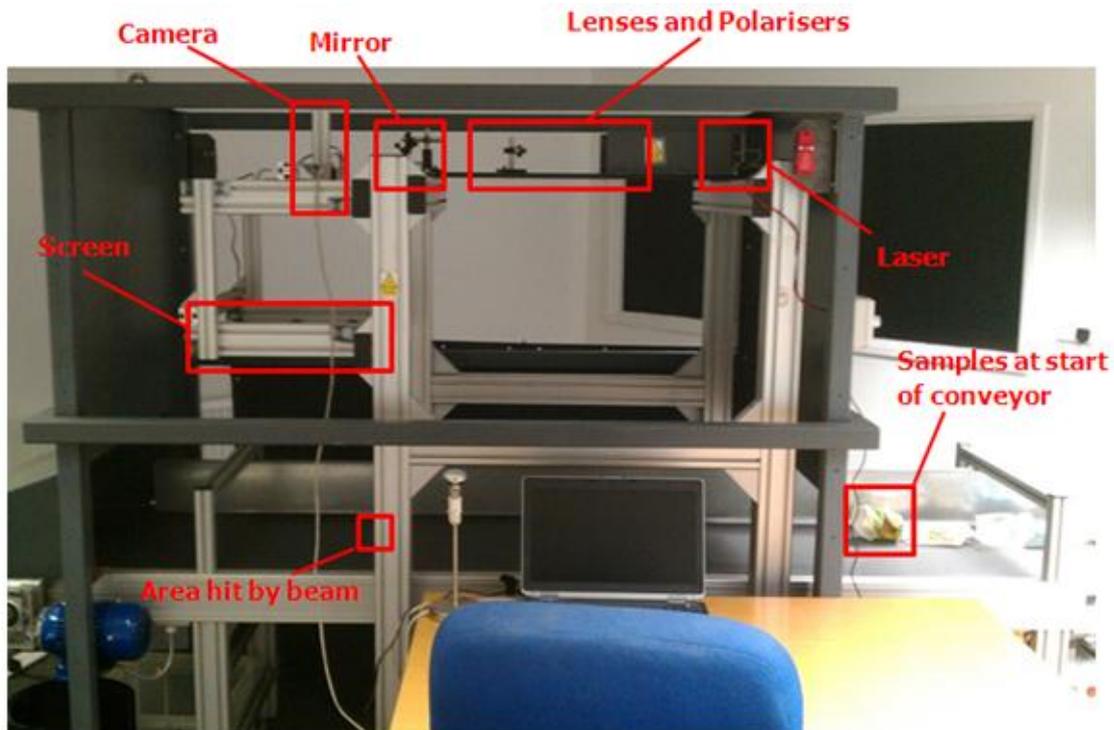
Figure 2 Project methodology flow diagram



2.0 Design and build of demonstration unit

In order to perform the trials on various diffraction grating samples and to demonstrate that the gratings could be detected automatically, a demonstration unit was designed and built. **Figure 3** shows the interior of the unit with the various components annotated.

Figure 3 Demonstration unit interior



The demonstration unit was modified halfway through the project to allow for the installation of a laser scanner and a higher frame rate camera.

The demonstration unit consists of the following:

- A laser which emits a beam of Near Infra-red (NIR) light at a wavelength of 980nm, with a maximum power of 200mW. The laser was changed to a 808nm 500mW unit for the trials using the scanning laser;
- Optical equipment including polarisers, lenses and a mirror to condition the laser beam and direct it onto the sample;
- An acrylic screen onto which the diffraction pattern is reflected from the sample;
- A camera which detects the NIR diffraction pattern on the acrylic screen;
- Adjustable housing for all the above equipment; and
- A conveyor belt to demonstrate detection of the gratings whilst in motion.

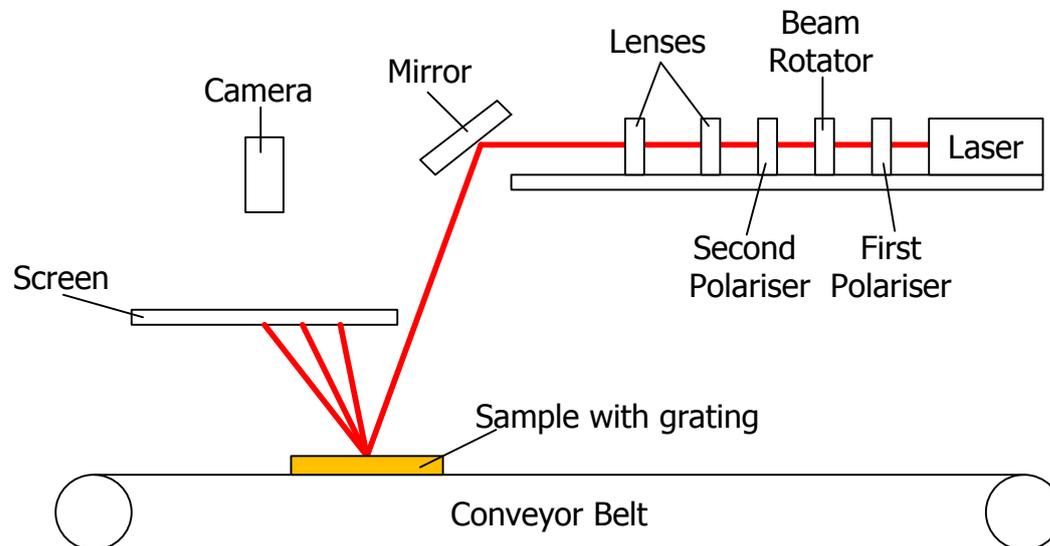
To ensure the trials were carried out safely a number of precautions were taken:

- Laser safety glasses were worn which filtered out specific wavelengths of light preventing the infra-red light damaging the eyes;
- A door interlock system was used which only allowed the laser to operate when all access doors were closed. The laser would turn off if any doors were opened to prevent injury to any unprotected personnel and a reset button required pushing before the laser could be operated again;
- The laser could only be switched on using a key in the possession of the authorised operator; and

- Guards were placed around the unit to prevent any of the infra-red light escaping during demonstrations.

The demonstration unit was designed to give clear, bright spots from diffraction gratings with line spacings of between 30 and 100 lines per mm. **Figure 4** shows a schematic of the demonstration unit.

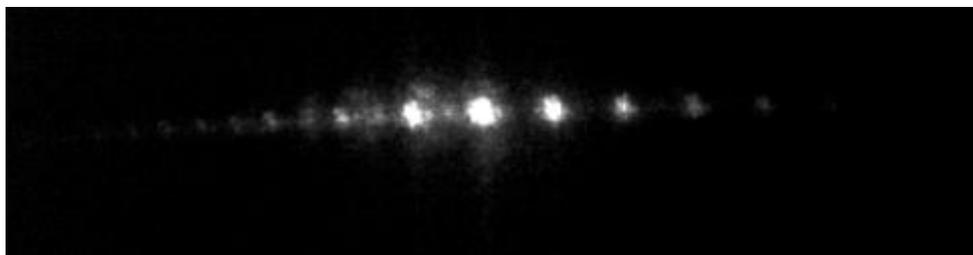
Figure 4 Schematic of laser path in the demonstration unit



When the light diffracts off the grating and hits the screen, a line of bright dots are seen. This diffraction pattern is unique to the grating, and the space between the dots is directly related to the number of lines per mm the grating has. **Figure 5** shows an example diffraction pattern. If no grating is present there is either a single reflected spot or a blur of light; these non-diffraction pattern images are referred to as noise.

Several images could be taken of the same grating depending on the speed at which the grating is travelling, the size of the grating and the frame rate of the camera. For example a large grating at a low belt speed and at a high frame rate would generate a large number of images from a single grating, whereas a small grating at a high speed and low frame rate would generate only a few images.

Figure 5 Example of a diffraction pattern



A program was developed, written first in Java using the open source software imageJ⁴, and later re-written in C++, to automatically analyse images to determine if a diffraction grating is present. The program is able to analyse a single image of a diffraction pattern, a folder of images or a video of a diffraction grating in motion.

⁴ National Institutes of Health, NIH, United States of America (<http://rsb.info.nih.gov/ij/>)

To determine if a diffraction grating is present the software automatically 'cleans' the image to reduce noise, identifies the centre of any bright points and calculates the distance and angle between all the points. If a set number of points are found with a similar distance between them at a relatively constant angle, the software identifies the image as a diffraction pattern.

3.0 Samples and grating production methods

A key to the success of using diffraction gratings to identify food contact packaging is how the gratings are applied to the packaging. The methods identified for investigation within this project were:

- Injection moulding a grating onto the surface of the packaging;
- Impression moulding a diffraction grating onto an item of packaging;
- Printing gratings onto packaging labels;
- Laminating labels with holographic film with a diffraction grating; and
- Laser engraving gratings onto packaging items.

This section details how samples for each of the above categories were manufactured. These samples were tested using the demonstration unit and the results and discussion on the suitability of each method is given in subsequent sections.

3.1 Injection moulded gratings

Previous studies⁵ have shown that around 35% of PP food packaging is injection moulded. One way of applying gratings to injection moulded items of packaging is to engrave a grating into the surface of the mould. This means that when the polymer is injected into the mould, the gratings will be present on the resulting packaging.

3.1.1 Preliminary injection moulded samples

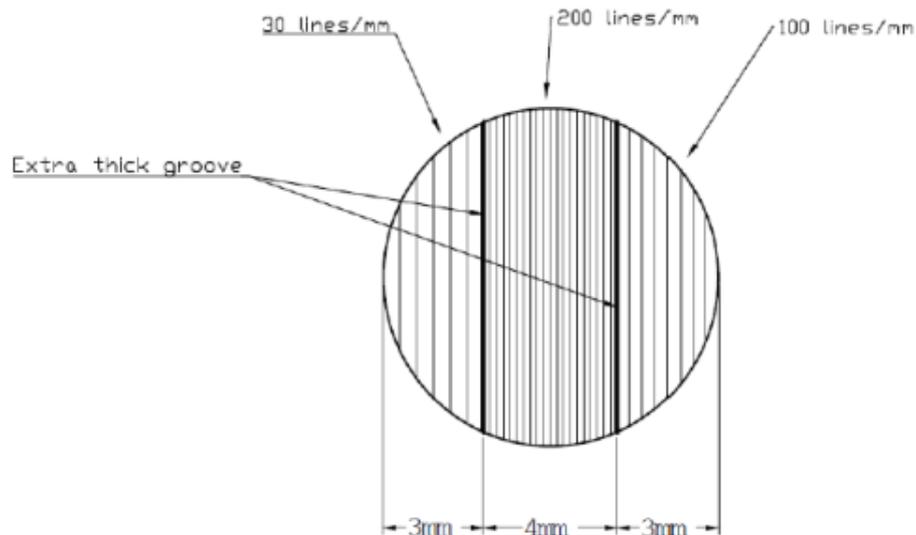
In order to assess this method initially, samples manufactured for a previous WRAP project⁶ were used. These samples had previously been tested on a small test rig built as part of an earlier project.

A schematic of the mould used to produce the samples is given in **Figure 6**. The mould contains three different diffraction gratings with 30 lines/mm, 100 lines/mm and 200 lines/mm. The mould is made from a hard metal alloy that is often used to make moulds for injection moulding.

⁵ WRAP, 2012 'UK market composition data of polypropylene packaging' (Axion Consulting), <http://www.wrap.org.uk/sites/files/wrap/Phase%203%20Food%20Grade%20rPP%20Market%20Final%20Report.pdf>

⁶ WRAP, 2012 'Sorting plastic for food use' (Axion Consulting): <http://www.wrap.org.uk/sites/files/wrap/Phase%203%20Food%20Grade%20rPP%20Prior%20Food%20Use%20Sorting%20Final%20Report.pdf>

Figure 6 Grating configuration – preliminary injection moulded samples



This mould was used to produce circular samples of both white and clear PP. **Figure 7** shows two of the samples produced. The samples were used to test this injection moulding concept; however, due to the small area of the gratings, testing was difficult to undertake.

Figure 7 White (left) and clear (right) preliminary injection moulded PP samples



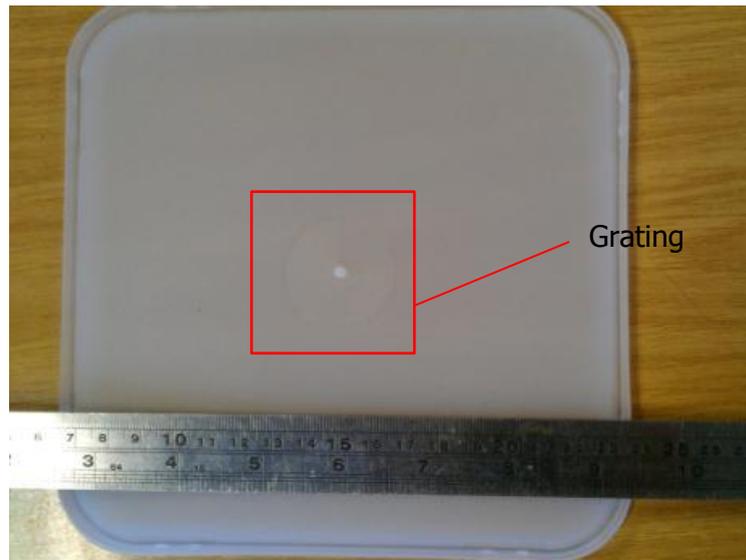
3.1.2 Commercial production injection moulded samples

Further work was undertaken on injection moulded samples in order to develop the initial injection moulding work and to provide larger size samples more suitable for testing on the demonstration unit. Axion worked with RPC to produce an injection moulded PP tub lid with a surface grating moulded on it. This injection moulded item of packaging is one of RPC's commercial products.

A diffraction grating was laser engraved onto the mould. This mould was then used in production to produce 100 samples with the diffraction grating on the surface.

The polymer from which the lid is made is a cloudy polymer with a matt finish, which allows for analysis of a different type of packaging. Clear samples from the same mould were also made which still had a matt finish due to the mould used. **Figure 8** shows the sample with the grating location highlighted. The grating in the circular area in the centre of the lid is barely visible by eye and is unlikely to be intrusive on packaging.

Figure 8 Injection moulded PP food tub lid with grating on



3.2 Impression moulded gratings

Since not all food packaging is injection moulded a method of applying the gratings onto blow moulded or thermoformed packaging was also needed. In order to produce this type of grating, a metal stamp with the diffraction pattern marked on its surface could be heated and then pressed onto the surface of the packaging to form the pattern.

3.2.1 Preliminary impression moulded samples

The same mould that was used to produce the injection moulded samples (see Section 3.1.1) was used by Packaging Automation to produce a sheet of PP with diffraction gratings impression moulded onto it. Packaging Automation used one of their test rigs to heat the mould to 140°C and press it onto the sheet of PP for 1 second under various pressures.

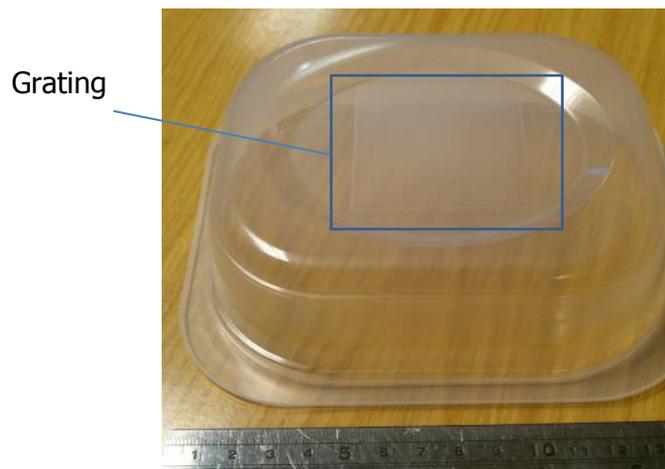
The relatively small initial samples were invaluable to prove the concept initially, but larger gratings were required for more convincing full scale demonstration trials.

3.2.2 Production impression moulded samples (University of Bradford)

The purpose of producing these additional samples was to build on the successful proof of concept work undertaken with Packaging Automation, by making larger size samples that could be tested on the demonstration unit.

Gratings were impression moulded onto the bottom of clear PP thermoformed trays. The mould used was a 500 x 500 mm stainless steel block covered in a 30 line/mm grating, with a grating depth of approximately 25µm. **Figure 9** shows the thermoformed tray with a grating on the base; again the grating is barely visible to the human eye.

Figure 9 Thermoformed tray with a diffraction grating impression moulded onto the base



3.3 Printed gratings

As well as forming physical gratings directly on the surface of packaging items, printing gratings onto packaging labels was also investigated. Two sets of samples were made, first a wide range of preliminary samples and then a smaller number of production samples.

3.3.1 Preliminary printed grating samples

In order to print gratings, closely spaced lines of one colour were either printed directly onto the label substrate or over a layer of black ink. A wide range of samples were produced by Systems Labelling and six different substrates were investigated:

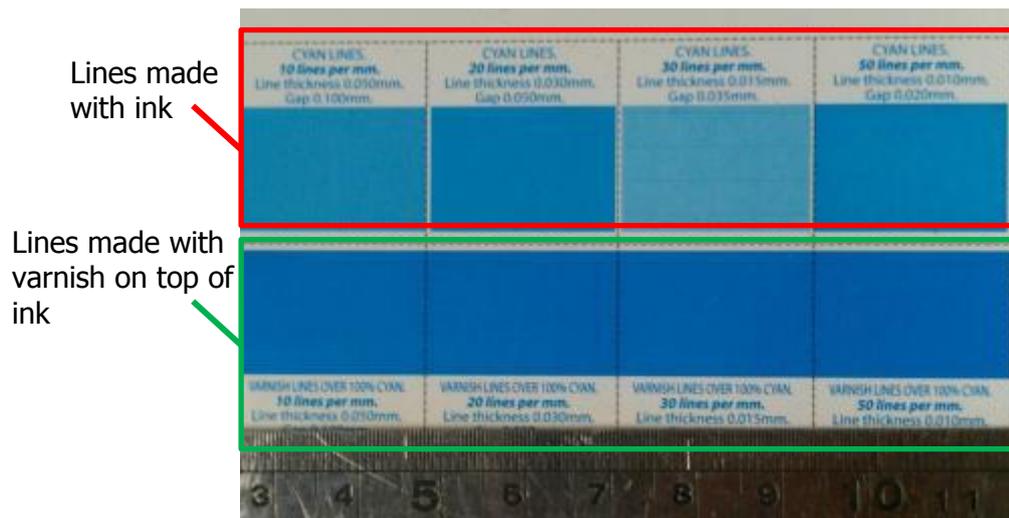
- White and clear In Mould Label (IML) film;
- White and clear wrap around film; and
- White and clear self-adhesive film.

For each of the above substrates 48 different diffraction grating patterns were produced as samples (288 samples in total of various colours, periods and substrates). These were patterns made with 10, 20, 30 and 50 lines/mm for each of the following:

- Black, cyan, magenta or yellow lines over the substrate;
- Cyan, magenta or yellow lines over solid black ink; and
- Lines of varnish over the substrate, solid black ink, solid magenta ink, solid cyan ink and solid yellow ink.

The varnish that was tested is a product that absorbs infra-red light. **Figure 10** shows the printed gratings made by cyan lines and also gratings made by varnish on top of cyan ink.

Figure 10 Cyan printed diffraction gratings



3.3.2 Production printed grating samples

Systems Labelling also produced samples using in-production label designs provided by The Co-operative Food. The production samples made were milk and cream product labels that had a grating printed into the solid area of colour in red, green and blue. The whole area of solid colour is a grating. They were printed on both white and clear self-adhesive labels. **Figure 11** shows the milk labels with the white labels on the left and the clear labels (on white paper) on the right. The cream product labels used similar colours but were IML.

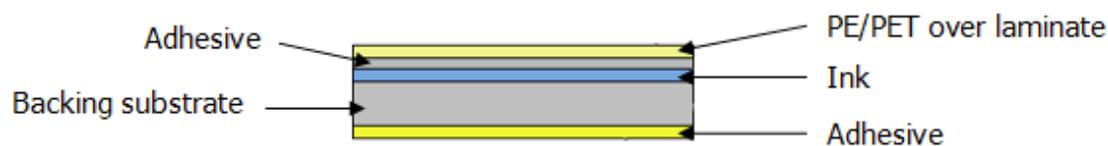
Figure 11 Production samples of milk labels



3.4 Holographic film gratings

Self-adhesive labels are composed of several layers, one of which is an over-laminate film generally made of polyethylene (PE) but other polymers such as PET can also be used. The film used is normally between 12 and 15 μm thick. It is possible to imprint a holographic grating in the over-laminate film. This results in an invisible diffraction grating over the entire surface of the label. **Figure 12** shows the construction of a typical self-adhesive label.

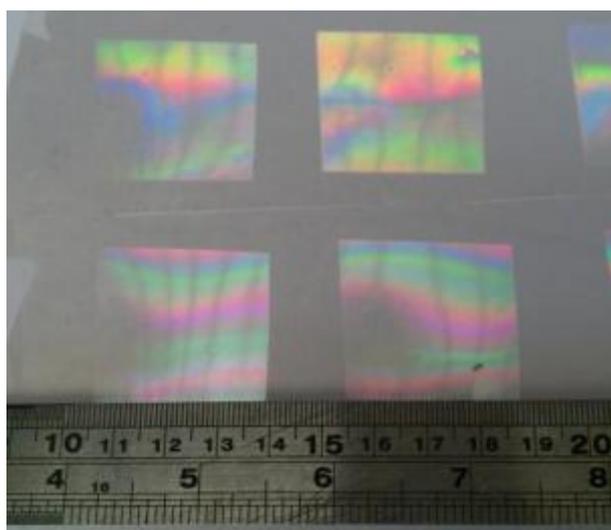
Figure 12 Construction of self-adhesive label



In order to produce the grating, the film is embossed with the holographic pattern, and then the pattern is fixed with a High Refractive Index (HRI) material. This fixing is required to prevent the pattern from becoming damaged which could easily happen if unprotected. Both the polymer film and the HRI material are transparent; therefore, the grating is transparent and does not affect the visual appearance of the label underneath and therefore won't have any impact on branding.

OpSec Security produced samples of PET film with diffraction gratings using a holographic manufacturing technique. An initial sample of film with a diffraction pattern of 100 lines/mm was produced on 50 and 500 μm thick PET. Each piece of film had nine 35mm x 35mm areas with the diffraction pattern on. A sample of the 50 μm film is shown in **Figure 13**.

Figure 13 Initial holographic film sample on 50 μm PET film



The above photograph shows film with 100 lines/mm gratings which show more obvious diffraction than 50 lines/mm gratings, resulting in the rainbow effect. At 50 lines/mm the grating will be less noticeable to the human eye and once placed over a food product label it will have little or no impact on the aesthetics of the product or packaging.

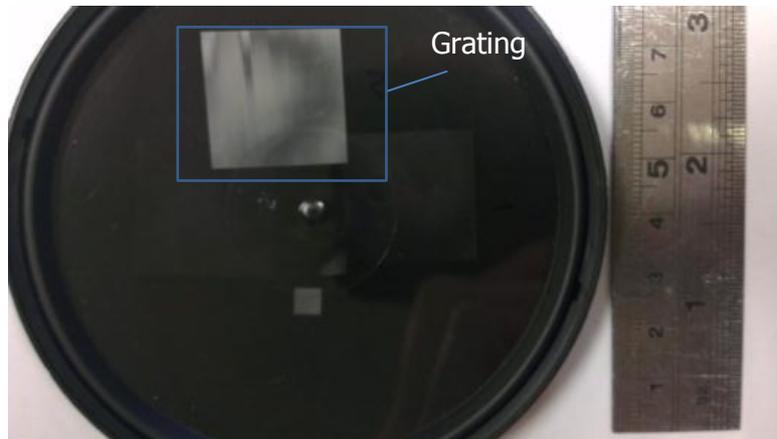
OpSec is continuing work as a result of this project to determine how to produce 100 line/mm holographic films on a large scale, as holographic equipment is generally designed for finer structures. They are positive that it is a viable technique worth exploring further.

3.5 Laser engraved gratings

The final method of applying gratings onto packaging was using lasers to engrave the diffraction gratings directly onto the packaging surface. Lasers are widely used to engrave patterns onto various materials, and so were identified as a potential way to apply gratings to packaging for the purposes of identifying food contact items.

Several initial samples were made by Fianium. A number of different items of PP food packaging were provided and gratings were produced of various periods. Using the laser it was possible to create samples of both surface and sub-surface gratings. The advantage of sub-surface gratings is that they would not fill with dirt/contamination or be destroyed through abrasion during either use of the packaging item or during the waste collection and processing activities. **Figure 14** shows a PP soup lid that has had a grating laser engraved in the surface.

Figure 14 Black soup pot lid with laser engraved gratings

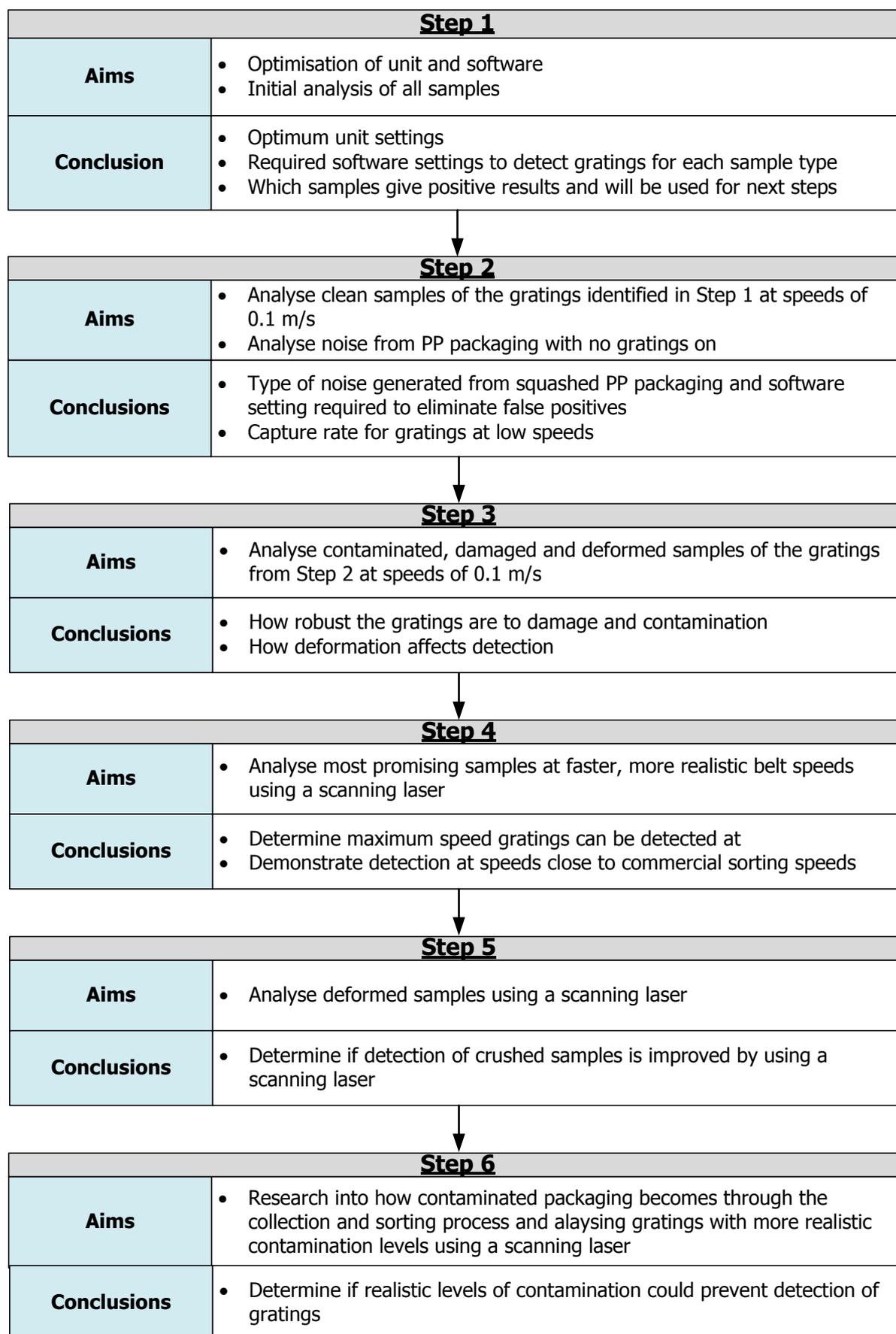


4.0 Demonstration trials methodology

This section details the steps undertaken in order to come to a conclusion on the potential of diffraction gratings when used as a technique to detect food grade PP.

In order to assess the potential for diffraction gratings as a method for identifying food contact packaging, a series of rigorous tests were undertaken using the demonstration unit. Six steps involving different demonstration trials were undertaken in order to reach informed conclusions on the suitability of diffraction gratings. **Figure 15** shows a flow diagram of how the demonstration trials progressed.

Figure 15 Flow diagram of demonstration trials undertaken



The first stage involved the set-up of the demonstration unit and was vital as all subsequent trials relied on the correct operation of the unit and the software. Since there is no commercial unit designed for this application, there was a reasonable risk that the demonstration unit and software would either not work, or would require a large amount of time and optimisation to enable trials to be undertaken.

The majority of analysis carried out was qualitative and it is imperative to note that neither the samples, demonstration unit nor the software have been fully optimised within the scope of this project. The data obtained can be used as evidence to indicate how efficient a sorting system may be, identify potential limitations of diffraction gratings and ways in which a commercial sorting unit could be designed to maximise efficiency.

5.0 Results from demonstration trials: Step 1

For Step 1 all the samples were static when pictures were taken and they are examples of the best quality diffraction patterns that could be obtained, and so are not necessarily representative of the diffraction patterns that would be obtained once the sample was in motion on a belt. This approach was necessary because the objective of this step was to determine which samples gave the best results and would be used in further steps, as well as optimising the demonstration unit and software.

5.1 Injection moulded samples

The preliminary injection moulded samples produced by The University of Bradford gave reasonably bright and defined diffraction patterns at 30 lines/mm and 100 lines/mm. The 30 lines/mm made using the clear PP gave the best patterns with the quality and brightness of the 100 lines/mm gratings being lower.

The white PP gave diffraction patterns but these were not as bright and were harder to obtain. The 200 lines/mm gratings did not give a visible pattern, which could either be because it was too fine a structure to mould or because the distance between the diffracted spots was too great to be detected using the demonstration unit.

The production samples made from the PP with a matt finish did not give a diffraction pattern. This is because the matt surface was not able to diffract the light, instead scattering it in all directions and not giving a reflection.

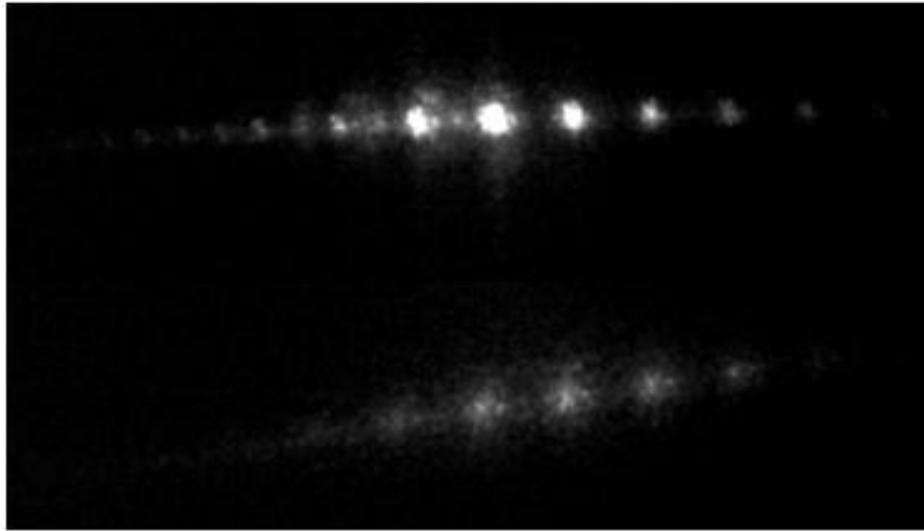
5.2 Impression moulded samples

A similar result was seen when analysing the preliminary impression moulded samples as the injection moulded samples, although the 100 lines/mm were more difficult to detect. This could again be because the structure was too fine to be moulded onto the PP, or because the moulding process had not been optimised and a different mould temperature or pressure would be required. The results from the 30 lines/mm gratings were good, giving a bright, defined diffraction pattern.

The production samples made using the clear thermoformed trays also gave good results, although the diffraction pattern was slightly less clear. This was because the moulding process was not optimised. Higher quality gratings should be achievable with further development.

A white impression moulded PP tray was also analysed. The pattern from the white tray was of a lower quality and not as well defined, suggesting applying gratings on the surface of white packaging would not be as effective as on clear packaging. **Figure 16** shows a comparison between the patterns obtained from the clear PP tray (top pattern) and the white PP tray (bottom pattern).

Figure 16 Comparison of diffraction patterns from a clear impression moulded tray (top) and white impression moulded tray (bottom)



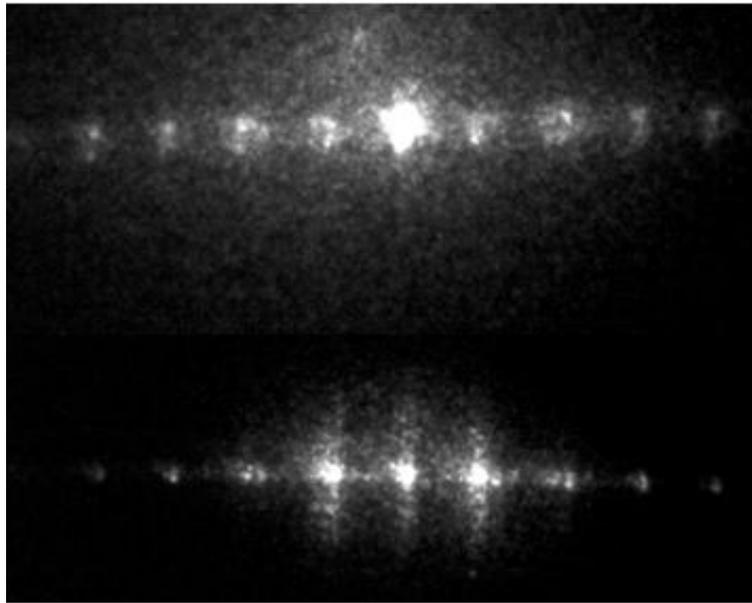
5.3 Printed diffraction gratings

The only printed gratings which gave a really obvious diffraction pattern were the preliminary samples made from lines of ink on the bare substrate on white self-adhesive labels, clear self-adhesive labels and clear IML. White IML gratings did not give a diffraction pattern. The gratings with the coloured ink over black, and the varnish over the various inks gave comparatively poor signals. No patterns were seen from the wraparound labels, typically used on PET drinks bottles.

Furthermore, all the gratings which gave relatively strong reflections were ones made with 30 lines/mm. Feedback from Systems Labelling was that this was most likely the highest obtainable resolution with the printing equipment used, which suggests the 50 lines/mm gratings would not be suitable.

Even though the clear self-adhesive, white self-adhesive and clear IML all gave diffraction patterns, the quality was lower than for the impression and injection moulded samples, with light being scattered as well as diffracted, creating more noise. **Figure 17** shows the diffraction patterns obtained from gratings made using magenta ink on white self-adhesive labels (top) and clear self-adhesive labels (bottom).

Figure 17 Diffraction patterns from gratings made using printed magenta ink on white self-adhesive labels (top) and clear self-adhesive labels (bottom)



No pattern was seen from any of the printed production samples. This was most likely to do with the viscosity of the ink being lower than on the preliminary samples, meaning it was not possible to hold the 30 lines/mm structure. This demonstrates that the printing of gratings is a complex process, requiring the right ink properties and high definition (HD) printing. It would probably be challenging to determine the required standards and to apply these across the industry.

5.4 Gratings in holographic film

The holographic film gave by far the brightest and most defined diffraction patterns of all the samples. **Figure 18** shows the diffraction pattern obtained from the holographic film, which could be used to laminate a label.

Figure 18 Diffraction pattern from 50 μ m thick PET with 100 lines/mm



5.5 Laser engraved gratings

The laser engraved samples all gave good quality images, with the patterns comparable to the injection moulded and impression moulded gratings. There appeared to be little difference between surface and sub-surface gratings.

6.0 Results from demonstration trials: Step 2

Step 2 involved analysing gratings in motion to determine if analysis could be done on videos of diffraction patterns and if movement of the samples had an effect on how easily the gratings were identified. The impression moulded clear thermoformed trays and clear self-adhesive labels were used for analysis during this step. Noise generated from un-marked packaging was also investigated.

Figure 19 shows a sample of crushed, un-marked PP packaging that would be present in the waste stream. It was found that the images created from the light reflected off these items was correctly identified by the analysis software as not being a grating, showing that the production of a high purity food contact PP product would be possible and there would be few false positives. A false positive in this instance is an image that is not a diffraction grating but is wrongly identified as one. A few images were wrongly identified (typically <1%) although with optimisation of the software this could be further reduced.

Figure 19 Crushed PP packaging without gratings



Table 2 shows the results from the analysis of the impression moulded gratings. In total ten trays with impression moulded gratings on were analysed which theoretically would result in 200 images of diffraction gratings. More than one image is captured per grating as the camera takes multiple images along the grating as it moves across the conveyor under the laser. The videos were analysed using the software, and were also inspected and identified manually by eye. The capture rate is the percentage of images that should show a grating that are correctly identified as a diffraction grating. One tray should show 20 images so only one in 20 images, or 5%, would have to be positively identified in order for the tray as a whole to be identified as food contact.

Table 2 Step 2 results for impression moulded clear thermoformed trays

	Capture rate (%)	
	Analysis using software	Analysis by visual inspection
Impression moulded gratings	50.5%	87%
Noise (images not showing a diffraction grating)	0.1%	0%

The analysis shows that a capture rate of just over 50% is achievable while reducing false positive identification to below 0.5% when using the developed software. This means that in an ideal situation with clean, undamaged gratings in the correct orientation, at least two images per grating would be needed to ensure identification.

Qualitatively, by eye 174 of the 200 gratings could be seen. This would relate to a capture rate of 87%, which may be achievable if more sophisticated and fully optimised software was used. This shows that when in motion the gratings could still be identified, whilst minimising the number of non-grating images wrongly identified. By visually assessing the images it is obvious which images show a grating and thus the capture rate for noise is zero.

Table 3 shows the analysis of different coloured ink gratings on clear self-adhesive labels.

Table 3 Capture rate for printed diffraction gratings

	Capture rate (%)	
	Analysis using software	Analysis by visual inspection
Black	18.8%	62%
Cyan	41.7%	64%
Magenta	50.0%	71%
Noise	0.3%	0%

The results show that the magenta ink labels have the highest probability of being detected, whereas the black ink gratings are more difficult to detect.

The analysis shows that a significant number of true positives can be identified from gratings made using coloured inks, while preventing false positives with flat samples in motion using the developed software. A true positive in this instance is an image of a diffraction grating which is correctly identified as a diffraction grating. However, as with the impression moulded samples, more gratings could be identified by eye, with a potential capture rate for the magenta ink labels of 71%. It would be possible to optimise the system and potentially achieve a higher capture rate.

7.0 Results from demonstration trials: Step 3

Step 3 aimed to give an understanding as to how robust the gratings were and how deformation effected the diffraction pattern. The three aspects investigated were:

- Contamination of gratings;
- Destruction of gratings; and
- Deformation of gratings and packaging.

The gratings were not analysed in motion and the results are only indicative of the effects of the above factors. Impression moulded gratings and printed gratings were investigated in this step. Steps 5 and 6 gave more in-depth analysis using a scanning laser.

7.1 Contamination of gratings

Three main types of contamination were investigated:

- Thick contamination from foodstuffs such as butter and soup;
- Liquid contamination from products such as milk and fizzy drinks; and
- Solid particle contamination, for example dust.

It was found that if the presence of the contamination prevented the light from reaching the grating it also prevented diffraction occurring. This was the case for butter and soup which created an opaque layer over the grating. Other contaminants such as fizzy drink residue and oil reduced the quality of the diffraction patterns and would make detection more difficult.

The observations were the same for the impression moulded and printed gratings. Further investigations into contamination were undertaken in Step 6.

7.2 Destruction of gratings

Gratings were manually handled and rubbed in a controlled manner for up to six minutes to re-create handling during an items lifetime. It was found that this handling, and more extreme destruction caused by rubbing the grating with a scourer had little effect on the quality of the grating and it is likely that a grating which has been handled roughly, for example in a waste compactor, would remain readable after it had been through the waste and collection system.

The packaging was also microwaved for two minutes on high power with no loss in quality of the grating. This is because microwaves impart heat by exciting water molecules which are not present in polymers and so no damage should occur.

7.2.1 Deformation of gratings

A tray (**Figure 20**) and a pot with magenta self-adhesive labels on (**Figure 21**) were manually crushed and analysed.

Figure 20 Crushed impression moulded thermoformed tray



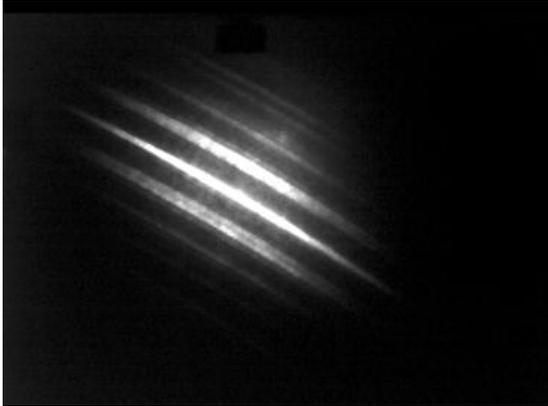
Figure 21 Crushed PP soup pot with printed magenta gratings



The crushing meant that when placed on the belt the diffraction pattern was formed away from the screen due to the angle of the packaging. It was therefore not captured by the camera and was not able to be detected. This would have to be taken into account during the design of a commercial sorting unit and could probably be addressed by covering a larger area with the screen.

As well as diffracting light off to the side, gratings on curved packaging produce lines rather than spots, as is shown in **Figure 22**. This pattern is still distinctive, and as long as the gratings are perpendicular to the curvature, the gratings should still be able to be detected using more sophisticated software.

Figure 22 Diffraction pattern from magenta ink printed gratings on clear soup pot



8.0 Results from demonstration trials: Step 4

The aim of this step was to demonstrate the detection of diffraction patterns at higher speeds using a scanning laser and to provide evidence to support whether the technology could be used for a commercial sorting operation. Step 4 trials primarily used the clear impression moulded thermoformed trays.

It was not possible to use the diffraction grating detection software for Step 4 onwards as the program was not able to process high frame rate videos. For this reason all images were manually inspected by eye to determine if a grating was present. With additional time and resources it would be possible to develop software to analyse high frame rate videos and this should not be considered a limitation of the sorting technique at this stage of the research.

Step 4 progressed from Step 3 with four major changes being made to the demonstration unit:

- Installation of a scanning unit to scan the laser beam across the width of the belt;
- Installation of an 808nm laser to give brighter images;
- Installation of a motor allowing for faster belt speeds, which are more representative of a commercial sorting process; and
- Installation of a high speed camera.

A video of four trays moving at 1m/s and captured at 500fps (frames per second) was recorded. **Figure 23** shows an example of one of the best quality diffraction patterns captured using the lower quality laser. The image is of a lower quality than produced with the 908nm laser as the 808nm laser was less expensive and refined. The image is also not as bright as the camera is operating at a much higher frame rate. 808nm lasers are readily available of equal quality to the 980nm laser used initially, so the lower quality of the lower cost 808nm laser used here is not a concern and can easily be rectified.

Figure 23 Example of a relatively clear diffraction pattern at 500fps



Table 4 gives an upper and lower capture rate. Two rates are needed as it cannot be determined how many images (between 8 and 15) were taken from a grating.

Table 4 Capture rate for thermoformed trays analysed with a scanning laser

Tray	Number of gratings seen visually	Capture rate
1	8	53% - 100%
2	7	47% - 87.5%
3	5	33.3% - 62.5%
4	7	47% - 87.5%

The analysis shows that at least five images, or a minimum of 33%, could be identified as diffraction gratings. Given the equipment used and the limitations this is a very positive outcome. A higher quality laser would, most likely, not only give clearer images at 500fps,

but could also enable a higher frame rate, allowing for either a wider scanning width, higher belt speeds or smaller distances between spots.

Figure 24 shows the diffraction pattern from the holographic film at 1,800fps. This is the maximum the camera is able to capture and, even at this rate, the image remains visible. The spots are blurred but this is due to the poorer quality of the spot generated by the lower cost 808nm laser.

Figure 24 Diffraction pattern from holographic film at 1,800fps



The analysis of the holographic film shows that the quality of the grating itself can have a huge effect on the quality of the diffraction pattern obtained. It is felt that with suitable revisions to the laser and camera set up, running at frame rates up to 2,000fps should be possible, which should be fast enough for commercial use (about 2m/s).

9.0 Results from demonstration trials: Step 5

Step 5 was undertaken to re-examine the effect squashing and crushing items of packaging had when detecting gratings. This follows on from Step 3 as a scanning laser was used for these trials. In theory by taking images from more points there is a greater chance of the laser hitting a relatively flat area of the packaging that would diffract the light onto the beam. Once again the samples used for these trials were the thermoformed trays.

Figure 25 shows a comparison between a PP tray that had been baled and was taken from a product stream at a Plastics Recovery Facility (PRF) and how the crushing was recreated manually on a sample.

Figure 25 Crushed PP tray taken from PRF (left) and manually crushed impression moulded tray (right)



It was found that from between the 64 to 120 images which should have shown a diffraction grating (laser hits each grating between eight to fifteen times and eight trays were analysed), there was only one image that showed a diffraction pattern, with another image that was a possible pattern. This means that only one in eight trays was able to be identified. **Figure 26** shows the diffraction pattern seen from the crushed tray.

Figure 26 Diffraction pattern from crushed tray



The images from the video show very few spots of light reflected from other items of the packaging without a grating, showing the shape of the packaging caused the light to be reflected away from the screen. The crushed packaging results in the gratings lying at an angle to the laser beam, resulting in the diffraction pattern being directed off at an angle, which can result in the diffraction pattern being out of the field of view of the camera.

This suggests that detecting food contact items after baling would be challenging with the possibility of lower efficiency; however, there are several ways in which the chance of detecting gratings from these samples could be greatly improved. More sophisticated optics could be used to ensure that the laser beam always hits the samples vertically and also the size of the screen and field of view of the camera could be increased.

10.0 Results from demonstration trials: Step 6

Step 6 also followed on from Step 3 as it aimed to assess more accurately the effect of contamination on gratings when analysed with a scanning laser. The same procedure was used in Step 6 as in Step 5, with a total of eight thermoformed trays analysed.

In order to gain meaningful results from Step 6 samples of PP were taken from a plastics reprocessing facility after they had passed through both a MRF and a PRF.

Figure 27 Contaminated PP chocolate tub taken from a reprocessing facility



This picture shows the type of contamination present on the packaging is not obvious, and it is unclear what proportion of the packaging is affected. In an attempt to recreate the contamination seen on the packaging which has been through the waste collection and sorting system, trays were first coated with a thin layer of oil (vegetable oil) and then small particles of dirt were added. Oil was used as it is likely that fats from foods will stick to the packaging surface, and, in turn, dirt will stick to the fat. **Figure 28** shows a tray sample with the dirt added to mimic that found on the sorted packaging.

Figure 28 Recreation of contamination on thermoformed tray



From both of the videos (eight samples analysed in total) there were no diffraction patterns seen. This means contamination could be a serious limitation to the gratings being detected.

It must be noted that the type and level of contamination investigated within these trials may not be the same as that seen in reality. Best efforts were made to understand the contamination likely to be present and to recreate it; however, it may still be far from what is actually seen on packaging that has been through the waste collection and sorting system. It may also be that in reality the whole surface of the packaging item is not contaminated and substantial areas of the packaging item are still relatively clean.

Significantly more work is needed into researching the contamination of gratings, as this may prevent or limit the technology from being used. It is suggested that the only way to truly assess the effect of contamination on gratings would be to undertake a large scale trial.

11.0 Additional properties of application methods

Table 5 gives a summary of how suitable each of the grating production techniques are for food contact packaging marking in terms of what types of packaging can be marked, the area the gratings can be placed over and how the gratings may interfere with branding. This is useful in terms of considering adoption of the diffraction grating technique by the plastics packaging supply chain.

A traffic light system has been used to rank the different properties of each method:

- Green presents an advantageous and positive property;
- Yellow is a property which is a minor limitation, which does not work entirely in favour of the method; and
- Red presents a property which can be considered a major limitation or negative property.

Table 5 Summary of advantages and disadvantages of grating application methods

Injection moulded	<ul style="list-style-type: none"> ■ Potentially large marking area depending on effect to clarity of packaging ■ May interfere with branding and aesthetics ■ Can only mark a maximum 35% of PP packaging on the market and is limited to working on only certain (non-matt) surfaces and less efficient on white PP
Impression moulded	<ul style="list-style-type: none"> ■ Can cover large area on base of trays ■ Can mark about 50% of PP packaging or more but is limited to working on only certain (non-matt) surfaces and less efficient on white PP ■ May interfere with branding and aesthetics
Printed	<ul style="list-style-type: none"> ■ May cover large or small area depending on limitation with suitable colours ■ Quality of grating depends on a large number of variables such as ink viscosity and substrate type ■ It would be challenging to standardise the printing to ensure gratings are readable ■ May be limited by colours and substrate types
Holographic film	<ul style="list-style-type: none"> ■ Low interference with branding ■ Able to cover entire area of label ■ Can be applied to all self-adhesive labels, about 50% of PP packaging. May also be possible to place on IML which would greatly increase usability
Laser engraved (surface and sub-surface)	<ul style="list-style-type: none"> ■ Can be used on any form of packaging in theory for surface gratings (red coding for sub-surface gratings as only works on clear packaging) ■ May interfere with branding and aesthetics heavily due to darkening of colours ■ Area is directly proportional to cost ■ Difficult to place gratings on curved surfaces

12.0 Economic analysis

Table 6 shows the estimated cost per item to apply the gratings for each method investigated in this project along with the percentage increase in cost. These estimated costs are based on the cost of additional equipment required and/or additional materials. The average cost of producing a ready meal tray is 7 pence⁷. This cost is used to calculate a percentage increase in cost for each application method. Larger packaging items will cost more and smaller packaging items less so the percentage increase is only an indication at this stage.

Table 6 Summary of estimated costs of applying gratings using various methods

Production method	Estimated cost to apply grating per item (pence)	Percentage increase of cost for a 7p tray
Injection moulded	0.17	2.4%
Impression moulded	0.06 – 0.18	0.9% - 2.6%
Printed	Negligible; however substantial investment required in HD printing technology	
Holographic film	0.1	1.4% – 14%
Laser engraved (surface)	18.57	265%
Laser engraved (sub-surface)	22.86	327%

Injection moulded, impression moulded and holographic film all give the same order of magnitude percentage cost increase. The costs of each of these three methods will vary for different packaging sizes although the cost increase as a percentage should remain in the same region of 1 – 5%.

Printing gratings themselves would have a negligible cost; however, HD printing is required, which the majority of label printers currently do not use and substantial investment would be needed to install new equipment in the sector.

Laser engraving is far more expensive, more than doubling the cost of the packaging, and is unlikely to be acceptable, especially as this technique is not able to offer additional advantages which cannot be obtained through using the other methods.

It is important to note these values are estimates and there are many variables which would affect the overall cost of gratings. Further research and more specific cases are needed to produce more accurate costs; however, these estimates can be used by the supply chain in these initial stages to gauge how feasible it would be to adopt this technology.

12.1 Benefits to recyclers

It has been estimated that the gratings can be applied to packaging for less than 1 pence. However, if there is no economic benefit to the recycler of sorting food contact from non-food contact packaging, they will not invest in a sorting machine.

An economic model has been developed based on a PRF currently producing bales of PP sold for further processing. The model is for the PRF installing a sorting system using diffraction grating sorting units and a manual sorter to produce a food contact PP bale and a non-food contact PP bale. The model would also be applicable to a food grade PP reprocessor

⁷ Communication with a large food retailer, March 2013

receiving bales of food contact and non-food contact PP, although it would be important to include further purification and extrusion as this increases the value of the product.

The economic model estimates the payback period and Net Present Value (NPV) for a ten year project with a 10% discount rate. Various assumptions have been made and key values used summarised in **Table 7**. In order to achieve 99% purity two sorting units in series and one manual sorter for final 'polishing' would be required.

Table 7 Assumptions for economic assessment

Assumption/variable	Value
Throughput of unit	19,200 tpa
Percentage of food grade PP in feed	60%
Value of non-food contact baled PP	£150 ⁸
Value of food contact baled PP	£250 ⁹
Efficiency of food contact material recovery	75%
Efficiency of reject of non-food contact	95%
Required purity of product	99%
Total capital cost for single diffraction grating sorting unit including conveyors and ancillary equipment	£500,000
Operating cost for single unit (£/year)	£60,000
Cost to employ one manual sorter per shift assuming 24 hour operation (£/year)	£100,000

Table 8 shows the potential benefit to a PRF or reprocessor estimated using the economic model. As NPV>0 and the payback period is about 3.5 years, this represents a positive investment that could be of interest to a PRF.

Table 8 Benefit for sorting PP at a PRF or reprocessor

Net additional revenue (£/year)	£298,976
Net Present Value (NPV) after ten years (£)	£812,078
Payback period (years)	3.4

A £100 per tonne premium on food contact baled PP may be a low side estimate for its value as there is growing demand from retailers and brand owners for food grade PP with recycled content. The economic model shows that the value of the sorted food contact PP has a large bearing on the economic benefits to a recycler. If the value of the food contact were £150 per tonne more than the non-food contact material, the payback period would be reduced to less than two years and the NPV after ten years would triple.

If two manual sorters are required then it would increase the payback period to 5.3 years and a cost difference between food contact and non-food contact of £125 to £150 per tonne would be required to reduce the payback period to between two to three years.

⁸ Price estimate from UK PRF as of May 2013

⁹ Price estimate for May 2013

Assuming a 50% yield through purification and extrusion, a food contact baled PP product with a value of £250 would require the food grade pellet to have a value in excess of £500. The pellet value would then also include the operating cost and profit margin for the purification and extrusion processes. Since the price of virgin PP is approximately £800¹⁰, it is likely a food grade PP pellet would be competitively priced depending on the cost of the purification and extrusion processes.

A potential barrier to this sorting technology may be the benefit to a sorting machine manufacturer. It is likely that companies currently producing NIR machines would develop the diffraction sorting technique and ultimately produce a commercial machine. A diffraction grating identification machine made only to sort food contact packaging, either PP or HDPE would only have a relatively small market, that is to say once a machine has been sold to the large PRFs and reprocessors in the UK, there would be little further use for this technology. If the diffraction marking technology was adopted across Europe or in other regions then the demand would be very much greater.

Considerable research and development costs would be required to produce a marketable sorting unit. It is therefore suggested that it would be advantageous to investigate opportunities beyond just the UK to increase the incentive to develop and manufacture these sorting machines.

¹⁰ Price estimate as of May 2013 provided by WRAP

13.0 Overall conclusions

The practical trials and preliminary economic assessment demonstrate the likely technical and commercial viability of sorting food contact packaging using diffraction gratings. Recommendations for further work which is required to address some of the remaining questions are presented in Section 14.0.

The trials demonstrated that all five methods of applying gratings to PP packaging items can produce a readable diffraction pattern when interrogated by a laser. Different aspects of each grating have been investigated, and the results summarised in **Table 9** using a traffic light grading system.

Table 9 Summary of properties of diffraction grating application methods

Production method	Ease of detection	Resistance to damage	Resistance to contamination	Suitability for packaging types	Coverable area	Branding and aesthetics interference	Cost
Injection moulded							
Impression moulded							
Printed gratings							
Holographic film							
Laser engraved (surface)							
Laser engraved (sub-surface)							

Key	
Very good	
Could be better	
Poor	
Undetermined – requires further work	

The following key conclusions can be made on diffraction gratings:

- There is strong evidence that clean gratings could be automatically detected at commercial speeds, maximising positive identification of gratings and minimising wrong identification of noise;
- Gratings are resistant to damage; however, the design of a sorting unit would have to allow for detection of deformed samples and significantly more work is required to determine how limiting the presence of contamination on packaging items would be;

- A variety of application methods would be required to mark all food contact PP placed on to the market;
- Applying gratings by impression moulding, injection moulding and holographic film would most likely cost less than one pence per item or lead to a 1 to 5% cost increase to an item of packaging. Printed gratings would require investment in HD printing technology and laser engraved gratings are unlikely to be commercially viable;
- The preliminary economic assessment suggests producing a food contact PP bale would be viable for a PRF operator with a payback period on the investment into sorting machinery being about 3.5 years; and
- A barrier to adoption may be the limited market in the UK for the machine manufacturers, with a large amount of development cost leading to the sale of few machines.

Although this project focuses heavily on PP, it may be advantageous to initially use this technology for the sorting of HDPE milk bottles. Natural HDPE is increasingly being used for non-food contact applications such as detergents, putting strain on the manual sorting processes currently being used by reprocessors recycling milk bottles. By focusing attention on the HDPE milk bottle market, it would be relatively straight forward to introduce gratings to a large number of packaging items and sort them by modifying equipment currently in place at PRFs. The dairy industry is already working collaboratively on design for recyclability of their packaging and on other sustainability issues such as the Dairy Roadmap. It is suggested one of the most promising methods to apply the gratings would be to use holographic film on the self-adhesive label, and this would be relatively easy to implement at the label manufacturers.

Once the technology is shown to work on HDPE milk bottles, it may give the industry more confidence to invest further to allow the technology to be used on PP. In addition to this the decontamination and extrusion of food contact PP is currently being researched by WRAP, and both the sorting and decontamination would have to be able to operate on commercial scales in order for either one to be used by a reprocessor. If a method of producing food contact PP from a 99% pure PP stream is not developed, then there would not be a drive in invest in the sorting technology.

14.0 Recommendations for further work

It is clear that the technique of diffraction gratings shows great potential in the identification and separation of food contact packaging for recycling. More work is required to address some issues which may prevent diffraction gratings from becoming a solution for food contact PP identification and sorting. Therefore diffraction gratings are not yet ready for commercial use until a full industry - wide solution has been developed and commercialised. It is suggested that the following work is required before this technology can be adopted by the supply chain:

- Optimise the different diffraction grating application methods to give higher quality gratings and allow for detection at commercial sorting speeds;
- More work on printed gratings to determine required ink properties and cost of upgrading equipment;
- Further work on holographic film to determine if film could be placed on IML packaging;
- A study on the types of PP packaging in the municipal waste stream focusing on which grating application methods would be most viable to the different types of packaging, the areas of packaging that could be marked and the associated cost;
- A study into actual levels and types of contamination that would be present on PP packaging in the waste stream. This could involve a large scale trial in which marked packaging with gratings is traced through the waste collection and sorting system and analysed to determine the impact of the presence of contamination, and any damage caused to the packaging, in identifying the diffraction grating;
- Design and manufacture a prototype sorting unit with more sophisticated optics to overcome issues of crushed packaging and allow for the detection of diffraction gratings at commercial sorting speeds;
- Develop further uses and markets for a diffraction grating sorting unit. This may include the use of diffraction gratings to sort HDPE milk bottles. This could help to encourage the sorting unit manufacturers to invest the necessary development time and resources into this technology by increasing the likely number of machines that would be required;
- Gain further feedback from retailers on the cost of applying gratings to packaging; and
- Set up an agreement or protocol with the plastics packaging supply chain to restrict the use of specific diffraction grating patterns for use on food contact PP, otherwise it could result in contamination of the product if the same grating was used on non-food contact material for other purposes.

**Waste & Resources
Action Programme**

The Old Academy
21 Horse Fair
Banbury, Oxon
OX16 0AH

Tel: 01295 819 900
Fax: 01295 819 911
E-mail: info@wrap.org.uk

Helpline freephone
0808 100 2040

www.wrap.org.uk/plastics

