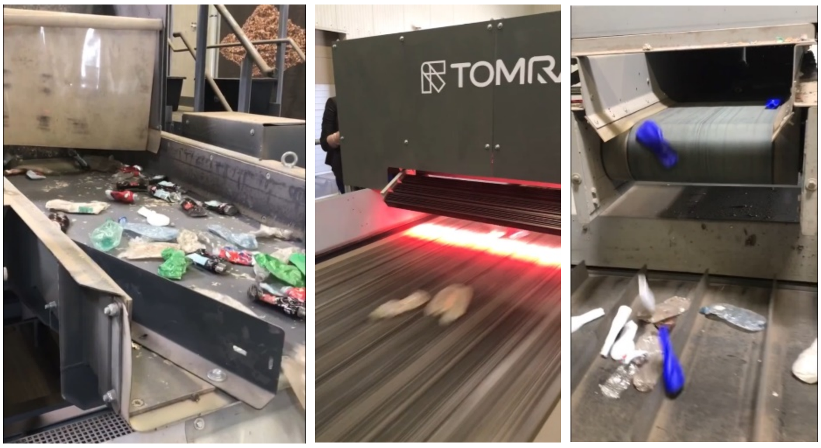
Differentiating between plastics in general and marked plastics in particular

When recycling plastics, it is necessary to sort them correctly into mono-material groups. Depending on the type of reuse of the recyclate, it can be necessary to sort them in terms of type, color and even previous use. For example, it is necessary to prevent a situation in which a plastic bottle used to store drain cleaning chemicals is recycled for use in the food industry.

Sensors for sorting plastic types and colors

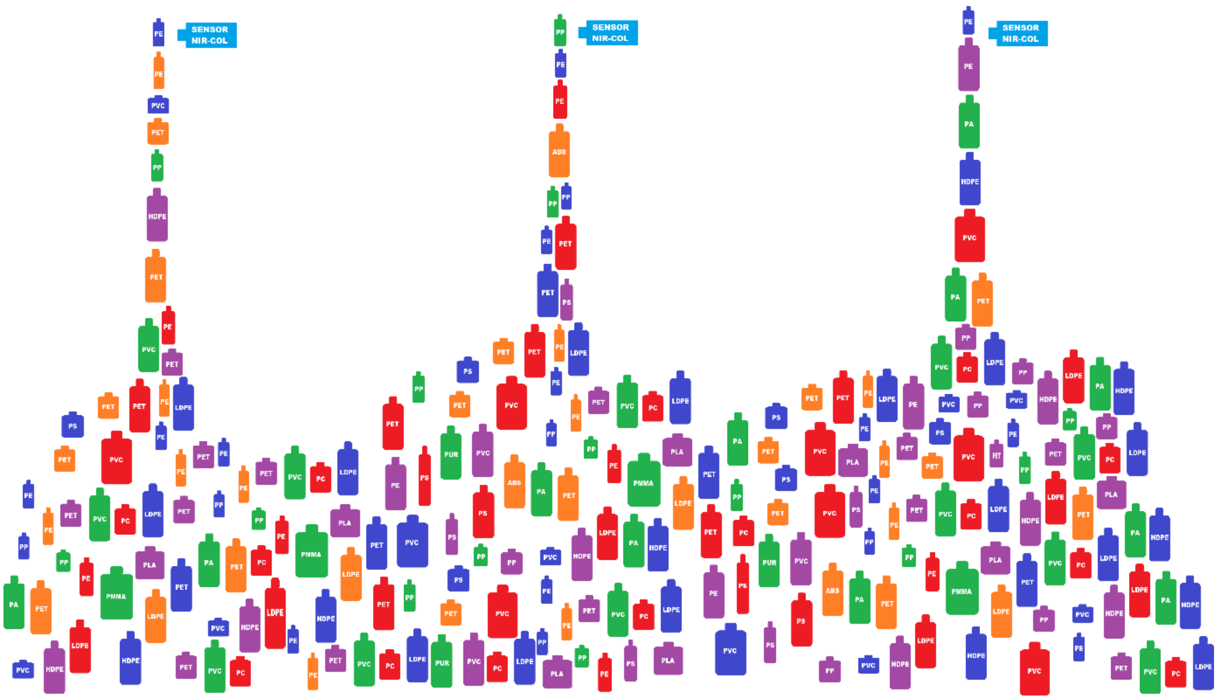
The plastics recycling industry already deploys machines for sorting plastics in terms of type and color. Shredded plastic recycling material is transported along a broad conveyor belt or a conveyor belt followed by a chute. A line scanner checks the entire width of the work area. A line scanner for sorting plastics is usually a NIR camera which records and evaluates spectra across a defined grid spaced area crosswise to the direction of transport of the recycling material. Tungsten lamps serve as an NIR light source (line array). The plastic in the respective segment detected using a specific NIR spectrum is then separated using the air blast segment assigned to the detector segment. A color line scan camera and a fluorescent lamp or a white light LED line is used to separate the various colors present across the width of the conveyor belt or chute. The complete detection area is subdivided into segments in this process. One of the blowing air strips belonging to the detector line performs the sorting.

⇧ A TOMRA NIR camera with NIR light unit

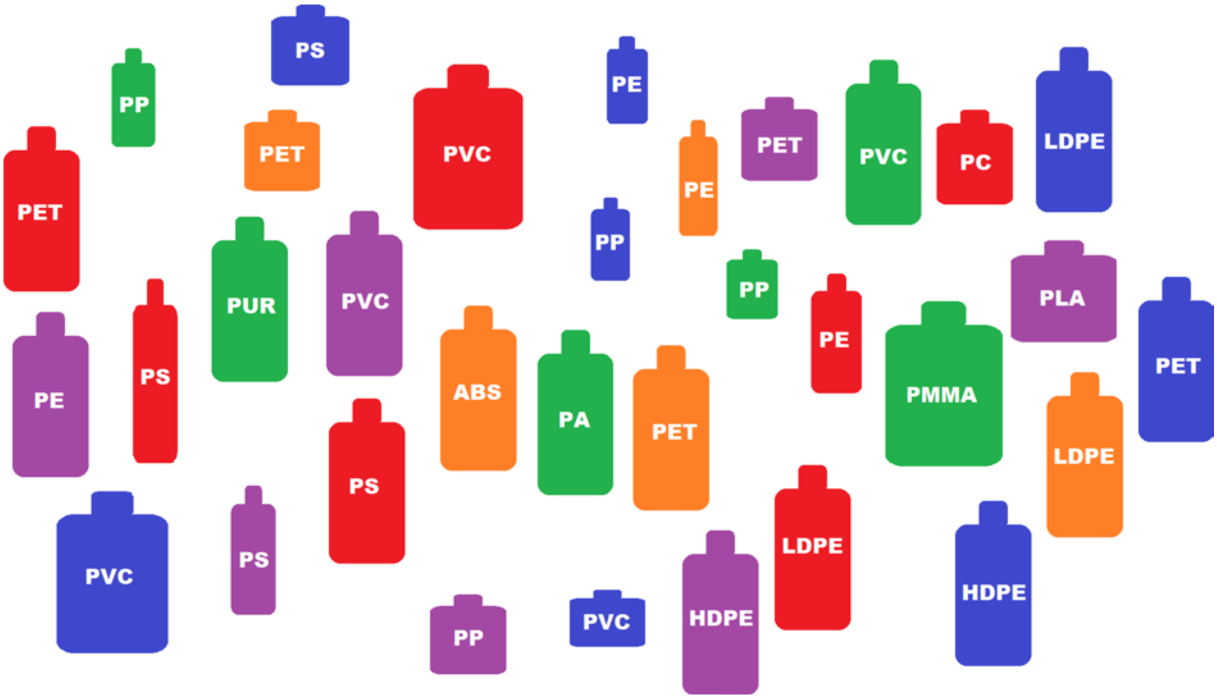


Feed of the plastic bottles via a conveyor belt. Detection of the bottles over the entire width of the conveyor belt. Linear NIR light unit and linear detection range. Sorting of the bottle via the blowing air strips.

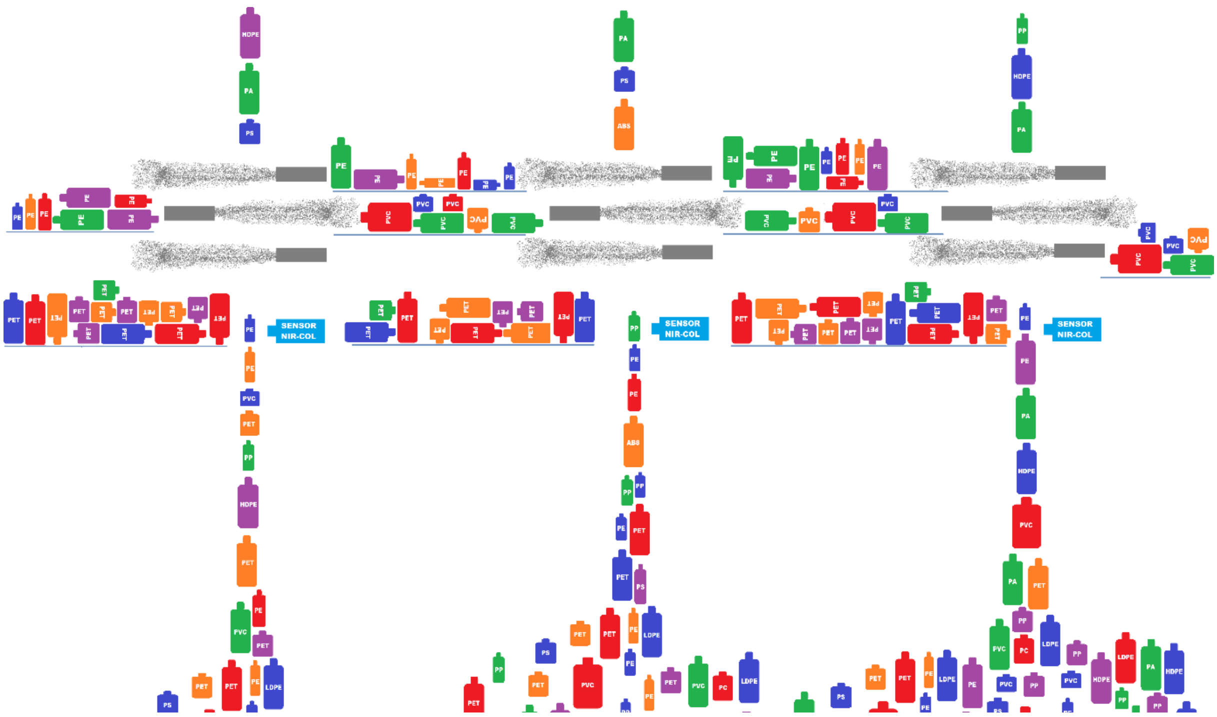
In contrast to glass, plastic recycling material is usually added to sorting machines whole. This permits a greater range of detection and sorting methods, which is of especial value, as NIR camera-based systems are very expensive and cannot be used at every location. For example, plastic containers must be placed individually in supermarket return stations; this requires the discrete detection of individual objects. The material to be disposed of can be led to the detector unit via a chute with a subsequent blow out device. Recycling companies can also use this economical type of detection and sorting. Multiple numbers of these detection and sorting lines can be operated in parallel to ensure the necessary throughput.

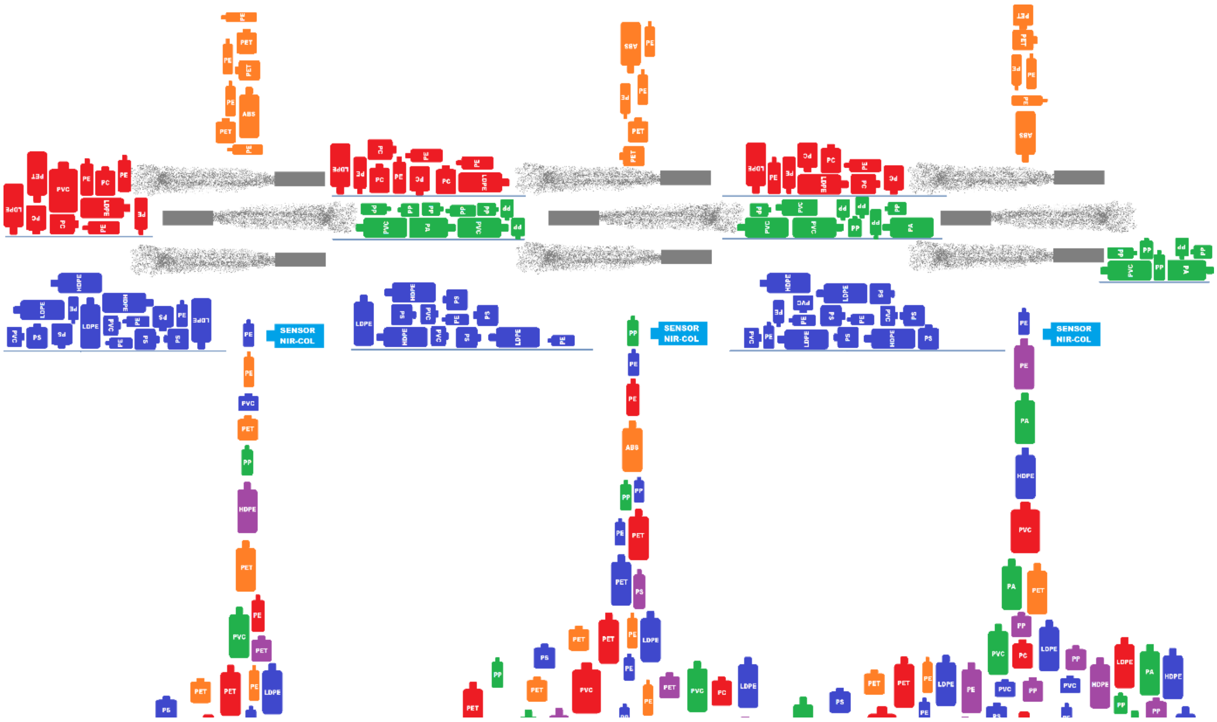


⇧ The establishment of multiple parallel sorting strands.



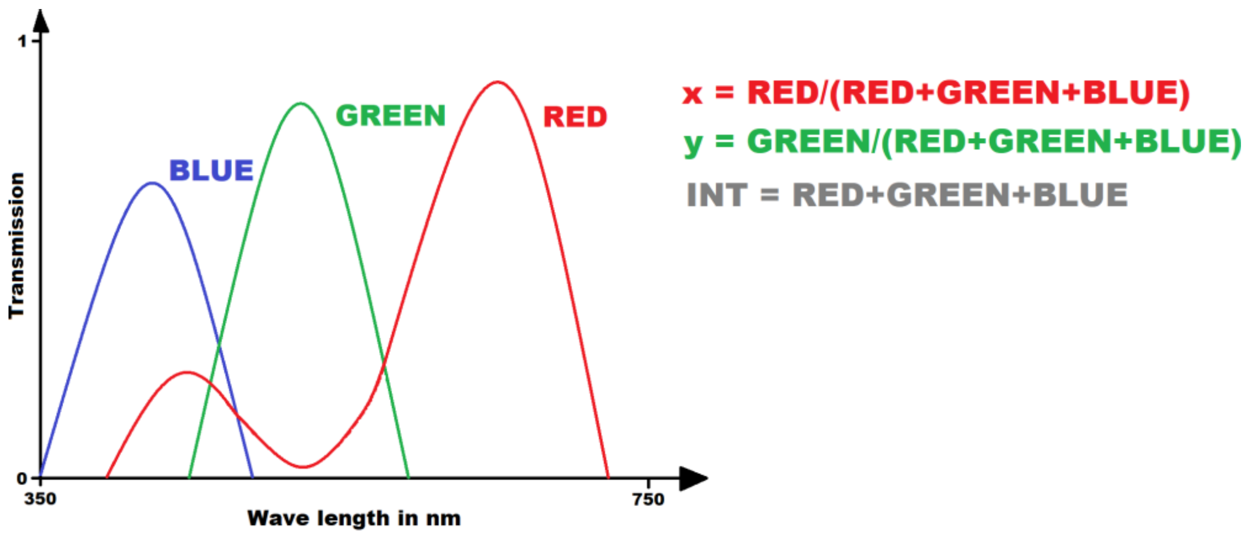
The recycling material usually consists of various types of plastic, colors, various forms and paper and plastic labels on the objects (for example on plastic bottles). The bottles should primarily be sorted in accordance with the plastic type; the majority of cases require separation by color.



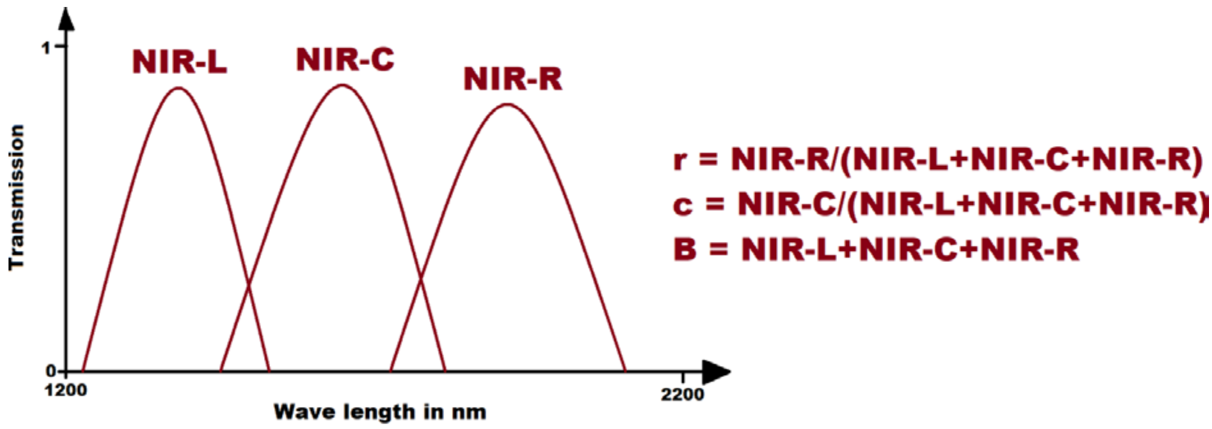


It is possible to separate according to color and then plastic type or the other way round. Synchronous separation by color and plastic type is possible, but would require a series of air blowing units one after another.

Whilst NIR cameras detect the respective type of plastic using spectral evaluation in the NIR range, the procedure described here determines the plastic matrix in accordance with the “three range procedure”. Following the example provided by nature (human daylight sight is based on the determination of the color value from the “photo receptors” (red, green and blue-sensitive cone cells) this procedure is already used successfully for color control (with SI of RGB in accordance with xyINT or siM) or for color measurement (RGB or YXZ in accordance with xyY or L*a*b*).



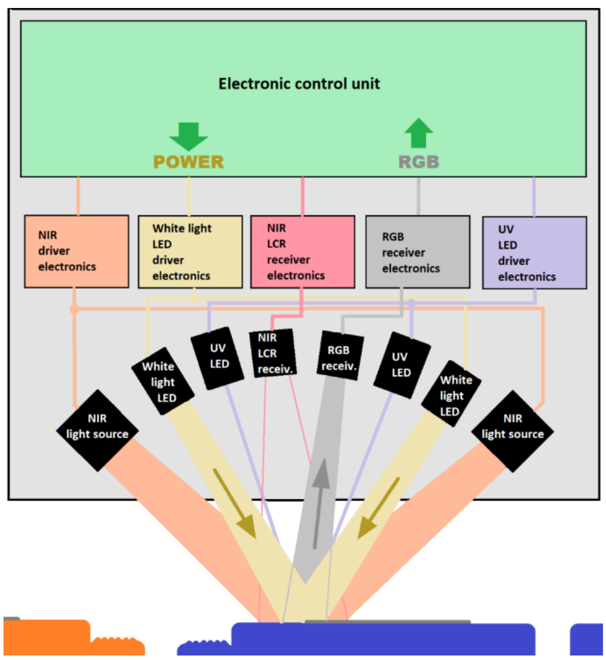
The wavelength range required to recognize the plastic type is subdivided in transmission ranges (three optical windows):



The optical filters are followed by conversion of the received light in three photocurrents NIR-L, NIR-C and NIR-R. The “raw signals” are then determined using the same algorithms as applied to the x,y,INT determination. Empirical investigations have shown that a wavelength range from 1200nm to 2200nm is especially suitable for differentiating the plastic types.

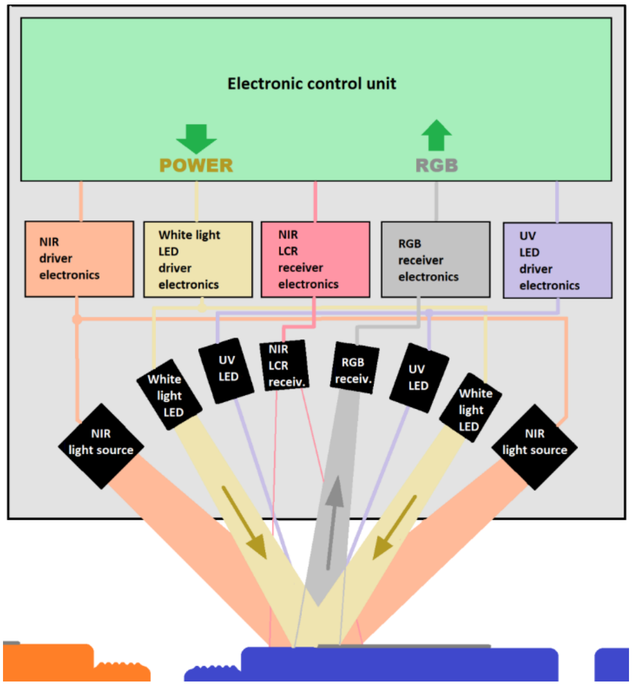
Both detector types should preferably be integrated in a single system to permit simultaneous ascertainment of the plastic type and color. The light required to perform the evaluation comes from the white light sources (white light LEDs) and NIR light sources integrated in the system. A UV light source is also required to improve detection of paper labels in particular.

Evaluating the NIR measured values:



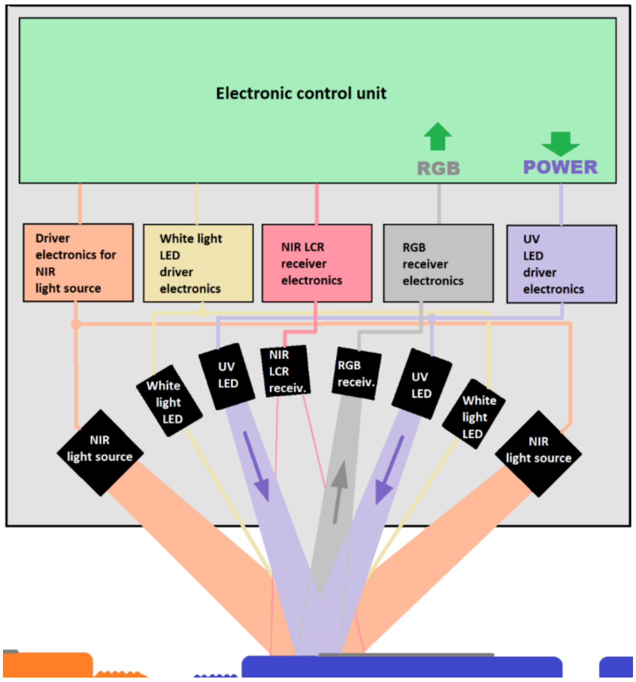
In addition to the three types of light source for UV-, VIS- (white light) and NIR range and the two detector units for visible and NIR light, the driver electronics, receiver electronics and control electronics required for the operation / evaluation are incorporated in the sensor system. Depending on the type of light source used, the continuous light is used for the NIR range, whilst the UV and white light LEDs are used on a pulsing basis.

Evaluating the color values (RGB)



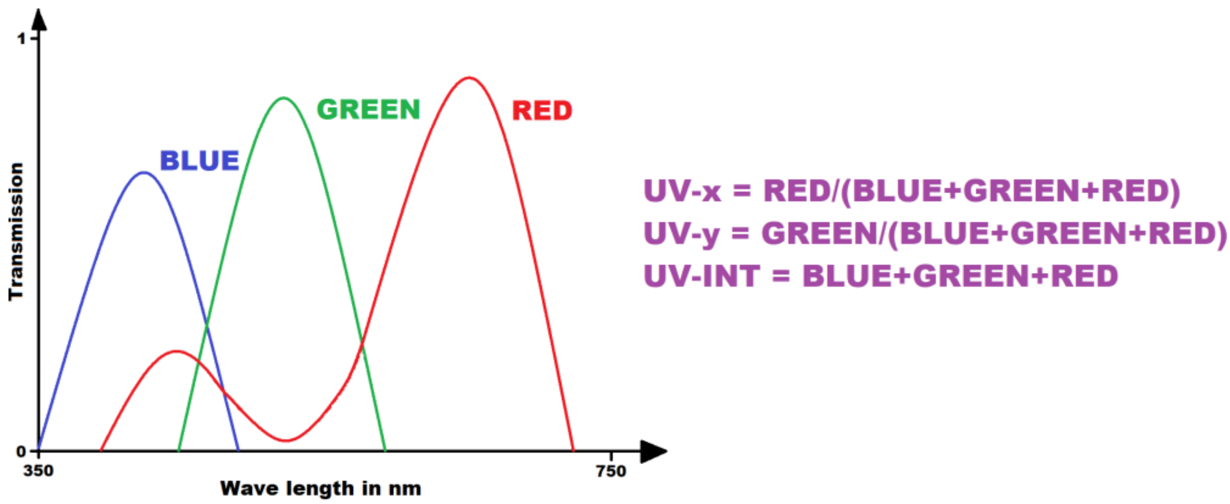
In this mode, the white light LEDs are activated in pulse mode in addition to the NIR light source. The RGB data is queried immediately *before* activation of the white light LEDs and then a further time with activated white light. Subtraction of both RGB value triplets provides an extraneous light-independent measuring result.

Evaluating the color values generated with fluorescent light (RGB):



In addition to the NIR light source, this mode operates UV-LEDs in a pulsing fashion. In a fashion similar to the evaluation method using activated white light LEDs, evaluation is performed here independently of extraneous light. It is necessary to ensure that only the light converted in the visible wavelength range using fluorescence coming for example from paper labels is used in the further evaluation.

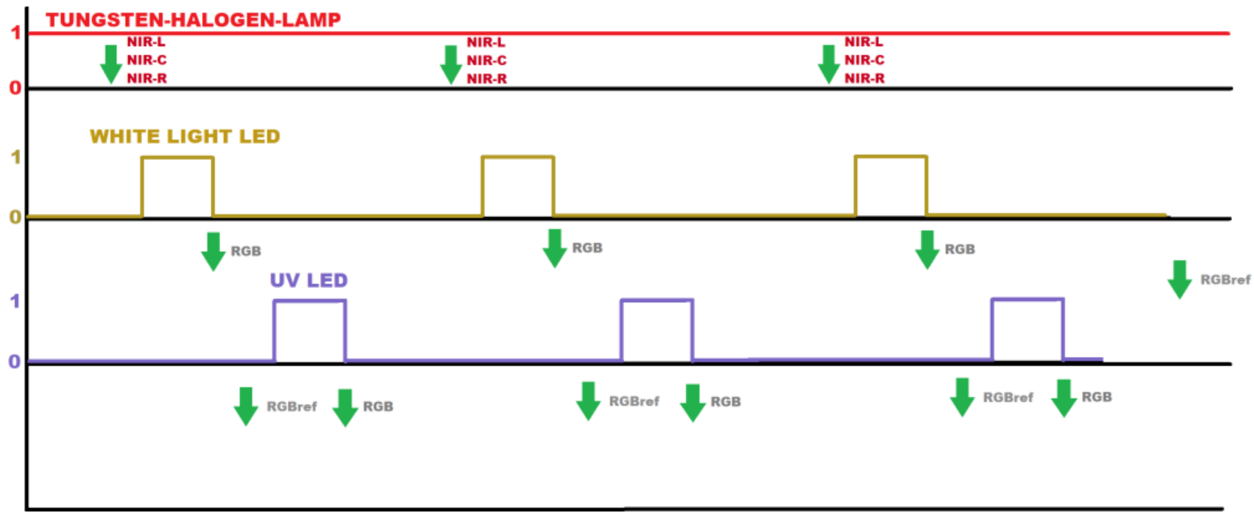
Brighteners are usually added to paper labels. UV light stimulates these brighteners to visible range florescence (with a significant maximum in the blue wavelength range). When evaluating the NIR data, the paper sections would have a negative impact on determining the correct plastic type, which is why this section is ignored.



The UV light converted in the visible wavelength range using brighteners is then transmitted from the RGB detector of the control electronics for further data processing.

Frequency of the individual pulse sequences:

The pulse frequency of both the white light LEDs and the UV-LEDs lies for example in the kHz range. In relation to the duration of the period (100%) the length of the light pulses amounts to c. 20%. White light and UV pulses are phase-delayed to prevent mutual interference.



Ascertaining the signal data and evaluation in the control electronics:

In addition to the complete control of the light sources, the control electronics also performs the time-synchronous evaluation of the raw data from the two receiver units. After ascertaining the individual "color spaces" the data is summarized in a table. There, the software can sort the objects in accordance with certain criteria (the "best hit" method and group mode) such as plastic type, plastic color or both. Software-based preparations must be taken to ensure appropriate timing of e.g. activation of the blowing air.

TYPE	1	2	3	4	5	...	59	60	61	62	63	64
UV-x												
UV-y												
UV-INT												
x												
y												
INT												
r												
c												
B												
C-GRP												
P-GRP												

A typical evaluation procedure could look like this:

Teaching:

First, all object classes which come into question must be taught in. To do so, either the experience values are used which were determined in previous sequences, or through targeted placement of the individual objects in the correct distance from and in the correct position to the sensor optics. The individual objects are then added as types. Each type is assigned the data triplet (UV-x,UV-y,UV-INT), (x,y,INT) and (r,c,B) ascertained from the raw data of the respective receiver units. Then the plastic color groups and the plastic type groups can be established. Depending on the software parametrization, a search is conducted in the complete matrix for the best hit or a search is made for the best hit within the color group or within the type group (P-GRP).

Evaluation procedure:

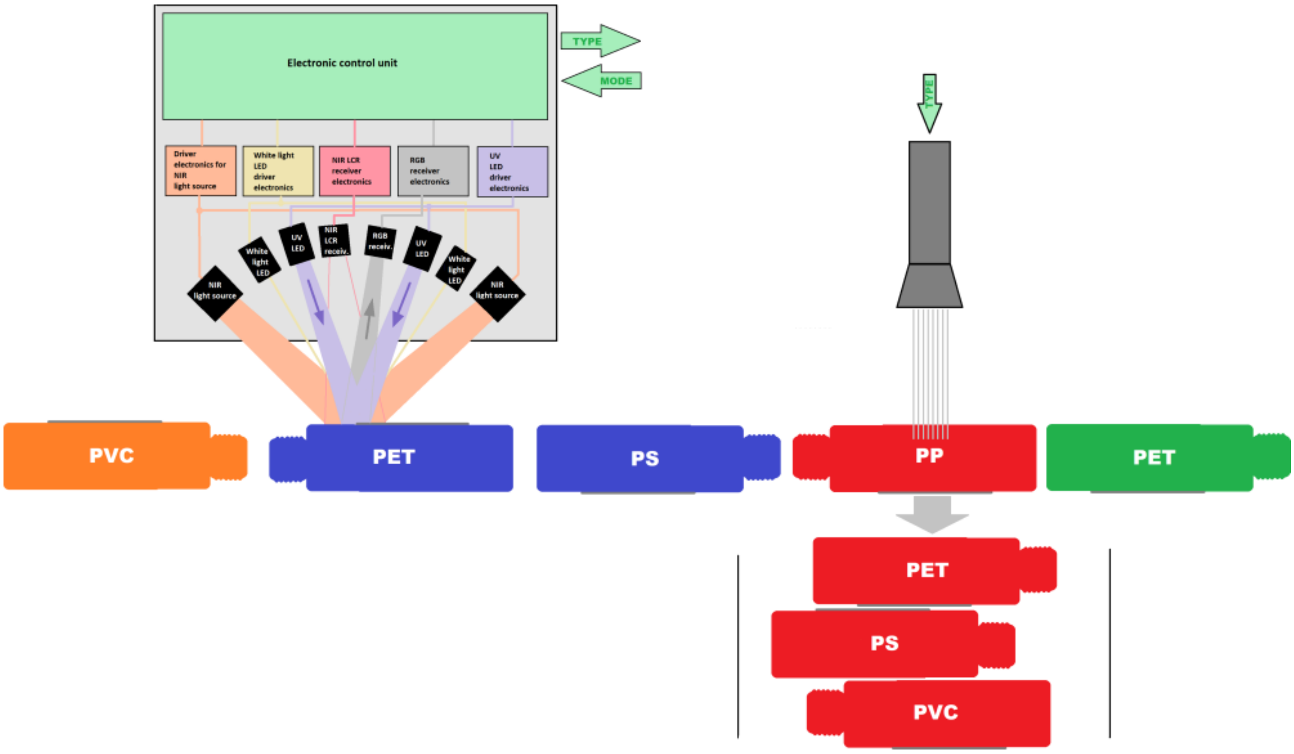
An object is detected (self-triggering) during normal operation. The triggering is performed using the integrated color sensor (predominantly via the measured value INT) then the three data triplets are ascertained and after the triggering procedure has ended in accordance with the majority principle (the number of the most hits) and depending on whether and which GRP function (C-GRP “on” or P-GRP “on”) has been activated, a corresponding object will be removed.

Example in accordance with color:

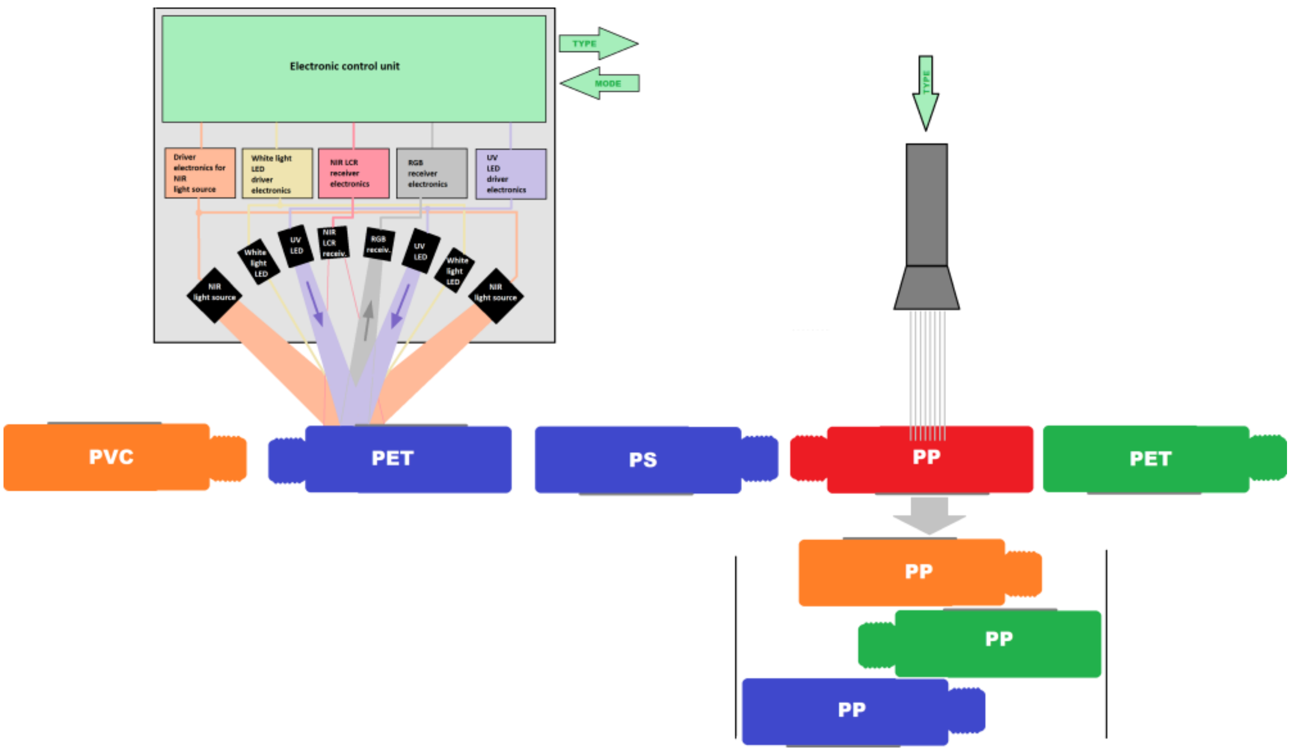
All red objects land in the same container; the remaining containers are filled in accordance with the same principle. Every color requires a blowing-out device.

For example, in accordance with type:

As the NIR values (r,c,B) are influenced by the color, reliable determination of the plastic type (here: PP) can only be performed through incorporating the respective color values (x,y,INT).



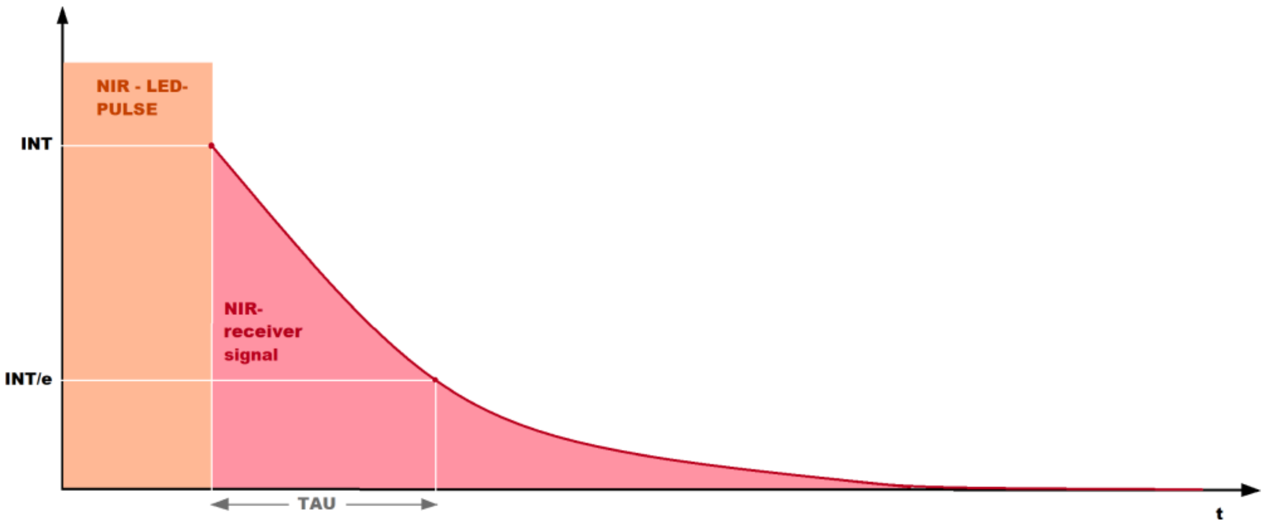
⇧ Sorting in accordance with plastic color



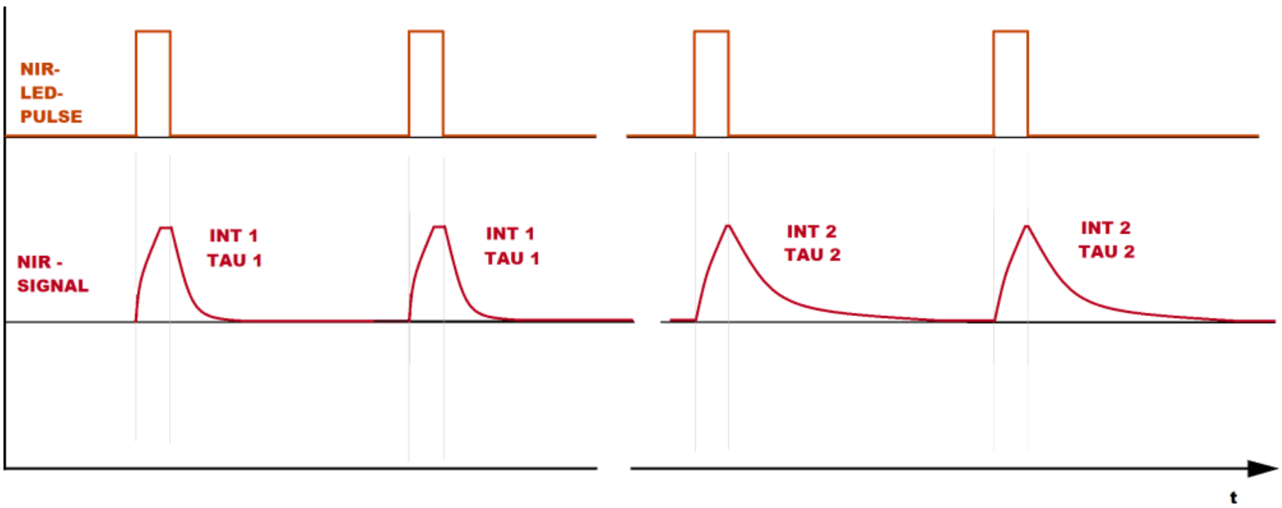
⇧ Sorting in accordance with plastic type

The use of additional markers to differentiate between the object uses

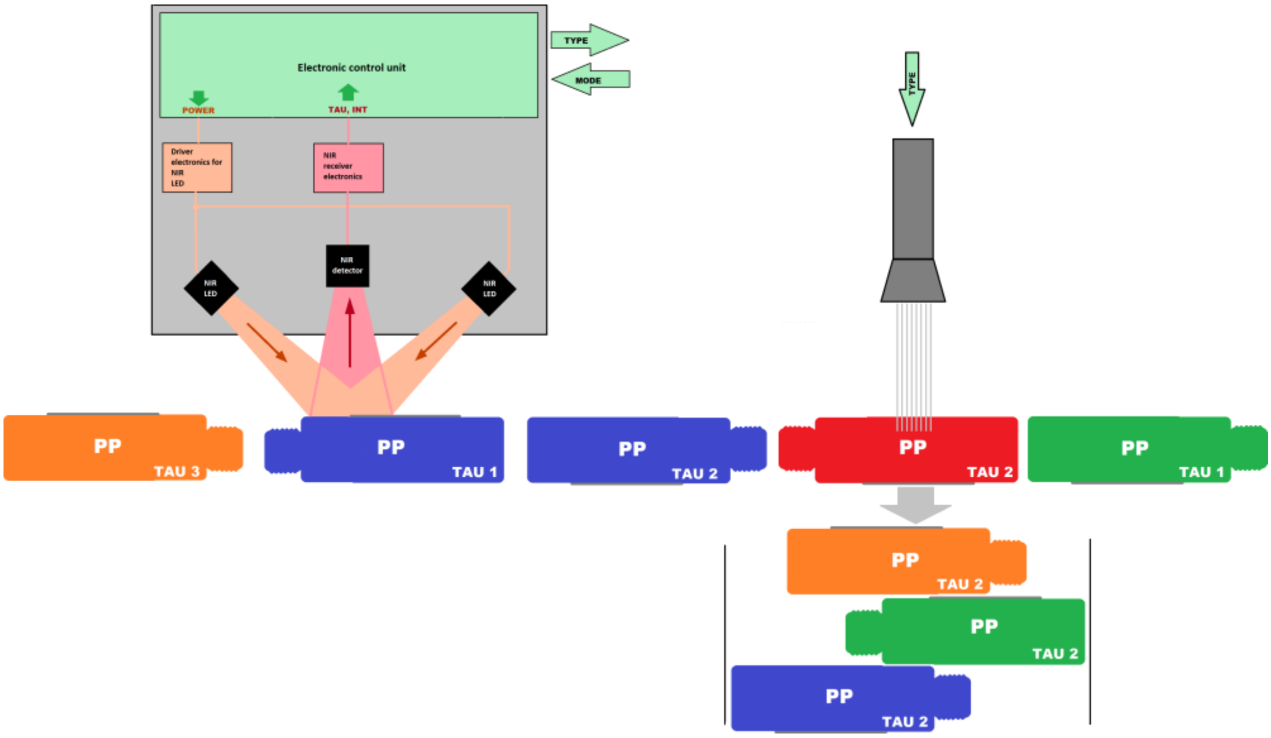
It is often insufficient to keep the correct plastic type in the respective color; it is necessary to sort the objects in accordance with their previous use (containers or packages for foodstuffs, liquid soaps, drain cleaners etc.). To this end, the objects must be marked in accordance with their use. For example, phosphorescent down converters can be used to this end. Pulsed stimulation with light in the suitable wavelength range (there are markers which can be stimulated in the UV range and emit a secondary emission in the visible wavelength range; there are also markers that can be stimulated with blue light or green light and provide a response in the red wavelength range or in the NIR range; and there are also markers which emit NIR light in a lower energetic wavelength range after stimulation with NIR light) results in secondary emission of the respective marker with a higher wavelength range emission than the primary emission and (with some of these markers) emit an afterglow. This luminescence is characteristic for the respective markers. As it is an exponentially abating process, it can be described with two parameters: time constant TAU and initial intensity INT0.



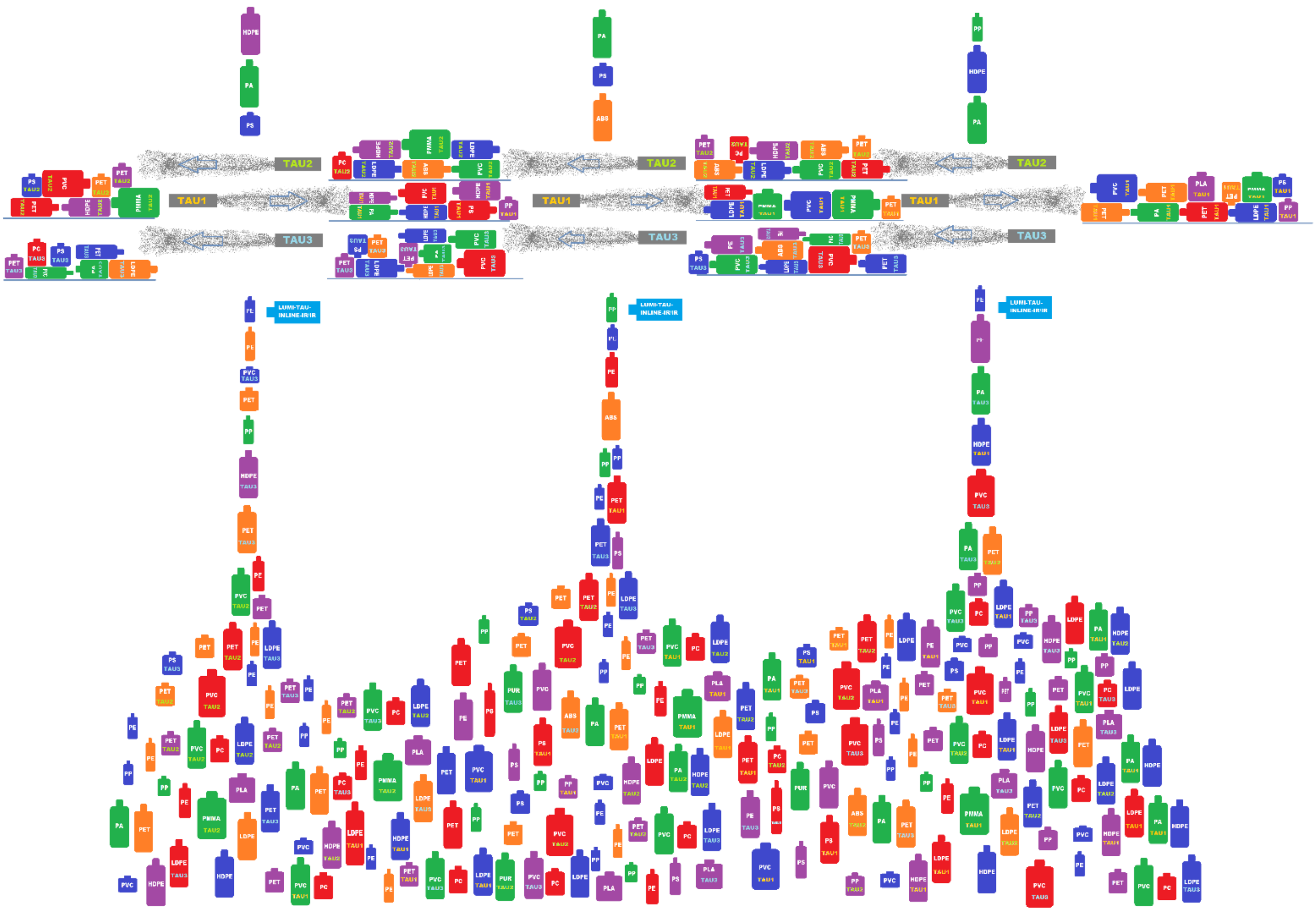
Various markers present different TAUs and INTs:



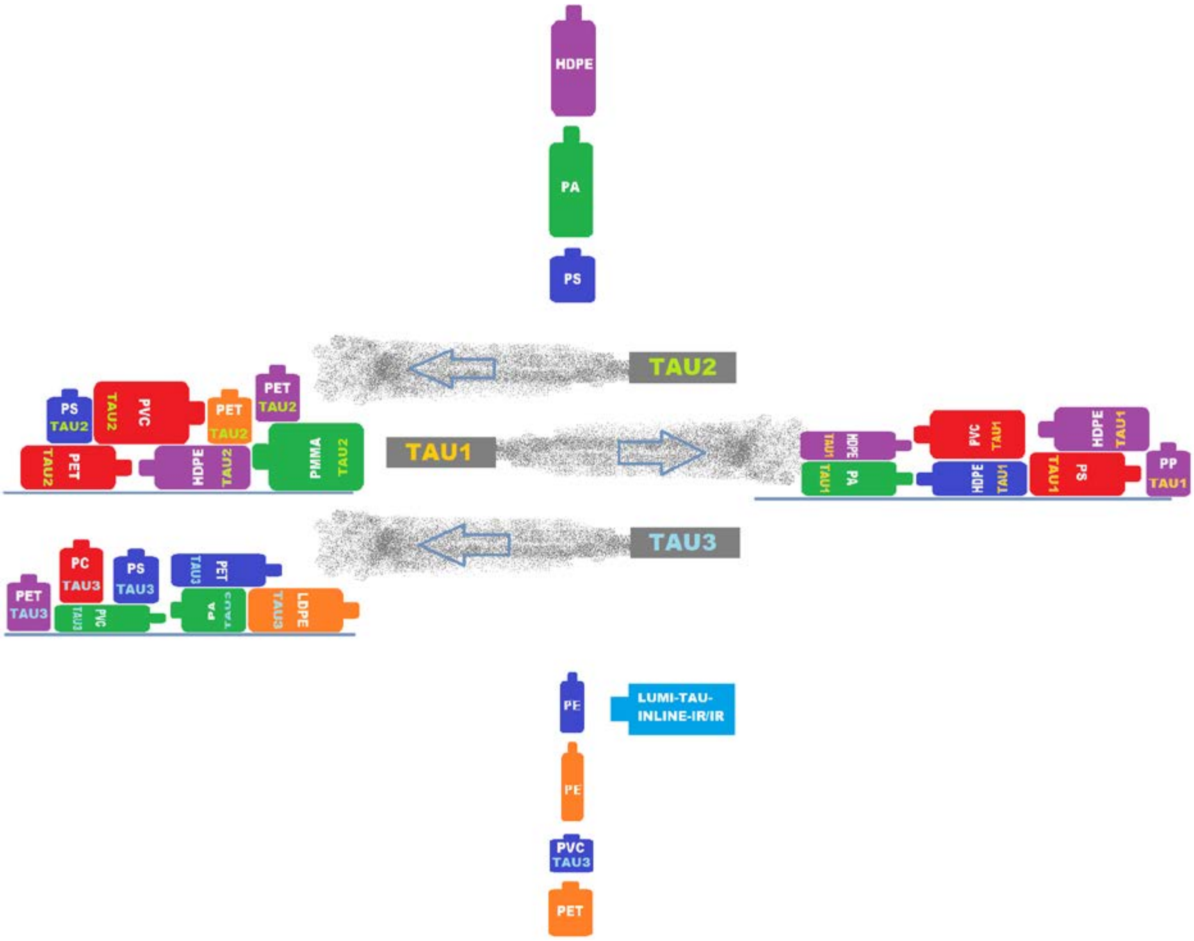
Sensor for differentiating between the respective objects according to marker type (TAU1, TAU2, TAU3):



Sorting in accordance with TAU:



Sorting in accordance with TAU (section: 1st line):



In addition, the marker information can also serve to ascertain the percentage of recycled material in the end project.

The idea:

A marker should be added to the recycling material before mixing it to the new material to ensure that the amount of recycled material in the end product as required by law can be checked. After adding the markers, the recycling material should present a constant concentration of markers. A constant marker concentration can be achieved through the use of suitable sensors and a controlled intervention in the respective metering unit. It is necessary to prevent a situation in which this process can be influenced by the end customer by their adding too much marker material (included in the masterbatch) and thus reducing the proportion of recycling material as required by law. In a fashion similar to the process used in the luxury foodstuffs and stimulants industry, where legal provisions specify process control (in the cigarette packaging process, a tax stamp is applied to the packaging before applying a transparent film seal and the number of tax stamps applied is checked by an official agency; random checks are also conducted on the process to ensure that it has been performed correctly) a check could be performed during and after the manufacturing process.

The following section uses the following sketches to explain the section of the recycling process in which the markers are inserted:

Shredded recylcing materal pre-sorted by plastic type: the sorting can be performed using e.g. the sensors stated above (NIR three range sensors). This sensor works in conjunction with a color sensor (separation of the recycling material according to color) and a UV color sensor (recognition of any paper labels) and constitutes a multi-sensor for the plastics recycling area). Shredded recylcing materal pre-sorted by plastic type is led to an extruder. Melted, processed into strands and then reduced to granulate, the recycling material is investigated for markers by sensor 1 (e.g. a TAU reader -> TAU + INT0) immediately in front of metering unit I. The result from sensor 1 influences metering units I and II. Metering unit II in conjunction with sensor 2 [a TAU reader (TAU + INT0) could also be used] ensure constant addition of markers in the recycling material through supply of the marked masterbatch (constant ratio between recycling material and marker). After adding the new material via metering unit III, outfeed control is performed using a further sensor (sensor 3) of the same type (TAU reader).