Introduction
Facing increased competition from electronic and other media channels, printing companies are increasingly looking for ways in which to offer innovative products to better satisfy customer needs and access new markets. Expanding the visual appeal of the printed product has proved to be an important method to respond to increasing customer demands. The use of metallic inks can be a tool for printers to expand their product offerings while providing their customers with new and unique products. The introduction of printing metallic inks into a company that has previously only printed standard inks introduces new challenges for process and quality control. The properties of metallic ink printing demand more complex measurement technologies than are normally found at most printing locations.

The packaging industry in particular has offered many applications for the use of metallic inks. The effects of metallic inks and an appearance which is distinctly different from standard, non-metallic color printing. To provide the appearance of metallic inks, metalized flakes are dispersed in the ink that create the appearance desired for this technique. The metalized flakes have a strong specular component when reflecting incident light. Metallic inks are known as being goniochromatic: this means that the printed ink changes its appearance when viewed from different angles. This condition magnifies the inherent limitations of many of the color measurement instruments typically used in printing operations. The ability to accurately monitor ink film thickness is fundamental to process control in printing procedures. Insufficient ink film thickness would lead to a reduction of the desired metallic appearance, and excessive use of metallic ink would reduce the ink mileage while not contributing to a superior result.

The present review will discuss the important published literature to date on this topic. It will begin with a review of the terminology that is commonly referred to in the pertinent research in this topic. Following the listing of terms, a review of color measurement instrumentation is included: it is relevant to understand the particulars of the types of color measurement instruments and resulting metrics that are available. A description of printing inks, both conventional and metallic, follows the discussion of measurement instruments and metrics. Finally, the literature review of important published works on the topic on the control of metallic inks is provided.

Terms
Due to the technical nature of the topic, it is important to clarify the terminology utilized in this text.

Gonio- or Multiangle Geometry:
Instrument that measures light reflected from a surface at multiple angles.

Sphere Geometry:
An integrating sphere collects all the light reflected from the surface of a sample placed against an opening into the sphere. (Berns, 2000)

$0°/45°, 45°/0°$ Geometry:
Instrument Geometry where the detector is at $45°$ incident to the light source.

Metallic Ink:
Ink with suspended metal flakes to give a metallic appearance.

Densitometer:
Densitometers are instruments designed to determine, indirectly, the light absorbed by a surface. They do this by comparing the intensity of the light that reflects off a surface to the intensity of the light shown upon it, and then calculate density via an accepted logical relationship. (Brehm, 1992)

Filter Status:
Standardized densitometer spectral response for the use in the graphic arts. Status T is pri-
Marilly used in North America and Status E in Europe.

Polarization Filter:
Polarization filters eliminate portions of specular reflection. They can be used in measurement instruments to better compare wet and dry ink.

Spectrophotometer:
A spectrometer designed to measure spectral reflectance or transmittance. (Berns, 2000)

Colorimeter:
An instrument used for measuring CIE tristimulus values for a stimulus. (Berns, 2000)

Color Measurement

Measurement Instruments used in the Graphic Arts Industry

In the past several decades, the use of measurement devices for process control realized wide adoption in the printing industry. The first such instruments were known as densitometers (here, the discussion is limited to color reflection densitometers.) These instruments served the industry well for process control of standard inks using the four color process of cyan, magenta, yellow, and black. The increased use of spot colors coupled with a desire to better control incoming materials and to better meet quality assurance goals, spectrally-based instruments are now common in printing press rooms. During this period, spectrally-based instruments became smaller, lighter, more durable, and less expensive. These spectrally-based instruments provided a reasonable level of accuracy and precision, and therefore they were adopted widely in the industry.

When discussing reflective color measurement instruments, one particular type dominates the printing industry: these instruments with a 45°/0° geometry. These instruments have a light source that emits light at a 45° angle onto the surface while the detector reads the reflected light at an angle of 0° that is also known as the surface normal angle. This particular geometry, and it’s equivalent counterpart that illuminates at a 0° angle and measures at a 45° angle, are typically called 0°/45° or 45°/0° instruments.

Figure 2 shows the 45°/0° ring geometry as it is used in the X-Rite EyeOne spectral instruments which are widely used in the graphic arts. It is important to note that presently all of the ANSI and ISO standards related to use in the printing industry specify the 45°/0° or 0°/45° geometry. This includes all of the recognized standards for color reflection densitometry, such as Status-T and Status-E (proposed), colorimetric and spectral measurement.

45°/0° ring illumination optics, DIN 5033

Figure 2: Ring Illumination geometry of an X-Rite EyeOne. Source X-Rite, (L7-456_i1_Solutions_de.pdf)

Pertinent to this discussion is the realization that light striking the surface of the sample reflects in either a diffuse or specular manner. The specular reflection is typically referred to as gloss. The glossier the appearance of the surface, the greater the specular component and the smaller the diffuse component. The 45°/0° (or 0°/45°) geometry only measures the diffuse component of the reflected light. Therefore, this type of instrument is almost blind when measuring mirror-like surfaces. While 45°/0° (or 0°/45°) instruments are an excellent choice for measuring standard printing inks, the unique reflection characteristics of metallic inks may diminish the usefulness of this particular instrument geometry. The strong specular component, which also can be directional (otherwise known as goinochromatic), may not be able to be captured with the type of measurement devices normally used in the printing industry. (Mouw, 2008)

This instrument family is very popular since it is affordable and delivers good results on most printing substrates and most ink’s.
Other Measurement Geometries

**Sphere Instruments**

Instruments with an integrating sphere illuminate the sample diffusely. To do so, the white surface at the inside of the sphere reflects the light in all directions. The light source does not directly illuminate the sample. The sample is viewed at an angle of 8° off the surface normal. Therefore, the corresponding specular angle is also 8° off the surface normal.

Spherical instruments can read the sample in two different ways. Either with the specular component included or excluded. Specular included measurements are referred as SPIN whereas specular excluded are called SPEX. The SPIN geometry does include the gloss (first surface reflection) into the measurement whereas SPEX doesn’t. Measurements of a glossy surface would show higher reflectance values when measured with SPIN. A matt surface with no or very little specular reflection would show almost identical reflectance values between SPIN and SPEX.

Spherical instruments illuminate the sample from all possible angles. This implies that all viewing angles are averaged into one reading. This is especially important for measurements of samples with different surface effects such as textures or gloss. This averaging of all angles creates measurements that do not necessarily correspond with the appearance of the sample at specific angles.

Spherical instruments have the ability to measure samples with a wide range of textures. The specular port allows taking different types of readings with one instrument. These instruments are not widely used in the graphic arts because they are more expensive and difficult to use in a print process control environment. For most printed products it is not important to take an integrated reading of a textured surface.

**Multi-Angle Instruments**

Metallic inks are goniochromatic, which means that they change color by changing the viewing angle. Therefore, these inks cannot be characterized with a simple 45°/0° geometry. To measure these inks, a more complex measurement geometry must be used. Multi-Angle instruments have one or more angles of illumination and many sensors placed at different angles. The aspecular angles are described as near-specular angle, face angle and flop angle. Near-specular angles describe the angles very close to the specular direction, which are usually less than 25° from the specular angle. Viewing a surface close to the surface normal when illuminated at 45° is called face angle. The flop angle describes viewing angles far from the specular angle, which is usually 70° ore more. (Berns, 2000)

![Figure 3: Aspecular Geometries (after Berns 2000)](image)

Multi-Angle instruments are widely used in the automobile industry where a lot of metallic ink is used. These instruments play an important role in quality control. Multi-angle-instruments deliver the most information among commercial instruments. Nevertheless, they are difficult to use and very expensive.

**Gloss Measurement**

Gloss is a surface property that is independent from the color of the surface. Nevertheless, gloss does affect the perceived color of an object. Hunter and Judd first defined specular gloss. The gloss was described as the ratio of the light reflected from a surface at a specific angle to that incident on the surface at the same angle on the other side of the surface normal (Hunter, 1939). Hunter recognized the perceived gloss involved more than just specular gloss. Therefore, he identified the following five types of gloss:

- Specular gloss as proportional to S/I
- Sheen as proportional to S/I at grazing angles of incidence and viewing
- Contrast gloss or lustre as proportional to D/S.
- Absence-of-bloom gloss as proportional to (B-D)/I
- Distinctness-of-image loss as the sharpness of the specularly reflected light

Where \( I \) describes the incident light, \( S \) the specularly reflected light, \( D \) the diffuse reflectance, and the off-specular angle as \( B \). A visualization of the different types of gloss is shown in Figure 4.

![Figure 4: Types of Gloss identified by Hunter. (Drawing after Hunt, 2011)](image)

A high glossy surface can have a very strong specular reflection. Hence, high glossy surfaces are very sensitive to measurement angle. A small error in the magnitude of a fraction of a degree can already cause a distinctive measurement error. (Hunt, 2011)

ASTM D523, Standard test method for specular gloss, defines three angles for gloss measurement which are 20°, 60° and 85°. Gloss is units are measured relative to a black glass standard where the 100 units represents the gloss of the black glass independent for each geometry.

**Description of Conventional Printing Inks**

Printing inks used in conventional printing processes such as lithographic printing are basically transparent. Nevertheless, real printing inks always have a scattering component. Pigments absorb some of the incident light hitting the ink film. Light that is not absorbed reaches the substrate and reflects back through the ink layer to the observer. The appearance of ink printed on paper is an interaction of the light source, the ink and the observer.

**Description of Metallic Inks**

To achieve the metallic appearance, small metallic flakes are dispersed in the ink. When the ink sets onto the substrate, these flakes are laid down parallel to the substrate. Flakes could be made of gold, bronze, copper, zinc, stainless steel, nickel graphite, and aluminum. (Berns, 2000) Different printing processes require different sizes of flakes. For lithographic inks, the flakes have to be extremely fine. An average particle size for lithographic printing is between 2 and 5μm. The size of the flake is an important property to control the type of reflection. Larger flakes result in a higher brilliance and a clearer color. Smaller flakes give a higher gloss and coverage. (Schlenk Metallic Pigments GmbH, 2011)

For cost reasons, most ink is formulated with aluminum flakes. Aluminum only produces a neutral appearance. To create more color variations, color pigments are added to the ink. Flakes are treated so that they either attract each other or repel. Repealing flakes are not able to produce a uniform coating of flakes and are therefore less shiny. The terms leafing or non-leafing are commonly used to describe the properties of flakes.

In the case where flakes are non-leafing, the light rays can bounce off from several flakes. When the light ray eventually leaves the ink layer, it does not show such a distinctive specular reflection as with leaving inks. (Rich & Mouw)

The more flakes are covering the substrate the greater the metallic appearance of the print. Once the substrate is fully covered by flakes, adding more ink would yield no improvement but waste ink and cause ink transfer and drying problems.
Literature Review about Color Measurement of Metallic Inks

Using Densitometers or Spectrodensitometers to Measure Metallic Inks
Densitometers and Spectrodensitometers are crucial process and quality control devices in the graphic arts. These instruments almost exclusively use the 45°/0° geometry as specified in DIN 5033. Most instruments used in press rooms are equipped with a polarization filter. Jorg Mannig & Ray Verderber at Eckart (Mannig & Verderber, 2002) as well as Dimitrios Ploumidis at RIT (Ploumidis, 2006) studied the effect of polarization filters for process control of metallic ink. Both studies conclude that the use of a polarization filter yield a better sensitivity to changes in ink film thickness. It was also found that Status I density readings are more sensitive than Status T measurements. To measure the chromatic dimension of bronze metallic colors, the use of an instrument without a polarization filter provided a higher sensitivity for chroma C* measurements. (Ploumidis, 2006)

Geometry for Measuring Metallic inks
A comparison of commercial available measurement geometries for metallic ink measurement was performed by Mouw. Bidirectional 45°/0°, spherical and multi-angle instruments were compared. The measurements were compared with the visual perception of the samples. The experiment concluded that using a multi-angle-instrument would be the proper choice to measure metallic inks (Mouw, 2008).

Photo-Goniometric Measurement
Since goniometric instruments are relatively expensive and difficult to use. A Photo-Goniometric measurement is much less complex and requires only a camera, a light source and a cylinder shaped sample holder. A uniform sample is mounted on a cylinder and illuminated with a point light source. A camera mounted in between then takes a picture of the sample. The captured image can then be used to calculate BRDF (Bidirectional Reflectance Distribution Function) parameters to characterize the sample. Suni evaluated the feasibility to measure metallic inks by using a light source and a commercial digital camera to characterize the appearance of printed metallic inks. (Suni, 2007) Matusik et al. also used the same concept. To get more information, color HDR capturing was used (Matusik, 2009).

Quality- and Process Control of printed first generation Interference Effect Colors
Hupp performed a study evaluating the most sensitive measurement angles used in commercial multi-angle instruments. Samples printed with different effect inks each with a range of ink film thickness were measured with a commercial instrument. Using the 45°/0° geometry as an anchor, it was found that the most sensitive geometry was 45°/30°. A measurement instrument with a 45°/0° and 45°/30° is proposed for quality inspection. The combination of these two geometries allow an evaluation near the gloss direction as well as for a viewing position far away from gloss. This would allow to build a fairly simple instrument with two geometries (Hupp, 2008). Furthermore, it was found that LH measurements have a good correlation with ink film thickness. The difference of L* of the color and the L* of the paper are proposed as additional process control measures using a conventional color measurement device. (Hupp, 2008)

Halftone Screening applied to Metallic Inks
The gloss of a metallic surface depends on the area of reflection. A larger area produces more specular reflection. The halftone screening used in common printing processes produces dots that are very small. Especially quarter and highlight tones produce particularly small dots. Such small dots don’t produce the same distinctive glossy reflection as larger dots. Therefore, these small dots loose their metallic appearance and simply appear as non-metallic colors. (NewPage, 2011)

Conclusion
Despite the availability of different kinds of commercial measurement devices, an ideal solution that can be implement in print production is not yet available. Whereas the automobile industry has widely established the use...
of goniochromatic instruments, the printing industry is not there yet. Several reasons hamper the printing industry from implementing these systems. At first, goniochromatic measurements require a much larger measurement area than conventional 45°/0° instruments. Often it is not practicable to have large process control elements printed on a print form. Measuring the object itself is not always possible. Since commercial goniochromatic instruments like the X-Rite MA98 need to be pressed onto the sample at a defined pressure, the ink has to be dry during the measurement process. This is not the case for all printing processes. Another factor is that it is difficult to interpret the readings of multiple angles at the same time during a production process. Calculating some sort of delta is one thing – making press settings based on these readings would be a new skill that press operators would have to learn.

Since multi-angle instruments are much more expensive than single angle instruments, they are very rarely used in the printing industry.

References


