The ability to monitor the healthy condition of rotating machinery can be applied to preventing faults and their consequences, and hence to preventing or reducing damage to the machinery. Vibration monitoring is the prevalent technique for condition-based maintenance of rotating machinery. The health assessment of the machinery is based on a comparison between vibration models of the rotating components (e.g., shafts, bearings, gears) and measured vibration signals of the components. Vibration analysis is commonly used in diagnostics. It is effective for detecting various faults and malfunctions, and already being used in monitoring jet engines, wind turbines, and other machines [2] [3]. Since rotating parts cause events to occur at specific angular positions rather than at specific times, the various methods of processing vibration signals require knowledge of the rotational speed of rotating components. Thus, an accurate estimate of the Instantaneous Angular Speed (IAS) is important for reliable diagnostics. Dynamic phenomena such as imbalance, misalignment, or eccentricity can lead to inaccurate estimates of the angular speed.

For bearings operating under stationary rotational speed, faults can be diagnosed in the frequency domain because each type of fault has a specific characteristic frequency that is proportional to the rotational speed of the shaft. If the rotational speed cannot be measured, the IAS can be estimated directly from the vibration signal by using one of the available methods, each with its advantages and disadvantages. One of the earliest methods to estimate IAS is based on the Fourier transform, and this approach remains the simplest to implement. Some commercial IAS-estimation software packages offer Fourier-based IAS evaluation. These methods were analyzed in detail by Ref. [4] with both qualitative and graphical analysis. Although Fourier-based methods are good for monitoring IAS in stationary conditions, they are unsuited for nonstationary regimes, in which variations in the rotational speed widen the spectral peaks.

The IAS serves as an essential ingredient in several processing techniques dedicated to the analysis of machines operating under nonstationary regimes. The IAS enables the synchronization of Fourier analysis on the shaft rotation – a practice known as higher order spectral analysis; or the tracking of the evolution of the Fourier coefficients as a function of speed - a practice known as order tracking [5–7]. Early successes of order tracking are exemplified by the Vold-Kalman filter [8–14], a model-based approach well suited to slow-speed variations and high SNRs. It is traditionally accepted that order analysis and order tracking apply to deterministic signals which exhibit modulated harmonic structures in the order domain. It is only recently that these ideas have been extended to broadband signals. The IAS is also an essential measurement in resampling machine signals in the angular domain for all applications where synchronization to the machine kinematics is essential to correctly identify and analyze events in the machine cycle [18–20]. The IAS is not only useful as a reference signal – it may serve as an intrinsic diagnostic quantity. It has been used in this capacity in the diagnostics of electric motors and internal combustion engines [25–27] and rolling element bearings [28, 29].

The measurement of the IAS is ideally achieved by a rotational speed sensor mounted on the machine, such as an angular accelerometer or a coder-based device. In turn, the signals are either directly sampled in the angular domain by using the tachymetric signal as an external clock to the ADC or resampled *a posteriori* by using digital processing algorithms. The latter strategy is sometimes referred to as computer order tracking. These approaches have been discussed by several researchers [31–35, 5]. Technological aspects of the measurement of the IAS and associated errors are have been extensively discussed in the literature [36–39, 29, 40–42].

In practice, direct measurement of rotational speed is often impossible, expensive or inaccurate for technological or cost reasons. In these situations, efforts have been made to calculate the IAS from machine signals (e.g. vibrations). This is a challenging but a very interesting task, since it does not require any specific instrumentation and can potentially return the exact IAS (e.g. the IAS used for re-sampling of machine signals). One of the first successful attempts in this direction is probably the non-parametric approach based on the complex envelope demodulation proposed in [14]. Following this impetus, several demodulation methods have been proposed during the last six years to extract the IAS from complex vibration signals in more general scenarios [44, 15, 45, 46]. Model based approaches, such as the Vold Kalmar Filter (VKF) demonstrate good accuracy [47-49]. Several researchers [12] [13] [14] [15] have discussed the issue of setting the filter passband, which is a fundamental characteristic of the VKF. However, theoretical framework for selecting the VKF bandwidth is incomplete and requires further investigation. Another approach is to use time–frequency representation for the vibration signal and estimate the angular speed based on this information [7, 8]. Also, [9] presents a method for the identification of time-varying components based on spectrogram information. Finally, several authors [10–13] present applications of these methods to estimate IAS of selected shafts in rotating machinery.

Even though these methods provide promising results and are used in analysis of mechanical vibrations, they suffer from a number of limitations. The method proposed by Bonnardot et al. [2] can estimate the IAS only when there are limited fluctuations in speed, being restricted by the phenomenon of harmonic components overlapping when presented with significant variations. Also, when dealing with significant changes in rotational speed, the spectral lines on the vibration spectrum corresponding to the rotating components might be relatively difficult to identify [5,14]. These obstacles can be overcome by application of time–frequency methods. However, this approach has limited frequency resolution which results in inaccurate estimation of the IAS, especially when dealing with signals that contain only low harmonics generated by the rotating shaft. In those cases, the variation of shaft related components might be relatively difficult to evaluate from time–frequency representation of the signals.

The variety of approaches proposed so far reflects the difficulty of the problem. One challenge stems from the multi-component nature of the signals, with many coexisting different families of harmonics, each characterized by many sub-components. Another challenge stems from the interaction between the orders and the structural resonance of the machine. A final challenge is to operate under low SNR as is often the case with vibration signals. All these challenges jeopardize the application of standard signal processing approaches that are dedicated to IAS estimation [56–59] and require specific handling approaches.