Development of Bioacoustic Nondestructive Testing Instruments for Early Detection of Bark Beetle Infestation

Richard Bruce Allison
Forest and Wildlife Ecology Department, University of Wisconsin-Madison

Abstract

Damage to trees from bark beetle attack presents an economic and aesthetic cost affecting forest crops and urban forest landscapes. Bioacoustic sensors have been used to nondestructively test for insect activity in wood and standing trees. Advancing technology and electronic component cost reductions for acoustic emission monitoring sensors provide the opportunity to develop tools to eavesdrop on the sounds generated by bark beetles hidden within trees.

Keywords: Bark beetle detection, bioacoustic sensors, nondestructive testing

Damage to trees from bark beetle attack presents an economic and aesthetic cost affecting forest crops and urban forest landscapes. In many cases early detection offers the option of therapeutic treatments. Though concealed from view under the tree bark, the sounds generated by larvae feeding, insect movement and stridulation provide telltale indications of bark beetle presence. Acoustic emission (AE) as defined by Eitzen and Wadley (1984) of the National Bureau of Standards is "the transient mechanical waves spontaneously generated by abrupt localized changes of strain within a body" They continue, "the surface motion due to an AE source contains information about both the location and characteristics of the source." Various sensors have been used for many years in industry to gather AE information. In the biological sciences, researchers have examined acoustic emissions from sources as varied as birds, marine life, mammals and insects. This area of study is bioacoustics. Bioacoustic sensors have been used to nondestructively test for insect activity in wood and standing trees. Advancing technology and electronic component cost reductions for acoustic emission monitoring sensors provide the opportunity to develop tools to eavesdrop on the very low amplitude sounds generated by bark beetles hidden within trees.

In a review of advances in insect acoustic detection and monitoring, Mankin (2011) points out that insect predators and parasitoids have always been eavesdropping on insect communications, feeding and movement sounds and vibrations to locate prey and hosts. Articles as early as 1909 (Main 1909) have been published on acoustic detection of termites and many since (Fujii et al. 1990; Lemaster et al. 1997; Mankin et al. 2002; Yanase et al. 1998, 2000). Several researchers have recently focused on the use of bioacoustic sensors for early detection of the red palm weevil (Hetzroni et al. 2016; Hussein et al. 2010; Mukhtar et al. 2011; Dosunmu et al. 2014, Potamitis et al. 2008), an invasive from Southeast Asia attacking the historically important date palm in the Middle East. Other insects have been the subject of bioacoustic researchers (Cross and Thomas 1978; Haack et al. 1988; Mankin et al. 2008; Mankin 2011; Osbrink 2013; Siriwardena et al. 2010) including serious bark beetle pests of pine bark beetle (Hofstetter et al 2014) and emerald ash borer (McCullough 2016). When the Asian long horn beetle attacked trees in Central Park, New York City, the USDA through Oak Ridge Laboratories developed piezoelectric sensor instruments as detection tools (Smith and Poland 2001). Mankin in his review states that even though the understanding of insect acoustical and vibrational communication has advanced the development and adoption of simple to use monitoring tools has lagged in part for the following reasons:

1. "limited understanding of acoustic signal attenuation across various substrates,"
2. "difficulties in interpreting weak insect signals in environments with high background noise,"
3. "limited knowledge of the behaviors of the cryptic targeted species that produce the signals"
4. "the small market for insect detection instrumentation."

Attenuation is the gradual loss of signal magnitude as a wave moves through a substrate. This is caused by absorption of the signal within the substrate, reflections at interfaces or dilution as the wave passes into a larger volume area. Within a wood substrate reflection is a significant factor when the signal moves across the wood fiber versus along the wood fiber. The attenuation coefficient, the rate of signal decay per unit distance, is approximately 2-5 times greater along the wood fiber than across it (Lemaster et al. 1997; Yanase et al. 2000). Wood has a low attenuation coefficient and thus is a good substrate for acoustic detection of insect activity. The area of detection, known as the active space, is greater in low frequency sounds than ultrasound (greater than 20KHz). Scheffrahn et al. (1993) detected termite high frequency sounds in an active space up to 2.2 m in wood. Mankin et al. (2011) detected some of the louder low frequency sounds of the red palm weevil over 4 m below the insects.

Of equal significance to the gathering of acoustic signals is the interpretation of the signal. Signal analysis requires not only being able to identify the unique insect sound but also differentiating the sound of the insects from background noise. Trained listeners can identify specific insect sounds but automated processing using software to sift through multiple sounds looking for the programmed specified wave characteristics is available as is newer voice recognition software (Chesmore and Schofield 2010; Pinhas et al. 2008; Potamis 2009; Watanabe et al. 2016)

The understanding of the behavior of certain bark beetles, specifically emerald ash borer and pine bark beetles, has increased significantly as a result of the intense research conducted in response to the unprecedented damage being done to the western forest crop and the urban forest landscape. It is not an exaggeration to say that the outbreak of pine bark beetles in the Western United States is the greatest in recorded fossil history and the invasion of Emerald Ash Borer in the Midwest United States rivals Dutch elm disease in the cost and disruption to the urban forest. Hofstetter et al (2014) propose acoustic methods to not only detect pine bark beetles but also use sounds imitating insect communication to dissuade insect infestation within forests (Aflitto and Hofstetter 2014). Professor Deborah McCullough at Michigan State University is actively researching acoustic detection and deterrence methods for Emerald Ash Borer (McCullough 2016). Increase in the global distribution of wood products has also stimulated an interest in the effective use of acoustic monitoring by national border regulators to avoid the importation of wood damaging insects (Brandstetter and Hubner 2015; Chesmore 2008; Schofield and Chesmore 2008).

The current small market available to developers of bioacoustic sensing instruments has not deterred some scientists from a thorough investigation into optimum sensor instruments (Scheffrahn et al 1993; Fiala et al. 2014; Hyvernaud et al. 1996; Mankin et al. 1996; Zahid et al. 2012; Rach et al. 2012; Wiest et al. 1996). Liu (2017) in a recent review of available technologies describes various instruments used as acoustic sensors. Accelerometers and piezoelectric sensors characterize vibration by measuring the acceleration of the substrates on which they are attached. Accelerometers can sense impact or vibration in one, two or three axes. Martin et al. (2013) using an accelerometer (MEMS MMA 7361, Fujitsu, Japan) was able to detect small larvae in palm trees. Piezoelectric sensors are composed of piezoelectric crystals having the ability to convert mechanical stress into an electric charge. By compressing or pulling the crystal charges are built up on opposite faces generating a current that can be measured between the faces. Sound waves or vibration is thus measured by a transform from acoustic signal to an electric signal (Janshoff et al. 2007). Kuroda (2012) observes that even physiological activity within the tree such as xylem embolism can be monitored by acoustic emission.

Microphones provide impact acoustic (IA) measurement of an acoustic signal (sound) striking a material like a metal plate or membrane. They can either be in contact with the substrate of interest or in non-contact. Mankin et al. (2011) observes that microphones do not interface well with wood or other solid materials and that accelerometers or piezoelectric generate superior results.

Another method of measuring vibration coming from insect activity in wood is the laser Doppler vibrometer (LDV). It has proved highly sensitive with the advantage of non-contact measurements (Zorovic and Cokl 2015). The cost however makes it currently prohibitive for common field applications. An inquiry to Polytec, Inc. USA, the manufacturer of the LDV (PVD-100) used in the Zorovic experiment, revealed a retail price of $40, 000 and a weekly rental of $1,500.

Two bioacoustic sensing instruments were developed with the assistance of an acoustic engineer in the University of Wisconsin School of Computer and Electrical Engineering. The first consists of an electret microphone and enclosed metal probe, specially designed amplifier that can drive headphones. The second has a uniaxial accelerometer (MEMS) attached to a scratch awl to be lightly hammered into the white wood, and a similar amplifier that can drive a headphone. The microphone has a frequency response range equal to the human hearing range of 20 Hz to 20 KHz. The accelerometer has a more limited frequency response range of 1 Hz to 2.5 KHz. Tests were conducted in August on ash trees in Madison, WI infested with Emerald Ash Borer. Both instruments were able to detect the pulsed clicking sound of the mandibles as the larvae were feeding below the bark.

These instruments were developed building on ideas from published research papers and consist of low cost components making them economical and available for general use by tree care professionals and scientists. Further development efforts are required on these instruments to provide recording and signal analysis making one or both of them adequate for field use in detection of a variety of bark beetles and other wood infesting insects.

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