Tripod-walking Gait

Insects have been associated with mankind for many different reasons, beneficially and harmfully. They are advantageous a biological control agent, can beneficially provide us with a food source, pollinate our flowers and assist in the production of honey, wax and silk products (Gillott, 2005). Deleteriously though, insects can be identified as large pests, causing damage and death to manufactured good, humans and agricultural forests or products. 1% of insects in the world are responsible for these human interactions (Gillott, 2005), and most recently, the biology of their lifestyles has also assisted humans for the insight of mechanical robots. Their basic tripod gat walking mechanism has gone onto be another beneficial interaction with humans. Even though insects can cause a lot of money and death as pests, it if wasn't for their presence, our world would be very different (Gillott, 2005).

Insects inhabit many different ways of locomotion. Depending on the species, insects can inhabit aerial locomotion such a flight and/or terrestrial locomotion. Flight is a very complicated and diverse way of movement, as well as the terrestrial insect-walking gait. The walking gait is also known as the 'tripod gait', seen in figure 1.

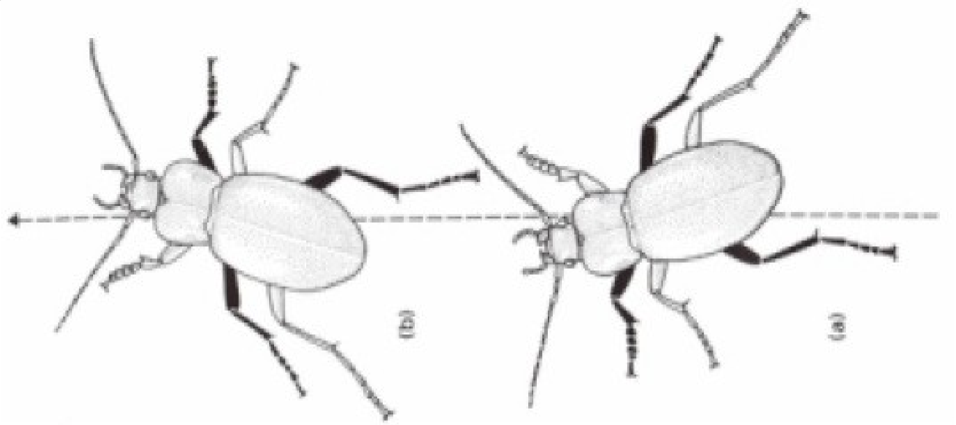

Figure 1: The Tripod Gait (adapted from Gullan et al., 2005)

Occurring within the subphylum hexapod, insects can be primarily identified due to their appendage count, six (Cruse et al., 2009). Their six-legged lifestyle enables them to undertake this ingenuous walking mechanism. Being such a stable and simple walking gait, many researchers have taken insight into this walking style as an appropriate model for robots. As well as insects, other hexapody species inhabit this tripod-walking gait.

Firstly, the sensory and physically anatomy of the legs (seen in figure 2), plays a large part in the gait. Cockroaches, having a distinctive tripod stance, underlie the primitive appendage structure for the tripod gait. The appendage has 4 segments, the coxa (the top segment), the femur, the tibia and the bottom segment, the tarsus. The entire appendage is externally covered in sensory hairs, that help detect the movement in the surrounding environment, and internally, the appendage comprises of muscle receptor and chordotontal organs (Chen et al. 2012). The chordotonal organs are not associated with external sensory structure but are found between the joints of the limbs as a cluster of sensilla that act as mechanoreceptors (Field *et al*., 1998). The muscle receptor organs respond to sensory stimuli through excitatory processes (Fedorova *et al.*, 2008).

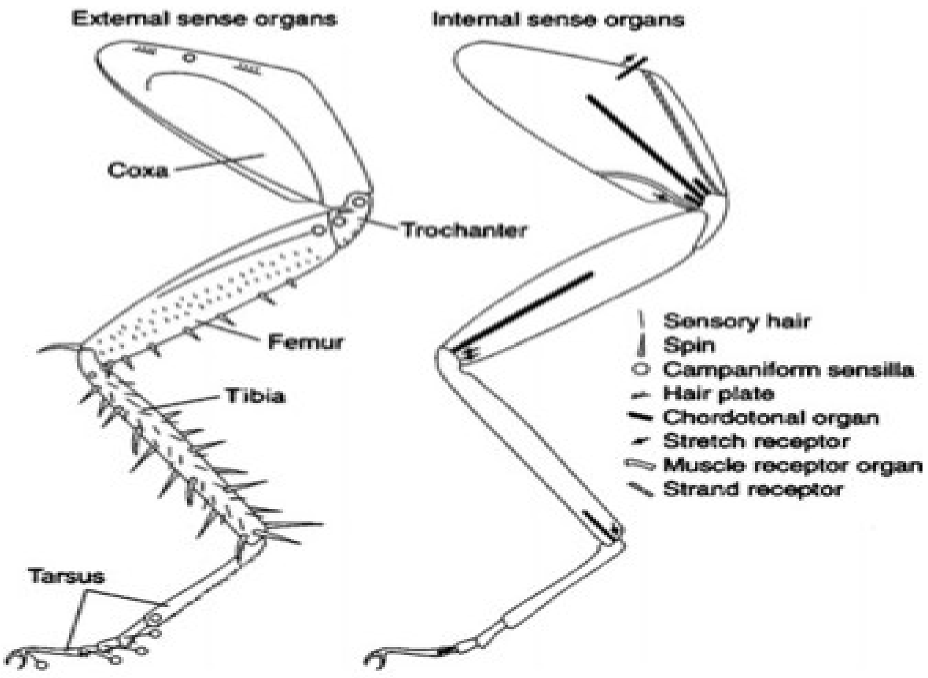

Figure 2: The physical anatomy and external and internal sense organs of the cockroaches' leg (adapted from Chen et al., 2012)

To demonstrate this walking gait, seen in figure 3, 6-legged insects have 3 legs on the ground at all times while the other 3 legs are lifted in a swinging motion. The swinging duration of the legs is dependent on the speed in which the insect is going (Cruse *et al.,* 2009). The tripod gait positions the animal in a way where the front and hind leg on one side of the insect move/swing together and work in a synchronized motion with one middle leg on the other side. As well as insects having at least 3 legs on a substrate at all times, their level of stability is increased even more due the adhesive structures on the end of their appendages, allowing them walk on vertical or horizontal structures (Cruse *et al.,* 2009).

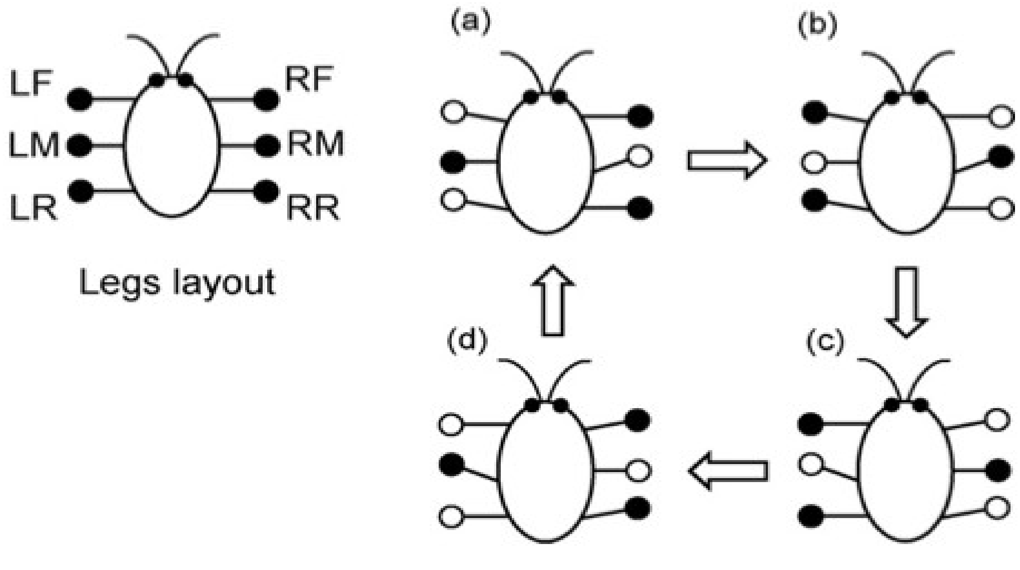

Figure 3: The walking pattern of the insect tripod gait (adapted from Iida et al., 2008)

As well as stability, the insect also inhabits control in their walking gait, which is generated by the Central Pattern Generator (CPG). The CPG is a series or neuronal circuits that are activated to produce rhythmic motor walking patterns. As well as walking, the CPG can also control other forms of locomotion such as fighting and swimming, and surviving mechanisms such as breathing (Marder *et al.,* 2001). The Central pattern generator works specifically by applying input on timing and rhythmic information (Marder *et al.,* 2001) without requiring sensory information (Chen *et al.,* 2012). To control the locomotive system though, the CPG requires a series of central oscillations that are generated by the ganglion (Chen *et al.,* 2012).

All insects demonstrate this walking mechanism some stage in their life. It is most strongly demonstrated though in the cockroaches (Cruse *et al.,* 2009).

Being adapted for Robots

Throughout the animal kingdom, different classes of animals have inhabited many diverse gait transitions. Humans walk with two legs, most mammals' walk with four legs and insect have employed six-legged locomotion, the tripod gait (Chen *et al.,* 2012). Humans have begun to take large insight though into the tripod gait as a very important way of leg movement. Compared to wheels or tracked movement, mechanical leg movement can be adapted to very diverse and various terrain types (Chen *et al.,* 2012). As well as the adaptable tripod gait mechanism, the Central pattern generator, being the rhythmic generator, has also been proposed for the mechanical structure of robots.

Compared to four-legged locomotion, six-legged locomotion is relatively simple. Insects are the most exploited animal used for the robotic structure due to their very primitive neural system and stabilized locomotion type (Chen *et al.,* 2012).

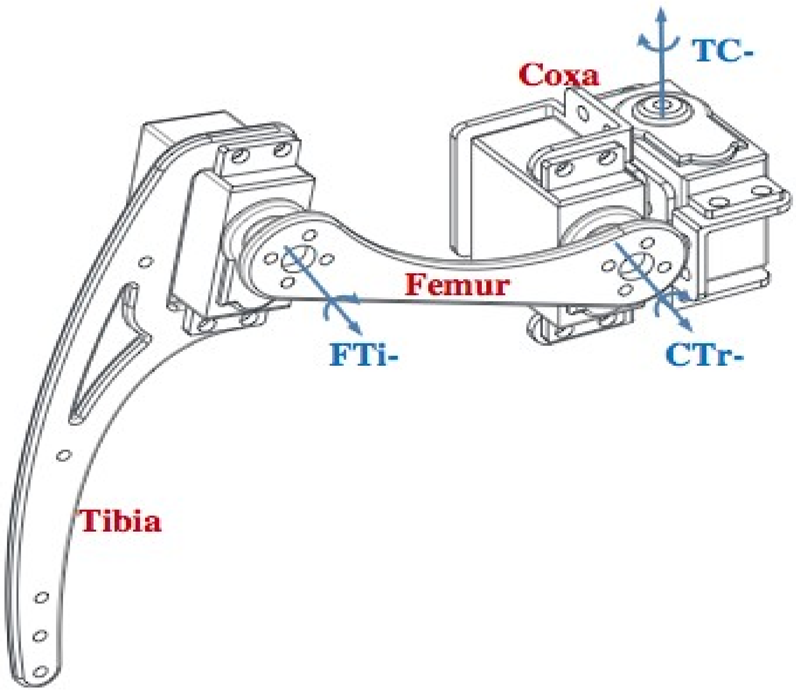

Figure 4: Robots legs based on the leg of an insect (adapted from Chen et al., 2012).
Robots' have been based respectively on the locomotion of insects, as seen in figure 4. Mechanically, the tripod gait has been modeled through inverse kinematics to undergo the

transfer phase (the swing of the 3 legs) and the support phase (the 3 legs based on the ground). If the gait were to change though, kinematics would have to be recalculated (Chen *et al*., 2012). To control each locomotive stride, the insects' CPG method has been modified mechanically to simply control the gait transition. In an insect, the ganglia generate the control of the gait by a series of spontaneous oscillations, where as the robot has been planned to undergo neural oscillations which control the robots motor directly without the requirement of computer kinematics (Chen *et al.,* 2012).

Robots influenced by the tripod gait walking structure have been proposed to have excellent mobility and stability. By undertaking the simple and unique characteristics of the six-legged insect, robots of this model can walk backwards, forwards and move in avoidance of substrates/barriers (Ming-dan *et al*., 2013). However, the robotic tripod gait may present some disadvantages.