Abstract

Flapping wing micro air vehicles (MAV) have broad applications such as exploration in hazardous environment, reconnaissance, search and rescue. Ionic polymer metal composites (IPMC) have emerged as a promising material in actuators and sensors for use in flapping wing of MAVs. Though IPMC satisfies most of the criteria needed for bio-inspired design, achieving high stiffness, actuation force, frequency and flapping angle remains a challenge. The main objective of this thesis is to study the various factors which influence the actuation performance of IPMC by mathematical modelling, optimize design parameters for fabrication of high performing IPMC, design an actuator-sensor array of IPMCs and fabrication of hybrid IPMC-polymer structure as dragonfly scale flapping wing of micro air vehicles. The dynamic mathematical modelling of IPMC is carried out by variational principle using the Buechler and Leo model and the performance of model actuators is studied. The structural modelling of nanocomposite-based IPMC has been carried out to study the effect of inherent properties of the materials used in IPMC fabrication. The studies reveal that the nanocomposite-based IPMC, IPMNC-RuO_2/Nafion and IPMNC-LbL CNC having low thickness and high Youngs modulus can be actuated for higher deflection at typical flapping frequencies (40-47 Hz). The structural modelling of unencapsulated IPMCs (u-IPMC) intended for use under dry and humid environment is carried out for optimization of design parameters for retention of water and to study the influence of water activity on the actuation. IPMC designed with Nafion having equivalent weight 900-1100, preheated at 30 °C and sodium cation is more promising for optimum retention of water and actuation. For operation in these environments, the actuation parameters can be tuned to the desirable level by changing the water activity and

temperature of the user environment. For the design of dragonfly size flapping wing, the flexural stiffness of IPMC should be comparable to that of the actual insect wing for proper flapping motion at higher flapping angle and deflection. Therefore, structural modelling of dragonfly scale IPMC is carried out. The IPMC actuator [IPMNC-RuO_2/Nafion with thickness 450 μm (Nafion 400 μm and both electrodes 50 μm), resonant frequency 31.5 Hz, Youngs modulus $\approx$ 2 GPa, mass 378 mg] modelled in dragonfly species, *Sympetrum Frequens*, shows better flapping and actuation than the other insect scale actuators. In structural design of insect scale flapping wing, the attachment of wing on the IPMC actuator as an array of actuator-sensor may lead to self-powered flapping. The influence of attachment of wing on the actuator on the actuation force and frequency to lift and flap the attached wing is studied. High frequency (20 Hz) actuator (170 mg semi wet) with an attached mass equivalent to the wing mass, produced higher actuation force, with reasonable frequency and deflection. The studies on the dragonfly scale flapping wing fabricated with IPMC-cyclic olefin copolymer (COC) membrane based hybrid structure and the performance of various wing configurations reveal that high frequency IPMC actuator fitted with the high modulus COC membrane with two-vein configuration (leading edge and centre of the wing) is the more promising structure as dragonfly scale flapping wing. In conclusion, with the analysis and design presented in this thesis, the optimized design and material parameters of IPMC can be exploited for increased actuation performance at the dragonfly (*Sympetrum Frequens*) insect size. The high frequency IPMC can act as flapping wing with capabilities of a sensor. The hybrid structure comprising high frequency IPMC actuator fitted with the high modulus COC polymer membrane is a promising flapping wing. The output voltage of IPMC wing could indicate the level of actuation performance of the wing at different conditions such as change in temperature, humidity or water content. Moreover, the actuator-sensor array can also help to predict the environmental conditions and also used as an input for control algorithms.