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ROBOT-CHAOS INTERACTION

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Abstract
This paper reviews the state-of-the-art technologies and principles underlying the novel interaction between the science of robotics and chaos theory which has resulted to the modelling and integration with various topological, dynamical and evolutionary characteristics associated with humans and mammals into robots and the interplay between these characteristics and new behaviours in mobile robots. Application of chaos in robotics has facilitated the emergence of a new genre of humanoids and other highly complex autonomous systems in the form of underwater, aerial and mobile robots that have found applications in the education, engineering, entertainment, medical and military fields. Current trend in robotics and the seemingly boundless world of chaos in robotic research are also discussed.

Keywords: Chaos, Interaction, Mobile robot, Robotics

1.0 Introduction

In recent years, the world of engineering has witnessed a surge in innovations, inventions, explorations and the widening of the frontiers of research on almost all spheres of human endeavours and even in areas never anticipated before now. In less than four decades ago, engineering and sciences were restrictive in the sense that authorities were localized. During these times, an electrical engineer naturally 'arrogates' all knowledge and pontificates on all issues relating to the electrical engineering field and could even attempts to "defend" the 'territorial integrity" of his profession. Ditto the Civil, Mechanical and other branches of engineering. Especially in Africa and Nigeria in particular, it was somewhat of an anathema for a Physicist, biologist, chemist, mathematician, accountant or an economist to critique the subject of engineering due to prevailing misconceptions. Nowadays, however, there is a new wave of 'globalization' that has led to an unprecedented interchange of knowledge and collaborations among experts of various disciplines, leading to the blending of those disciplines to produce new ones, effectively obliterating the fault lines of "intellectual dictatorship". For example, there is now 'mathematical Biology', 'Applied Biochemophysics', 'Neural Engineering', 'Genetic Algorithm', 'Fuzzy Control', 'Biomechanics', 'DNA Computing" amongst a large body of similar nomenclatures. These new interfacial specializations are the results of cross-fertilization of knowledge fueled by the collective desire of humankind to make the world a better place.

The Electrical and Electronic engineering discipline has expanded considerably in recent years, evolving into more than a hundred sub-disciplines and continues to grow. These sub-disciplines have resulted from the synergy between two or more dissimilar or divergent fields. As the dynamics of modern societies continue to grow in complexities, the challenges of engineering grow exponentially because the society depends on engineering for security and development. In this context, one of the most refreshingly active areas of interdisciplinary and multidisciplinary research in applied engineering sciences is robotics, due to its tentacular role in managing several challenging tasks that humans and mammals are unfit or unwilling to execute, especially for security reasons.

2.0 Understanding Robots, Chaos and Chaos Theory

According to the Robotic Institute of America, a robot *is a programmable, multifunctional manipulator designed to move materials parts, tools or specialized devices through various programmed motions for the performance of a variety of tasks* (Koren 1985). These tasks traverse various aspects of human endeavours. Robots could be immobile or mobile. Immobile robots are those that have jointed arms and gripper assembly and are essentially mounted on a rigid platform to execute various tasks such as industrial robots. Mobile robots, on the other hand, are those that have the capability to move around and interact with their immediate environment (Nedjah et al. 2007). Mobile robots may be classified based on the environment in which they operate e.g. aquatic, terrestrial and aerial robots (Barett et al. 1999), based on their control strategy and intelligence e.g. line following, tele-operated, autonomously guided robots (Siegwart and Nourbakhsh (n.d.) and also based on their complexity and computing power such as the swarm robot ((Mondada et al. 2004). Mobile robots have found applications in such tasks as entertainments (Dautenhahn et al. 2006), military engagements of de-mining, patrol, bomb disposal and bomb detection (Anwar and Khammari 2011), intricate surgeries (Taylor 2004), firefighting (Tavera et al. 2011) amongst many other applications.

Chaos is a phenomenon prevalent in deterministic nonlinear complex dynamic systems that are extremely sensitive to disturbances in their initial states and structures (Bolotin et al. 2009). This implies that a slight perturbation in their initial conditions can lead to unpredictability of their future outcomes. The characteristics of chaos which include determinism, ergodicity and topological transitivity have been exploited considerably by engineers and applied scientists to model, analyse and optimise complex systems. Extensive inquests has established the presence of chaotic phenomena in almost all man-made and natural systems. ***THERE IS CHAOS IN EVERYTHING!***

Chaos theory is a blanketing theory that describes chaotic phenomena in all their ramifications and occurrences in natural and man-made systems. Chaotic systems are those systems that exhibit chaotic behaviours. Chaotic systems have proliferated during the last decade as extensive research resources have been plunged into the study of this intriguing dynamics. Among these systems that have been evolved and studied and also controlled by other authors are the Lorenz system (Lorenz 1963), Sundarapandian-Pehlivan system (Sundrapandian and Pehlivan 2012), Rabinovich system (Pikovsky 1998), Lorenz-Rossler system (Umoh 2013a), Ai-Yuan-Zhi-Hao hyperchaotic system (Umoh 2013b), Yu-Wang (Umoh 2015) and the Matsumoto-Chua-Kobayashi circuit (Matsumoto et al. 1986) amongst a large body of others in the literature.

3.0 Concepts of Autonomy in Robots

The concept of autonomy in robotics is an inclusive one which covers intelligence, knowledge, design methodologies and algorithms for trajectory control, obstacle avoidance and map building (Adouane et al. 2011). Applications of classical robots to real life tasks was limited by inflexible path planning and navigational algorithms. Trajectories were preplanned, predictable and also followed a well-defined mapping of the navigation environments. Robot algorithms developed a complete path from source point to target point even before the robot initializes its motion (Li et al. 2013). Some of these path planning methods are well-documented and they include such classical methods as roadmap methodology where the robot connects the source point to target point by curved or straight lines (Mohanty and Parhi 2013), cell decomposition techniques, in which a robot is programmed to discriminate between geometric areas or cells that are free and those that are occupied by obstacles (Shojaeipour et al. 2010) and artificial potential field method, in which artificial forces generated by an obstacle or target are applied to a task robot to enable it traverse a mapped out environment collision-free (Meyer and Guillot (n.d)). Other methods that have been applied to enhance the performance of robots are heuristic methods which include fuzzy control (Chunhua 2011), adaptive control (Huang and Chien 2010), genetic algorithm, particle swarm optimization and ant colony optimization amongst others (Hoffman 1994). Although the above-mentioned techniques succeeded in enhancing the performances of robots, they still fell short of meeting the criteria required to tackle challenges in unmapped environments.

4.0 Robots-Chaos Interactions

To be able to interact with humans, robots need basic skills and intelligence and should be able to behave in socially acceptable ways. The interdisciplinary study of interaction dynamics between humans and robots is called Human-Robot Interactions (HRI) (Goodrich and Schultz 2007). According to Feil-Seifer and Mataric (n.d), HRI research is a convergence of engineering (electrical, mechanical, industrial), computer science (computer vision, artificial intelligence and human-computer interaction), social sciences (Psychology, cognitive science, anthropology) and humanity (ethics and philosophy). In order to mimic the complex behaviours of humans, animals and birds, nonlinear chaotic dynamics are incorporated into the kinematics of mobile robots (Nakamura and Sekiguchi 2001). For the sake of simplicity, the term "Robot-Chaos Interaction" is used to describe this interaction. These interaction dynamics enable a robot to exhibit spontaneous and erratic behaviours and gaits that matches their functions and environments similar to the way humans and animals respond to stimulus and their environments.

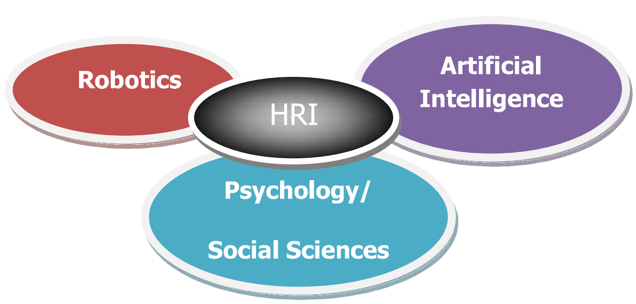


Fig.1: Human-Robot Interaction

In this paper, the outcome of researches into robot-chaos interactions which has resulted in the design of mobile robots which are imbued with artificial intelligence, giving rise to a generation of robots for RISE (Risky Intervention and Surveillance Environment) applications (Bedkowski 2011) is discussed. The interaction between robotics and chaos theory is illustrated in Fig.2. Some of the characteristics of these genre of robots are adapted from (Vepa 2009) and illustrated in Fig.3.

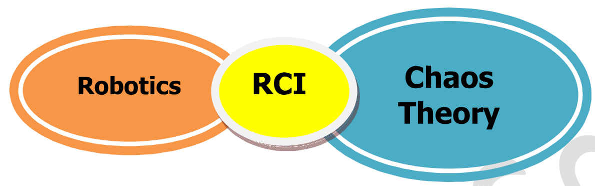


Fig.2: Robot-Chaos Interaction

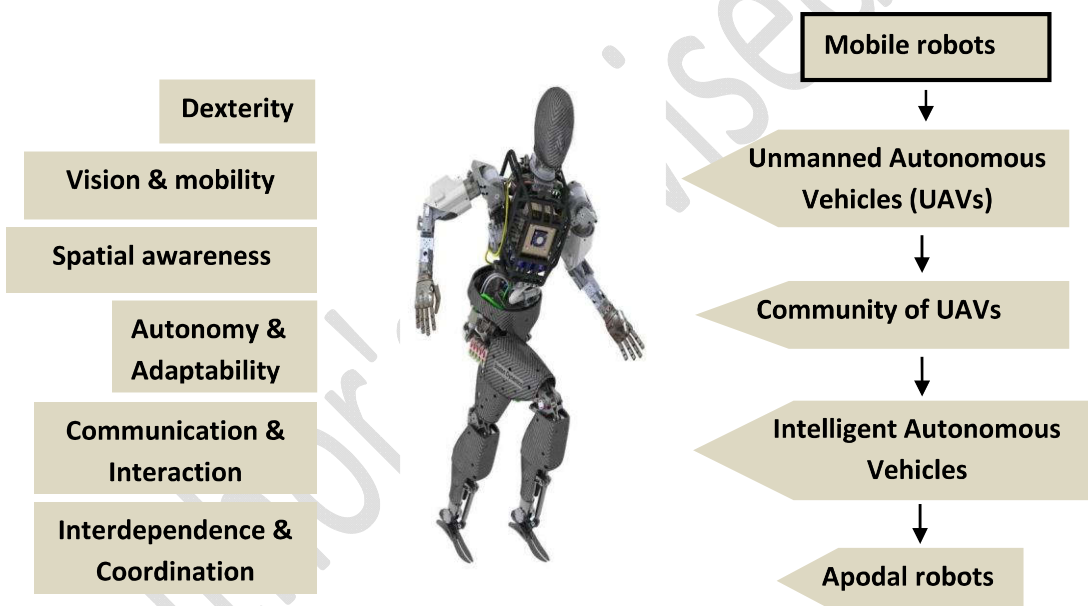


Fig.3: Robot's behavioural characteristics

Source: Adapted from (Vepa 2009)

4.0 Results of RCI in Robotic Research

In general, non-chaotic mobile robots are capable of multiple intelligences, spatial awareness, communication and interactions, vision and mobility, interdependence and coordination as can be seen for example, in many unmanned autonomous vehicles. However, the introduction of chaos into the dynamics of these robots add peripheral human behaviours and instincts to the robot's behavioural tendencies. Three outstanding features than have enhanced robot's performance in search and rescue operations and various military field operations are the unpredictability of robot's trajectories, unconstrained behaviours (spontaneity), dexterity and adaptability to the unmapped environments (clustered, hilly, stony or amphibious).

a. Dexterity: This is the ability of a robot to flex its muscles and limb to grab, push pull things in all spatial dimensions as in rescue robots and Gecko robot (Lizard) shown in Fig.4.These robots can climb walls like Geckos (Saunders et al. 2006), trees like Lizards (Spenko 2006), sense and run like cockroaches (Clark et al. 2001) and walk and bear burden like mules (Poulakakis et al. 2005).

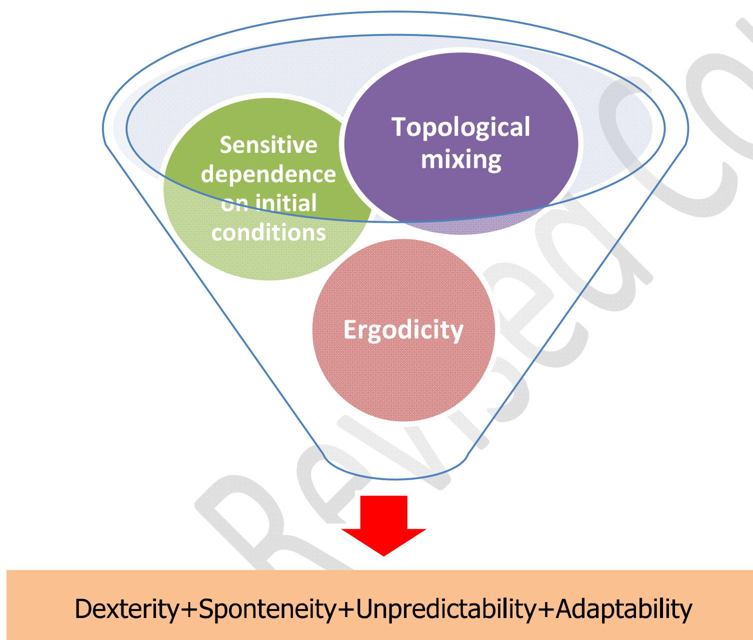


Fig. 4. Results of chaotic features in mobile robots

b. Spontaneity: Unlike non-chaotic mobile robots which are practically constrained by the embedded algorithm leading to some predictability of their trajectories, the behaviour of a chaotic mobile robot is unconstrained, and therefore largely unpredictable. This features add security to them when in used in risky environments.

c. Adaptability: Chaos has made it possible to invent robotics such as vacuum cleaners and lawn mowers that can carry out apportioned tasks faster than those manually operated by a taskmaster. These systems are capable of covering a workspace of unmapped environments. A special advance in robotic research is the breakthrough in producing snake robots. These robots exhibit serpentine locomotions, charges and reacts much in the same way as a serpent (Hirose 1993; Hirose and Fukushima 2004). These robots can adapt to rocky and hilly terrains and tunnels much in the same way as real snakes do.

Many humanoid robots can move with gaits similar to humans and can interact and response to verbal cues, blink their eyes and smile like the Kismet robot (Hirose and Fukushima 2004) and Uando robot (MacDorman and Ishiguro 2006).

5.0 Gallery of Prototypical Mobile Robots

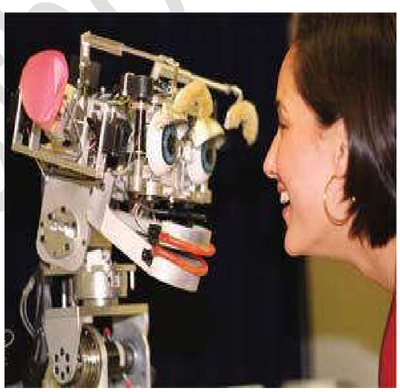
The following pictures in Fig.5 (a) – (j), extracted from different sources show the prototypes of mobile robots with possible chaotic or chaos-enhanced behaviours

(a)

(b)

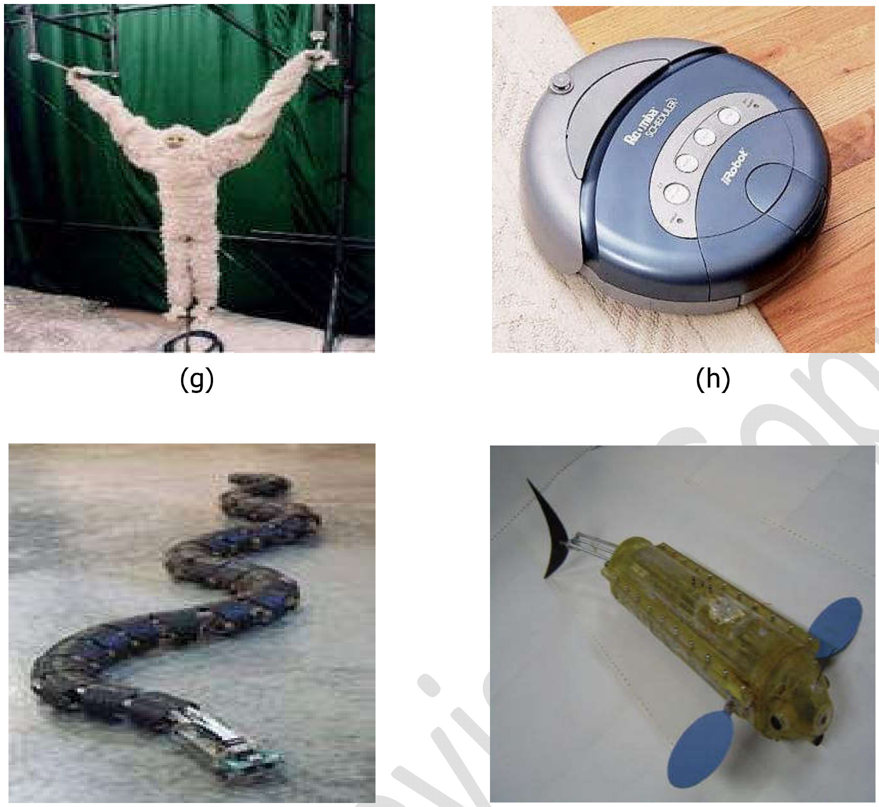
(c)

(d)



(e)

(f)



(g) (h)

(i) (j)

Fig. 5. Gallery of prototypical mobile robots

a. Stickybot (Saunders et al. 2006)
b. RiSE (Robot in Scansorial Environment) robot (Spenko 2006)
c. Cricket robot (Clark et al. 2001)
d. BigDog (Poulakakis et al. 2005)
e. Kismet (Anthropopathic or human-friendly robot) (Hirose and Fukushima 2004)
f. Uando robot (MacDorman and Ishiguro 2006)
g. Brachiator robot (Gibbon) (Saito and Fukuda 1996)
h. Vacuum cleaner robot (Roomba) (www.youtube.com)
i. Fish robot (Zhou et al. 2008)
j. Snake robots (Hirose 1993)

6.0 Future research directions in RCI

Intensive research is still ongoing in many universities and research centres around the world on the evolvement of robots with advance intelligence and human-character prototypes. Evolutionary algorithms, soft computing, hybrid sciences have been advanced through genetic- and bio-inspirations. In this context, inspirations from bird flocking, ant foraging, mammals, ocean creatures and insects are continuously studied. In the near future, unpredictability will be the keyword in engineering designs!

7.0 Conclusion

This paper reviews the direction of current developments in the sciences of robotics and chaos theory where their interaction has engendered an unprecedented advance in research and development of new genre of robots endowed with ruggedness, artificial intelligence and functionalities that moves them closer to humans and mammals. Forecasts about the directions of technology are no longer reliable, just as Moore's law for integrated circuits has floundered in the face of current realities in the world of technology. Engineering is about development and development is about engineering. The synergy between these two will continue to drive the evolution of modern society in all ramifications. Understanding the role of chaos in bring these technological changes will go a long way in assisting engineers to maximize it for modelling, analysis and design.

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