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Literature Review for the Design and Implementation of the Archer Robot

Alexander C. Abad* and Elmer P. Dadios

***Abstract* — This paper presents a literature review for the design and implementation of the Archer Robot that is capable of knocking an arrow to a standard recurved bow, drawing the arrow, and hitting a target. Ancient and current human-like mechanical archers, machine vision, and intelligent controllers that can be the bases for the future Archer Robot are discussed in this paper.**

Keywords: **Archer Robot, archery, artificial intelligence, machine vision**

I. Introduction

Humans have a long history of creating something that looks and moves like a human [1]. One of the earliest accounts of human-like automaton (a machine that can move by itself, plural form: automata [2]) was written in the Lie Zi text in China, which dates back to the third century B.C. [3,4]. Inside the text is a story about King Mu of Chou, who encountered Yen Shih, an artificer who presented a life-like humanoid (human resembling) automaton that can sing and act. The king was astonished by the skills of the humanoid robot. The humanoid even winked its eye and made advances to the ladies that made the king very angry and want to execute the artificer. Due to fear of death, the artificer destroyed the humanoid automaton and showed to the king that it is just made of leather, wood, glue, and lacquer, colored with white, black, red, and blue. The king was convinced and delighted with the skill of the artificer that he exclaimed, "Can it be that human skill is on a par with that of the great Author of Nature?" [4].

In the following centuries, many human-like automata or moving dolls and statues were developed such as the automaton of Hero of Alexandria (100 A.D.), the humanoid automaton of Al-Jazari (1200), the humanoid automaton of Leonardo da Vinci in the late 15th century, the Jacquet-Droz's family of androids in Europe, and the mechanical dolls of Japan, known as "karakuriningyo," both developed in the 18th century [1, 5].

Human-like automata flourished in the 20th century. Humanoid animatronics systems with programmable human-like movements synchronized with audio became an attraction at theme parks. These systems were fixed open-loop without sensing their environment. Later on, with the advancement of digital computing, humanoid animatronics were incorporated with the ability to sense, control, and actuation at the end of the 20th century [1]. Automata with a closed-loop system were later called "robots." The term *robot* was derived from *robota*, which means subordinate labor in the Slav languages. The term was first introduced by Karel Capek in his play "Rossum's Universal Robots (R.U.R.)" in 1920 [5].

The 21st century has been labeled by many roboticists as the "age of the robots." Intelligent autonomous machines will gradually substitute for many automatic machines [6]. These robots are not only programmed to do certain tasks but are capable of learning from their environment. Humans' dream of creating something like them in movement and thinking is becoming a reality in the field of humanoid robotics. This area of research is like a "mirror" that can help us reflect and understand ourselves relative to motion, sensing, perception, and thinking.

Eye–hand coordination has been mastered by humans through experience. Humans are capable of estimating depth and distance of objects within their reach. In the field of robotics, visual servoing is the counterpart of eye–hand coordination. Robust and intelligent algorithms are needed to perform efficient, repeatable, and accurate control of robotic arms to perform tasks such as putting an arrow to a bow and pulling it to shoot a target.

Generally, even humans have difficulty in tracking and shooting an object within the environment. This human ability to adapt and to adjust body movements in order to shoot a target is difficult to incorporate in a robotic system.

The Archer Robot in this study will use a standard recurved bow used in archery competition. It will be designed to knock an arrow to a bow, draw the arrow,

Alexander C. Abad* and Elmer P. Dadios, De La Salle University, Manila, Philippines
*(e-mail: alexander.abad@dlsu.edu.ph)

and hit a static target. It will use artificial intelligence algorithms for control and machine vision (MV) for its feedback. The robot will have a static lower body but with an upper body capable of pivoting to the left or right by turning its waist.The Archer Robot will track and shoot the official 80-cm target spot face based on the FITA beginners' manual [7]. The shooting of a static target will be characterized at different distances relative to the Archer Robot. Distances will be 6 m (FITA Red Feather), 8 m (FITA Gold Feather), 10 m (FITA White Feather), 14 m (FITA Black Feather), and 18 m (FITA Blue Feather—official FITA indoor distance) [7]. All testing will be held indoors to neglect wind resistance.

II. Significance of the Archer Robot

The Archer Robot can be a very good platform for education. With regard to control systems, this study can contribute to the growing area of intelligent control. It can be a programming project wherein a robot can be treated as a black box to be programmed in order to display a concrete physical manifestation of the programming codes [8].

The Archer Robot can be a learning focus because a robot can stimulate students to be interested in science, technology, and engineering. It can promote life-long learning results in areas such as teamwork, problem solving, and self-identification with technology-focused careers [8]. This study can be a point of collaboration among engineering courses especially in the fields of mechanical engineering, electronics engineering, and computer engineering because it covers a wide area of knowledge and applications.

The Archer Robot can be a learning collaborator wherein a robot can enhance the learning process by imbibing dedication in learning. It can be a source of discovery and wonder for students [8].

The Archer Robot not only is for education but can also be for entertainment. Due to advancements in the field of robotics, educational robot tournaments are becoming popular [8]. Sooner or later, there will be an archer robot competition among different schools and universities. This study can be a very good platform in preparation for this future competition.

The feedback mechanism of the Archer Robot using MV can be used for industry applications and also for security and surveillance applications. The MV algorithm that will be developed in this study can be used in a manufacturing plant. This can be used in the industry for inspection of parts, color matching, gauging, quality checking, and robotic guidance for picking up or segregating a moving object in a conveyor belt. In military, it can also be used in the interception of flying attackers such as drones.

III. Review of Related Literature

This section focuses on research regarding human-like archer automata, humanoid archer robots, and some robotic arms that can play like humans. It also covers research on machine control and MV.

1) Archer Automata

a) Karakuriyumiiridōji, ("bow-shooting boy") by Hisashige Tanaka:

Fig. 1. *Karakuriyumiiridōji,* ("bow-shooting boy") by Hisashige Tanaka [10].

Kakakuri can be translated as "a tricky mechanical device or gadget" [9]. It is a self-operating wooden puppet equivalent to Western automata with clockwork mechanisms [10]. Figure 1 shows the whole setup of the Japanese archer automata created by Hisashige Tanaka (1799–1881) [10], inventor and founder of Shibaura Engineering Works (a predecessor of Toshiba) [9].

Yumi-iri Doji has four small arrows in a case at his side and removes each arrow one by one into his bow and shoots by pulling back on the bow. The whole process is shown in Figure 2, which is lifted from [9, 10]. A YouTube video link of a*karakuri* can be found in [11].

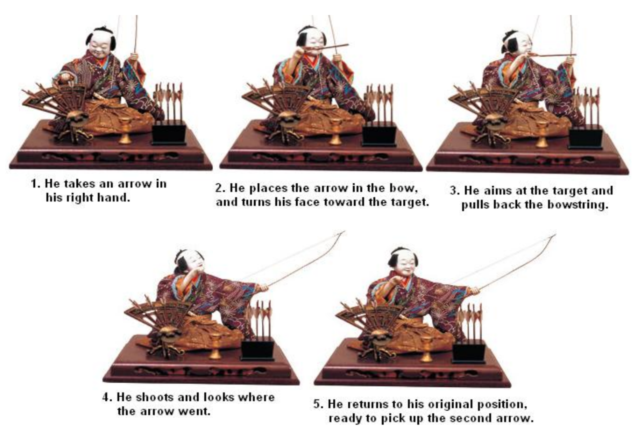

Fig. 2. *Karakuriyumiiridōji,* ("bow-shooting boy") steps in shooting [9, 10].

b) Samurai Archer by Hideki Higashino:

According to [12], Hideki Higashino is one of the few remaining craftsmen who continue the Japanese *karakuri* tradition that dates back 200–300 years to the Edo period. His *karakuri* samurai archer shown in Figure 3 can draw arrows, put them in the bow, and pull it to shoot a target. These steps are very similar to Figure 2.2, but the archer is in a standing position and the arrow can stick to the target. A video of this *karakuri* samurai archer is accessible through the links provided in [12, 13].

Fig. 3. Samurai archer by Hideki Higashino [13].

c) Yabusame ("Horseback Archer") Karakuri by Tsuyoshi Yamazaki:

Another version of archer *karakuri* is the *yabusame* or the horseback archer made by retired engineer Tsuyoshi Yamazaki. This *yabusamekarakuri* was the first-prize winner in the "World Karakuri Contest" in the 2005 World Expo, Nagoya, Japan [14]. Shown in Figure 4 is a *karakuri* archer riding a horse and shooting three targets. The archer is moving horizontally as it shoots the target. A video clip of this *karakuri* in action is available in the link provided in [15].

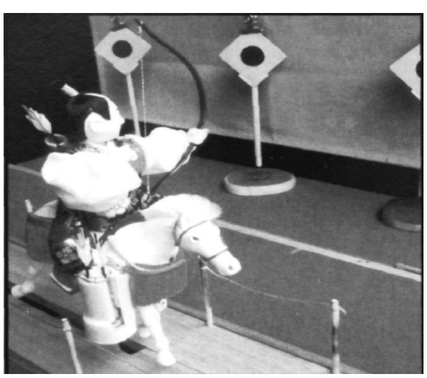

Fig. 4. *Yabusamekarakuri* by Tsuyoshi Yamazaki [14].

2) Toylike Humanoid Archer Robot

a) Hammerhead:

This lightweight (less than 3kg) humanoid robot of the Osaka Sangyo University Waling Project [15] demonstrated its arrow shooting capability during the 16th Robo-One Championship held last 2009 in Toyama City, Japan [16]. This archer robot shot an arrow at a glass plate target. The arrow has a suction cup tip and was able to stick on the glass plate when Hammerhead shot it [17]. Shown in Figure 5 is a snapshot of Hammerhead from a YouTube video [18].

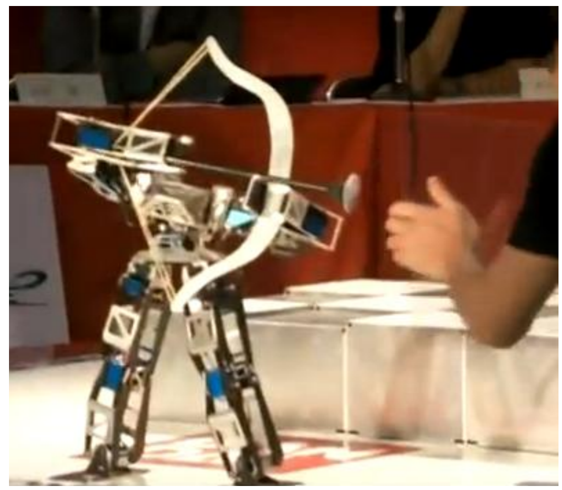

Fig. 5. Hammerhead in the 16th Robo-One Championship [18].

b) i-SOBOT Archer:

i-SOBOT is a 6.5-inch humanoid robot thatis certified as "The World's Smallest Humanoid Robot in Production" by the Guinness World Records [19]. Figure 6 shows an i-SOBOT archer capable of shooting an arrow. A video clip is available on YouTube [20].

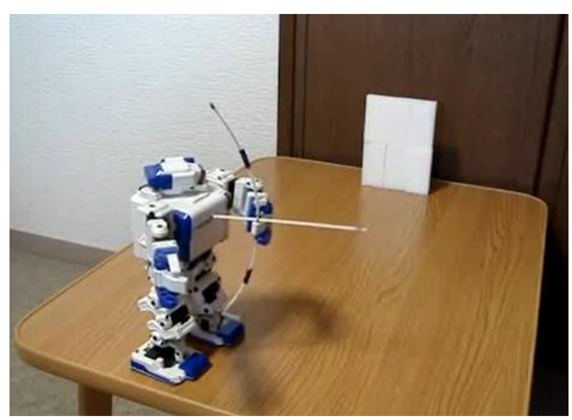

Fig. 6. i-SOBOT Archer [20].

c) The iCub Archer:

The 53-degrees of freedom (DOF) humanoid robot iCub shown in Figure 7 was programmed with a learning algorithm called ARCHER (Augmented Reward CHainEd Regression) to hold the bow, release the arrow, and learn by itself to aim and shoot arrows at the given target. It was able to learn to hit the target in only eight trials [21]. The paper [21] and the video [22] of iCub Archer were presented at the 2010 IEEE-RAS International Conference on Humanoid Robots, Nashville, TN, USA. Unlike the karakuri archers [9–15] that can put arrows to the bow, iCub used a loaded bow.

Fig.7. iCub Archer Robot [22].

So far, toy-like archer automata and archer robots were presented above. The bow and arrow used are not official archery tools. Though not related to archery, life-size robots with human-like skills are presented in the next sections. They can be a great source of motivation for the future Archer Robot.

3) Robots With Dexterous Arms

The following are robots with dexterous arms performing some human tasks with flexibility, mobility, and agility. Most of them are being used by different universities as an educational platform. All of them utilize an MV feedback system for closed loop control.

a) Sword Wielding Robots:

Inspired by the movie *Star Wars*, the Yaskawa Company showed at the 2009 International Conference on Robotics and Automation (ICRA), in Shanghai, two industrial robots with "lightsabers" performing a choreographed motion of sword wielding with each other [23]. Shown in Figure 8 is a snapshot from [24] for the "Jedi vs Sith" robotic arm demonstration.

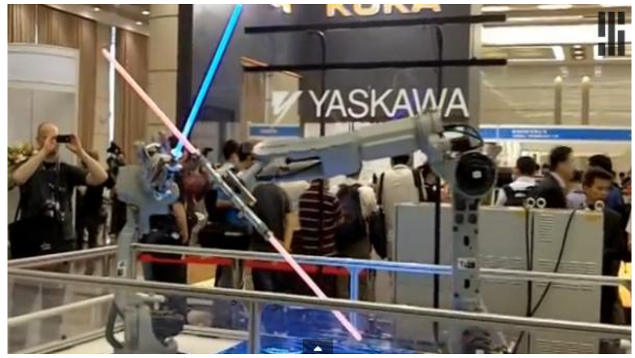

Fig. 8. "Jedi vs Sith" [24].

Another sword wielding performed by a robot was demonstrated in 2011 by students at Stanford University under the supervision of Prof. Oussama Khatib. This robot, called "Jedibot," has been programmed to attack and to defend versus a human opponent. Using a Kinect sensor, it can track the motions of color-coded foam swords [25, 26]. A snapshot of "Jedibot" from a Stanford video clip [27] is shown in Figure 9.

Fig. 9. "Jedibot" [27].

The "Jedibot" is just one of the projects in Khatib's Experimental Robotics course at Stanford. Other robot projects include a robotic arm that plays golf, a robotic arm that can write, and a robotic arm that can cook hamburgers [25].

b) "Wu and Kong":

Two life-size humanoid robots, Wu and Kong, developed at Zheijiang University in China, were able to play table tennis. The two robots were designed to have ball tracking technology, accurate identification, location prediction, motion modeling, and balance [28]. A snapshot of Wu and Kong from a Reuters video clip [29] is shown in Figure 10.

Fig. 10. Wu and Kong [29].

c) Motoman SDA10 Robot:

The Motaman SDA10 is an industrial dual-arm robot created by Yaskawa Electric Corporation and has been programmed to perform many complex tasks [30–33]. Figure 11 is a snapshot from a YouTube video clip [31] showing how the Motoman SDA10 cooks *okonomiyaki*. The cooking ability of the robot was demonstrated at the Food Machinery and Technology Expo in Tokyo 2008 [33]. The Motoman SDA10 cook in Figure 2.11 was developed by Prof. Paul Rybski and a pair of graduate students from Carnegie Mellon University. They used a $20,000 laser navigation system, sonar sensors, and a Point Grey Bumblebee 2 stereo camera that functions as the eyes of the robot [33].

Fig. 11. Motoman SDA10 cooking [31],

In another video clip recorded in 2008 [32], with a snapshot in Figure 12, the Motoman SDA10 was able to assemble a camera and take a picture at the end of the task.

Fig. 12. Motoman SDA10 assembles a camera [30].

d) Rollin' Justin:

Rollin' Justin is a mobile humanoid robot with two arms. It is designed for research on sophisticated control algorithms for complex kinematics and mobile two-handed manipulation and navigation. It has 3 DOF in the torso, 7 DOF in each arm, 12 DOF in each hand, and 2 DOF in its head [34]. This robot is capable of catching flying balls and preparing coffee. It is capable of carrying out dynamic and sensitive tasks [35]. Justin can catch not only one ball but two balls thrown at the same time. A snapshot from a video clip [36] of Justin is shown in Figure 13.

Fig. 13. Rollin' Justin catches two balls [36].

4) MVVersus Computer Vision

MV is not the same as computer vision (CV) [37]. In general, MV is more of a system utilizing CV. MV is more practical while CV is more theoretical. Although MV and CV relate to artificial vision systems, MV is more on the hardware architecture and application of a vision system, while CV is more on the software or algorithm aspect of MV. Table I, based on [37], shows a comparison between MV and CV. Entries in the MV column are related to a factory-floor machine.

TABLE I
COMPARING MV AND CV

Feature	**MV**	**CV**
Academic/practical motivation	Practical	Academic
Advanced in theoretical sense	Unlikely (practical issues are likely to dominate over academic matters).	Yes. Academic papers often contain a lot of “deep” mathematics.
Cost	Critical	Likely to be secondary of importance
Dedicated electronic hardware for high-speed processing	Very likely	No (by definition)
Designers willing to use nonlogarithmic solutions to solve problems	Yes (e.g., are likely to benefit from careful lightning)	No
In situ programming	Possible	Unlikely
Input data	A machine part, piece of metal, plastic, glass, wood, etc.	Computer file
Knowledge of human vision influences system design	Most unlikely	Very unlikely
Most important criteria by which a vision system is judged	(a) Ease of use (b) Cost effectiveness (c) Consistent and reliable operation	Performance
Multidisciplinary	Yes	No
Nature of an acceptable solution	Satisfactory performance	Optimal performance
Nature of subject	Systems engineering, practical	Computer science, academic (i.e., theoretical)
Operates free-standing	(a) Interactive prototyping system must be able to interact with its human operator (b) Factory floor (target machine) must be able to operate free-standing	May rely on human interaction
Operator skill level required	(a) Interactive prototyping system: medium/high (b) Factory floor (target machine) must be able to cope with low skill level	May be very high
Output data	Simple signal to control external equipment	Complex signal for human being
Speed of processing	(a) IPT enough for effective interaction (b) Real-time operation is very important for TM	Not of prime importance
User interface	Critical feature for IPT and TM	May be able to tolerate weak interface

Note. Entries in the MV column relate to the factory-floor target machine, unless otherwise stated [37].

In order to create an MV system, the person in charge must take into consideration different technologies such as the ones presented in Table II. The MV system is an integration of diverse technologies. The person in charge is a system engineer rather than a scientist [37].

TABLE II
TECHNOLOGIES NEEDED TO DESIGN AN MV SYSTEM [37]

Technology	Remarks
Mechanical handling	(i) Presenting objects to the camera for viewing (ii) Mounting camera and lights rigidly and without causing undue obstruction within the camera's field of view
Lightning	Critical part of any MV system
Optics	Lightning and optics can often convert a very difficult problem into a trivial one
Sensor	Camera, line-scan sensor, laser scanner, ultra-sonic sensor, x-ray sensor
Systems architecture design	Organization of the overall system
Analog and video electronics	Normally used principally for preprocessing
Digital electronics	To reduce the data rate
Algorithms and heuristics Software	CV normally claims these twoareas for itself. MV has a "legitimate interest" in them too.
Industrial engineering	Design for robustness in the hostile factory environment
Communications	(i) Networking to computers in company and other vision systems (ii) Connection to other factory machines, programmable logic controllers, etc.
User interface	Design for ergonomic interface to a human operator
Quality Control	Design for industrial, operational, and environmental
Production Engineering	Compliance with current working and quality-control practices. It may be possible to modify the product or process to make inspection easier/more reliable.

a) Active and Passive 3D Vision Systems

Depth perception is one of the most investigated aspects of biological and MV [38]. With depth perception, a three-dimensional (3D) view of the environment can be realized. The use of 3D information is vital in the field of robotics, especially in MV systems, in order to detect and avoid obstacles in a 3D workspace, to recognize objects, and to map environments [39]. Depth perception has been utilized for distance or range measurements. The development of accurate, low-cost, and compact vision-based range sensors is a dynamic area of research in the field of robotics. Vision systems for depth perception or range sensing techniques in the field of robotics can be classified as active or passive. Active range sensing uses a reflected beam of light coming from a light source, which is commonly a laser, while passive range sensing depends only on ambient light [40]. Laser range finders have been around for half a century. They were first used and demonstrated by John D. Myers in 1965 [41]. Direct and active range finding techniques in MV or CV involve light time-of-flight (TOF) estimation and triangulation systems [42]. Active triangulation is one of the first range imaging approaches used in robotics [39]. It is a well-established technique for measuring distance (range) to surfaces, which is composed of a light source and a camera placed at a certain lateral distance (baseline) from the source [43]. Active techniques, such as laser scanning and contrived lighting (striped light, grid coding, and moiré fringe contouring), intentionally project illumination into the scene in order to construct easily identifiable features and minimize the difficulty involved in determining correspondence [42, 44]. Depth perception using the triangulation technique is not only for active vision systems but has been also implemented in passive vision systems [44–46]. Triangulation in passive range finding techniques does not require structured illumination. Such techniques are much more flexible than the active ones [45]. In general, passive methods have a wider range of applicability since no artificial source of energy is involved and natural outdoor scenes (lit by the sun) fall within this category [42]. Depth perception via passive techniques can be monocular image-based or stereo-based. Monocular image-based range finding includes texture gradient analysis, photometric methods (surface normal from reflectance), occlusion effects, size constancy, and focusing methods [42]. On the other hand, the passive stereo ranging technique is also a triangulation technique with the same geometric characteristics as active triangulation, except the range is computed by triangulation between the locations of matching pixels in images rather than between a known source and an observed pixel [39]. A taxonomy of vision techniques via optical sensor has been presented in [45] and is shown in Figure 14.

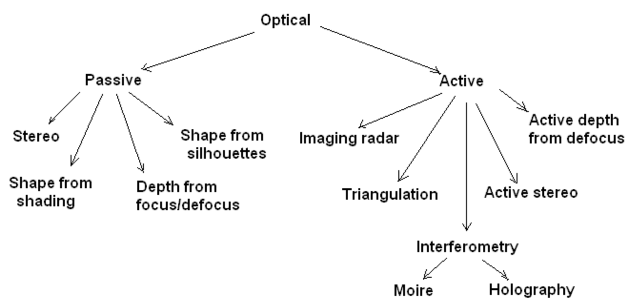

Fig. 14 Taxonomy of vision techniques [45].

The 3D scene reconstruction from projections on a 2D sensor is inherently ambiguous. In the field of robot vision, there are many proposed methods for depth perception such as stereoscopic vision, depth from motion parallax, and depth from oculomotor parallax [38]. Among these techniques, there have been many studies with regard to stereo vision, and some of them are discussed in the next section.

b) Stereo Vision

Range sensing is vital in the field of robotics to detect obstacles or target within the surrounding. Scanning lasers are the most widely used range sensor for robotics, but they are not the only way. There is an increasing popularity of stereo vision range sensing techniques for mobile robots. Compared to scanning lasers, stereo vision has passive camera sensors that are lightweight, power efficient, and low-cost. The cameras in stereo vision do have sensitive mirrors, and the optics found in scanning lasers make them more robust to vibration, shock, and the effect of strong magnetic fields. Stereo vision is well suited for use on moving platforms, unlike lasers that scan the environment in a sequential manner from which any movement during laser scanning can skew the results unless it is taken into consideration. The stereo vision technique produces dense 3D data, compared to the relatively sparse 2D data of a single 2D laser scan [47]. Stereo vision has been used in long-distance ranging [39] such as the one presented in [48], which is capable to detect 14 cm or 35.56 in obstacles at over 100 m (109.36 yards) for on-road obstacle detection. A study in [49] shows encouraging results comparing stereo vision performance with a laser rangefinder. It was reported that a stereo rangefinder (SRF) can be an alternative to a laser rangefinder (LRF) for operating at short–medium ranges in man-made environments.

c) Visual Servoing

Visual servoing means a closed-loop position control for a robot end-effector using MV. The term is generally called visual feedback [50]. A survey of visual servoing for manipulation can be found in [51], where it discusses theories, applications, and comparisons of the different visual approaches for robotic manipulation during the past three decades.

On the other hand, [50] presented a tutorial introduction to robotic servo control that focused on the fundamentals of coordinate transformations, image formation, feedback algorithms, and visual tracking.

Visual servoing is the use of CV data to control the motion of a robot. The vision data comes from a camera, which is mounted directly on the robot or on a fixed position in the workspace observing the robot. Visual servoing relies on image processing, CV, and control theory [52]. Generally, there are two camera configurations: eye-in-hand, wherein the camera is mounted on or near the end-effector, and eye-to-hand wherein the camera is at a distance from the robot manipulator capturing a panoramic vision of the environment [53]. According to [54], there are two basic approaches to visual servoing control, which are image-based visual servo (IBVS) and position-based visual servo (PBVS). In IBVS, the error signal that is measured directly in the image is mapped to actuator commands, while PBVS utilizes CV techniques to reconstruct a 3D workspace on which the actuator commands are computed. A hybrid method combining the advantages of IBVS and PBVS has been reported in [55] and is called 2D 1/2 visual servoing. It is based on the estimation of the camera displacement between the current and desired views of an object.

According to [52], the main goal of any vision-based control system is to minimize an error $e(t)$, defined by

$$e(t) = s[m(t), a] - s^* \tag{1}$$

where:

$m(t)$ = a set of image measurements (e.g., image coordinates, parameters of image segments);

$s[m(t), a]$ = a vector of k visual features computed using image measurements;

a = a set of parameters that represent potential additional knowledge about the system (e.g., coarse camera intrinsic parameters or 3D model of objects); and

s^* = a vector that contains the desired values of the features.

Visual servoing systems differ according to how s is expressed. In IBVS, s consists of a set of features that are immediately available in the image data, while in PBVS, s consists of a set of 3D parameters. Once s is selected, designing the visual control can be quite simple. One straightforward approach is to design a velocity controller based on the relationship between the time variation of s and the camera velocity. Let the spatial velocity of the camera be denoted by $u_c = (v_c, \omega_c)$ where v_c is the instantaneous linear velocity of the origin of the camera frame and ω_c is the instantaneous angular velocity of the camera frame. The relationship between the first derivative of s which is $\dot{s}$ and u_c is given by

$$\dot{s} = L_s u_c \tag{2}$$

where $L_s \in \mathbb{R}^{k\times 6}$ is called the interaction matrix related to s [52].

Shown in Figure 15 is the block diagram of a simple closed-loop visual servoing image-based system [52].

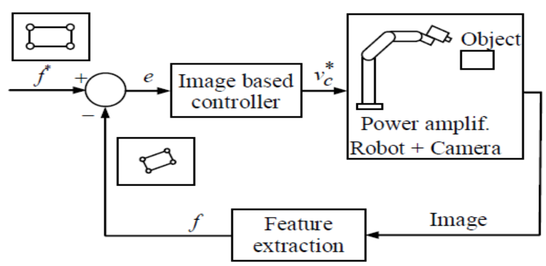

Fig. 15. Closed-loop visual servoing [52].

With regards to PBVS control, a 3D camera calibration is needed in order to map the 2D data of the image features to the Cartesian space data. Intrinsic (e.g., lens and CCD sensor properties) and extrinsic (e.g., relative pose of the camera system with respect to a generic world reference system) parameters of the camera must be evaluated. The extrinsic parameters matrix coincides with the homogeneous transformation between the camera and the object reference systems:

$$T_o^c = \begin{bmatrix} R_o^c & t_o^c \\ 0^T & 1 \end{bmatrix}(3) \tag{3}$$

where:

- c = camera;
- o = origin;
- T_o^c = the homogeneous transformation matrix of the camera relative to the origin;
- R_o^c = the rotation matrix of the camera relative to the origin; and
- t_o^c = the translation vector of the camera relative to the origin [56].

5) *Intelligent Robot Controller*

Robot controllers based on mathematical descriptions such as differential equations, transfer functions, and first order vector matrix differential equations based on the state space method shown in the previous sections of this chapter can be classified as classical controllers. In the mid-1990s, Dr. Elmer Dadios suggested, demonstrated, and proved, using the flexible pole-cart balancing platform, that there are other techniques that can be used to control complex and highly nonlinear systems. At least three nonclassical or intelligent robot controllers were reported, presented, and effectively demonstrated, which are the fuzzy logic controller, genetic algorithm (GA)–based controller, and artificial neural network (ANN)–based controller and a combination of two of these intelligent controllers [57–60].

a) *The Fuzzy Logic Controller*

Zadeh introduced the concept of fuzzy sets in 1965 [61]. Fuzzy logic uses linguistic descriptions to describe complex systems. Information is described using fuzzy sets, which are made precise by defining associated membership functions. These membership functions enable the fuzzy system to interface with the outside world. The membership function output is real numbers ranging from 0 to 1. Fuzzy sets are combined with fuzzy rules to define specific actions in the form of a fuzzy associative matrix (FAM). Figure 16 shows the block diagram of the fuzzy logic system. It is composed of a fuzzifier, rules, an inference engine, and a defuzzifier. Once the rules are established, the fuzzy logic system can be considered as a mapping of inputs to outputs. Rules are collection of IF–THEN statements, e.g., IF the temperature is too hot, THEN fan speed is maximum. The fuzzifier maps crisp input numbers into fuzzy sets, which activates rules in terms of linguistics variables that have associated fuzzy sets. The inference engine generates output in terms of fuzzy values. It handles the way in which rules are combined. The defuzzifier maps the output in crisp numbers which are used for the control action [57, 60, 62].

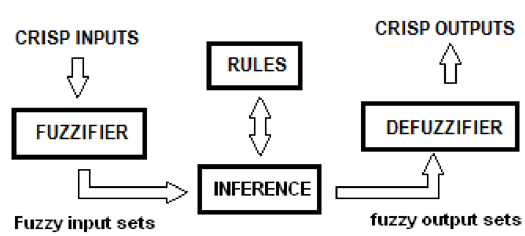

Fig. 16. Fuzzy logic system.

The effectiveness of fuzzy logic in controlling complex, highly dynamic, and nonlinear systems was demonstrated in a number of robot systems such as the micro soccer robots with navigation, tracking, and obstacle avoidance capability [63–66], micro-golf robot [67], ball-beam balancing robot [62], and humanoid robot [68]. Fuzzy logic can also be applied in image processing for dynamic color object detection and recognition such as the ones reported by Reyes and Dadios [69,70].

b) Genetic Algorithm

Genetic algorithm (GA) is a type of evolutionary algorithm which is loosely based on Darwinian principles of biological evolution where it operates on a population of individual strings called chromosomes [71]. These chromosomes are possible solutions to the problem. Chromosomes have elements called alleles which can be encoded using binary alphabet, integers, or real numbers. GA begins with an initial set of randomly generated chromosomes, called population, which are evaluated using a fitness function in order to determine the level of correctness of a particular solution. Chromosomes are ranked relative to their fitness, and the top-ranking chromosomes are selected to form a mating pool from which a new set of chromosomes will be generated. Two chromosomes from the mating pool are selected for reproduction. Genetic operators such as crossover and mutation are applied to generate two children chromosomes. After several generations, the GA hopefully converges for an optimal solution to the problem [59,71,72]. Shown in Figure 17 is a sample GA process based on [72]:

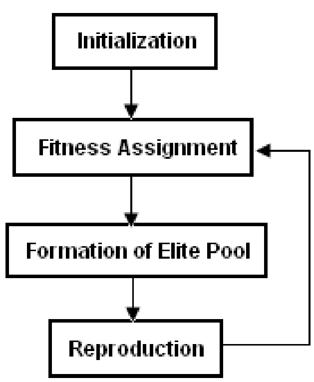

Fig. 17. GA process [94].

c) ANN

ANN is loosely based on biological neural cells. It is an information processing system composed of interconnected processing elements (PE) that is nonalgorithmic, nondigital, and intensely parallel [58]. The first layer is the input layer, and the last layer is the output layer. In between the input and the output layers is the hidden layer/s. The processing elements of an ANN are connected by a number of weighted links through which signals can flow. They translate different stimuli into a single output response. The transfer function of the PE is a mathematical expression that describes the translation of the input stimulus to the output response signal [58]. ANNs have been applied to solve different problems in control systems, image processing and robotics [58,73–75]. Shown in Figure 18 is an ANN general structure.

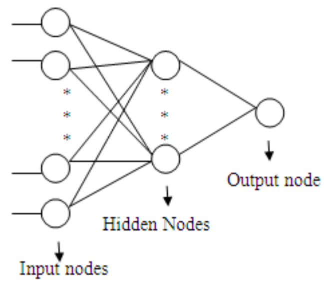

Fig. 18. ANN general structure.

6) Cost of Some Robotic Arms

Based on [52], commercial and custom-made robotic arms that cost over US$100,000 as of 2011 are the Barret WAM, Meka A2 arm, PR2 robot, DLR-LWR III arm, Schunk Lightweight Arm, Robonaut, Cog, Domo, Obrero, Twendy-One, and Agile Arm. But [76] also reported some low-cost robotic arms, such as the R17 arm of ST Robotics, whichcosts US$10,950;the arms of the Dynamaid robot, which have a total cost of at least US$3,500; and the KUKA youBot arm being sold for €14,000. Due to the high cost of robotic arms, [76] created a low-cost 7-DOF robotic arm that costs only US$4,135.

IV. Conclusions

This paper presented a review of related literature for the design and implementation of the Archer Robot. Discussions covered ancient and current human-like mechanical archers, MV, and intelligent controllers that can be used for the future Archer Robot. So far, the mechanical archers presented have an arrow already loaded in the bow. The future Archer Robot will be capable of knocking an arrow to a standard recurved bow, drawing the arrow, and hitting a target. There are toy-like archer robots and robots with dexterous arms, which will be the bases in the design and implementation of the Archer Robot.

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