Robotic Marionette Puppet Controller with Shadow Effect

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Abstract— *Puppetry is an ancient entertainment method used by people to release their stress and represent stories. The puppet figure may be an object that resembles a person, an animal, or a mythical character controlled by a human using external help like rods or strings. The human who controls the puppet is known as the puppeteer. There are various types of puppets namely; marionettes, hand puppets, rod puppets, shadow puppets, and finger puppets. With the advancement of technology, the popularity of the art of puppetry has decreased with time due to many reasons. The main reason is the lack of new puppeteers to continue puppetry and puppeteers get lower earnings, so new puppeteers don't motivate to continue the puppet industry. Another reason is that with the advancement in technology, people have lost interest in traditional entertainment methods like puppetry, because of the increase in new entertainment methods like TV and mobile phones. After several studies, we decided that marionettes are the most suited type of puppet to develop an automatic puppet theatre base on robot technology. According to the data we collected, there are four automatic systems and they all uses different mechanisms to control the puppet including quadrotors, motion capture data, and automatic stage management technologies. This comparative research is conducted to study the existing systems and robotic technologies to identify the most suited requirements and mechanisms for a robotic based automatic puppet system and design the most effective automatic puppet controller based on the information found. Finally, we hope this research will be helpful to protect the art of puppetry to stay alive for a longer period in Sri Lanka and other countries as well.*

Keywords— **puppetry, Rukada, marionette, puppets**

I. INTRODUCTION

Puppetry is a very ancient form of theatre, which is the art of operating puppets. A puppet is an object that is controlled or manipulated by a person who is called a puppeteer. Generally, puppets resemble a person, animal, or mythical character. The puppet's body, head, limbs, and, occasionally, its lips and eyes are moved by the puppeteer using motions of their hands, arms, or control tools like rods or strings. Often, the puppeteer will talk in the puppet's character's voice, coordinating the mouth motions with the spoken words.

Puppetry can be referred to as one of the most ancient forms of entertainment methods in the world and puppetry has been developed in countries like Sri Lanka, India, China, Austria, and England. In each country, puppetry has different characteristics according to their religions and beliefs. The language, movements of the puppets, costumes of the puppets, and the storyline of the show are different in each country. (Aravind et al., 2014) There are many types of puppets including, marionettes, hand puppets, rod puppets, shadow puppets, finger puppets, and sock puppets. In each of these types, the puppet can be a figure, a character, or representing a person, only the mechanism of movements will differ from each other.

In Sri Lanka, puppets are known as "Rukada" which was derived from "Sanskrit rupa" which gives the meaning of 'miniature figure', or 'a doll'. Rukada or Sri Lankan puppets were carved on kaduru wood by hand that represent life and the ancient times of the country. Puppetry or "Rukada kalawa" has been popular in Sri Lanka for centuries, and the town of Ambalangoda is the birthplace of puppets in Sri Lanka which is also known as the home of puppet dances. According to this article (archives.dailynews.lk, n.d.), a few reasons have been identified as the issues for the art of puppetry to be a dying art in Sri Lanka. These issues include, puppeteers does not getting propper encouragement from the government to perform, they don't get paid much by continuing puppetry, not a lot of puppet shows are held in Sri Lanka, and there is lesser marketing conducted for the puppet industry. This review is conducted to identify the gaps between the traditional art of puppetry and the reasons that this art has been categorized as a dying art in Sri Lanka and propose a solution in combination of new technology. For that, a critical review has been conducted to identify the existing systems that had developed over the past years and identify the most suitable approach to build a robotic marionette puppet controller that has the shadow effect on the puppet.

The basic idea in this proposed system is to automate only the puppet controller since there are several systems which have built the puppet as a robot. But here we suggest to automate only the controller of the puppet which protects the originality of a traditional marionette puppet. In Sri Lanka, some people don't like the idea of puppetry being combined with technology because it looks fake and artificial. But from this proposed solution we want to make sure that the original effect of a traditional puppet show is being protected as well as it wil provide a solution for the lack of new puppeteers and puppetry being a dying art in Sri Lanka.

The idea behind this research is when a human does a movement that has been recognized as a puppet movement, that movement of the human will captured through a camera, and if it is a movement that the system has been trained the puppet will also do the same movement. As an example, assume that someone who is

not a puppeteer lift his right arm up infront of the camera. That movement will be captured through the camera, processed, and the puppet will also lift his right arm up. From this solution, we hope to protect the originality of the puppet by only automating the controller of the puppet. We want our puppet to act as close as possible to a traditional marionette puppet controlled by a well-trained puppeteer.

We are in-progress of developing a mechanism to connect the puppet controller with the real-time motion capturing. The design for the puppet controller and the string structure used is described in the system design section.

In this paper, section II contains the literature review where the other's work has been reviewed. Section III will explain the methodology that describes the approach we used to conduct this research process. Next, the experimental design and the discussion has described in section IV and section V respectively. Finally, section VI provides the conclusion of this review.

II. LITERATURE REVIEW

This research was conducted under two categories which are, puppet mechanisms and robotics.

A. Puppet mechanisms

The Marionette puppet theater built in (Aravind et al., 2014) study consists of 5 puppets with an automatic stage management system containing automated stage lighting, curtain control, video effects, and possible special effects. The puppets were made of papier-mâché for them to be light weighted. In this system, there are robot manipulators that each have 16 degrees of freedom which are linked via a WIFI network. The main highlights of this system are;

- This puppet show can be dubbed into any language making it break the language barrier for puppet shows and enabling the puppeteers to present the show in any language.

- Since there are three modes, keyboard, body motion, and pre-defined motion libraries, the puppeteer gets to see the direct visual feedback while programming in any of the above modes.

- Since the show is not conducted by a human, the show can be performed every time with a little number of breaks.

The article (Chen et al., 2004) has introduced the evolution and engineering aspect of traditional marionette design and manipulation. They have identified two types of marionette controllers while developing their system, which are,

1) *Western marionette controllers*: In the early days, string puppets were controlled by horizontally laid strings. In the 19th century marionettes with vertical strings were in two forms, which are dramatic marionettes to perform in dramatic scenes and variety marionettes that were mainly designed for tricks and variety. In modern puppet troupes, we can see both horizontal and vertical marionette controllers in one.

2) *Chinese marionette controller*: They have used a controller called "Gou Pai" which is a single piece of plate that all the strings are connected to it in a systematical sequence. This method of the controller is very practical and simple since they have about 16 to 50 strings sometimes.

This researcher has focused on developing a robotic puppet mechanism that is portable and universal. Here, they have described portability, as the puppeteers can perform puppet shows side by side with puppeteers using manually operated marionettes. They have developed three versions of robotic marionette systems, ROM I, ROM II, and ROM III. ROM I was built as the prototype system that they used to understand the pulley-motor concept for puppeteering tasks. ROM II and III were built as life-like figures and they used standard embroidery threads for controlling strings. The difference between the prototype, ROM I, and ROM II and III is that in ROM the pulleys were laid horizontally whereas they were vertical in the other two.

The following table represents the specification of ROMS-I, II, and III.

Table1.Specifications of ROM-I, II, and III

	ROMS-I	ROMS-II	ROMS-III
Type of joint	8 s-joint (3-DOF)	9 s-joint (3-DOF) 1 u-joint (2-DOF)	s-joint (3-DOF) 5 r-joint (1-DOF)
Height (cm)	31.2	30.5	29.5
Weight (g)	314	214	259

Source: Marionette: From Traditional Manipulation to Robotic Manipulation

According to the (Kim, Choi and Lee, 2017) researchers, marionette shows are a play of puppets where puppets were controlled from above-using wires or stings by humans. Their goal is to analyze the skilled marionette puppeteers to recreate those movements using quadrotors instead of human hands. In their system, they have taken rigid trajectories of the control stick as inputs and each trajectory data point is measured with three positions and three rotations. The puppet they built has two wires which are connected to the head and the tail. The puppet can express movements including sitting, standing up, walking, and eating. They used a proportional differential controller to allow the quadrotor to allow the movement precisely. They have used both a position controller that controls the x, y, and z translation and yaw rotation and an attitude controller that controls roll, pitch, yaw rotation, and translations for the z-direction. With the use of multiple quadrotors, more complicated and sophisticated puppets and puppet movements can be generated.

The researcher (Yamane, Hodgins and Brown, n.d.) has used motion capture data from human actors and data recorded to control a motorized, string-driven marionette puppet. It is a difficult task to produce hand-driven movements from robotics. For that, these researchers have used full-body motion data of humans to produce movements. Their interface allows the preservation of a given performance as well as allows the creation of new

performances. They have used a four-step method that includes;

1. Identify the controller design
2. Mapping of human motion in marionette's workplace
3. Apply the controller
4. Compute the motor commands

When developing their system, they considered the inverse kinematics algorithms to apply the desired movements into the marionette they also determined the motor angles that satisfy the physical constraints including joint motion ranges, length, and orientation of the strings, desired marker positions, and the potential energy.

B. Robotics

The (Patidar and Tiwari, 2016) survey is focused on a robotic arm and its development, which describes the parameters of a robotic arm including, the number of axes, degree of freedom, working envelope and working space the arm covers, kinematics, payload, speed and acceleration, accuracy and repeatability, motion and drive of an arm. They have solved all the issues related to a multiple-axis robotic arm and tried to create one. These researchers have tried to increase the degree of freedom of a robotic arm by increasing the number of joints and by increasing the number of axis and DOFs they have tried to increase the working envelope and working space. Also, they have tried to increase the kinematics, accuracy, repeatability, payload, speed, and acceleration using simulation tools. This study is very helpful in understanding the factors affecting the performance of a robotic arm and how it can change the performance into an efficient robotic arm.

This Thambot system (Goonatilleke and Hettige, 2021) is a robotic approach for the lack of traditional drummers in Sri Lanka. They have built a robotic system that can be used to play Thammattama which is one of the traditional drums in Sri Lanka. This system consists of two arms that each arm holding the thammattam stick. From this research they have identified important factors including, the musical notes of the Thammattama, the drum locations where the sound is being produces and the styles that can play the drum. In their system the robot was able to move along the x-axis and the y-axis covering a 2D space to produce sound. These researchers have used PIC 16F877A and other components like solenoids, relays, servo motors etc.

C. AI and Machine Learning

According to these researchers, (Soori, Arezoo and Dastres, 2023) autonomous navigation, object recognition and manipulation, natural language processing, and predictive maintenance are some of the application of Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL). They have presented an overview of current developments in AI, ML, and DL in advanced robotics systems and discusses various applications of the systems in robotic modifications. According to them, term Machine Learning provide an understanding of a machine's capacity to carry out operations that originally require human intelligence, like speech recognition, understanding of natural language, and decision making.

With the help of AI robots can be built to detect and interact with their surroundings, make judgements, and carry out difficult tasks. Machine Learning is a branch of AI that uses algorithms to give the ability to learn from data. Deep Learning is a type of ML that uses artificial neural networks which help computers to learn from massive amounts of data. In simple terms, AI is used to build robots that can act autonomously, perceive, and reason in complex environments while ML is used to make the robots learn from their experiences and improve their performance over time. Deep learning is used to solve the problems that are hard to solve by using the traditional machine learning techniques. In their study, they have described about the key areas related to AI, ML, and DL such as, advantages, challenges, and applications of AI, ML, and DL in advance robotics.

This research (Yin et al., 2017) is the 1st systematic comparison of CNN and RNN on a wide range of natural language processing tasks. There are two DNN architectures which are Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN). There are two prevailing RNN types that are Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU). Generally, CNNs are hierarchical and RNNs are sequential architectures. CNN is suitable for classification tasks such as sentiment classification, and RNNs are most suitable for sequence modelling tasks such as language modelling. These researchers have compared the three most widely used DNN types which are CNN, GRU and LTSM.

This paper (Mahesh, 2019) provides and introduction to the most popular machine learning algorithms and a survey of them. Machine learning is the scientific study of algorithms and statistical models that computers use to perform a set of tasks on their own. In this paper, a brief review and future prospect of the vast applications of machine learning algorithms has been made. They have reviewed and covered all the sub topics under ML which are, supervised learning, naïve bayes, support vector machine (SVM), unsupervised learning, K-Means clustering, principal component analysis, semi supervised learning, transductive SVM, generative models, self-training, reinforcement learning, multitask learning, ensemble learning, boosting, neural networks, supervised neural network, unsupervised neural network, reinforcement neural network, instance-based learning, and K-Nearest Neighbor (KNN). Simply, supervised learning is suitable when you have lesser amount of data and clearly labeled data for training. Unsupervised learning would be most suitable for systems that have larger datasets.

In this paper, (Yin, Zhang and Shao, 2019) these researchers have created a system by combining the characteristics of CNN and RNN which they named as CNN-RNN model. Their proposed CNN-RNN model contains an improvement in accuracy to a certain level of the image recognition problems, but it increases the complexity of the model, reduces the training speed, and increase risk overfitting. The model uses RNN to calculate the dependency and continuity features of the intermediate layer which connects the characteristics of these middle tiers. They have tested their CNN-RNN model on a

widely used dataset which is CIFAR-10. In the training of their model, they have found that the standard VGG model will occur vanishing gradient problem because of the deepness in the network hierarchy. From their test results it has been proven that the proposed model has a better classification effect than the original CNN network. in simple terms, this paper has proposed a system named as CNN-RNN model that extract features from the CNN layer through the RNN network.

This paper (Bae et al., 2017) contains a proposal for a model-free continuous integral sliding model controller for robust control of robotic manipulators without any need for the system model. To achieve the control under a load disturbance and nonlinear parameter variations, they have made the controller constructed with three continuous terms including an integral term that acts as an adaptive controller. The main issues in robot control problems according to them is, that accurate refence tracking, load disturbance rejection and robustness to parameter variations. The performance of their controller was illustrated on the PUMA 560 robotic manipulator and compared with the performance of the PD plus gravity controller. The numerical results from the test proves that the model-free control method is capable of providing a non-overshoot response, fast settling time, zero steady-state error under load disturbance and measurement noise.

The founding of these researchers (Zhou, 2018) including showing that convolutional neural networks can approximate continuous functions when input and output values have the same shape, the minimum depth of the CNN required for approximation was presented and proved that it is the optimal value, and verified that CNN with sufficiently deep layers have universality when the number of channels is limited. Universal property/ universal approximation refers to the ability of a particular set of functions to approximate the sufficiently wide range of the functions. According to them, universality occurs because of zero padding interfered with invariance. Their research contributions are:

- Proved that CNN has the universal property in the continuous function space as a function that preserves the shape of the input data.

- They have found that the optimal number of convolutional layers for a function with d-dimensional input to have universal property.

- Proved that deep CNN with $C_x + C_y + 2$ Has the universal property, where C_x and C_y are the number of channels of the input and output data, respectively.

Simply, in their study they have dealt with the universal property of convolutional neural networks with both limited depth and unlimited width, and with limited width and unlimited depth.

III. METHODOLOGY

This section contains the methodology and the approach followed to gather data and information for the analysis of this research. In this research, a systematic strategy is used to collect and analyze the data collected. For that, a quantitative research approach is being followed that includes six steps as follows.

Figure 1. Quantitative Research Approach Steps

First, we identified the problem by finding answers to the question "Why puppetry is not popular as it was in past?". Then, we did our literature review by studying the systems that have already been created. Next, we specify our purpose for this study and created a survey-based questionnaire for data collection. Finally, we analyzed the data we collected and created the final evaluation of our proposed system.

IV. EXPERIMENTAL DESIGN

This section contains the three sections which the first secrion describes the design for the data collection process, the second section describes the design for the proposed system, and the third section describes the decided puppet movements to implement on this project.

A. *Data Collection*

The most suitable method for data collection for a large audience in a short period is through a survey or a questionnaire. It is not efficient to conduct a physical survey by printing a questionnaire since there is a shortage of paper in Sri Lanka at the moment. Therefore, the best method for conducting the survey is through a "Google form" which was conducted online, and it was easier to collect a large amount of data in a short period. The link to the form was distributed through social media, for students and people who are interested in the art of puppetry/ "Rukada". The questionnaire contained 15 questions, and we were able to collect 132 responses. Personal information like gender and age was not collected as it is not an important factor in this research project. Since puppetry/ "Rukada" is a traditional art in Sri Lanka, the questionnaire was given in both English and Sinhala languages.

Some important questions asked in the questionair were as followed:

1. Do you think puppetry is a dying art in Sri Lanka?

   රූකඩ කලාව ශ්‍රී ලංකාව තුල අභාවයට යන කලාවක් ලෙස ඔබ සිතන්නේද ?

2. Do you think an automatic puppet theatre will help to build up the interest in puppetry in young kids?

   ස්වයංක්‍රිය රූකඩ සංදර්ශනයක් මගින් තරුණ සහ බාළ පරම්පරාවේ ආශාව යලිත් රූකඩ කලාව වෙත යොමු කල හැකි වේ යයි ඔබ සිතන්නේද ?

3. Do you think each puppet show (for one story) is the same with regard to the lightening, voices, music and the movements of the puppets? (Ex: every puppet show has the same voice, same lights, same music, and same movements in the puppets)

   සෑම රූකඩ සංදර්ශනයකම (එක්තරාකතා මළාවකට අනුව) ආලෝක්කරණය, හඬ කවීම්, සංගීතය සහ රූකඩයන්ගේ අංග චලනයන් එක හා සමන යයි ඔබ සිතන්නේද ?

4. Do you think a Robotic based automatic puppet theatre will be a solution for the consistency of the puppet shows (issue mentioned in question 9)?

   ඒ සඳහා රොබෝ තාක්ෂණික රූකඩ සංදර්ශන වේදිකාවක් විසඳුම වේ යයි ඔබ සිතන්නේද ? (ප්‍රශ්න අංක 9)

5. Do you think Robotic puppet theatre will be a solution for the lack of new puppeteers?

   රොබෝ තාක්ෂණික ස්වයංක්‍රිය රූකඩ සංදර්ශන වේදිකාවක්, රූකඩ නටවන ශිල්පීන්ගේ හිඟයට විසඳුමක් වේ යයි ඔබ සිතන්නේද ?

B. System Design

The purpose of this proposed system based on the research conducted is to develop a robotic based puppet controller that has the shadow effect. In other words, our target is to automate only the puppet controller, not the puppet itself.

This system will be consist of few steps. There will be a human which representing the puppeteer, and a camera module. The motion performed by the human will be captured through the camera module and then through the geasture recognition algorithm the captured motion will be transformed into a signal and will be sent to the puppet, or the puppet controller.
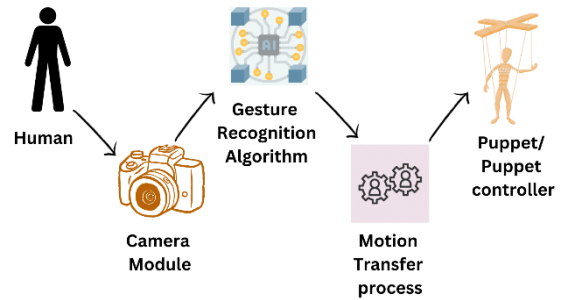

Figure 2. System Modular Design

As shown in the Fig 3. below, the string of the puppet will be connected to the right and left sides of the head (orange colored strings), right and left shoulder (pink colored strings), right and left knees (green colored strings), and the right and left wrists of the puppet (blue colored strings).
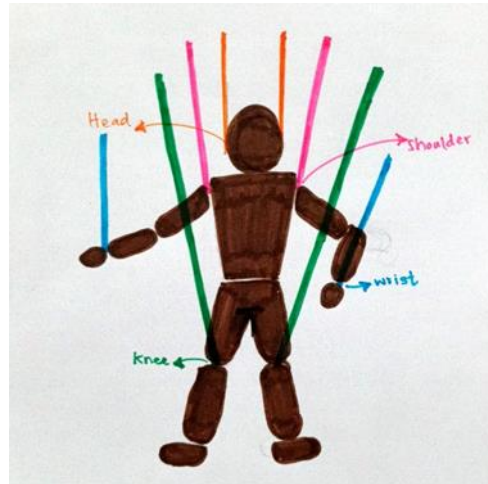

Figure 3. String Connection of the Puppet

As shown in the Fig 4. below, it shows the string connection to the puppet controller. The brown color circles represents the motiors and the strings are color coded according to the strings connected to the puppet as mentioned above.
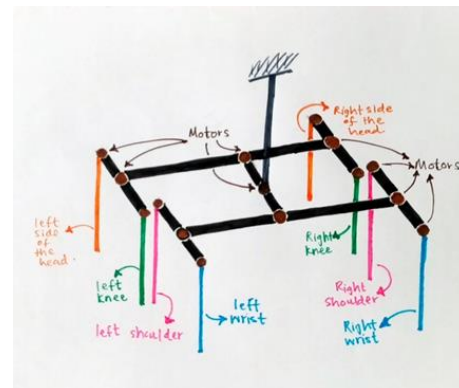

Figure 4. String Connection of the Puppet Controller

C. Puppet Movements

For this robotic based automatic puppet we decided to implement six (6) movements in this stage. As shown in the Fig 5. the movements will be left hand raise, right

hand raise, left leg raise up, and as shown in the Fig 6., right leg raise up, head tilt to left, and head tilt to right.
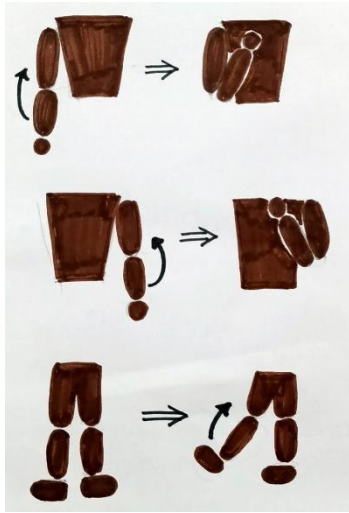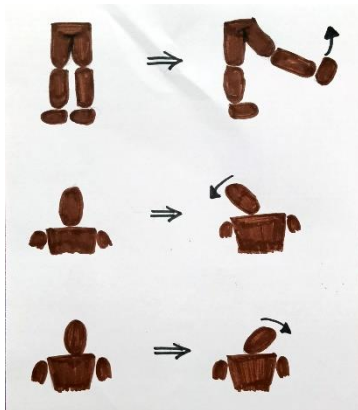

Figure 5. Puppet Movements 1

Figure 6. Puppet Movements 2

V. DISCUSSION

In (Aravind et al., 2014), the motion data, audio, and video streams in real time are synchronized with the software developed for the user interfaces at the front end and the back end. This system uses three modes to capture the motions of the puppets which are, direct human body capture, motion programming through a joystick, and the use of motion library modules. The puppets designed in this study were able to move in the x direction from one end of the stage to the other and the puppet is given a 90 of motion. The wrist of the hand is given only two-degree freedom while the leg is given one-degree motion along the Y direction. The entire body of the puppets in this system is movable in the Y direction and rotatable around its vertical axis. The actuation is done by DC servo motors. The robot puppet architecture in this research consists of a master controller and a Linux machine that interacts with several slave puppet manipulators which can be communicated via WIFI.

A summary of the feedback from the data we collected is described below. We were able to collect 132 responses and from the first question we understood that most of the people had the basic idea of what is a puppet/ "Rukada".

Table 2. Summary of the Questionnaire

Question	Description
Do you think puppetry is a dying art in Sri Lanka?	74.2% of people are agreeing that puppetry is a dying art in Sri Lanka, while 24.2% of people think it is "maybe" a dying art.
Do you think it is good to further promote the art of puppetry in Sri Lanka?	A majority of 96.2% of responders think that puppetry should be further promoted in Sri Lanka.
Do you think an automatic puppet theatre will help to build up the interest in puppetry in younger kids?	81.8% of responders agree that an automatic puppet theatre will draw more attention to puppetry among young kids.
Do you think a robotic based automatic puppet theatre will be a solution for the consistency of the puppet shows? (Issue mentioned in question 9)	60.6% of responders are agreeing that each puppet show for the same story can have differences in lighting, voice, music, and movements in puppets. Out of all the responders, 36.4% think an automatic puppet theatre will be a solution for that issue, while 50.8% think it "maybe" be a solution for this issue.
Do you think robotic puppet theatre will be a solution for the lack of new puppeteers?	39.4% of people think that a robotic-based puppet theatre can be the solution for the lack of new puppeteers and 47.7% of responders think that this "maybe" be the solution for the lack of new puppeteers.

VI. CONCLUSION AND FURTHER WORKS

Puppetry is an ancient entertainment method used to perform a story by using puppet figures. Puppetry comes under different types, and the person who performs puppetry is known as the puppeteer. Puppetry has lost its popularity today because with the advancement in technology there is an increase in new entertainment methods and since puppetry is not a high-salary occupation, there is a lack of new puppeteers to continue the puppetry for the future. We conducted this research to study the art of puppetry and find a solution that combined with new technology including robotics.

In this study, we studied about robotic puppet systems that uses different technologies, motion capturing techniques, machine learning and artificial intelligence technolgogies.

We are in progress of eveloping a mechanism to capture the motion of the human and sending it as a signal to the controller. As the future work, we will develop this system according to the design and hope this study would be a help to protect the art of puppetry being a dying art not only in Sri Lanka, but in other countries as well.

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