ASEC 2022

*Proceeding Paper*

# Motion Planning of Triple Links Robotic System †

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† Presented at the 3rd International Electronic Conference on Applied Sciences; Available online: https://asec2022.sciforum.net/.

**Abstract:** The Robogymnast is a complex system formed from a triple-inverted pendulum and mimics the action of a gymnast as they hang by their hands from the high bar and perform progressive upswings to eventually rotate completely around the bar. The three links of the Robogymnast can be compared to the lower limbs, torso, and upper limbs of a gymnast, with a single passive joint and two further stepper-motor powered joints. There is sensor equipment attached to the different links to gather data and control signals. While this system has been physically constructed previously, the current paper describes the approach to automating the 3- link pendulum, as well as describing the system, its parts and set-up. Following this, STM32 is applied for programming, system operation and to present results.

**Keywords:** Robogymnast; multi-link robotic; swing-up; stepper motor

**Citation:** Abdul samad, B.; Mohamed, M.; Anayi, F. Motion Planning of Triple Links Robotic System. *Eng. Proc.* **2022**, *4*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s):

Published: 1 December 2022



## 1. Introduction

The Robogymnast was chosen to represent a complex, underactuated multiple-link mechanical system in order to evaluate and compare control systems based on a range of methods [1]. Designing a control system with under-actuation presents challenges because full-state feedback linearisation around a fixed point of equilibrium is often not possible for this type of mechanism, which is also frequently not small-time local controllable (STLC) [2].

This has led to considerable research interest in the underactuated system in the spheres of control engineering and robotics [3]. Inverted pendulums involve a component hich swings freely from the fixed location it is suspended from under the action of gravitational forces. Work on regulating movement frequently uses this type of mechanism, and both hybrid and chaotic systems can be demonstrated in this approach [4,5]. An important robotics challenge is presented by the problem of balancing triple- inverted pendulum systems, and this is based on their similarity to due to structural and balance factors for the human body. The Acrobat is a robotic system which mimics acrobatic activity in humans, has an inverted pendulum form, and is designed to have instability and underactuation. This makes the robot ideal for theory- and practice-based work on non-linear controls [3,6]. The Acrobat was made to balance using a specially-developed, intelligent controller which blended conventional control, fuzzy control and adaptive-fuzzy control in order to achieve swing, catch and balance in inversion [7]. The controllers tested were based on state variable feedback, proportional integral-derivative and linear quadratic regulation approaches.

## 2. Related Work

Studies presented in [8–12] focus on autonomous upswing for triple-link robots with a single non-actuated and two actuated joints. The contribution of this study is to assess movement performance across the 3 links. Such multiple-link inverted pendulum-based systems have various real-world contributions:

- In research investigating problems of movement for disabled or injured individuals who do not have full use of their arms or legs [13].
- If such systems could be effectively controlled through the exploitation of the dynamic properties within them, machines could be developed which were more energy-efficient and moved smoothly in line with natural moving systems [14] Other studies previously conducted have examined how stability can be achieved in multiple link robotic systems using a swing mechanism through examining various types of controllers, including LQR [15] PID [16] Fuzzy-PD [17] and FLQR [18].

The current work makes an original contribution to this by implementing and making comparisons between the varied movements found in a 3-link robot across each of the three links. In addition, it presents a new approach to controlling the movement of the pendulum system through synchronising, as well as investigating the performance of the stepper motor.

This paper is structured in the following way: the second section gives an overview of related work previously conducted, while the third section first describes the system in general, before discussing its set-up further. In Section 4, the results for motion across each link are provided under various conditions, and the final section gives a summary of the research and presents conclusions.

## 3. System Description and Setup

### *3.1. System Description*

This work is applied to the triple-link Robogymnast mechanism, which imitates the gymnastics-based action of swinging up to freely rotate over the high bar. The diagram given in Figure 1 illustrates the system's major components, in which the first link is representative of the upper limbs of the gymnast (without modelling joints at elbow and wrist), link 2 relates to the head and trunk, as one component without different joints, and link 3 corresponds to the legs, with no jointing for knees and ankles. Robogymnast's first joint is unactuated, using passive action, while the remaining two joints, which can be related to the gymnast's shoulder and hip joints, are active in their operation [13]. Figure 2 illustrates the robotic system through a block diagram, in which it is operated via two stepper motors, each subject to stepper driver control to achieve smooth movement. Control system programming is done through the microcontroller STM32 using C++ language for translating commands between the robotic system and the control system and the PC. Each link has its own sensor, and link one connects to a rotary encoder, with the remaining links connecting to potentiometers 2, and 3 respectively, to allow for the detection of absolute angles across every position [15].

**Table 1.** Robogymnast Parameters.

| Symbol | Parameters | Mean Value |
|---|---|---|
| $L1$ | The length of 1st link | 0.16 m |
| $L2$ | Middle Link Length | 0.18 m |
| $L3$ | Lower link 3 Length | 0.24 m |
| $m1$ | The weight of Link 1 | 1.2 kg |
| $m2$ | Weight of 2nd link | 1.2 kg |
| $m3$ | Weight of lower link 3 | 0.5 kg |
| $q1$, $q2$, $q3$ | Angles initial values | 0 (rad) |
| $g$ | gravity | 9.81 $m/s^2$ |

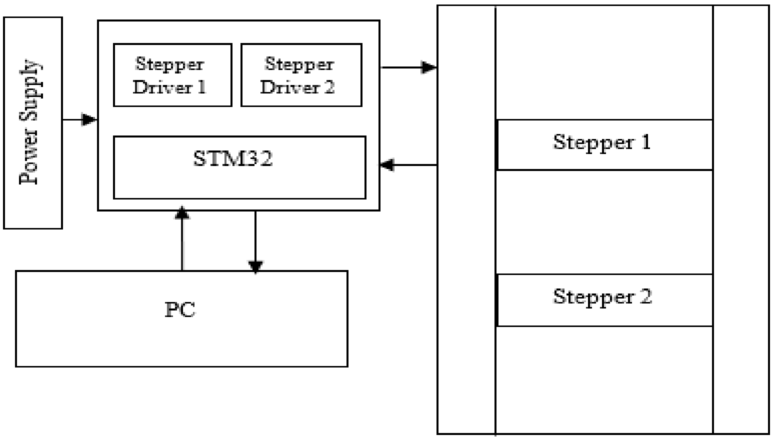
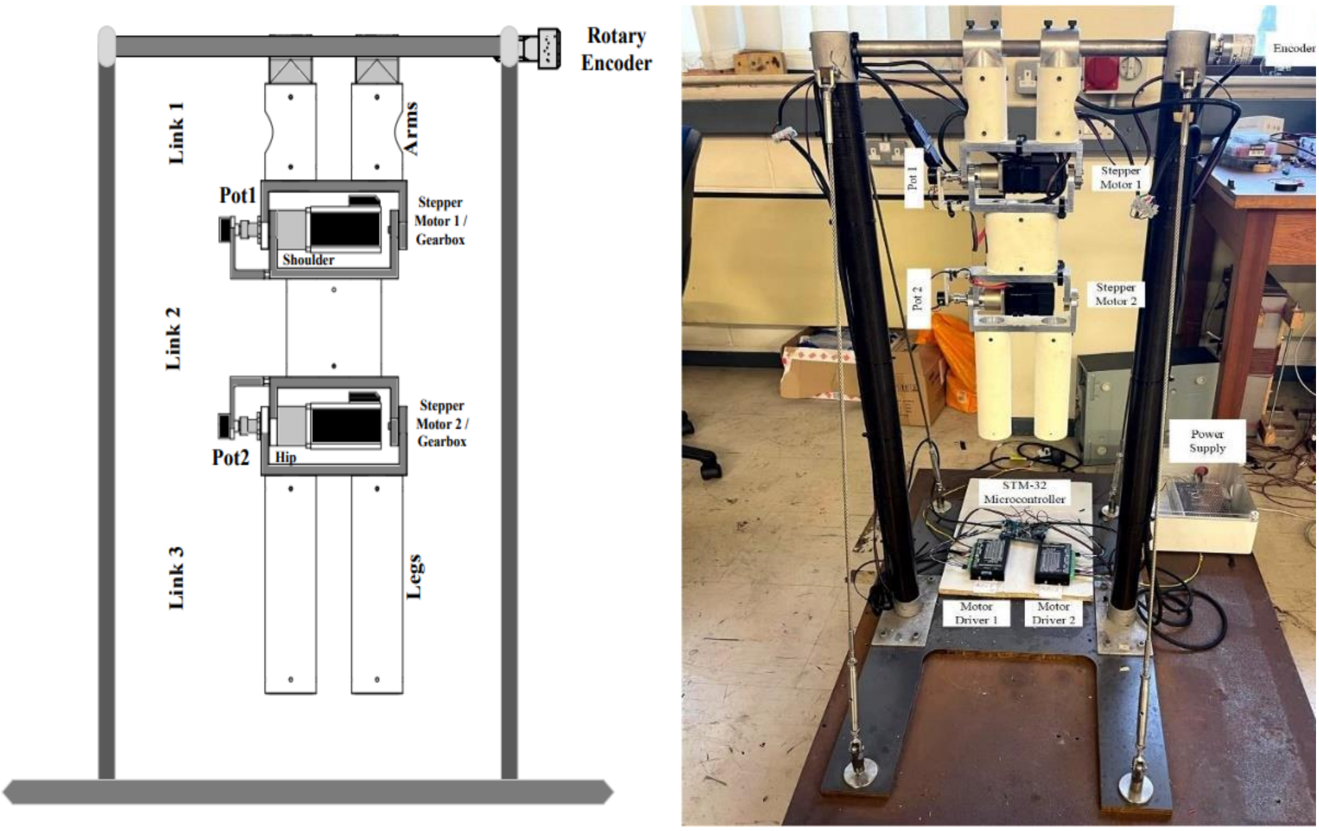



**Figure 1.** Robogymnasy operatoin sysem.

### *3.2. System Setup*

This section considers the set-up of the system, where attaching the system itself by connecting to joint 2,3 with dual potentiometers as sensors, and then the header connects with the encoder to detect the absolute value of motion. On the other hand, the operating system as shown in Figure 1 contains 2 stepper drivers powered by 5v along with programming by an STM-32 microcontroller connecting to a PC to instruct the movement of the system, then to read the signal returned from sensors. Lastly, Figure 2a,b illustrates the Robogymanst-designed diagram and an achieved system prepared to run.




(**a**) (**b**)

**Figure 2.** (**a**) Robogymnast diagram; (**b**) Robogymanst system.

## 4. Results

*Discussion*

Figure 3a–c demonstrates that each link is in motion simultaneously, in which theta 1 represents the t2 (stepper 1) and t3 (stepper 2) response, based on the opposing motion of the two motors. The second joint is operated by stepper 1, and if it is moving in the positive direction, stepper 3 then moves in the opposing direction. In addition to this, the bottom link, which is link 3, is operated by stepper 2, and this begins to reverse at the point where the first motor moves forward, beginning the movements towards upswing of the robot in this system. Based on this, Table 2 provides estimated values for the degree of motion in the multiple-link mechanism in both scenarios in average in the maximum point is both direction positive and negative (forward and back).

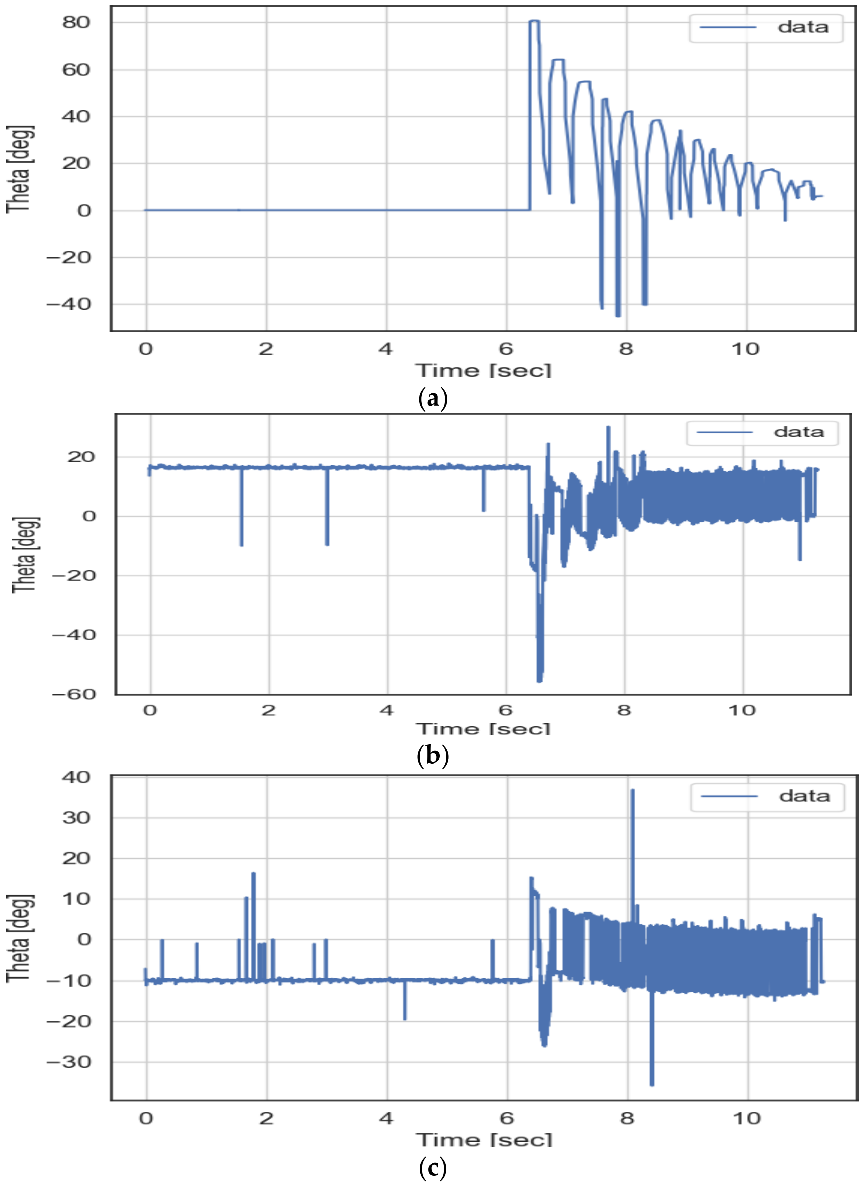



**Figure 3.** (**a**) Upper Link Free Rotate; (**b**) middle Link (stepper motor 1); (**c**) Lower Link (stepper 2).

**Table 2.** Robogymnast Motion Results.

| Symbol | Parameters | Average (Degrees)° | Max Point (Degrees)° |
|---|---|---|---|
| $\theta 1$ | Link 1 (free rotate) upper | (−5) to 25 | (−45) to 80 |
| $\theta 2$ | Link 2 (Motor 1) middle | (−5) to 15 | (−45) to 25 |
| $\theta 3$ | Link 3 (Motor 3) lower | (−10) to 10 | (−35) to 35 |

## 5. Conclusions

In this work, planned movement for swing-up in a 3-link inverted pendulum-based robot has been presented. A description has been given of how this system was set up, considering the connection of each component of the system. Subsequent studies will examine this movement further and consider how this 3-link system can be modulated for upswing, as well as developing the controller further for optimisation of the algorithms and their implementation in future work.

**Author Contributions:** Conceptualization, B.A.s. and M.M.; methodology, B.A.s. and F.A.; software, B.A.s. and M.M.; validation, B.A.s. and M.M.; formal analysis, B.A.s. and F.A.; investigation, B.A.s. and M.M.; resources, B.A.s. and F.M.; data curation, B.A.s. and M.M.; writing— original draft preparation, B.A.s. and F.A.; writing—review and editing, B.A.s. and F.M.; visualization, B.A.s. and M.M.; supervision, B.A.s. and F.A; project administration, F.A.; funding acquisition, B.A.s. All authors have read and agreed to the published version of the manuscript.

**Funding:** This paper is part of the research of the corresponding author, B.A.s., who is sponsored by the Ministry of Higher Education and Scientific Research in Libya.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The authors would like to thank Cardiff University/School of Engineering and the ministry of higher education–Libya for their support.

**Conflicts of Interest:** The authors declare no conflict of interest.

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