

Software Requirements Specification for Pendulum

Olu Owojaiye

May 26, 2021

Contents

| | | |
|----------|--|-----------|
| 1 | Reference Material | 2 |
| 1.1 | Table of Units | 2 |
| 1.2 | Table of Symbols | 2 |
| 1.3 | Abbreviations and Acronyms | 3 |
| 2 | Introduction | 4 |
| 2.1 | Scope of Requirements | 4 |
| 3 | Specific System Description | 4 |
| 3.1 | Problem Description | 4 |
| 3.1.1 | Terminology and Definitions | 4 |
| 3.1.2 | Physical System Description | 4 |
| 3.1.3 | Goal Statements | 5 |
| 3.2 | Solution Characteristics Specification | 5 |
| 3.2.1 | Assumptions | 6 |
| 3.2.2 | Theoretical Models | 6 |
| 3.2.3 | General Definitions | 9 |
| 3.2.4 | Data Definitions | 20 |
| 3.2.5 | Instance Models | 24 |
| 3.2.6 | Data Constraints | 26 |
| 3.2.7 | Properties of a Correct Solution | 27 |
| 4 | Requirements | 27 |
| 4.1 | Functional Requirements | 27 |
| 4.2 | Non-Functional Requirements | 28 |
| 5 | Traceability Matrices and Graphs | 28 |
| 6 | Values of Auxiliary Constants | 30 |
| 7 | References | 30 |

1 Reference Material

This section records information for easy reference.

1.1 Table of Units

The unit system used throughout is SI (Système International d'Unités). In addition to the basic units, several derived units are also used. For each unit, **Tab: ToU** lists the symbol, a description and the SI name.

| Symbol | Description | SI Name |
|--------|-------------|----------|
| ° | angle | degree |
| Hz | frequency | hertz |
| kg | mass | kilogram |
| m | length | metre |
| N | force | newton |
| rad | angle | radian |
| s | time | second |

Table 1: Table of Units

1.2 Table of Symbols

The symbols used in this document are summarized in **Tab: ToS** along with their units. Throughout the document, symbols in bold will represent vectors, and scalars otherwise. The symbols are listed in alphabetical order. For vector quantities, the units shown are for each component of the vector.

| Symbol | Description | Units |
|--------------------|------------------------------------|-------------------------------|
| a_x | x -component of acceleration | $\frac{\text{m}}{\text{s}^2}$ |
| a_y | y -component of acceleration | $\frac{\text{m}}{\text{s}^2}$ |
| a | Acceleration | $\frac{\text{m}}{\text{s}^2}$ |
| F | Force | N |
| f | Frequency | Hz |
| g | Gravitational acceleration | $\frac{\text{m}}{\text{s}^2}$ |
| I | Moment of inertia | kgm^2 |
| $\hat{\mathbf{i}}$ | Unit Vector | — |
| L_{rod} | Length of the rod | m |
| m | Mass | kg |
| p_x | x -component of position | m |
| p_x^i | x -component of initial position | m |
| p_y | y -component of position | m |

| Symbol | Description | Units |
|--------------|---|---------------------------------|
| p_y^i | y -component of initial position | m |
| \mathbf{p} | Position | m |
| T | Period | s |
| \mathbf{T} | Tension | N |
| t | Time | s |
| v_x | x -component of velocity | $\frac{\text{m}}{\text{s}}$ |
| v_y | y -component of velocity | $\frac{\text{m}}{\text{s}}$ |
| \mathbf{v} | Velocity | $\frac{\text{m}}{\text{s}}$ |
| α | Angular Acceleration | $\frac{\text{rad}}{\text{s}^2}$ |
| θ | Angular Displacement | rad |
| θ_i | Initial pendulum angle | rad |
| θ_p | Displacement angle of the pendulum | ° |
| π | Ratio of circumference to diameter for any circle | — |
| | Torque | Nm |
| Ω | Angular frequency | s |
| ω | Angular Velocity | $\frac{\text{rad}}{\text{s}}$ |

Table 2: Table of Symbols

1.3 Abbreviations and Acronyms

| Abbreviation | Full Form |
|--------------|-------------------------------------|
| 2D | Two-Dimensional |
| A | Assumption |
| DD | Data Definition |
| GD | General Definition |
| GS | Goal Statement |
| IM | Instance Model |
| PS | Physical System Description |
| R | Requirement |
| SRS | Software Requirements Specification |
| TM | Theoretical Model |
| Uncert. | Typical Uncertainty |

Table 3: Abbreviations and Acronyms

2 Introduction

A pendulum consists of mass attached to the end of a rod and its moving curve is highly sensitive to initial conditions. Therefore, it is useful to have a program to simulate the motion of the pendulum to exhibit its chaotic characteristics. The program documented here is called pendulum.

The following section provides an overview of the Software Requirements Specification (SRS) for Pendulum. This section explains the purpose of this document, the scope of the requirements, the characteristics of the intended reader, and the organization of the document.

2.1 Scope of Requirements

The scope of the requirements includes the analysis of a two-dimensional (2D) pendulum motion problem with various initial conditions..

3 Specific System Description

This section first presents the problem description, which gives a high-level view of the problem to be solved. This is followed by the solution characteristics specification, which presents the assumptions, theories, and definitions that are used.

3.1 Problem Description

A system is needed to efficiently and correctly to predict the motion of a pendulum.

3.1.1 Terminology and Definitions

This subsection provides a list of terms that are used in the subsequent sections and their meaning, with the purpose of reducing ambiguity and making it easier to correctly understand the requirements.

- Gravity: The force that attracts one physical body with mass to another.
- Cartesian coordinate system: A coordinate system that specifies each point uniquely in a plane by a set of numerical coordinates, which are the signed distances to the point from two fixed perpendicular oriented lines, measured in the same unit of length (from [2]).

3.1.2 Physical System Description

The physical system of Pendulum, as shown in [Fig:pendulum](#), includes the following elements:



Figure 1: The physical system

PS1: The rod.

PS2: The mass.

3.1.3 Goal Statements

Given the mass and length of the rod, initial angle of the mass and the gravitational constant, the goal statements are:

Motion-of-the-mass: Calculate the motion of the mass.

3.2 Solution Characteristics Specification

The instance models that govern Pendulum are presented in [Section: Instance Models](#). The information to understand the meaning of the instance models and their derivation is also presented, so that the instance models can be verified.

3.2.1 Assumptions

This section simplifies the original problem and helps in developing the theoretical models by filling in the missing information for the physical system. The assumptions refine the scope by providing more detail.

pend2DMotion: The pendulum motion is two-dimensional (2D).

cartCoord: A Cartesian coordinate system is used.

cartCoordRight: The Cartesian coordinate system is right-handed where positive x -axis and y -axis point right up.

yAxisDir: The direction of the y -axis is directed opposite to gravity.

startOrigin: The pendulum is attached to the origin.

3.2.2 Theoretical Models

This section focuses on the general equations and laws that Pendulum is based on.

| Refname | TM:acceleration |
|-------------|---|
| Label | Acceleration |
| Equation | $\mathbf{a} = \frac{d\mathbf{v}}{dt}$ |
| Description | \mathbf{a} is the acceleration ($\frac{\text{m}}{\text{s}^2}$) t is the time (s) \mathbf{v} is the velocity ($\frac{\text{m}}{\text{s}}$) |
| Source | [1] |
| RefBy | |

| | |
|-------------|--|
| Refname | TM:velocity |
| Label | Velocity |
| Equation | $\mathbf{v} = \frac{d\mathbf{p}}{dt}$ |
| Description | <p>\mathbf{v} is the velocity ($\frac{\text{m}}{\text{s}}$)</p> <p>$t$ is the time (s)</p> <p>\mathbf{p} is the position (m)</p> |
| Source | [3] |
| RefBy | |

| | |
|-------------|--|
| Refname | TM:NewtonSecLawMot |
| Label | Newton's second law of motion |
| Equation | $\mathbf{F} = m\mathbf{a}$ |
| Description | <p>\mathbf{F} is the force (N)</p> <p>m is the mass (kg)</p> <p>\mathbf{a} is the acceleration ($\frac{\text{m}}{\text{s}^2}$)</p> |
| Notes | The net force \mathbf{F} on a body is proportional to the acceleration \mathbf{a} of the body, where m denotes the mass of the body as the constant of proportionality. |
| Source | — |
| RefBy | |

| | |
|-------------|---|
| Refname | TM:NewtonSecLawRotMot |
| Label | Newton's second law for rotational motion |
| Equation | $\tau = \mathbf{I}\alpha$ |
| Description | <p>τ is the torque (Nm)</p> <p>\mathbf{I} is the moment of inertia (kgm^2)</p> <p>α is the angular acceleration ($\frac{\text{rad}}{\text{s}^2}$)</p> |
| Notes | The net torque on a rigid body is proportional to its angular acceleration α , where \mathbf{I} denotes the moment of inertia of the rigid body as the constant of proportionality. |
| Source | — |
| RefBy | IM: calOfAngularDisplacement and GD: angFrequencyGD |

3.2.3 General Definitions

This section collects the laws and equations that will be used to build the instance models.

| | |
|-------------|---|
| Refname | GD:velocityIX |
| Label | The x -component of velocity of the pendulum |
| Units | $\frac{\text{m}}{\text{s}}$ |
| Equation | $v_x = \omega L_{\text{rod}} \cos(\theta_p)$ |
| Description | <p>v_x is the x-component of velocity ($\frac{\text{m}}{\text{s}}$)</p> <p>$\omega$ is the angular velocity ($\frac{\text{rad}}{\text{s}}$)</p> <p>$L_{\text{rod}}$ is the length of the rod (m)</p> <p>θ_p is the displacement angle of the pendulum ($^\circ$)</p> |
| Source | — |
| RefBy | |

Detailed derivation of the x -component of velocity: At a given point in time, velocity may be defined as

$$\mathbf{v} = \frac{d\mathbf{p}}{dt}$$

We also know the horizontal position

$$p_x = L_{\text{rod}} \sin(\theta_p)$$

Applying this,

$$v_x = \frac{dL_{\text{rod}} \sin(\theta_p)}{dt}$$

L_{rod} is constant with respect to time, so

$$v_x = L_{\text{rod}} \frac{d \sin(\theta_p)}{dt}$$

Therefore, using the chain rule,

$$v_x = \omega L_{\text{rod}} \cos(\theta_p)$$

| Refname | GD:velocityIY |
|-------------|---|
| Label | The y -component of velocity of the pendulum |
| Units | $\frac{\text{m}}{\text{s}}$ |
| Equation | $v_y = \omega L_{\text{rod}} \sin(\theta_p)$ |
| Description | v_y is the y -component of velocity ($\frac{\text{m}}{\text{s}}$) ω is the angular velocity ($\frac{\text{rad}}{\text{s}}$) L_{rod} is the length of the rod (m) θ_p is the displacement angle of the pendulum ($^\circ$) |
| Source | — |
| RefBy | |

Detailed derivation of the y -component of velocity: At a given point in time, velocity may be defined as

$$\mathbf{v} = \frac{d\mathbf{p}}{dt}$$

We also know the vertical position

$$p_y = -L_{\text{rod}} \cos(\theta_p)$$

Applying this again,

$$v_y = - \left(\frac{dL_{\text{rod}} \cos(\theta_p)}{dt} \right)$$

L_{rod} is constant with respect to time, so

$$v_y = -L_{\text{rod}} \frac{d \cos(\theta_p)}{dt}$$

Therefore, using the chain rule,

$$v_y = \omega L_{\text{rod}} \sin(\theta_p)$$

Therefore, using the chain rule,

| Refname | GD:accelerationIX |
|-------------|---|
| Label | The x -component of acceleration of the pendulum |
| Units | $\frac{\text{m}}{\text{s}^2}$ |
| Equation | $a_x = -\omega^2 L_{\text{rod}} \sin(\theta_p) + \alpha L_{\text{rod}} \cos(\theta_p)$ |
| Description | a_x is the x -component of acceleration ($\frac{\text{m}}{\text{s}^2}$) ω is the angular velocity ($\frac{\text{rad}}{\text{s}}$) L_{rod} is the length of the rod (m) θ_p is the displacement angle of the pendulum ($^\circ$) α is the angular acceleration ($\frac{\text{rad}}{\text{s}^2}$) |
| Source | — |
| RefBy | |

Detailed derivation of the x -component of acceleration: Our acceleration is:

$$\mathbf{a} = \frac{d\mathbf{v}}{dt}$$

Earlier, we found the horizontal velocity to be

$$v_x = \omega L_{\text{rod}} \cos(\theta_p)$$

Applying this to our equation for acceleration

$$a_x = \frac{d\omega L_{\text{rod}} \cos(\theta_p)}{dt}$$

By the product and chain rules, we find

$$a_x = \frac{d\omega}{dt} L_{\text{rod}} \cos(\theta_p) - \omega L_{\text{rod}} \sin(\theta_p) \frac{d\theta_p}{dt}$$

Simplifying,

$$a_x = -\omega^2 L_{\text{rod}} \sin(\theta_p) + \alpha L_{\text{rod}} \cos(\theta_p)$$

| | |
|-------------|---|
| Refname | GD:accelerationIY |
| Label | The y -component of acceleration of the pendulum |
| Units | $\frac{\text{m}}{\text{s}^2}$ |
| Equation | $a_y = \omega^2 L_{\text{rod}} \cos(\theta_p) + \alpha L_{\text{rod}} \sin(\theta_p)$ |
| Description | <p> a_y is the y-component of acceleration ($\frac{\text{m}}{\text{s}^2}$) ω is the angular velocity ($\frac{\text{rad}}{\text{s}}$) L_{rod} is the length of the rod (m) θ_p is the displacement angle of the pendulum ($^\circ$) α is the angular acceleration ($\frac{\text{rad}}{\text{s}^2}$) </p> |
| Source | – |
| RefBy | |

Detailed derivation of the y -component of acceleration: Our acceleration is:

$$\mathbf{a} = \frac{d\mathbf{v}}{dt}$$

Earlier, we found the vertical velocity to be

$$v_y = \omega L_{\text{rod}} \sin(\theta_p)$$

Applying this to our equation for acceleration

$$a_y = \frac{d\omega L_{\text{rod}} \sin(\theta_p)}{dt}$$

By the product and chain rules, we find

$$a_y = \frac{d\omega}{dt} L_{\text{rod}} \sin(\theta_p) + \omega L_{\text{rod}} \cos(\theta_p) \frac{d\theta_p}{dt}$$

Simplifying,

$$a_y = \omega^2 L_{\text{rod}} \cos(\theta_p) + \alpha L_{\text{rod}} \sin(\theta_p)$$

| Refname | GD:hForceOnPendulum |
|-------------|--|
| Label | Horizontal force on the pendulum |
| Units | N |
| Equation | $\mathbf{F} = ma_x = -\mathbf{T} \sin(\theta_p)$ |
| Description | <p>\mathbf{F} is the force (N) m is the mass (kg) a_x is the x-component of acceleration ($\frac{\text{m}}{\text{s}^2}$) \mathbf{T} is the tension (N) θ_p is the displacement angle of the pendulum ($^\circ$)</p> |
| Source | — |
| RefBy | |

Detailed derivation of force on the pendulum:

$$\mathbf{F} = ma_x = -\mathbf{T} \sin(\theta_p)$$

| | |
|-------------|--|
| Refname | GD:vForceOnPendulum |
| Label | Vertical force on the pendulum |
| Units | N |
| Equation | $\mathbf{F} = ma_y = \mathbf{T} \cos(\theta_p) - m\mathbf{g}$ |
| Description | <p>\mathbf{F} is the force (N) m is the mass (kg) a_y is the y-component of acceleration ($\frac{\text{m}}{\text{s}^2}$) \mathbf{T} is the tension (N) θ_p is the displacement angle of the pendulum ($^\circ$) \mathbf{g} is the gravitational acceleration ($\frac{\text{m}}{\text{s}^2}$)</p> |
| Source | — |
| RefBy | |

Detailed derivation of force on the pendulum:

$$\mathbf{F} = ma_y = \mathbf{T} \cos(\theta_p) - m\mathbf{g}$$

| | |
|-------------|--|
| Refname | GD:angFrequencyGD |
| Label | The angular frequency of the pendulum |
| Units | s |
| Equation | $\Omega = \sqrt{\frac{g}{L_{\text{rod}}}}$ |
| Description | <p>Ω is the angular frequency (s)</p> <p>g is the gravitational acceleration ($\frac{\text{m}}{\text{s}^2}$)</p> <p>$L_{\text{rod}}$ is the length of the rod (m)</p> |
| Notes | The torque is defined in TM: NewtonSecLawRotMot and frequency is f is defined in DD: frequencyDD . |
| Source | – |
| RefBy | GD: periodPend and IM: calOfAngularDisplacement |

Detailed derivation of the angular frequency of the pendulum: Consider the torque on a pendulum defined in [TM: NewtonSecLawRotMot](#). The force providing the restoring torque is the component of weight of the pendulum bob that acts along the arc length. The torque is the length of the string L_{rod} multiplied by the component of the net force that is perpendicular to the radius of the arc. The minus sign indicates the torque acts in the opposite direction of the angular displacement:

$$= -L_{\text{rod}} m g \sin(\theta_p)$$

So then

$$\mathbf{I}\alpha = -L_{\text{rod}}m\mathbf{g}\sin(\theta_p)$$

Therefore,

$$\mathbf{I}\frac{d\frac{d\theta_p}{dt}}{dt} = -L_{\text{rod}}m\mathbf{g}\sin(\theta_p)$$

Substituting for \mathbf{I}

$$mL_{\text{rod}}^2\frac{d\frac{d\theta_p}{dt}}{dt} = -L_{\text{rod}}m\mathbf{g}\sin(\theta_p)$$

Crossing out m and L_{rod} we have

$$\frac{d\frac{d\theta_p}{dt}}{dt} = -\left(\frac{\mathbf{g}}{L_{\text{rod}}}\right)\sin(\theta_p)$$

For small angles, we approximate $\sin \theta_p$ to θ_p

$$\frac{d\frac{d\theta_p}{dt}}{dt} = -\left(\frac{\mathbf{g}}{L_{\text{rod}}}\right)\theta_p$$

Because this equation, has the same form as the equation for simple harmonic motion the solution is easy to find. The angular frequency

$$\Omega = \sqrt{\frac{\mathbf{g}}{L_{\text{rod}}}}$$

| | |
|-------------|--|
| Refname | GD:periodPend |
| Label | The period of the pendulum |
| Units | s |
| Equation | $T = 2\pi\sqrt{\frac{L_{\text{rod}}}{g}}$ |
| Description | <p>T is the period (s)</p> <p>π is the ratio of circumference to diameter for any circle (Unitless)</p> <p>L_{rod} is the length of the rod (m)</p> <p>g is the gravitational acceleration ($\frac{\text{m}}{\text{s}^2}$)</p> |
| Notes | The frequency and period are defined in DD: frequency DD: period respectively |
| Source | – |
| RefBy | |

Detailed derivation of the period of the pendulum: The period of the pendulum can be defined from **GD: angFrequency** equation

$$\Omega = \sqrt{\frac{g}{L_{\text{rod}}}}$$

Therefore from the equation **DD: angFrequency**, we have

$$T = 2\pi\sqrt{\frac{L_{\text{rod}}}{g}}$$

3.2.4 Data Definitions

This section collects and defines all the data needed to build the instance models.

| Refname | DD:positionIX |
|-------------|--|
| Label | x -component of initial position |
| Symbol | p_x^i |
| Units | m |
| Equation | $p_x^i = L_{\text{rod}} \sin(\theta_i)$ |
| Description | p_x^i is the x -component of initial position (m) L_{rod} is the length of the rod (m) θ_i is the initial pendulum angle (rad) |
| Notes | p_x^i is the horizontal position p_x^i is shown in Fig:pendulum . |
| Source | — |
| RefBy | |

| | |
|-------------|--|
| Refname | DD:positionIY |
| Label | y -component of initial position |
| Symbol | p_y^i |
| Units | m |
| Equation | $p_y^i = -L_{\text{rod}} \cos(\theta_i)$ |
| Description | <p>p_y^i is the y-component of initial position (m)</p> <p>L_{rod} is the length of the rod (m)</p> <p>θ_i is the initial pendulum angle (rad)</p> |
| Notes | <p>p_y^i is the vertical position</p> <p>p_y^i is shown in Fig:pendulum.</p> |
| Source | — |
| RefBy | |

| | |
|-------------|--|
| Refname | DD:frequencyDD |
| Label | Frequency |
| Symbol | f |
| Units | Hz |
| Equation | $f = \frac{1}{T}$ |
| Description | f is the frequency (Hz) T is the period (s) |
| Notes | f is the number of back and forth swings in one second |
| Source | — |
| RefBy | GD: periodPend, DD: periodSHMDD, and GD: angFrequencyGD |

| | |
|-------------|---|
| Refname | DD:angFrequencyDD |
| Label | Angular frequency |
| Symbol | Ω |
| Units | s |
| Equation | $\Omega = \frac{2\pi}{T}$ |
| Description | <p>Ω is the angular frequency (s)</p> <p>π is the ratio of circumference to diameter for any circle (Unitless)</p> <p>T is the period (s)</p> |
| Notes | T is from DD: periodSHMDD |
| Source | — |
| RefBy | GD: periodPend |

| | |
|-------------|--|
| Refname | DD:periodSHMDD |
| Label | Period |
| Symbol | T |
| Units | s |
| Equation | $T = \frac{1}{f}$ |
| Description | T is the period (s) f is the frequency (Hz) |
| Notes | T is from DD: frequencyDD |
| Source | — |
| RefBy | GD: periodPend and DD: angFrequencyDD |

3.2.5 Instance Models

This section transforms the problem defined in [Section: Problem Description](#) into one which is expressed in mathematical terms. It uses concrete symbols defined in [Section: Data Definitions](#) to replace the abstract symbols in the models identified in [Section: Theoretical Models](#) and [Section: General Definitions](#).

| | | | |
|--------------------|--|--|--|
| Refname | IM:calOfAngularDisplacement | | |
| Label | Calculation of angular displacement | | |
| Input | $L_{\text{rod}}, \theta_i, \mathbf{g}$ | | |
| Output | θ_p | | |
| Input Constraints | $L_{\text{rod}} > 0$ $\theta_i > 0$ $\mathbf{g} > 0$ | | |
| Output Constraints | $\theta_p > 0$ | | |
| Equation | $\theta_p(t) = \theta_i \cos(\Omega t)$ | | |
| Description | θ_p is the displacement angle of the pendulum (°) t is the time (s) θ_i is the initial pendulum angle (rad) Ω is the angular frequency (s) | | |
| Notes | The constraint $\theta_i > 0$ is required. The angular frequency is defined in GD: angFrequencyGD . | | |
| Source | — | | |
| RefBy | FR: Output-Values and FR: Calculate-Angular-Position-Of-Mass | | |

Detailed derivation of angular displacement: When the pendulum is displaced to an initial angle and released, the pendulum swings back and forth with periodic motion. By applying Newton's second law for rotational motion in **TM: NewtonSecLawRotMot**, the equation of motion for the pendulum may be obtained:

$$= \mathbf{I}\alpha$$

Where τ denotes the torque, \mathbf{I} denotes the moment of inertia and α denotes the angular acceleration. This implies:

$$-m\mathbf{g} \sin(\theta_p) L_{\text{rod}} = mL_{\text{rod}}^2 \frac{d^2\theta_p}{dt^2}$$

And rearranged as:

$$\frac{d^2\theta_p}{dt^2} + \frac{\mathbf{g}}{L_{\text{rod}}} \sin(\theta_p) = 0$$

If the amplitude of angular displacement is small enough, we can approximate $\sin(\theta_p) = \theta_p$ for the purpose of a simple pendulum at very small angles. Then the equation of motion reduces to the equation of simple harmonic motion:

$$\frac{d^2\theta_p}{dt^2} + \frac{\mathbf{g}}{L_{\text{rod}}} \theta_p = 0$$

Thus the simple harmonic motion is:

$$\theta_p(t) = \theta_i \cos(\Omega t)$$

3.2.6 Data Constraints

Table:InDataConstraints shows the data constraints on the input variables. The column for physical constraints gives the physical limitations on the range of values that can be taken by the variable. The uncertainty column provides an estimate of the confidence with which the physical quantities can be measured. This information would be part of the input if one were performing an uncertainty quantification exercise. The constraints are conservative, to give the user of the model the flexibility to experiment with unusual situations. The column of typical values is intended to provide a feel for a common scenario.

| Var | Physical Constraints | Typical Value | Uncert. |
|------------------|----------------------|---------------|---------|
| L_{rod} | $L_{\text{rod}} > 0$ | 44.2 m | 10% |
| θ_i | $\theta_i > 0$ | 2.1 rad | 10% |

Table 4: Input Data Constraints

3.2.7 Properties of a Correct Solution

Table:OutDataConstraints shows the data constraints on the output variables. The column for physical constraints gives the physical limitations on the range of values that can be taken by the variable.

| Var | Physical Constraints |
|------------|----------------------|
| α | $\alpha > 0$ |
| θ_p | $\theta_p > 0$ |

Table 5: Output Data Constraints

4 Requirements

This section provides the functional requirements, the tasks and behaviours that the software is expected to complete, and the non-functional requirements, the qualities that the software is expected to exhibit.

4.1 Functional Requirements

This section provides the functional requirements, the tasks and behaviours that the software is expected to complete.

Input-Values: Input the values from **Table:ReqInputs**.

Verify-Input-Values: Check the entered input values to ensure that they do not exceed the data constraints mentioned in **Section: Data Constraints**. If any of the input values are out of bounds, an error message is displayed and the calculations stop.

Position-Of-Mass: Calculate the following values: θ (from **IM: calOfAngularDisplacement**) and θ_p (from **IM: calOfAngularDisplacement**).

Output-Values: Output L_{rod} (from **IM: calOfAngularDisplacement**) and L_{rod} (from **IM: calOfAngularDisplacement**).

| Symbol | Description | Units |
|------------------|------------------------------------|---------------------------------|
| L_{rod} | Length of the rod | m |
| m | Mass | kg |
| α | Angular Acceleration | $\frac{\text{rad}}{\text{s}^2}$ |
| θ_i | Initial pendulum angle | rad |
| θ_p | Displacement angle of the pendulum | ° |

Table 6: Required Inputs following **FR: Input-Values**

4.2 Non-Functional Requirements

This section provides the non-functional requirements, the qualities that the software is expected to exhibit.

Correct: The outputs of the code have the properties described in [Section: Properties of a Correct Solution](#).

Portable: The code is able to be run in different environments.

5 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an “X” should be modified as well. [Table:TraceMatAvsA](#) shows the dependencies of assumptions on the assumptions. [Table:TraceMatAvsAll](#) shows the dependencies of data definitions, theoretical models, general definitions, instance models, requirements, likely changes, and unlikely changes on the assumptions. [Table:TraceMatRefvsRef](#) shows the dependencies of data definitions, theoretical models, general definitions, and instance models with each other. [Table:TraceMatAllvsR](#) shows the dependencies of requirements, goal statements on the data definitions, theoretical models, general definitions, and instance models.

| | A: pend2DMotion | A: cartCoord | A: cartCoordRight | A: yAxisDir | A: startOrigin |
|-------------------|-----------------|--------------|-------------------|-------------|----------------|
| A: pend2DMotion | | | | | |
| A: cartCoord | | | | | |
| A: cartCoordRight | | | | | |
| A: yAxisDir | | | | | |
| A: startOrigin | | | | | |

Table 7: Traceability Matrix Showing the Connections Between Assumptions dependence of each other.

| | A: pend2DMotion | A: cartCoord | A: cartCoordRight |
|---------------------|-----------------|--------------|-------------------|
| DD: positionIX | | | |
| DD: positionIY | | | |
| DD: frequencyDD | | | |
| DD: angFrequencyDD | | | |
| DD: periodSHMDD | | | |
| TM: acceleration | | | |
| TM: velocity | | | |
| TM: NewtonSecLawMot | | | |

| | A: pend2DMotion | A: cartCoord | A: cartCoordRigh |
|--|-----------------|--------------|------------------|
| TM: NewtonSecLawRotMot | | | |
| GD: velocityIX | | | |
| GD: velocityIY | | | |
| GD: accelerationIX | | | |
| GD: accelerationIY | | | |
| GD: hForceOnPendulum | | | |
| GD: vForceOnPendulum | | | |
| GD: angFrequencyGD | | | |
| GD: periodPend | | | |
| IM: calOfAngularDisplacement | | | |
| FR: Input-Values | | | |
| FR: Verify-Input-Values | | | |
| FR: Calculate-Angular-Position-Of-Mass | | | |
| FR: Output-Values | | | |
| NFR: Correct | | | |
| NFR: Portable | | | |

Table 8: Traceability Matrix Showing the Connections Between Assumptions Items

| | DD: positionIX | DD: positionIY | DD: frequencyDD | DD: an |
|------------------------------|----------------|----------------|-----------------|--------|
| DD: positionIX | | | | |
| DD: positionIY | | | | |
| DD: frequencyDD | | | | |
| DD: angFrequencyDD | | | | |
| DD: periodSHMDD | | | X | |
| TM: acceleration | | | | |
| TM: velocity | | | | |
| TM: NewtonSecLawMot | | | | |
| TM: NewtonSecLawRotMot | | | | |
| GD: velocityIX | | | | |
| GD: velocityIY | | | | |
| GD: accelerationIX | | | | |
| GD: accelerationIY | | | | |
| GD: hForceOnPendulum | | | | |
| GD: vForceOnPendulum | | | | |
| GD: angFrequencyGD | | | X | |
| GD: periodPend | | | X | |
| IM: calOfAngularDisplacement | | | | X |

GS: Motion-of-the-mass
FR: Input-Values
FR: Verify-Input-Values
FR: Calculate-Angular-Position-Of-Mass
FR: Output-Values
NFR: Correct
NFR: Portable

6 Values of Auxiliary Constants

There are no auxiliary constants.

7 References

- [1] Wikipedia Contributors. *Acceleration*. <https://en.wikipedia.org/wiki/Acceleration>. June 2019.
- [2] Wikipedia Contributors. *Cartesian coordinate system*. https://en.wikipedia.org/wiki/Cartesian_coordinate_system. June 2019.
- [3] Wikipedia Contributors. *Velocity*. <https://en.wikipedia.org/wiki/Velocity>. June 2019.
- [4] R. C. Hibbeler. *Engineering Mechanics: Dynamics*. Pearson Prentice Hall, 2004.