Design of Agricultural Type Coconut Climbing and Plucking Robot

Sharath Kumar Karakkattu Sivanandan, Cezary Rzymkowski
Warsaw University of Technology, Faculty of Power and Aeronautical Engineering, Nowowiejska 24, 00-665 Warsaw, Poland

Abstract: The conventional method of coconut plucking followed in coconut farms is arduous as well as a perilous job. There are abounding cases of trauma in which most of them has ended up in the death. Here comes the significant demand for a robot to do this task which would be decisive in mitigating the perils and to meet the everlasting demand of coconut. The foremost intention of the project was to design a climber with a 5 DoF serial chain robot (plucker), which together is supposed to do the coconut climbing and plucking task and also should be available to the farmers at an affordable cost. In the current version, the robot is expected to work complying the commands given by the farmer from the ground who can see the bunch of coconuts through the eyes of robot (cameras) as the robot is not shrewd enough to identify which drupe is ready to be plucked or not. For being cost effective, and light weight, the entire robot skeleton is structured in aluminium alloy with the minimum feasible dimensions of its size and the motor drive selection is also given imperative consideration.

Keywords: agricultural type robot, serial chain robot, climbing robot, plucking robot, kinematic analysis, FEM analysis

1. Introduction

Coconut is one of the most widely produced drupe being a versatile source of food, drink, fiber, cosmetics, etc. recognized as “The Tree of Life” in Philippines. It is produced in over 90 countries worldwide with an average measure of 52 billion nuts annually. The dominant producers of coconut are Indonesia, Philippines, and India being the top 3 leading in the world, while India is having one of its well-governed states in south known in the name of coconut as “Kerala”.

The demand for coconut is everlasting due to its diverse uses, whereas the number of workers choosing to work as coconut pluckers are declining day by day because of the heavy risk involved in it as any misjudged step during the work can be fatal. This causes the average production output of the coconut agriculture industry to descend and also the demand for coconut plucking labors to escalate.

In the present scenario with an irresistible demand for a coconut plucking robot, designing such a robot would be a helping hand enabling the farmers to use it and thus the yield could be increased by getting deprived of all the detriments aforementioned. Appropriate selection of drives and other materials for the robot construction will result in a highly cost effective design that makes the robot presentable in medium level markets.

2. Related work

The two fundamental duties assigned for the proposed robot design are climbing the coconut palm and plucking a coconut. There are varieties of pole climbing robots that were developed in the past [5, 7, 9, 17], but robots made exclusively for coconut climbing were quite fewer. Various companies manufacture robots for fruit plucking in farms but, they are only used on ground level operation and none of them doing both climbing and plucking task is commercially produced.

Boston Dynamics came up with its pole climbing robots RiSE V1 [11], RiSE V2 [12], RiSE V3 [13] as a part of the Rise (Robots in Scansorial Environments) project inspired by biological climbers like lizards and insects (Fig. 1). The three robots are designed to perform the climbing tasks in outdoor natural environment surfaces such as trees and building walls.

RiSE V1 is a 6 legged robot equipped with differential mechanism to control its legs by using two motors. RiSE V2 is also a hexapedal robot and is designed exclusively for climbing outdoor surfaces like trees. In the first glance though RiSE V1 and RiSE V2 robots looks similar, RiSE V2 can be considered as a modified version of RiSE V1 with improvements such as the added space availability inside the body which enables it to assemble the battery within it and the increased space between

Autor korespondujący:
Cezary Rzymkowski, czarek@meil.pw.edu.pl

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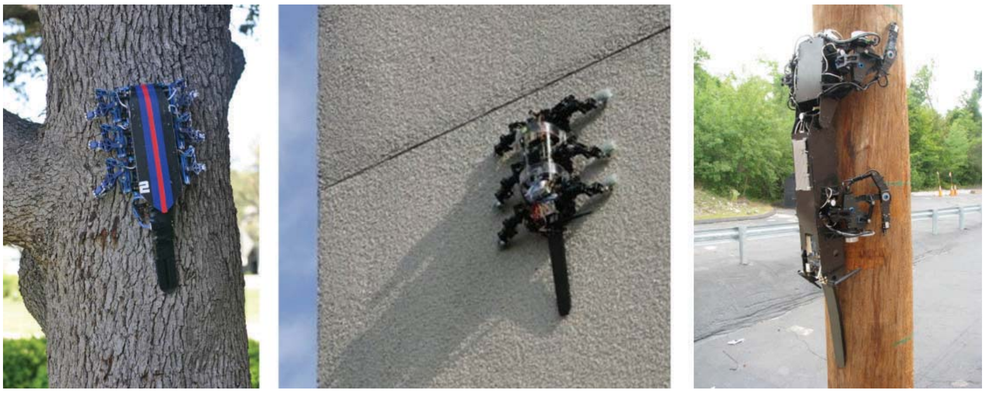


a) b) c)

Fig. 1. RiSE robots Boston Dynamics: a) Rise V1 [11], b) RiSE V2 [12] and c) RiSE V3 [13]
Rys. 1. Roboty RiSE Boston Dynamics: a) RiSE V1 [11], b) RiSE V2 [12], c) RiSE V3 [13]

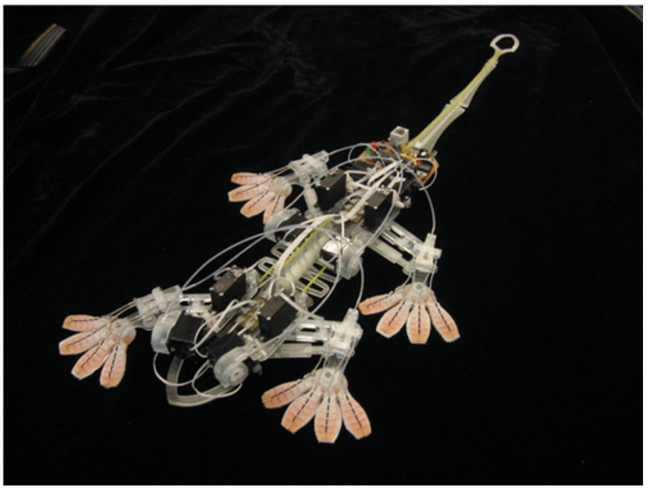


Fig. 2. Climbing robot with sticky feet inspired by Gecko lizard [1]
Rys. 2. Robot wspinający się za pomocą przyssawek wzorowanych na łapkach gekona [1]

the legs that avoids any collisions in between them. The RiSE V3 robot is a quadrupedal robot that can climb poles with a greater velocity (up to 22 cm/s) and is designed with both horizontal and vertical climbing capabilities. The requirement of greater power demand which makes the robot to be heavier than its previous two versions is the major impediment to its hassle free operation.

Stanford Stickybot [1] is a bio-inspired robot which uses its sticky foot to climb vertical surfaces, inspired from lizard. Continuous improvements are being done on its design to obtain the most sophisticated model and right now, Stanford III or Gecko Lizard robot (Fig. 2) is the most advanced version. The adhesive feet are using special suction cups and just sticks to smooth surfaces, thanks to Van der Waals forces.

Numerous universities and robotic companies have developed several kinds of climbing robots with diverse kinds of climbing mechanisms implemented in them. However, they have not got widespread application in practice as far as the fruit plucking tasks are concerned and thus they are not much popular among the farmers. The climbers are used for close inspection of fruits at the tree top using cameras and are not used for any fruit plucking task.

There are several on-ground fruit plucking robots used in practice, for example, the Apple-picking robot (that uses vacuum suckers to pluck the fruits from the tree) by the Abundant Robotics [4] (Fig. 3a) and the first commercial autonomous robot SW6010 [3] to pluck strawberry (Fig. 3b) introduced by a Spanish company Agrobot (AGB) in May 2012. In case of the Spanish robot, based on the maturation and size of the strawberries, harvesting is done with the help of a set of robotic manipulators with high precision to maintain the fruit delicacy and is moved to the packing box through a flexible conveyer system. The robot uses AGvision which has been developed by AGB and adopt artificial intelligence techniques to detect the strawberries.

The necessity of a coconut climbing and plucking robot is developing day by day due to the hiking demand of coconut and coconut products and the declining number of coconut plucking workers. Zero human casualty and minimized labor charge can be assured by the introduction of such a robot.

Because of lack of commercially produced robots that can both climb the palm tree and pluck the nuts, the robot design

a) b)

Fig. 3. a) The Apple-picking robot by the Abundant Robotics [4], b) SW6010 robot to harvest strawberries [3]
Rys. 3. a) Robot do zbierania jabłek firmy Abundant Robotics [4], b) Robot SW6010 do zbioru truskawek [3]

proposed in this work, taking into account its moderate cost, could be quite promising solution for the current dilemma in the coconut agriculture industry.

3. Kinematic analysis

The robot is working in a workspace that can be defined in terms of its joint parameters or in terms of the position and orientation of the end effector in the Cartesian space. The kinematic analysis of the robot [15, 16] is essential to define the robot pose in terms of Cartesian parameters or vice versa. The kinematic data is necessary to generate the control signals that are fed to the actuators. The robot has two assemblies which are the climber subassembly (1 DoF) and the plucker sub assembly (5 DoF serial manipulator).

3.1. Kinematics of the climber

The kinematics calculation of the climber is simple as it has only one translational degree of freedom (Fig. 4). The climber assembly has mainly two subassemblies, which are the two frames of aluminium alloy that slides over each other. Only 1 DoF is present for the climber assembly, which can be actuated by only one linear actuator.

The climber is supposed to do its expected task by gripping the coconut palm using two metallic steel wires connected on the assembly. (Fig. 4). The wire gripper is under a tensile force of the spring of a solenoid actuator. This tensile force keeps the gripper in touch with the tree surface even when the gripper is not holding any weight of the robot.

The push-pull solenoid is employed to release the steel wire gripper (upper and lower alternately) from the palm tree surface during moving up and down the tree. A small movement of the solenoid can release the gripper from the surface.

The climber make a step along the direction of Z1 and Z2 during climbing up and in opposite direction during climbing down. The step length made by the climber is equal to the stroke produced by the actuator (maximum 400 mm for the selected linear actuator that is employed). During the climb, there can be small slip (0 mm to 15 mm) that can occur due to the irregular surface of the coconut tree bark (Step length = Actuator Stroke – Slip).

The climbing up process involves the continuous step up sequence of the frames one after the other till it reaches the required height. The climbing down process is also the same as the climbing up process but in the opposite direction in which the slip is added up to the actuator stroke to give the step length (Step length = Actuator Stroke + Slip).

Fig. 5. General view of the 5 DoF serial manipulator with a cutter wheel
Rys. 5. Widok ogólny manipulatora szeregowego o 5 stopniach swobody z narzędziem tnącym

3.2. Kinematics of the plucker

The plucker is a 5 DoF kinematic serial chain manipulator that has a cutter wheel at its end to cut down the coconut from the coconut palm (Fig. 5).

4. Design of the robot

The robot is designed to perform its intended task with the least possible weight, low power consumption and maximum performance. The design of all the parts, assemblies and sub-assemblies are done in Creo 2.0 [2] in which the mechanisms like gears and belts are also used. The robot is divided into two sub-assemblies, the climber (Fig. 4) and the plucker (Fig. 5) for which, the selection of servo motors, linear actuator and push-pull actuator is done based on necessary calculation of torque and force and their technical specifications are also well studied.

The plucker manipulator is expected to rotate over a semi-circular path in order to achieve the maximum workspace so that the cutter would be able to reach all the required coconuts. After designing the plucker manipulator, it is placed over the rotating base of the climber assembly and bolted. The rotating base is driven through a circular guideway (depicted in blue colour in Fig. 6).

The climber mechanism operates in a step by step process executed in two modes – the climbing mode and the gripping mode. While making a step, the frames never works simultaneously in the same mode as one frame act as climber while other act as gripper and they switch their respective modes in each consecutive steps.

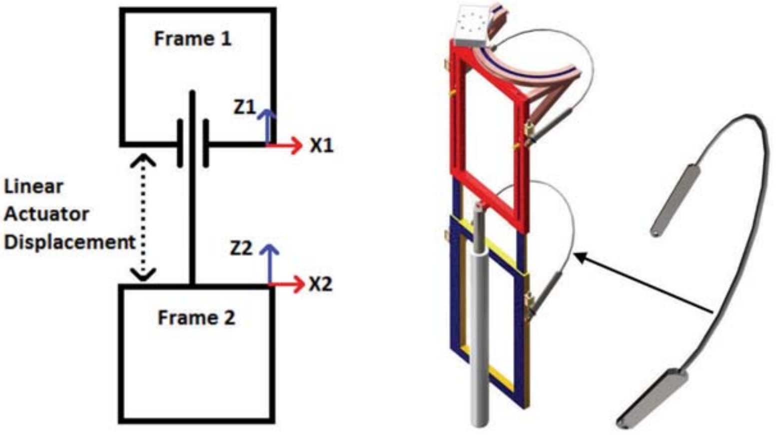


Fig. 4. Displacement of the climber frames of the robot
Rys. 4. Przemieszczenie elementów części wspinającej się robota

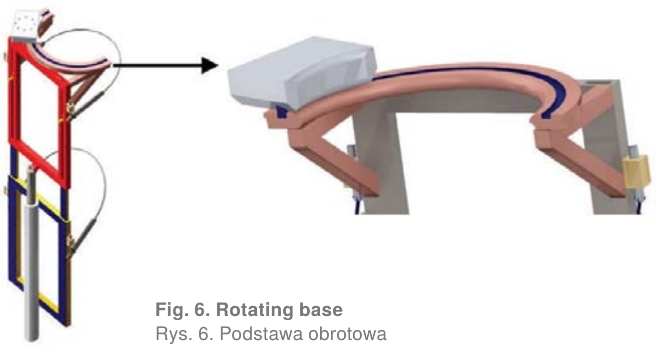


Fig. 6. Rotating base
Rys. 6. Podstawa obrotowa

Fig. 7. Cutter assembly
Rys. 7. Zespół noża tnącego

Unlike other trees, coconut trunk has no protruding branches or other projections on their trunk and this makes the climb hassle free. The inner surface of the rotating base that comes in touch with the trunk is made in curved shape (Fig. 6) in order to minimise the friction due to surface rubbing.

The necessary parts required are selected from leading part manufacturers such as Pittman [14] (servo motors), Nadella [10] (linear and rotational guideways), Iglide [6] (slewing bearing), Meditronik [8] (joystick), etc. The climber is supposed to do its expected task by gripping the coconut palm using a metallic steel wire. Steel is a high strength metal with a tensile strength of 400 MPa which makes is trustable to carry the entire weight of the robot as well as it give the necessary gripping on the tree surface.

The cutter assembly (Fig. 7) consists of a DC motor mounted on the clamps to fix it at the end of link 2 (Fig. 8a) and the centre of the cutting wheel coincides with the axis of rotation of the fifth degree of freedom of the plucker manipulator. In order to reduce the weight of the whole robot, light weight metal aluminium alloy is used to build the robot frame for both the climber and the plucker assembly. The low density of aluminium alloy, which is only about one third of the density of the steel, which enables it to achieve high strength to weight ratio and also its corrosion resistance property makes it the apt material for the robot body.

The entire robot assembly (Fig. 8b) is obtained by the assemblage of the climber and plucker sub assemblies by means of bolts and nuts which makes it easier for a service personnel to detach them each other in case if any technical malfunction of either climber or plucker occurs. Plucker manipulator is bolted on the rotating base of the climber sub assembly to facilitate the half way rotation of the plucker around the palm.

5. Force and strength analysis

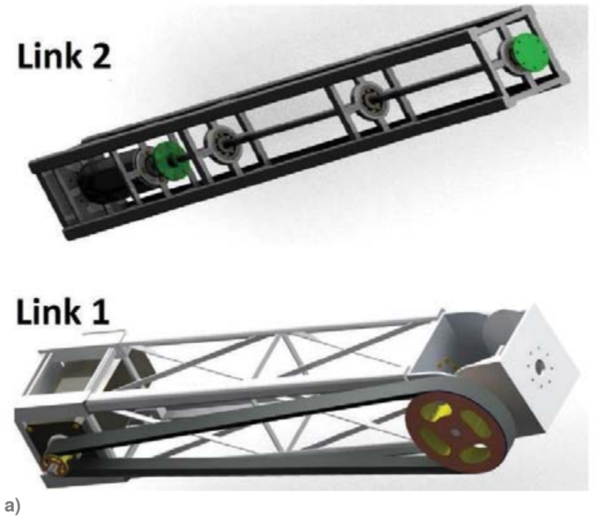
The robot may go different configurations during its operation and this causes continuous deflection in the forces and moments acting at each point of the robot. The robot is designed to withstand all these fluctuations of force and moment and do the expected task without failure in normal working conditions. The stress, strain and deformations of the designed robot have been thoroughly tested (using the ANSYS 15.0 system) to make sure that all of those values exists within the permitted limit.

The worst probable scenarios of maximum deformation that can cause failure of any part of the designed robot were carefully selected and extensive FEM analysis performed. In all the cases, all parameters determining the strength and appropriate stiffness both of individual parts and the overall structure of the robot are found to be in safe range which affirms that the structure is capable of performing the task without failure due to any deformation.

6. Operator control

The idea of having a robot carrier is significant as it is cumbersome for the operator to carry the robot from tree to tree. Thus it is taken from one palm to another using a trolley (Fig. 9).

Once the trolley reaches straight down the tree, the robot can be attached to the tree using the steel wire gripper which is connected to the frame using a key. After attaching the robot on the tree, the operator should move to a safe distance with the trolley in order to prevent the coconut falling on him.



a)

b)

Fig. 8. a) Links 1 and 2 occupied with motors in them, b) Full robot assembly
Rys. 8. a) Człony 1 i 2 z zabudowanymi w nich silnikami, b) widok całościowy zmontowanego robota

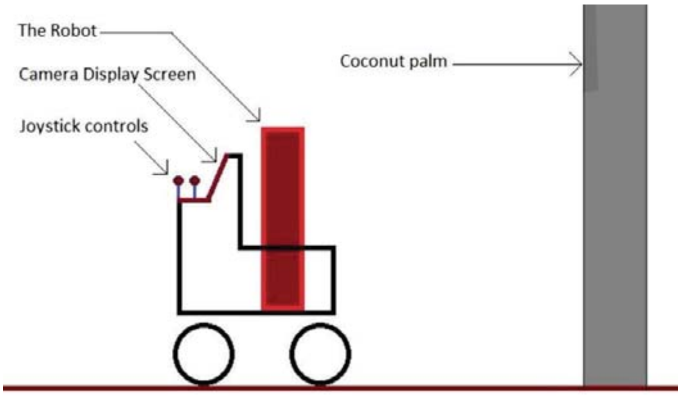


Fig. 9. Trolley carrying the Coconut Climbing and Plucking Robot
Rys. 9. Wózek transportowy dla wspinającego się robota do zrywania kokosów

a) b)
Fig. 10. Meditronik joystick: a) 30JHK and b) C90JAM [8]
Rys. 10. Joysticki Meditronik: a) 30JHK i b) C90JAM [8]

From the safe distance, the operator can view the video streamed by the camera assembled in the plucker manipulator through the display screen. The operator can ask the robot to climb up using the DPDT switch on the control panel on the trolley. Once the robot has attained the necessary height, the plucker can be controlled with the joystick levers by observing the camera view of the robot.

To make the control task quite smooth, use of two joysticks is proposed: one to control the orientation of link 1 (e.g. Meditronik, model 30JHK (Fig. 10a) and the second one to control the orientation of link 2, control the rotating base of climber assembly, control the angle of cutter assembly and the cutter on/off control (e.g. Meditronik, model C90JAM (Fig. 10b).

7. Conclusion and future improvements

The design of an agricultural type coconut climbing and plucking robot has been successfully made which is intended to be available in the market for an affordable price. It is evident from the literature review that there is an undeniable need of such a robot in the current scenario.

The kinematics of the robot is defined by considering the robot into two different kinematic structures: the climber and the plucker.

Kinematics of the climber is straightforward as it is having only one translational degree of freedom of movement while the rotating base does not have any role in the climbing process.

Kinematics of the manipulator has the forward (simple) and the inverse (more complex) calculations. The inverse kinematics calculation starts from the result of the forward kinematics. By the comparison of the appropriate elements of the resultant matrix of the forward kinematics problem with the elements of a generic known matrix, several equations are obtained which on further mathematical calculations lead to the inverse kinematics solution. The kinematically singular configurations of the manipulator were investigated and the solution for the inverse kinematic problem at the singularities was obtained by the suitable combination of some joint angle values that should commensurate with few mathematical conditions.

The proposed design of the robot was drawn in Creo 2.0 software [2]. The climber sub-assembly and the plucker sub--assembly were designed separately. The DC motor, rotational servo, push-pull solenoid actuator, linear motor and the control joysticks were selected from the official catalogue and the websites of the leading part manufacturers post performing the necessary calculations to find the moment or force requirements at each joint.

Basic simulation tests (in CREO environment) which allowed the assessment of mobility were performed. The finite element method analyses allowed for reducing the masses of robot segments (which is important in the case of a climbing robot) while maintaining adequate rigidity and strength.

The construction of the prototype and the performance of experimental tests is planned in the near future (depending on the development of the Cov-19 pandemic). The prototype developed is to serve, among others, as a platform for testing various solutions aimed at creating a fully autonomous robot climbing trees (or poles) for coconut harvesting (but also for other applications) using advanced methods of artificial intelligence.

The prototype will be built at the Warsaw University of Technology, where preliminary tests will be carried out. This first phase of testing will be carried out using the ‚model' tree trunk. Its purpose will be to check the functional capabilities of the robot, such as the effectiveness of climbing and holding in the assumed position, „smoothness" of movement, stability of the entire robot with different (including most demanding) configuration of the arms, the influence of climbing speed and operations performed by the end effector on the quality of movement, etc.

After making the necessary corrections taking into account results of the first phase tests, it is planned to organize and conduct the appropriate real tree-top experiments in India, in the state of Kerala (roughly 45% of India's coconuts are produced there).

In coconut farms, the harvest demand would be for a particular stage of maturity. The coconuts on the same bunch are of almost the same level of maturity. So, all the bunches of the required maturity are cut down. From one palm, there would only be maximum of three of four bunches of coconuts to pluck. That means only three or four stems are only needed to be cut from a single tree.

The more mature bunches are at the bottom and the less mature ones are at the top. The majority of the coconut agriculture industry aims for the coconut oil and milk production and thus they need 10 to 12 months old coconuts, which hangs comparatively lower to the other coconut bunches.

Reaching out for the main stem is easy while it is difficult to cut down individual coconuts from a thick bunch. In order to get more outreach, mini reciprocating saw blades or mini chainsaw cutters can be employed.

Though the paper concentrates only on a user operated robot design, the robot can be made fully automatic by adding more advanced control system and training it to climb and pluck.

The climbing task is quite easy while the plucking task is hard as the robot does not know which fruit is ready to be plucked and which is not. This is determined according to the requirement of the farmer. The uses of coconut is defined by its level of maturity, which can be described in seven stages of its growth form stage 1 (Poppers stage, 7 months old) when coconut shell is full of water and is used as a wonderful refreshing drink to stage 7 (Sprouters stage, 14 to 20 months old) — the stage of the coconut which can grow to a fully matured coconut palm provided the sufficient nutrition is available. There are several techniques to identify if the coconut is ready by which the improved version of the robot can be equipped with which will it be capable of making decisions of its own automatically.

The plucker manipulator can reach all the points in its workspace while some of the combinations of position and orientation are unachievable which causes the inverse kinematics solution give irrelevant outputs. When the robot is fully automatic, it by itself defines its poses and trajectories to do the task in terms of the task space parameters which is then be transformed to the joint space parameters in order to generate the appropriate control signals for the servo motors. To get rid of the issue in inverse kinematics, the manipulator can be fitted with a spherical wrist end effector which makes any position-orientation combination achievable within its workspace.

In the proposed design, the power supply to the robot is provided by auto-rewind power chord which unwinds when climbing up and rewinds when climb down. By the advancements of battery technologies in future, more powerful batteries of less weight can be used to power up the robot which makes it a wireless robot.

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Projekt wspinającego się po drzewach robota rolniczego do zrywania orzechów kokosowych

Streszczenie: Konwencjonalna metoda zrywania orzechów stosowana na uprawach kokosów jest męcząca i ryzykowna. Często dochodzi do wypadków prowadzących nawet do śmierci. Pojawia się zatem istotna potrzeba zastąpienia pracy ludzkiej przez odpowiednio skonstruowane roboty — pozwoli to na rozwiązanie problemów związanych z zagrożeniami, przy zapewnieniu poziomu produkcji odpowiadającego ciągłemu popytowi na orzechy kokosowe. Głównym celem pracy było opracowanie projektu robota modułowego — mobilnej wspinającej się po pniu platformy transportującej część wykonawczą (robota o pięciu stopniach swobody), której zadaniem jest odcinanie kiści orzechów. Robot powinien być możliwie tani, aby był dostępny dla szerokiej grupy rolników. W wersji, będącej przedmiotem pracy, robot będzie pracował pod nadzorem rolnika pozostającego na ziemi, który będzie decydował, na podstawie obserwacji wizualnej przekazywanej przez kamerę zainstalowaną na końcówce robota, które orzechy nadają się do zerwania. Dla zapewnienia niskiego kosztu i małej masy, szkielet robota jest zbudowany ze stopu aluminium o minimalnych możliwych wymiarach zapewniających jednak odpowiednią sztywność i wytrzymałość. Podobne warunki wzięto pod uwagę przy wyborze silników.

Słowa kluczowe: robot do zastosowań rolniczych, robot szeregowy, robot wspinający się, zrywanie kokosów, analiza kinematyczna, analiza MES

Sharath Kumar Karakkattu Sivanandan, MSc

sharathapril92@gmail.com
ORCID: 0000-0003-2447-8765

He received his BE (2015) in Mechatronics engineering from Anna University, India and MSc (2019) in Automatic control and robotics from Warsaw University of Technology, Poland. His areas of study interest are climbing machines, serial manipulators, mobile robots and computer vision. His prominent works in BE programme were land mine detection and diffusing robot and the design of Direction Controllable Bearing (applied in robotics as well as in automobiles) and his masters dissertation dealt with the application of robotics in coconut agriculture industry.

prof. Cezary Rzymkowski, PhD, DSc

czarek@meil.pw.edu.pl
ORCID: 0000-0003-1131-8113

He is currently an associate professor and Head of the Virtual Safety Engineering and Biomechanics Lab (ViSEB) at the Institute of Aeronautics and Applied Mechanics, Warsaw University of Technology (WUT). He received his MSc (1978) in „Fundamental Technological Sciences" from Faculty of Applied Physics and Mathematics (WUT), PhD (1988) in "Robotics and Automation" and DSc (2014) in "Mechanics" from Faculty of Power and Aeronautical Engineering (WUT). His research areas are: computational methods of biomechanics (especially biomechanics of impact/injury), passive safety in cars and light aircrafts, multi-body systems dynamics, numerical/computer simulation methods. He has participated in many international projects in this field, funded by European Commission.