Technical solution

Program system ORVER

(for **RFCPR** system, Rigid ropes F-type Cable-suspended Parallel Robot)

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This research was supported by the Ministry of Education, Science and Technological Development, Government of The Republic of Serbia for financing the national research project “Ambientally intelligent service robots of anthropomorphic characteristics” TR-35003 and partially supported by the project: SNSF Care-robotics project no. IZ74Z0_137361/1.

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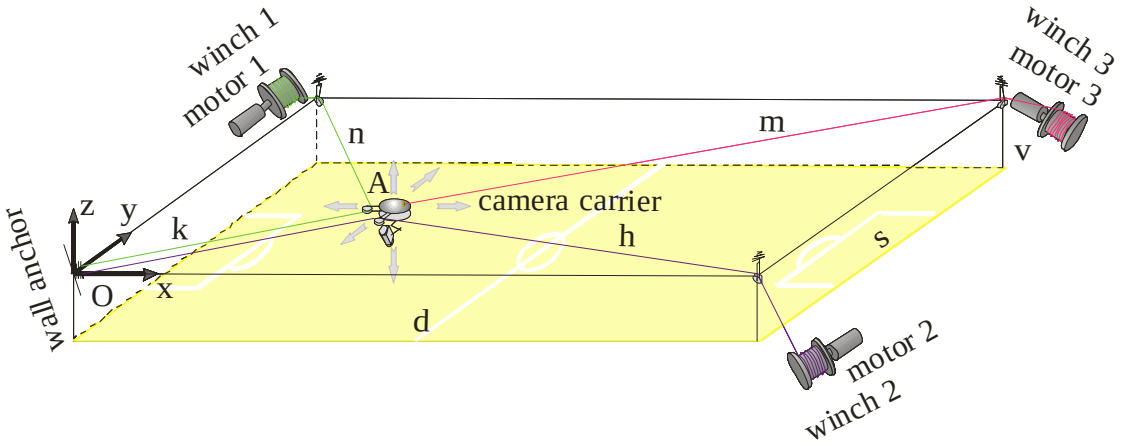

Figure1. **RFCPR**, in the 3D space.

This program system is generated in MATLAB. This program system presents a methodology for kinematic and dynamic modeling of the selected Rigid ropes F-type Cable-suspended Parallel Robot (**RFCPR**) with the unstretchable ropes. The **RFCPR** system is used for the workspace observation. The complex construction of the selected aerial robot requires in depth study of the relationship between external and internal forces. This system is constructed such that its geometric structure requires

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the adaptation of the Lagrange principle of virtual work. The **RFCPR** model is utilized for very complex tasks using the intelligent control system. The software packages named **ORVER** has been used for the **RFCPR** model verification.

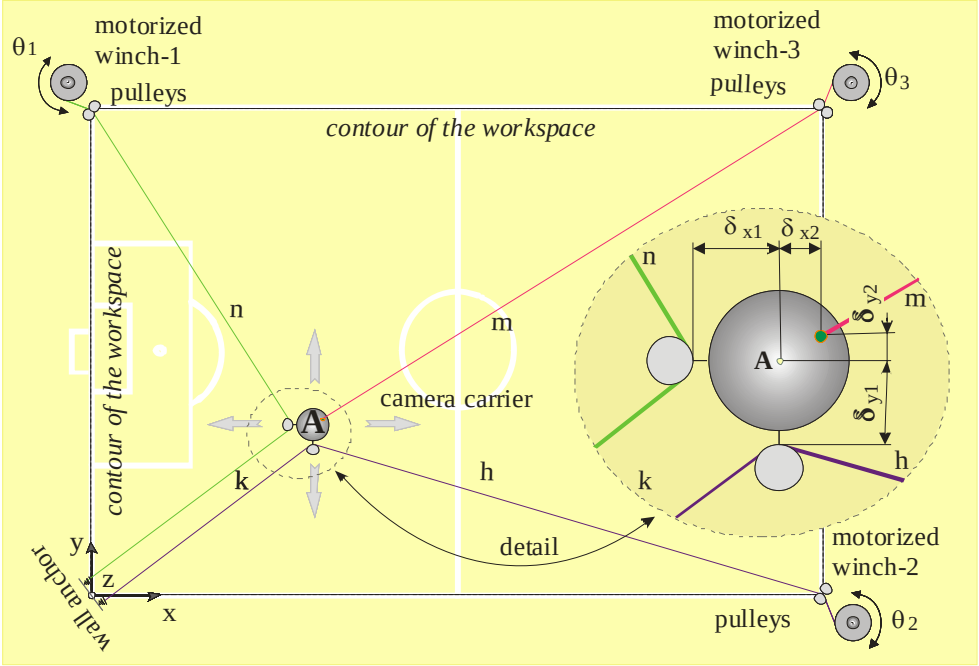

Figure2. **RFCPR**, top view.

The area to which the technical solution refers

Synthesis and analysis of **RFCPR** system, *Robotics, Theory of Mechanics*.

Problem solved by technical solution

This technical solution solves the problem of efficient synthesis and analysis of aerial robot model in its construction, as well as testing its behavior under simulated real conditions of **RFCPR** system task realization.

State of the problem solution in the world

One strong class of mechanisms used for different camera motions of **CPR** type has been developed strongly in last three decades. For three decades, researchers have dealt with the mechanisms that carry a camera for observation of the space or moving

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objects in space. Implementation of this system uses the latest technical knowledge. This is achieved using the latest computer, network and new types of motors, combined with confirmed high quality camera and video components.

Specially trained camera operator is responsible for process and quality recording. It is clear that for the full functioning of such a complex system must be responsible a team of experts of various profiles.

The modular design system for observation of workspace and light weight components and a small force in the ropes allow the successful setting up a system to almost any location, which offers wide possibilities for its use in closed or open space, which can be small or large sizes. It may be placed in the most unlikely places, for example when filmmaking of different genres or for military or police purposes.

Regardless of the purpose and in which areas the system installed, top priority is definitely a high safety of participants in the recorded event. In this sense, the system should get certified according to the highest European standards. The **CPR** system should fly over the audience without being able to be off and fall to the ground.

In the case of an emergency or failure, the security concept would immediately halt the system. The protection system works by activating all the brakes and the winches deactivated in milliseconds. Stopping the system can be run (provided) manually by the operator, by pressing one of the buttons provided for the alarming situation, or automatically by one of the integrated security protocols. The most important components of the security system are:

- a sensor that measures the force in each rope,
- rotating torque sensor, control unit for checking the winding,
- mechanical check of the brake functionality,
- continuous monitoring of the functionality of the brake contactor, motor contactor, servo-amplifiers, the stop commands to stop the system and fiber optic connections,
- continuous monitoring of the geometry and position of the camera carrier.

Each circuit has a double security system. In addition, there are two brakes for each winches, each brake is strong enough to respond quickly and to higher loads and no electricity. If a sudden cancellation of all motors, all brakes will be activated

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automatically.

Who first developed a **CPR** system? There are different claims. Source http://www.spidercam.net , the company Skycam claims that it was discovered in 1984 by Garrett Brown. Source http://broadcastengineering.com/infrastructure/cablecam , Broadcast Engineering firm claims to have discovered it in 1985 by Jim Rodnunsky. The source http://en.wikipedia.org/wiki/Spidercam writes that it was Jens C. Peters, a researcher from CCSytems Inc. It is certain that all of them are big names in this field because they contributed to the development of this system.

In its initial phase the system was used in limited circumstances that the technology's development allowed. Because of that its development has been slow, due to the support of computers technique. From that time until now the use of this system has been constantly expanding. During the transfer of sporting or other public events (football, basketball, hockey or other games, tennis or athletic competitions, Eurovision, concerts of various musical genres etc.) the presence of **CPR** system used for recording can be noticed. But in many areas this system has not yet appeared.

It should be noted here that the position of the camera is controlled via joystick by the operators, who are located to monitor the whole workspace with moving subjects. In this case the operator via the joystick moves the camera in all directions left, right, up, down etc. This system in its functioning depends on the concentration and the responsibility of the operators. Their skill and experience play a major role. Since the implementation of task observation of an event can last for hours, it's a pretty big responsibility for operators. Lack of concentration and their fatigue during the period indicates a significant dependence of this system on the human factor, which as a result can have a number of unavoidable inaccuracies during the operation.

Illogical assumption in the functioning of this system is that the relationship between the coordinates $\theta_1 \Leftrightarrow x$, $\theta_2 \Leftrightarrow y$, $\theta_3 \Leftrightarrow z$ is uniquely defined. Unlike previous approaches this program package proposes the application of theoretical methods in solving specific problems.

The essence of the technical solution

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This program system **ORVER** has aims at using the mathematical model for **RFCPR** system according to the original scientific principles. In this program package the **RFCPR** system for tracking of moving objects is analyzed and synthesized. This may be a working hall or space for recording of cultural, sporting, exhibition or promotional events.

The highly authentic general mathematical model for the **RFCPR** system has been developed.

The advantage synthesized and modeled structures is that the carriage moves the camera in the working space of the parallelepiped shape, which was powered over three ropes, which coil or uncoil winches and each of them is driven by the motor. This means the system has four pivot points but motions of the camera carrier are driven by three motors.

The kinematic model is defined for the monitored system via the Jacobian matrix. The generalized coordinates selected for the **RFCPR** model are motors angular positions θ_1, θ_2, θ_3, named internal coordinates. The camera motion is defined in the Cartesinan space, described with the x, y, z coordinates, named external coordinate system. The relation between internal and external coordinate systems are described by the Jacobian matrix J_F. This relation represents the kinematic model of the **RFCPR** system.

The relation between the resultant forces and the forces acting at the camera carrier is described by the Lagrange principle of the virtual work. This calculation shows that in this relation the Jacobian matrix is involved.

Because of the **RFCPR** system complexity, the Lagrange principle of virtual work had to be adapted to support the presence of two ropes in the k direction. This requires the multiplication of the Jacobian matrix J_F elements which includes length k, by the factor $\Diamond$. The obtained adopted Jacobian matrix is named $J_{\Diamond F}$.

The software package **ORVER** has been developed and used for individual analysis of the **CPR** model from various aspects such as selecting different workspace dimensions, a camera carrier mass, the external disturbances, the choice of control law, the reference trajectory, the singularity avoidance and many other characteristics.

The motor type, significantly affect the response of the system or accuracy of the

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trajectory tracking.

The formulated program package **ORVER** (based on its mathematical model) has a special significance because it is the foundation for further development and implementation of this system.

Detailed features description

The graphical representation of the **RFCPR** is shown in Fig. 1 and 2.

The camera carrier of the **RFCPR** structure is guided through the work area of the parallelepiped shape with three ropes connected with three winches, each powered by the motors.

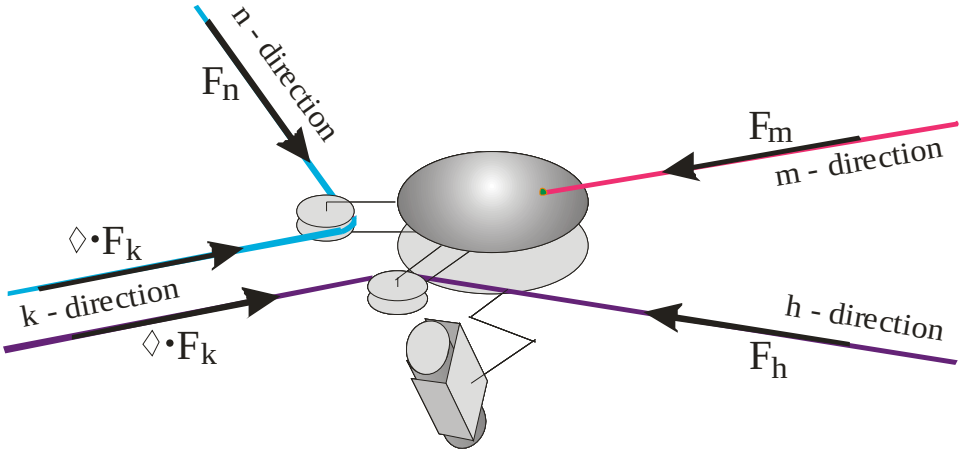

Fig. 3. The ropes forces carry a camera (**RFCPR**).

The ropes of the pulley system are run on the winches (reel) 1, 2, 3, powered by the motors. The ropes coil or uncoil on the winches of radius R_1, R_2, and R_3. The motors rotate winches directly and its angular positions are θ_1, θ_2, and θ_3. This motion moves the camera in the x, y, z Cartesian coordinates.

The first step towards the dynamic model of the **RFCPR** is the development of its kinematic model. This calculation involves accurate definition of the geometric relationship between the camera motion in the Cartesian x, y, z space (external coordinates) and motor angular positions θ_1, θ_2, θ_3, (internal coordinates).

The relation between the internal and external coordinates is defined by the Jacobian matrix J_F, which relates the velocities of external coordinates $\dot{p} = [\dot{x} \quad \dot{y} \quad \dot{z}]^T$ with the

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velocities of the internal coordinates $\dot{\phi} = [\dot{\theta}_1 \quad \dot{\theta}_2 \quad \dot{\theta}_3]^T$. For the generation of any trajectory in x, y, z space (the desired motion trajectory of the camera carrier), it is necessary to provide very precise and mutually coordinated motion of all three motors θ_1, θ_2, θ_3.

The 3D recorded space has a parallelepiped shape of length d, width s, and height v. In this 3D space it can be seen that the camera is connected with the ropes. See Fig. 2. The connecting dimensions are δ_{x1}, δ_{x2}, δ_{y1}, δ_{y2}. These dimensions are very small in comparison with the complete 3D recorded space. From this observation it is clear that $\delta_{x1} \approx 0$, $\delta_{x2} \approx 0$, $\delta_{y1} \approx 0$, $\delta_{y2} \approx 0$. It is also assumed that the pivot point A height z is equal to the heights of all three connecting points.

This fact allows us to choose a point A as a hanging position of the camera carrier for all three ropes, see Figure 2. This camera carrier system can be easily constructed. This assumption simplifies the definition of geometric relations between camera carrier motion in Cartesian coordinates and coordinated motions of all motors.

By this approach, the new research prospects have been opened.

Emphasis is placed on the importance of these results in the field of robotics, which develops very extensively and it becomes the inspiration in this research for the development of areas such as dynamics of nonlinear phenomena of **RFCPR** structures and its stability.

Program package **ORVER** that is synthesized specially for the purpose of comfort analysis of such complex system served for obtaining simulation results and validation theoretical contributions.

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Subject: Opinion on meeting the criteria for recognition of the technical solution

According to the submitted material and in accordance with the provisions of The Rules of procedures and methods of evaluation and quantitative presentation of scientific research results of researchers, brought by the National Council for Scientific and Technological Development of Serbia ("Official Gazette of the Republic of Serbia", No. 38/2008) **reviewer: Prof. dr Ana Djuric, Wayne State University, 4855 Fourth St. Detroit, MI 48202, U.S.A.,** *has evaluated that conditions for the recognition of the properties of the technical solution are fulfilled for the following result of the scientific research paper:*

Title: **program system ORVER** (for **RFCPR** system, Rigid ropes F-type Cable-suspended Parallel Robot) (*Project:* Ambientally intelligent service robots of anthropomorphic characteristics, TR-35003 and the project: SNSF Care-robotics project no. IZ74Z0_137361/1*)*

Author: **Mirjana Filipovic**

Category of technical solution: **M85** *„Acknowledged program system"* ***– Software.***

Explanation

Objective and significance: *The objective is to use this technical solution for the efficient synthesis and analysis of the **RFCPR** system, Rigid ropes F-type Cable-suspended Parallel Robot as well as testing its behavior in the real conditions along the task realization. During the research, the laws and the phenomena at the motion of **RFCPR** system, Rigid ropes F-type Cable-suspended Parallel Robot should be discovered and applied the same to synthesis, analysis, realization, control and exploitation of such robotic configurations. Areas where **RFCPR** system, Rigid ropes F-type Cable-suspended Parallel Robot are applied are: football, basketball, hockey or other games, tennis or athletic competitions, Eurovision, concerts of various musical genres and for military or police purposes.*

Proposed solution is done in: *2013.*

Area to which the technical solution refers is: *Robotics, Theory of Mechanics.*

Problem that is being solved with this technical solution: *This technical solution is used for solving the problem of the effective implementation of the model of RFCPR system, Rigid ropes F-type Cable-suspended Parallel Robot in their construction, as well as testing their behavior in designed implementation conditions of the robotics task. It also points to the need for implementation of various control laws.*

State of the problem solution in the world: *Control structures are very low. Illogical assumption in the functioning of this system is that the relationship between the coordinates* $\theta_1 \Leftrightarrow x$, $\theta_2 \Leftrightarrow y$, $\theta_3 \Leftrightarrow z$ *is uniquely defined. The previous approaches propose the application of non theoretical*

methods in solving these specific problems.

Essence of technical solution. Only highly intelligent control systems, based on high fidelity mathematical model of the system, can provide the realization of very complex tasks. The established mathematical model provides an opportunity to modernize **RFCPR** significantly and to make its application become much wider. The aim of this paper is to ensure, in the future, accurate and highly automated guidance of the camera in space with minimal involvement of the human factor in the realization of the task for several hours.

Characteristics of the proposed technical solution are following:
This technical solution enables:

- *A new approach for kinematic and dynamic (kinetic) modeling of the **RFCPR**.*
- *The importance of generating the Jacobian matrix J_s. This procedure is named KinCPR-Solver (Kinematic Cable Parallel Robot Solver).*
- *Because of the **RFCPR** system complexity, the Lagrange principle of virtual work had to be adapted to support the presence of two ropes in the k direction.*
- *The software package **ORVER** has been developed for the **RFCPR** model evaluation.*
- *The influence of changing any parameters of the system can be analyzed through the **ORVER** software package.*

Possibility of implementation of proposed technical solution: *The real system **RFCPR** cannot work in real time conditions without the use of software package **ORVER**. .*

On the basis of the above mentioned, the reviewers have concluded that the result of the scientific research paper titled: program system ORVER presents the recognized program system that beside expert component also provides the original scientific research contribution.

December 2013.

Reviewer:

Prof. dr Ana Djuric,
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DECLARATION

OF USING THE PROGRAM SYSTEM **ORVER**

The program system: **ORVER** (for **RFCPR** system, Rigid ropes F-type Cable-suspended Parallel Robot), *Projects:* "Ambientally intelligent service robots of anthropomorphic characteristics" TR-35003 and SNSF Care-robotics project no. IZ74Z0_137361/1, whose author is **Mirjana Filipovic**, Ph.D,El.Eng., presents a scientific and technical achievement in robotics which we, the below-signed, use in education and research purposes as well as during the realization of our theoretical and practical solutions. We, the below-signed, confirm that we have used the program system **ORVER** since July 2013.

January 2014.

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JANUARY, 09, 14
DATE _____

DIVISION OF ENGINEERING
WSU
APPROVED AN
ENDORSED

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December 2013.

Prof. dr Dragutin Debeljković,
The University of Belgrade,
Faculty of Mechanical Engineering,
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Vice Dean for
Research and Development

Prof. dr Vojkan Lučanin,
The University of Belgrade,
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ИНСТИТУТ „МИХАЈЛО ПУПИН“ доо
Број: 41/2-14
8. јануар 2014. године
Б е о г р а д

На основу чл. 25. Статута Института „Михајло Пупин“ доо Београд – *пречишћен текст* („Билтен“ бр. 9/2013.) а у складу са одредбама Правилника о поступку и начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача („Службени гласник РС“ бр. 38/2008), Научно веће Института „Михајло Пупин“ доноси следећу:

О Д Л У К У

Прихвата се техничко решење под називом:

„Program system **ORVER** (for **RFCPR** system, **R**igid ropes **F**-type **C**able-suspended **P**arallel **R**obot)“.

Техничко решење је резултат рада на пројекту:

Ambientally intelligent service robots of anthropomorphic characteristics, 2011-2014;

Шифра пројекта:
TR-35003

Техничко решење спада у категорију: Program system, software, **M85.**

Аутор: Мирјана Филиповић.

Кратак опис решења:

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Рецензенти:

- Prof. dr Ana Djurić, Engineering Technology Division, Wayne State University, 4855 Fourth St. Detroit, MI 48202, U.S.A.

- Prof. dr Dragutin Debeljković, The University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia.

На основу позитивног мишљења два рецензента – експерта из области техничког решења, Научно веће је донело предметну одлуку.

ПРЕДСЕДНИК НАУЧНОГ ВЕЋА
ИНСТИТУТА „МИХАЈЛО ПУПИН“ д.о.о.

Др Драган Радојевић*, дипл. инж.,*
Научни саветник

Достављено:

- ауторима
- Секретаријату Института