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# DIRECT KINEMATICS OF A MANIPULATOR WITH THREE MOBILITIES

*Florian Ion Tiberiu Petrescu*
*IFToMM, Romania*
*E-mail: fitpetrescu@gmail.com*

*Relly Victoria Virgil Petrescu*
*IFToMM, Romania*
*E-mail: rvvpetrescu@gmail.com*

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***ABSTRACT***

In the industrial halls it is often necessary to handle large objects, with a large and large table, which have to be transported not over long distances but moved from one place to another, raised, then lowered to various levels, left or right. Such repeated manipulations of heavy and dangerous objects can be done only with the help of a manipulator, which can be a crane, a specially designed trolley, a complicated robot or a simple manipulator as is the case for the one presented in the paper. The paper briefly presents the kinematic study of a manipulator with three mobilities, which can be used both in industrial halls and in garages, depending on its suitably chosen constructive size, which at smaller dimensions can be handled very easily. This manipulator can carry large loads, thus easing the work of the human being and preventing it from major dangers that can occur during the transport of large pieces and a large mass.

**Keywords**: Robots; Mechatronic Systems; Structure; Kinematics; Machines; Balancing

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## 1. INTRODUCTION

In the industrial halls it is often necessary to handle large objects, with a large and large table, which have to be transported not over long distances but moved from one place to another, raised, then lowered to various levels, left or right. Such repeated manipulations of heavy and dangerous objects can be done only with the help of a manipulator, which can be a crane, a specially designed trolley, a complicated robot or a simple manipulator as is the case for the one presented in the paper.

Figure 1: The crane with ECO5 column is extremely easy to handle, it provides convenient access to all points of the space, with a pivoting angle of maximum 270 °, being the indispensable accessory of all workstations.

Workers are prevented from using it to get various diseases because of the repeated lifting of heavy objects. In the past, an interior crane built on different systems walks through the respective hall to carry the heavy objects.

The system was cumbersome to operate and even a little dangerous without permanent attention to the fact that it is moving so that workers can be warned permanently about its movements. Such expensive and difficult systems to handle and maintain are today generally on the verge of extinction, because the vast majority of industrial operations have been taken over by specialized intelligent robots, but in some places a manipulator may be needed which can be automated or manually depending by the size of the place where it is implemented.

In the maritime ports there are still used systems with large cranes, but also there the systems that traveled on large surfaces began to reduce or even disappear, being replaced by the individual, punctual cranes, some of them even being robotic, specialized on different unloading-loading operations.

The swivel crane with ECO5 column is extremely easy to handle, it provides convenient access to all points of the space, with a pivoting angle of maximum 270 °, being the indispensable accessory of all workstations.

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Manufactured from rigid torsion steel, fixed by means of anchor bolts to the concrete foundation. Up to 2 m, the electricity supply is made in the cable tube, with a rubber cable of circular diameter, in the case of the arm with larger openings with the help of the C rail, with a cable trolley and a flat cable. The power switch is mounted on the column (Figure 1).

The ECO3 pivoting wall crane is extremely easy to handle, with a pivoting angle of maximum 180 °, being the indispensable accessory of all workplaces. Thanks to the height-mounted console, it makes optimal use of the lifting height even in the lower rooms. Made of rigid profile steel at torsion, fixed by the console to a steel beam, concrete pole. Up to 2 m, the electricity supply is made in the cable tube, with a rubber cable of circular diameter, in the case of the arm with larger openings with the help of the C rail, with a cable trolley and a flat cable (Figure 2).

The ECO6 mobile pivoting crane is successfully folded to different situations in the factory. It can be moved manually to the desired location and fastened with the support screws. It has a lifting capacity of up to 500 kg and a pivoting angle of 360 °. The electricity supply is made using the contacts through the collector rings.

For lifting loads, this variant requires filling the body of the crane with counterweights (Figure 3).

Figure 2: The ECO3 pivoting wall crane


Figure 3: The ECO6 mobile pivoting crane

The ECO6 mobile pivoting crane is successfully folded to different situations within a section, halls, factories, or even in a hangar, or larger garage, which can be moved manually to the desired location and fixed with the support screws, having a capacity of lifting up to 500 kg. Such a crane model was inspired by modern manipulative robots, which instead of the drilling, welding, handling, dyeing, crane system was added. Its advantage is that it can be more penetrating, like a specialized robot, but with a lower purchase price than robotic systems.

Such a crane is generally easier to handle itself, to implement, to use, to maintain, and also to have a lower purchase price, which is often more convenient than robotization, where

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handling of heavy objects and bulky is necessary, but not the automation of the operation itself (Aabadi, 2019; Antonescu *et al*., 2000a; 2000b; 2001; Aversa *et al*., 2019; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2016a; 2016b; 2016c; 2016d; 2016e; 2016f; 2016g; 2016h; 2016i; 2016j; 2016k; 2016l; 2016m; 2016n; 2016o; Cao *et al*., 2013; Dong *et al*., 2013; Duan et al., 2019; Comanescu, 2010; He *et al*., 2013; Lee, 2013; Lin *et al*., 2013; Liu *et al*., 2013; Padula and Perdereau, 2013; Perumaal and Jawahar, 2013; Petrescu, 2019; 2011; 2015a; 2015b; Petrescu and Petrescu, 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e; 2011a; 2011b; 2012a; 2012b; 2013a; 2013b; 2013c; 2013d; 2013e; 2016a; 2016b; 2016c; Petrescu *et al*., 2009; 2016; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; 2018a; 2018b; 2018c; 2018d; 2018e; 2018f; 2018g; 2018h; 2018i; 2018j; 2018k; 2018l; 2018m; 2018n; Rulkov *et al*., 2016; Agarwala, 2016; Babayemi, 2016; Ben-Faress et al., 2019; Gusti and Semin, 2016; Mohamed *et al*., 2016; Wessels and Raad, 2016; Maraveas *et al*., 2015; Khalil, 2015; Rhode-Barbarigos *et al*., 2015; Takeuchi *et al*., 2015; Li *et al*., 2015; Vernardos and Gantes, 2015; Bourahla and Blakeborough, 2015; Stavridou *et al*., 2015; Ong *et al*., 2015; Dixit and Pal, 2015; Rajput *et al*., 2016; Rea and Ottaviano, 2016; Zurfi and Zhang, 2016 a-b; Zheng and Li, 2016; Buonomano *et al*., 2016a; 2016b; Faizal *et al*., 2016; Ascione *et al*., 2016; Elmeddahi *et al*., 2016; Calise *et al*., 2016; Morse *et al*., 2016; Abouobaida, 2016; Rohit and Dixit, 2016; Kazakov *et al*., 2016; Alwetaishi, 2016; Riccio *et al*., 2016a; 2016b; Iqbal, 2016; Hasan and El-Naas, 2016; Al-Hasan and Al-Ghamdi, 2016; Jiang *et al*., 2016; Sepúlveda, 2016; Martins *et al*., 2016; Pisello *et al*., 2016; Jarahi, 2016; Mondal *et al*., 2016; Mansour, 2016; Al Qadi *et al*., 2016b; Campo *et al*., 2016; Samantaray *et al*., 2016; Malomar *et al*., 2016; Rich and Badar, 2016; Hirun, 2016; Bucinell, 2016; Nabilou, 2016b; Barone *et al*., 2016; Bedon and Louter, 2016; Santos and Bedon, 2016; Fontánez et al., 2019; De León et al., 2019; Hypolite et al., 2019; Minghini *et al*., 2016; Bedon, 2016; Jafari *et al*., 2016; Orlando and Benvenuti, 2016; Wang and Yagi, 2016; Obaiys *et al*., 2016; Ahmed *et al*., 2016; Jauhari *et al*., 2016; Syahrullah and Sinaga, 2016; Shanmugam, 2016; Jaber and Bicker, 2016; Wang *et al*., 2016; Moubarek and Gharsallah, 2016; Amani, 2016; Shruti, 2016; Pérez-de León *et al*., 2016; Mohseni and Tsavdaridis, 2016; Abu-Lebdeh *et al*., 2016; Serebrennikov *et al*., 2016; Budak *et al*., 2016; Augustine *et al*., 2016; Jarahi and Seifilaleh, 2016; Nabilou, 2016a; You *et al*., 2016; AL Qadi *et al*., 2016a; Rama *et al*., 2016; Sallami *et al*., 2016; Huang *et al*., 2016; Ali *et al*., 2016; Kamble and Kumar, 2016; Saikia and Karak, 2016; Zeferino *et al*., 2016; Pravettoni *et al*., 2016; Bedon and Amadio, 2016; Mavukkandy *et al*., 2016; Yeargin *et al*., 2016; Madani and Dababneh, 2016; Alhasanat *et al*., 2016; Elliott *et al*., 2016; Suarez *et al*., 2016; Kuli

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*et al*., 2016; Waters *et al*., 2016; Montgomery *et al*., 2016; Lamarre *et al*., 2016; Daud *et al*., 2008; Taher *et al*., 2008; Zulkifli *et al*., 2008; Pourmahmoud, 2008; Pannirselvam *et al*., 2008; Ng *et al*., 2008; El-Tous, 2008; Akhesmeh *et al*., 2008; Nachiengtai *et al*., 2008; Moezi *et al*., 2008; Boucetta, 2008; Darabi *et al*., 2008; Semin and Bakar, 2008; Al-Abbas, 2009; Abdullah *et al*., 2009; Abu-Ein, 2009; Opafunso *et al*., 2009; Semin *et al*., 2009a; 2009b; 2009c; Zulkifli *et al*., 2009; Marzuki *et al*., 2015; Bier and Mostafavi, 2015; Momta *et al*., 2015; Farokhi and Gordini, 2015; Khalifa *et al*., 2015; Yang and Lin, 2015; Demetriou *et al*., 2015; Rajupillai *et al*., 2015; Sylvester *et al*., 2015; Ab-Rahman *et al*., 2009; Abdullah and Halim, 2009; Zotos and Costopoulos, 2009; Feraga *et al*., 2009; Bakar *et al*., 2009; Cardu *et al*., 2009; Bolonkin, 2009a; 2009b; Nandhakumar *et al*., 2009; Odeh *et al*., 2009; Lubis *et al*., 2009; Fathallah and Bakar, 2009; Marghany and Hashim, 2009; Kwon *et al*., 2010; Aly and Abuelnasr, 2010; Farahani *et al*., 2010; Ahmed *et al*., 2010; Kunanoppadon, 2010; Helmy and El-Taweel, 2010; Qutbodin, 2010; Pattanasethanon, 2010; Fen *et al*., 2011; Taher et al., 2019; Thongwan *et al*., 2011; Theansuwan and Triratanasirichai, 2011; Al Smadi, 2011; Tourab *et al*., 2011; Raptis *et al*., 2011; Momani *et al*., 2011; Ismail *et al*., 2011; Anizan *et al*., 2011; Tsolakis and Raptis, 2011; Abdullah *et al*., 2011; Kechiche *et al*., 2011; Ho *et al*., 2011; Rajbhandari *et al*., 2011; Aleksic and Lovric, 2011; Kaewnai and Wongwises, 2011; Idarwazeh, 2011; Ebrahim *et al*., 2012; Abdelkrim *et al*., 2012; Mohan *et al*., 2012; Abam *et al*., 2012; Hassan *et al*., 2012; Jalil and Sampe, 2013; Jaoude and El-Tawil, 2013; Ali and Shumaker, 2013; Zhao, 2013; El-Labban *et al*., 2013; Djalel *et al*., 2013; Nahas and Kozaitis, 2013; Petrescu and Petrescu, 2019a-b; 2014a; 2014b; 2014c; 2014d; 2014e; 2014f; 2014g; 2014h; 2014i; 2015a; 2015b; 2015c; 2015d; 2015e; 2016a; 2016b; 2016c; 2016d; Fu *et al*., 2015; Al-Nasra *et al*., 2015; Amer *et al*., 2015; Sylvester *et al*., 2015b; Kumar *et al*., 2015; Gupta *et al*., 2015; Stavridou *et al*., 2015b; Casadei, 2015; Ge and Xu, 2015; Moretti, 2015; Wang *et al*., 2015; Petrescu et al., 2017 af-al, 2018 o-w; Petrescu, 2015c, 2018 a-b; Petrescu and Petrescu, 2018 a-b; Petrescu, 2011; 2015a; 2015b; Petrescu and Petrescu, 2000a; 2000b; 2002a; 2002b; 2003; 2005a; 2005b; 2005c; 2005d; 2005e; 2011a; 2011b; 2012a; 2012b; 2013a; 2013b; 2013c; 2013d; 2013e; 2016a; 2016b; 2016c; Petrescu *et al*., 2009; 2016; 2017a; 2017b; 2017c; 2017d; 2017e; 2017f; 2017g; 2017h; 2017i; 2017j; 2017k; 2017l; 2017m; 2017n; 2017o; 2017p; 2017q; 2017r; 2017s; 2017t; 2017u; 2017v; 2017w; 2017x; 2017y; 2017z; 2017aa; 2017ab; 2017ac; 2017ad; 2017ae; 2018a; 2018b; 2018c; 2018d; 2018e; 2018f; 2018g; 2018h; 2018i; 2018j; 2018k; 2018l; 2018m; 2018n; Petrescu and Petrescu, 2014a; 2014b; 2014c; 2014d; 2014e; 2014f; 2014g; 2014h; 2014i; 2015a; 2015b; 2015c; 2015d; 2015e; 2016a; 2016b; 2016c; 2016d; Petrescu et al., 2017 af-aj, 2018 o-v; Petrescu, 2015c, 2018 a-b; Petrescu and Petrescu, 2018 a-b;

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Petrescu and Petrescu, 2014 f, 2014 g, 2014 h, 2014 I; Petrescu et al., 2018 a-ac; Petrescu and Petrescu, 2019 a-d; Petrescu, 2019 a-m).

## 2. MATERIALS AND METHODS

Such a manipulator that is also a crane can be built even simpler, in various dimensions, depending on where the system will have to work. It can be fully or partially machined, it can be constructed so that it can be manipulated and manually. He will be presented from a constructive, geometrical and kinematic point of view, within the present work, presenting briefly its direct kinematics.

In figure 4 is presented such a constructive model capable of moving and transporting various heavy objects through a whole section. The manipulator with three degrees of mobility, can lift a heavy and bulky object and then transport it from one place to another, over short or even greater distances. The man can push a stroller to be fixed such a manipulator with three mobilities. The constructive model presented can be adapted and redesigned in other mechanical variants, the one that will be presented in the paper being only a possible constructive variant. It balances simply, according to the classic balancing model with the companion, generally achieving a static or almost total static balance. In addition, not only does the counterweight mounted on the extension of arm 3 (Figure 5) help but also the constructive scheme, because a great part of the efforts and even a partial balancing will be supported by the upper-class D coupling of the fourth class, which allows simultaneous rotation. and relative translation of its component elements 3 and 0 (Figure 5).

It should also be mentioned that in the direct kinematic study performed in figure 5, only three movable elements, 1, 2, 3, and a planning mechanism with two mobilities are considered, in order to simplify the study of the mechanism. In fact, as can be seen from the construction scheme (Figure 4), the supporting element 0 is also a movable part having a rotation around its own axis, vertically, so that the whole system can be rotated at the desired angle, increasing thus the workspace and transforming the flat movement of the 2R system into a spatial movement 3R. The rotation can be left to be complete if this is considered necessary.

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Figure 4: Constructive scheme of a manipulator with three mobilities

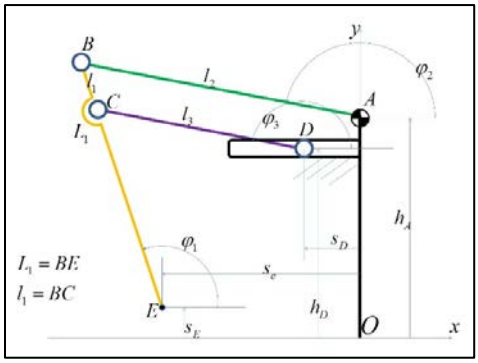


Figure 5: Kinematic diagram of the planar mechanism 2R from the component of the 3R space manipulator.

In the direct kinematics we know, (Give): L1 [m]; L1 [m]; L2 [m]; L3 [m]; hD [m]; harness]; The input parameters are also required: sD [m], FI2 [deg], and four output parameters of the mechanism must be determined kinematically (see kinematic diagram):

FI1 [deg]; Fi3 [deg]; and [m]; se [m], for both possible variants I and II. It must be specified that the mechanism can be positioned in two different ways when setting the input parameters so that at the output we will have one of the two real working situations, both variants (I and II) can be determined with the computation relays. lower:

$$\begin{cases} \textit{Version} \quad I \quad \textit{with} \; - \\ A = (l_2 \cdot \cos\varphi_2 - s_D)^2 + (h_A - h_D + l_2 \cdot \sin\varphi_2)^2 + l_1^2 - l_ \\ B = -2 \cdot l_1 \cdot (l_2 \cdot \cos\varphi_2 - s_D) \\ C = 2 \cdot l_1 \cdot (h_A - h_D + l_2 \cdot \sin\varphi_2) \\ \cos\varphi_1 = \dfrac{-A \cdot B - C \cdot \sqrt{B^2 + C^2 - A^2}}{B^2 + C^2} \Rightarrow \\ \Rightarrow \varphi_1 = \arccos(\cos\varphi_1) \\ \cos\varphi_3 = \dfrac{l_2 \cdot \cos\varphi_2 - l_1 \cdot \cos\varphi_1 - s_D}{l_3} \\ \sin\varphi_3 = \dfrac{l_2 \cdot \sin\varphi_2 - l_1 \cdot \sin\varphi_1 + h_A - h_D}{l_3} \\ \varphi_3 = semn(\sin\varphi_3) \cdot \arccos(\cos\varphi_3) \\ \\ s_E = h_A + l_2 \cdot \sin\varphi_2 - L_1 \cdot \sin\varphi_1 \\ s_e = l_2 \cdot \cos\varphi_2 - L_1 \cdot \cos\varphi_1 \end{cases} \quad (1)$$

$$\begin{cases} \textit{Version} \quad II \quad \textit{with} \; + \\ A = (l_2 \cdot \cos\varphi_2 - s_D)^2 + (h_A - h_D + l_2 \cdot \sin\varphi_2)^2 + l_1^2 - l_3^2 \\ B = -2 \cdot l_1 \cdot (l_2 \cdot \cos\varphi_2 - s_D) \\ C = 2 \cdot l_1 \cdot (h_A - h_D + l_2 \cdot \sin\varphi_2) \\ \cos\varphi_1 = \dfrac{-A \cdot B + C \cdot \sqrt{B^2 + C^2 - A^2}}{B^2 + C^2} \Rightarrow \\ \Rightarrow \varphi_1 = \arccos(\cos\varphi_1) \\ \cos\varphi_3 = \dfrac{l_2 \cdot \cos\varphi_2 - l_1 \cdot \cos\varphi_1 - s_D}{l_3} \\ \sin\varphi_3 = \dfrac{l_2 \cdot \sin\varphi_2 - l_1 \cdot \sin\varphi_1 + h_A - h_D}{l_3} \\ \varphi_3 = semn(\sin\varphi_3) \cdot \arccos(\cos\varphi_3) \\ \\ s_E = h_A + l_2 \cdot \sin\varphi_2 - L_1 \cdot \sin\varphi_1 \\ s_e = l_2 \cdot \cos\varphi_2 - L_1 \cdot \cos\varphi_1 \end{cases} \quad (2)$$

## 3. RESULTS AND DISCUSSION

S In a calculation example, in the diagram in figure 6 (for version I) and figure 7 (for version II) one can observe the output values of the angles FI1 and FI3, depending on the value imposed at the input of the angle FI2 on the abscissa.

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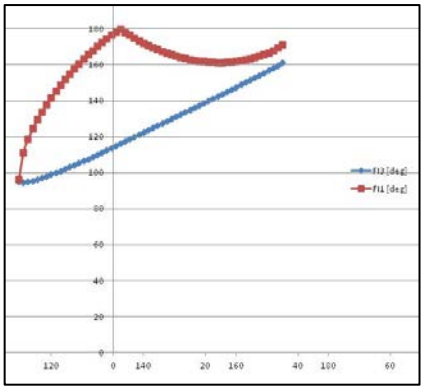

Figure 6: Output values of the angles FI1 and FI3, depending on the value imposed at the input of the angle FI2 on the abscissa, for version I

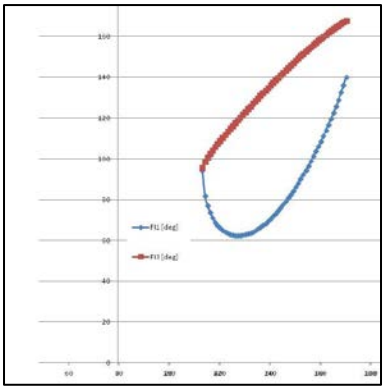

Figure 7: Output values of the angles FI1 and FI3, depending on the value imposed at the input of the angle FI2 on the abscissa, for version I

The variation of FI3 is represented by blue and the angle of FI1 with red. The values used for the lengths in the calculation example are given in table 1.

Table 1: The values used for the lengths

| | |
|---|---|
| L1 [m] | 2 |
| l1 [m] | 0.25 |
| l2 [m] | 2 |
| l3 [m] | 1.8 |
| hD [m] | 2.3 |
| hA [m] | 2.5 |

The values of sD [m] corresponding to the angle FI2 [deg] of input are collected from the graph shown in figure 8.

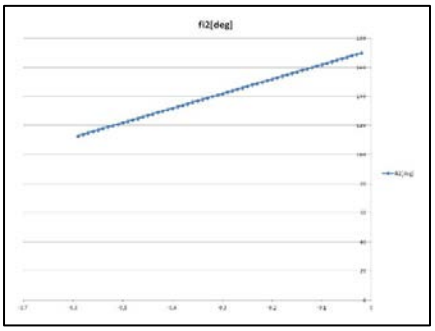


Figure 8: The values of sD [m] corresponding to the angle FI2 [deg]

## 4. CONCLUSIONS

In the industrial halls it is often necessary to handle large objects, with a large and large table, which have to be transported not over long distances but moved from one place to another, raised, then lowered to various levels, left or right. Such repeated manipulations of heavy and dangerous objects can be done only with the help of a manipulator, which can be a

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**Figure 02,** https://www.ecocranes.ro/wp-content/uploads/2016/01/ECO3.jpg

**Figure 03,** https://www.ecocranes.ro/wp-content/uploads/2016/01/ECO6.jpg