COBEM 2015

23rd ABCM International Congress of Mechanical Engineering
December 6-11, 2015, Rio de Janeiro, RJ, Brazil

NEW KINEMATIC STRUCTURES FOR ONE-SIDE STITCHING DEVICES

Estevan Hideki Murai
Henrique Simas
Daniel Martins
Federal University of Santa Catarina
eng.estevan.murai@gmail.com
henrique.simas@ufsc.br
daniel.martins@ufsc.br

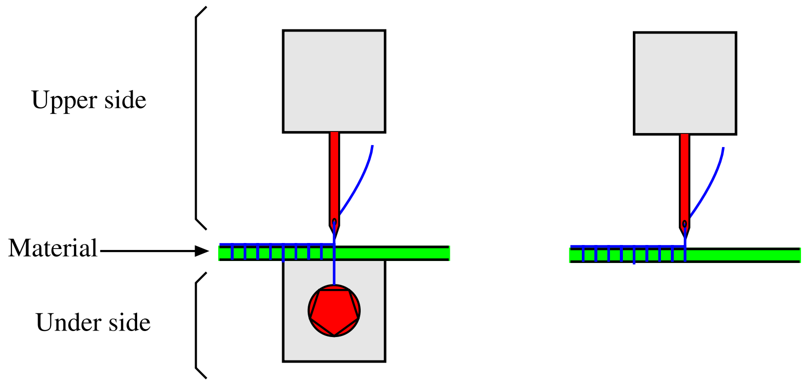
Abstract. *The design of mechanisms is frequently done as an intuitive task. However, this approach does not guarantee to find all feasible results or the optimum solution and it is a designer-dependent approach. Mechanisms design methodologies are important means to systematize the designing process and search for good feasible solutions regardless the designer. On this paper, a screw-based methodology presented in a previous work is used to make the number and type synthesis of one-side stitching devices (1-SSDs). The objective of this work is to extend the previous works results by developing new mechanisms for 1-SSD, however, focusing on the medical applications. Initially, a state of the art survey on 1-SSDs for medical applications is presented. Then, the requirements for an 1-SSD capable of performing chain stitches are listed. Once the requirements are defined, an enumeration method is used to generate all possible kinematic chains and mechanisms. Next, the design requirements are used to identify and eliminate the unfeasible partitions, kinematic chains, mechanisms and placements of the actuators and end-effectors. Then, three new mechanisms for one-side stitching devices are presented. Finally, one mechanism is chosen for type synthesis and three new mechanisms with type of pairs defined are presented.*

Keywords: *one-side stitching device, number synthesis, type synthesis, screw theory.*

1. INTRODUCTION

Stitching devices are typically associated with garment industries, however, sewing machines are just one application of them. The general function of stitching devices is to join two or more parts using threads. By this point of view, they can be specialized to several other applications such as composite material stitching and suturing.

Stitching devices can be classified according to its required access. While a two-side stitching device (2-SSD) requires access to both upper and under sides of the material in order to stitch, an one-side stitching device (1-SSD) only requires access to one side of the material. Figure 1a shows a 2-SSD and Fig. 1b shows an 1-SSD. Most stitching device applications use 2-SSDs, however, some applications inherent require 1-SSDs, such as composite material stitching (Brandt *et al.*, 2001).



(a) 2-SSD. (b) 1-SSD.

Figure 1: Examples of two-side stitching device and one-side stitching device.

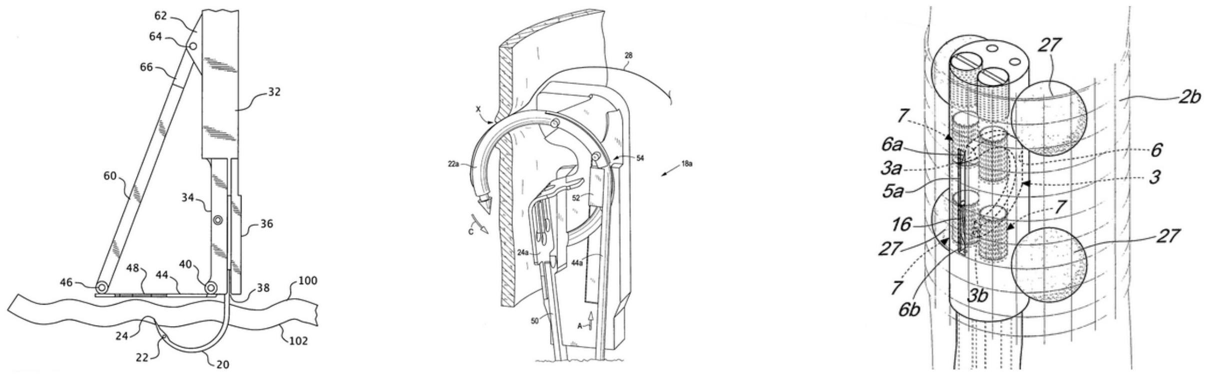
In medicine, great efforts have been made to develop tools and techniques for minimally invasive surgeries (MIS), (Verdonck, 2008). MIS uses the body's empty internal volumes to gain access to the surgery location and it presents great advantages in relation to conventional surgeries, such as lower recovering time, probability of having an infection, loss of blood and mortality rate (Saadi *et al.*, 2006). However, MIS tools development presents difficulties such as miniaturization, use of aseptic materials, control, feedback forces and confined workspace. Considering suturing devices for MIS, the use of 1-SSDs is necessary since only the inner side of the empty internal volume is accessible.

This work is a sequel of the works developed by Murai *et al.* (2013) but focusing on medical field, hence, a few structural and design requirements will be modified or added. Also, the number of feasible kinematic structures for 1-SSD, presented in the previous work, will be expanded here by synthesizing and analysing kinematic structures with three independent loops. Three new mechanisms for one-side stitching devices capable of performing chain stitches are presented. Then, type synthesis is carried out for a chosen mechanism, resulting in three innovative kinematic structure for 1-SSDs.

2. STATE OF THE ART SURVEY

The designing of 1-SSDs in general was previously studied by Murai *et al.* (2013). This section will focus on 1-SSDs for medical applications.

As this work focus is mechanism design, the state of the art survey emphasizes on existing endoscopic suturing devices based on stitch forming mechanisms. Several commercial devices were found, however, all of them were suture passers. In general, a suture passer device manipulates an integrated needle to pass it through the tissue but it is up to the surgeon to manipulate the device in order to make a stitch. The device usually performs interrupted stitches or running stitches and cannot produce chain stitches or lock stitches. Figure 2 shows a few suture passers. Examples of commercial suture passers are Smith & Nephew® FIRSTPASS™, EndoEvolution® Endo360°™, Ethicon® Suture assistant™, Boston Scientific® Capio®, Apollo® OverStitch™, GORE® Suture Passer™, Cayenne Medical® CrossFix® and Quattro®, Ceterix Orthopaedics® NovoStitch®, Covidien® Endo Stitch™and Covidien® SILS™Stitch Articulating Suturing Device.



(a) Adapted from Griffith (2012). (b) Adapted from Rioux and Sauvageau (2011). (c) Adapted from Adami *et al.* (2008).

Figure 2: Examples of suture passer devices.

No commercial endoscopic suturing devices capable of automatically perform continuous chain stitches or lock stitches was found, however, this type of suturing devices was already studied (Lokuge, 2003). Other wound closure commercial devices or prototypes based on other principles were found, such as laser tissue soldering (Fraunhofer, 2011; Wehner *et al.*, 2015), staples (Covidien® Poly Surgiclip™), glues (Lang *et al.*, 2014) and nanoparticles-based bonding (Meddahi-Pellé *et al.*, 2014). Also, several works approached the endoscopic suturing problem by designing a grasper mechanism with high degree of freedom in order to manipulate a curved needle, such as Kapoor *et al.* (2005).

Several patents of endoscopic suturing passing device were found, such as those from Meade *et al.* (2014); Griffith (2012); Rioux and Sauvageau (2011); Adami *et al.* (2008); Stokes *et al.* (2007) and Toy *et al.* (1997). It was also found patents of 1-SSDs capable of automatically executing chain stitches (Yamamoto and Chung, 2007; Baxter, 1998; Moll and Schlondorff, 1988; Nomoto *et al.*, 1984) and lock stitches (Shonteff and Chambers, 2009).

It was noted that the number of patents greatly exceeded the number of commercial devices. Several design characteristics found in the patents, such as a complex mechanism or kinematic pairs hard to miniaturize, decreased the patents feasibility. Thus, a patent survey and analysis is an important tool to aid structural and design requirements listing and enhance design feasibility.

3. STRUCTURAL AND DESIGN REQUIREMENTS

The devices found in Sec. 2 were analyzed according to their structural and design characteristics, such as needle type, loop catching, screw system and mobility (Murai *et al.*, 2013). These characteristics were discussed by Murai *et al.* (2013) and used to guide the structural and design requirements listing. As this work focus on medical devices, some design requirements of the previous work are modified or added.

In the medical field, endoscopic tools actuated by cables are desirable. It is possible to remotely rotate the cable to actuate a revolute pair, however, a better power transmission and control is obtained when such cable is used to actuate a prismatic pair. Hence, a prismatic actuators-only configuration is desirable for medical applications. Thus, one structural requirement is that all actuators must be placed in prismatic pairs.

A discussion regarding the screw-system was presented by Murai *et al.* (2013) and it resulted in the choice of the fifth special two-system, according to Hunt (1978). In this screw-system, all revolute and helical pairs must be coaxial. Also, prismatic pairs axes must be parallel to the axis of all revolute and helical pairs.

In the chosen screw-system, prismatic pairs must have a constant axis direction. However, the position of a prismatic pair may change during the mechanism operation when this pair is not directly connected to the fixed link. If such pair has an actuator, then the control cables also moves during operation and it can interfere the mechanism operation (specially in confined spaces). Hence, one structural requirement is that all actuators must be placed on the fixed link to avoid cable entanglement and reduce the design complexity.

During the stitching process only one degree of freedom is necessary, however, one additional degree of freedom is desired for adjustments (Murai *et al.*, 2013). Thus, the mechanism must have two mobilities: the main mobility and the adjustment mobility. The main mobility is used to operate the mechanism during the stitching process, while the adjustment mobility is used to resynchronize the motions of needle and looper. More details about those mobilities is shown by Murai *et al.* (2013). The degree of control is defined as the minimum number of actuators required to determine the relative position of two given links (Belfiore and Di Benedetto, 2000). Considering the main and adjustment mobilities concept, it is noted that both mobilities must be defined to completely position the needle in relation to the looper, therefore, the degree of control between needle link and looper link is two.

A configuration in which each actuator controls one end-effector (needle or looper) is unfeasible because the mechanism would not have one main mobility and one adjustment mobility (Murai *et al.*, 2013). This results that chains with body fractionation on the fixed link are unfeasible, since this fractionation divides the chain in two subchains and each subchain will have one actuator that only controls its subchain (Tischler *et al.*, 1995b; Martins *et al.*, 2010). Also, chains that have a non-fixed link presenting body fractionation are unfeasible because it is not possible to place all actuators on the fixed link. Therefore, one structural requirement is that the kinematic chain cannot present body fractionation.

Murai *et al.* (2013) showed that as the fixed link must connect to the needle, the looper and the adjustment link, the fixed link must be at least ternary. As two prismatic actuators are desired, it is possible to place the actuators on the pairs that connect looper with fixed link (being this actuator the main mobility) and adjustment link with fixed link. Notice that among the links and pairs necessary to synchronize looper and needle motions there is a miniaturized pin-in-slot pair and this pair is the critical kinematic pair in the mechanism regarding manufacture and maintenance. When the main mobility is placed at the looper, all the power necessary for the needle to puncture through the material is transmitted by the same critical pair that synchronizes needle and looper motions. In order to avoid malfunctions and maintenance problems, the main mobility should not be actuated by the looper. Also, configurations in which the power for the needle comes through this pin-in-slot pair are not desired.

Therefore one additional pair is required in the fixed link to place the main mobility. Thus, the fixed link must be at least quaternary and three independent loops are required. Although it is possible to generate a kinematic chain with a quaternary link and only two independent loops, such chain would be fractionated and would not generate feasible results.

As this works focus on synthesis and selection of appropriated kinematic structures for 1-SSD, further steps will not be carried out. Therefore, no discussion such as aseptic material selection, joints physical realization, miniaturization, mechanism deployment, thread tensioning system, 1-SSD positioning system and dimensional synthesis will be done in this paper.

The list of structural and design requirements for an 1-SSD for medical applications is presented below. Notice that list includes the requirements from Murai *et al.* (2013).

- The screw system selected is the fifth special two-system ($\lambda = 2$).
- The mobility of the mechanism is two ($M = 2$): main mobility and adjustment mobility.
- The number of independent loops will be three ($\nu = 3$).
- The needle link must be connected to the fixed link by a revolute pair.
- The looper link must be connected to the fixed link by a prismatic pair.
- The degree of control between the needle and the looper links is two.
- The actuators must be placed on prismatic pairs located at the fixed link;
- The fixed link must be at least quaternary.
- The kinematic chain cannot present body fractionation.

4. NUMBER SYNTHESIS OF ONE-SIDE STITCHING DEVICES

Once the structural requirements were listed, the number of links and pairs were determined using mobility and Euler equations (Tsai, 2000), respectively,

$$M = (n - j - 1)\lambda + j \tag{1}$$

and

$$\nu - 1 = j - n, \tag{2}$$

where n is the number of links and j is the number of kinematic pairs. Considering the structural requirements defined in Sec. 3, the number of links and pairs are, respectively, six and eight. Once the number of links and pairs are known, it is possible to determine all kinematic partitions. Table 1 exposes the number of elements of kinematic pair that each link has, *e.g.*, the fourth partition has one link with four elements, two links with three elements and three links with two elements.

Table 1: Partitions of the kinematic chains with $M = 2$, $\lambda = 2$ and $\nu = 3$. Polygonal links are greyed out.

	Link					
Partition	1	2	3	4	5	6
1	6	2	2	2	2	2
2	5	3	2	2	2	2
3	4	4	2	2	2	2
4	4	3	3	2	2	2
5	3	3	3	3	2	2

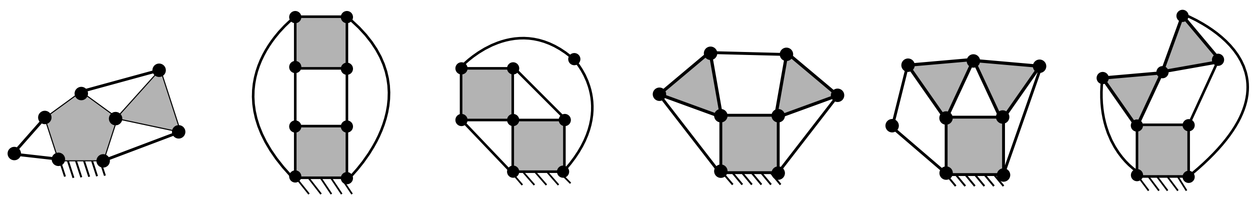
Partition one generates only kinematic chains with truss, therefore, it is unfeasible. Analyzing Tab. 1 it is noticed that partition five does not have a quaternary link, thus, it is an unfeasible partition. Figure 3 shows all possible mechanisms for the remaining partitions, note that only inversions with at least a quaternary fixed link is considered. Also, as the order of the screw system is two, a kinematic chain with three binary links connected in a truss fashion has one mobility.

Partition two generates only one kinematic chain, see mechanism 1 from partition 2 (M1P2) in Fig. 3a. However, this chain is unfeasible because it presents body fractionation. In partition 3, the symmetry of the first mechanism makes all binary links equivalent, thus, the actuators can be placed in any two pairs in the fixed link. Then, the end-effectors can be placed in the remaining two pairs of the fixed link. Regarding number synthesis, this mechanism is considered feasible, however, a further analysis will be necessary during type synthesis.

Mechanisms M2P3, M1P4 and M2P4, respectively exposed in Fig. 3c, 3d and 3e, have several combinations for actuators and end-effectors placements. Nevertheless, all combinations result in unsatisfied design requirements such as each actuator controlling one end-effector or the end-effectors links not being adjacent to the fixed link. Thus, these mechanisms are considered unfeasible.

In mechanism 3 from partition 4, it is possible to place the actuators and end-effectors in a feasible arrangement. Therefore, regarding number synthesis, this mechanism is considered feasible.

All mechanisms enumeration in this section was manually done using Farrell's method and it was validated using a graph enumeration program. More details about enumeration methods can be seen in Tischler *et al.* (1995a), Mruthyunjaya (2003), Simoni *et al.* (2009) and Simoni *et al.* (2011).



(a) M1P2. (b) M1P3. (c) M2P3. (d) M1P4. (e) M2P4. (f) M3P4.

Figure 3: Kinematic inversions from partition two, three and four.

5. ACTUATORS AND END-EFFECTORS PLACEMENTS

Section 4 identified and eliminated mechanisms in which any combination of actuators and end-effectors placements would be unfeasible. Mechanisms M1P3 and M3P4 can yield feasible results, however, not all combinations of actuators and end-effectors placements will be feasible. In this section, all feasible placements of actuators and end-effectors in M1P3 and M3P4 will be listed.

Figure 4a exposes the only feasible non-isomorphic placement for the end-effectors in M1P3. For M3P4, link 1 is the only feasible choice for the fixed link, as show Fig. 4b and 4c. Also, as the actuators and end-effectors must be placed in the fixed link, all links connected to link 1 must have an end-effector or be directly actuated.

The subchain composed of links 1, 2 and 4 has mobility one, therefore, it is unfeasible to place the actuators in pairs *e* and *g*. In addition, the degree of control between links 2 and 4 is one, thus, it is unfeasible to place the end-effectors in those links. Therefore, there are two feasible options: to place the first actuator in pair *g* and the first end-effector in link 4 or to place the first actuator in pair *e* and first end-effector in link 2. The second end-effector can be placed in link 6 and the second actuator in pair *h*, the other way around is possible but it is equivalent given the chain symmetry.

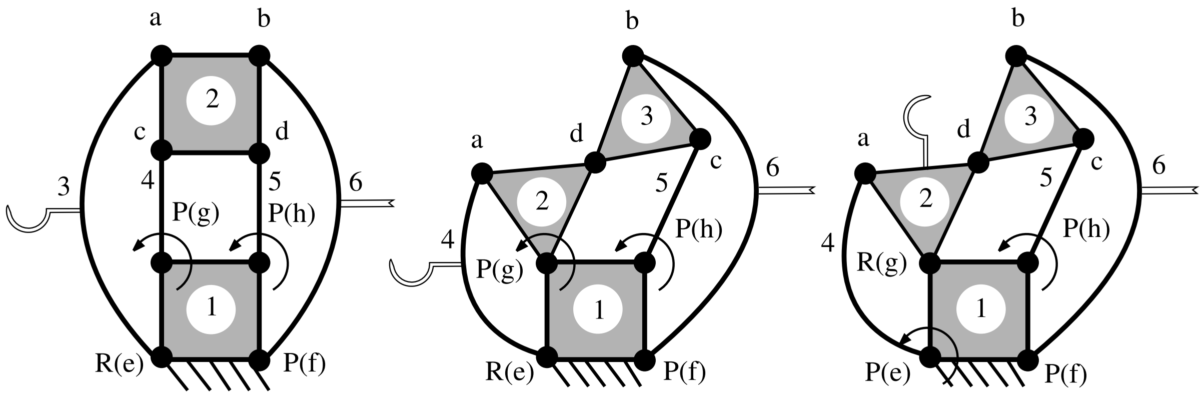
The actuators placement are defined, however, which actuators will perform the main mobility and which will perform the adjustment mobility still needs to be determined. The first actuator affects both end-effectors and the second actuator affects only the second end-effector. Thus, the main mobility must be operated by the first actuator and the adjustment mobility must be operated by the second actuator.

Regarding the end-effectors, when the first end-effector is the looper, the needle will be in link 5 or 6. Only the main mobility is active during the stitching process, thus, the power that moves the needle and make it punctures the material will come from the first actuator. Given the locations of the first actuator and the needle, the power from the first actuator will reach the needle by passing through the pin-in-slot pair. As mentioned in Sec. 3, this configuration is unfeasible. Therefore, the first end-effector cannot be the looper.

Hence, the two possible combinations of actuators and end-effectors placements are possible:

- the needle is located in link 4, the looper is in link 6, the main mobility is actuated in pair *g* and the adjustment mobility is actuated in pair *h* (see Fig. 4b);
- the needle is located in link 2, the looper is in link 6, the main mobility is actuated in pair *e* and the adjustment mobility is actuated in pair *h* (see Fig. 4c).

Finally, once the actuators and end-effectors are placed, the mechanisms proceed to type synthesis. However, in this paper we will focus on the type synthesis of the mechanism exposed in Fig. 4c.



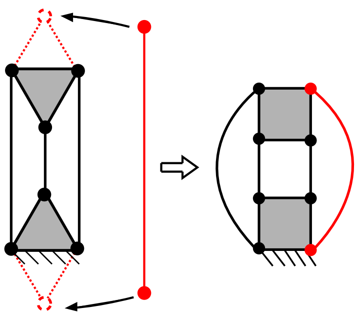
(a) Pairs of M1P3. (b) Pairs of M3P4. (c) Pairs of M3P4.

Figure 4: Feasible results for an 1-SSD.

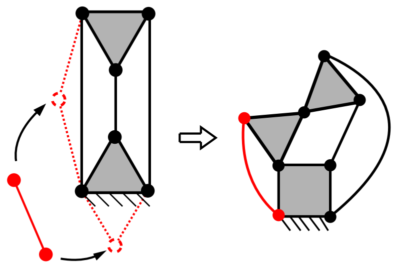
6. TYPE SYNTHESIS OF ONE-SIDE STITCHING DEVICES

Section 5 identified three feasible mechanisms for M1P3 and M3P4. When compared to the feasible mechanism from Murai *et al.* (2013) it is noted that the kinematic chain of M1P3 and M3P4 can be generated by adding the simplest Assur group for two-system. Figure 5 exposes how the mechanism from Murai *et al.* (2013) can generate M1P3 and M3P4. This descendant characteristic can be used to shorten type synthesis process since part of the mechanism already had its type synthesis done and the unfeasible combinations of types of pairs identified and excluded.

When Assur groups are added to a mechanism, the mechanism mobility is not changed (Tischler *et al.*, 1995b; Manolescu, 1968). This intrinsic characteristic of Assur groups is valid as long as the unconnected pairs of the Assur group are attached to different links. Therefore, it is possible to add Assur groups to a kinematic chain to change its actuation characteristics while keeping its mobility (Tischler *et al.*, 1995b). More advantages of using Assur groups to generate kinematic chains are exposed in Martins *et al.* (2010) and Mruthyunjaya (2003).



(a) Generating M1P3.



(b) Generating M3P4.

Figure 5: Generating M1P3 and M3P4 from the mechanism of Murai *et al.* (2013).

Considering the fifth special two-system, the only types of kinematic pairs available are prismatic (P), revolute (R) and helical (H). Pairs *e*, *f*, *g* and *h* are already known from design requirements, as Fig. 4 indicates, therefore, only pairs *a*, *b*, *c* and *d* need to have their type determined.

When pair *a* is a prismatic pair, the conditions of the fifth special two-system requires that its direction be parallel to pair *e* direction (Hunt, 1978). Hence, disregarding friction, actuating pair *e* will not transmit any power to the rest of the kinematic chain since any displacement in pair *e* would be followed by an equally displacement in pair *a*. In addition, the fifth special two-system imposes that pair *g* rotation axis be parallel to pair *a* translation axis. Thus, a translation in pair *a* cannot generate a rotation in pair *g*. Similarly, when pair *a* is a revolute pair, a translation in pair *e* cannot generate a rotation in pair *a*. Therefore, pair *a* can only be a helical pair.

The remaining unknown pairs, *b*, *c* and *d*, can be prismatic, revolute or helical. However, to transform the needle rotation (revolute pair *g*) in to the looper translation (prismatic pair *f*), at least one of the remaining unknown pairs must be helical. Also, similarly to the type synthesis of pair *a*, the screw system imposes constraints in the type synthesis of pairs *b*, *c* and *d*. Once pairs *f* and *h* are prismatic, pairs *b* and *c* cannot be prismatic. Regarding pairs *a* and *d*, they cannot be revolute pairs because pair *g* is already a revolute pair. Therefore, the pairs left to have their type determined and the constrains in the type assignments are equivalent to those exposed by Murai *et al.* (2013).

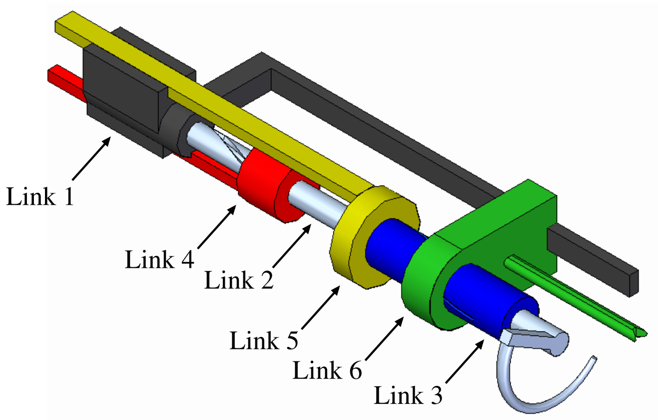
Generating all possible combinations and excluding unfeasible results, three promising mechanisms are found, as Tab. 2 exposes. Mechanisms *T2* and *T3* have the advantage of using only two helical pairs: one for transforming the main mobility translation to the needle rotation and other to transform the needle rotation to the looper translation. Thus, the dimensional synthesis, miniaturization and manufacture of mechanisms *T2* and *T3* will be easier in comparison with mechanism *T1*.

The three mechanisms were modelled in CAD as a generic solution (without any specific dimension). Figure 6a exposes the assembled view and it indicates the links according to the numbering shown in Fig. 4c. Figure 6b, 6c and 6d expose the exploded view of mechanisms *T1*, *T2* and *T3*, respectively.

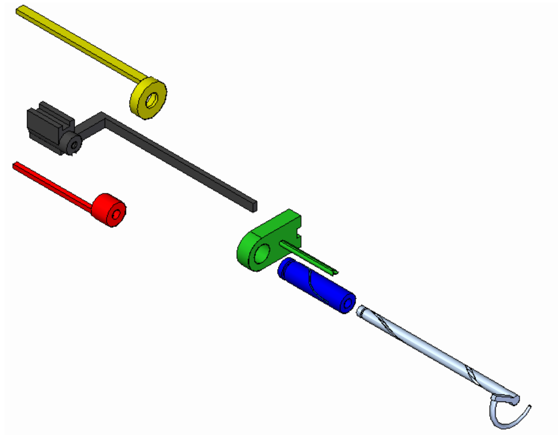
The dimensional synthesis of mechanisms *T1*, *T2* and *T3* as well as further developments of the mechanisms exposed in Fig. 4a and 4b are left to be done in future works.

Table 2: Feasible mechanisms with type of kinematic pair defined for M3P4(c).

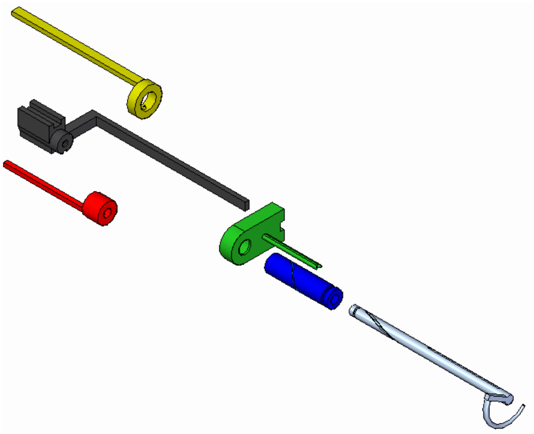
Mechanism M3P4(c)	T1	T2	T3
Pair a	H	H	H
Pair b	H	R	H
Pair c	R	H	R
Pair d	H	P	P



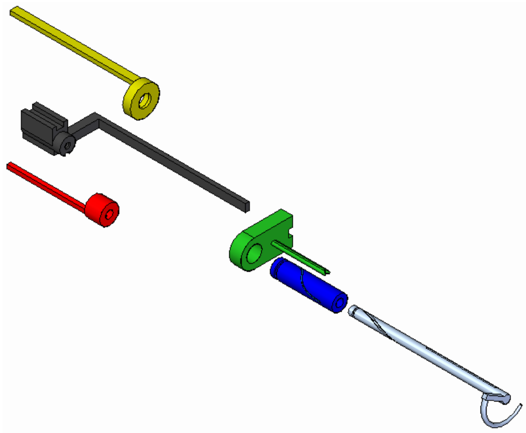
(a) Assembled device.



(b) Exploded view of mechanism T1.



(c) Exploded view of mechanism T2.



(d) Exploded view of mechanism T3.

Figure 6: Kinematic structures for an 1-SSD.

7. CONCLUSIONS

The methodology presented in a previous paper (Murai *et al.*, 2013) was applied to generate feasible mechanisms for 1-SSDs for medical applications. A state of the art survey of 1-SSDs for medical application searching for both commercial products and patents was presented. This survey was useful as a guide to elaborate the structural and design requirements. As this work is an extension of a previous work, some design requirements remained the same. Other design requirements were included or changed considering a medical applications.

An enumeration technique was used to generate all kinematic chains and the structural and design requirements were used to identify and eliminate unfeasible results. Three new mechanisms with actuators and end-effectors placed were found feasible. One of those mechanisms was chosen for type synthesis, resulting in three innovative kinematic structures for 1-SSDs for medical applications.

The type synthesis of the mechanisms exposed in Figures 4a and 4b and the dimensional synthesis of all the mechanisms are left to be done in future works.

8. ACKNOWLEDGEMENTS

The authors would like to thanks CNPq for the financial support.

9. REFERENCES

Adami, C.A., Calvi, R., Patorno, L. and Tuscano, G., 2008. “Device for sewing elements that can be sutured”. US Patent 2008/0177289 A1.

Baxter, S., 1998. "Blind stitching apparatus and composite material manufacturing methods". US Patent 5,829,373.
Belfiore, N.P. and Di Benedetto, A., 2000. "Connectivity and redundancy in spatial robots". *The International Journal of Robotics Research*, Vol. 19, No. 12, pp. 1245–1261.
Brandt, J., Drechsler, K. and Filsinger, J., 2001. "Advanced textile technologies for the cost effective manufacturing of high performance composites". In *Proceedings of RTO AVT Specialist Meeting on Low Cost Composite Structures*. NATO-RTO, Loen, 69(II).
Fraunhofer, I.P.T., 2011. "Minimally invasive surgeries: Laser suturing". <https://www.fraunhofer.de/en/press/research-news/2011/february/minimally-invasive-surgeries-laser-suturing.html>. Accessed: 25/10/2014.
Griffith, D., 2012. "Curved needle suturing tool". US Patent 8,100,922.
Hunt, K., 1978. *Kinematic geometry of mechanisms*. Oxford engineering science series. Clarendon Press.
Kapoor, A., Simaan, N. and Taylor, R.H., 2005. "Suturing in confined spaces: constrained motion control of a hybrid 8-dof robot". In *Advanced Robotics, 2005. ICAR'05. Proceedings., 12th International Conference on*. IEEE, pp. 452–459.
Lang, N., Pereira, M.J., Lee, Y., Friehs, I., Vasilyev, N.V., Feins, E.N., Ablasser, K., O'Cearbhaill, E.D., Xu, C., Fabozzo, A., Padera, R., Wasserman, S., Freudenthal, F., Ferreira, L.S., Langer, R., Karp, J.M. and del Nido, P.J., 2014. "A blood-resistant surgical glue for minimally invasive repair of vessels and heart defects". *Science Translational Medicine*, Vol. 6, No. 218ra6, pp. 1–10.
Lokuge, P.D.H., 2003. *Design of remote endoscopic suturing device*. Ph.D. thesis, Massachusetts Institute of Technology.
Manolescu, N., 1968. "For a united point of view in the study of the structural analysis of kinematic chains and mechanisms". *Journal of Mechanisms*, Vol. 3, No. 3, pp. 149–169.
Martins, D., Simoni, R. and Carboni, A., 2010. "Fractionation in planar kinematic chains: Reconciling enumeration contradictions". *Mechanism and Machine Theory*, Vol. 45, No. 11, pp. 1628 – 1641.
Meade, J., Griffiths, J., DiFrancesco, F. and Clark, R., 2014. "Apparatus and method for minimally invasive suturing". US Patent 8,821,519.
Meddahi-Pellé, A., Legrand, A., Marcellan, A., Louedec, L., Letourneur, D. and Leibler, L., 2014. "Organ repair, hemostasis, and in vivo bonding of medical devices by aqueous solutions of nanoparticles". *Angewandte Chemie International Edition*, Vol. 53, No. 25, pp. 6369–6373.
Moll, A.R. and Schlondorff, R.G., 1988. "Surgical suturing machine". US Patent 4,747,358.
Mruthyunjaya, T., 2003. "Kinematic structure of mechanisms revisited". *Mechanism and Machine Theory*, Vol. 38, No. 4, pp. 279–320.
Murai, E.H., Martins, D. and Simas, H., 2013. "Number and type syntheses for an one-side stitching device". In *Proceedings of the 22nd International Congress of Mechanical Engineering - COBEM 2013*. Ribeirão Preto, Brazil.
Nomoto, R., Takahashi, M. and Ebata, Y., 1984. "Suturing instrument for surgical operation". US Patent 4,484,580.
Rioux, R. and Sauvageau, D., 2011. "Remotely-reloadable suturing device". US Patent 7,935,128.
Saadi, E.K., Gastaldo, F., Dussin, L.H., Zago, A.J., Barbosa, G. and Moura, L., 2006. "Tratamento endovascular de aneurismas de aorta abdominal: experiência inicial e resultados a curto e médio prazo". *Brazilian Journal of Cardiovascular Surgery*, Vol. 21, No. 2, pp. 211–216.
Shonteff, H. and Chambers, F., 2009. "Micro sewing device". US Patent 12/380,686.
Simoni, R., Carboni, A.P. and Martins, D., 2009. "Enumeration of kinematic chains and mechanisms". *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, Vol. 223, No. 4, pp. 1017–1024.
Simoni, R., Carboni, A., Simas, H. and Martins, D., 2011. "Enumeration of kinematic chains and mechanisms review".
Stokes, M.J., Albrecht, T.E., Ortiz, M.S., Zeiner, M.S., M., Z.A. and Shelton IV, F.F., 2007. "Method for instrument insertion through a body orifice". US Patent 2007/0239177 A1.
Tischler, C., Samuel, A. and Hunt, K., 1995a. "Kinematic chains for robot hands - i. orderly number-synthesis". *Mechanism and Machine Theory*, Vol. 30, No. 8, pp. 1193–1215.
Tischler, C., Samuel, A. and Hunt, K., 1995b. "Kinematic chains for robot hands - ii. kinematic constraints, classification, connectivity, and actuation". *Mechanism and machine theory*, Vol. 30, No. 8, pp. 1217–1239.
Toy, F., Smoot, R. and LaPrad, R., 1997. "Endoscopic suture passer and method". US Patent 5,618,290.
Tsai, L., 2000. *Mechanism Design: Enumeration of Kinematic Structures According to Function*. Mechanical Engineering Series. Taylor & Francis.
Verdonck, P., 2008. *Advances in biomedical engineering*. Elsevier.
Wehner, M., Aden, M., Toedter, N. and Rosenkranz, B., 2015. "Two-wavelength approach for control of coagulation depth during laser tissue soldering". In *SPIE BiOS*. International Society for Optics and Photonics, pp. 932109–1–932109–9.
Yamamoto, T. and Chung, S.C., 2007. "Endoscopic suturing device". US Patent 7,175,636 B2.

10. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.