Applied Mechanics and Materials Vol 162 (2012) pp 384-393 *Online: 2012-03-27*
© (2012) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.162.384

Design Process of a Robotized Tele-Echography System

T. Essomba[1&2,a], L. Nouaille[1,b], M. A. Laribi[2,c], G. Poisson[1,d] and S. Zeghloul[2,e]

[1]PRISME Laboratory - PRES Loire Valley University, France

[2]PPRIME Institute - CNRS - University of Poitiers – ENSMA, UPR 3346, France

[a]terence.essomba@etu.univ-orleans.fr, [b]laurence.nouaille@bourges.univ-orleans.fr,
[c]med.amine.laribi@univ-poitiers.fr, [d]gerard.poisson@bourges.univ-orleans.fr,
[e]said.zeghloul@univ-poitiers.fr

Keywords: mechanical, design process, tele-echography robot, medical gesture analysis.

Abstract. This paper deals with the design process of a particular mechatronic system: a tele-echography robot. First, we describe the principle of robotized tele-echography and the prototypes already designed. Then, after having chosen the design process, we show two medical gestures analysis performed to define the required specifications of a tele-echography robot. Several kinematic synthesis allow demonstrating that the serial spherical wrist is the most adapted structure to this medical application. The kinematic performance of this structure is limited by the singularity position located at the centre of the workspace. An inclined spherical wrist structure is proposed to displace the singularity position in a less used workspace zone that the normal direction to the patient's skin. In the dimensional synthesis phase, this structure is optimized. Then, a collaborative design study with designers is presented to improve aesthetic and ergonomic of the robot. This step was very interesting because it brought innovative propositions. Finally, a detailed phase allows defining the PROSIT 1 robot. It was manufactured and will be soon tested in clinical environment.

Introduction

For all kind of abdominal examinations, the ultrasound is widely used. This technique is fast, easy and cheap to perform and the patient can be given a diagnostic immediately. The tele-echography allows a medical expert to perform this clinical act on a distant patient. The doctor, located in expert site, operates a fictive probe (Fig. 1). Its motion parameters are sent to a slave robot by satellite or terrestrial links. The robot holds the real ultrasound probe on the patient's body and reproduces the fictive probe movement. Ultrasound images are sent back from the patient site to the medical expert so he can perform his diagnosis in real time like he would perform a classic ultrasound examination.

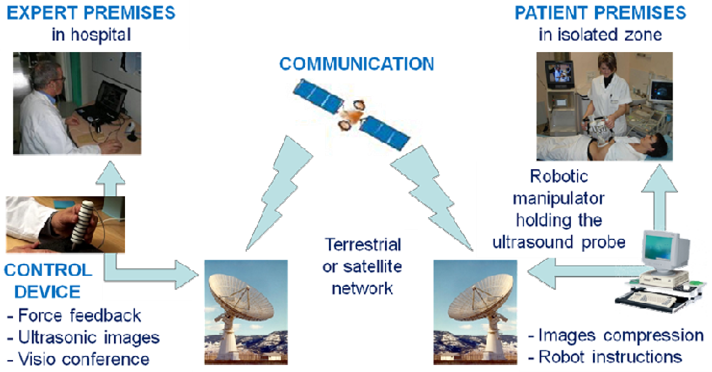

Fig. 1. Overview of the tele-echography.

In the last decade, several robots were developed for this medical application. In 1998, the concept of robotized tele-echography is validated with the SYRTECH prototype from the French Vision & Robotic Laboratory [1]. Then, TER [2] and TERESA (Fig. 2) robots were designed and clinically validated between 1999 and 2001. The European project OTELO allowed the design of two industrial prototypes: OTELO 1 and OTELO 2 in 2001 [3]. The same year, two Japanese robots were developed: the 7-dof robot RUDS [4] and the Masuda's robot designed with a hybrid structure [5] (Fig. 3). In 2006, the Medirob robot was marketed by a Swedish company [6]. This robot is a classical 6-dof serial robot carried by a mobile platform. In France, Robosoft launches ESTELE robot, developed by PRISME laboratory, from Teresa structure. In 2008, Najafi from Manitoba University, Canada, proposed a new parallel robot based on pantograph kinematics [7].

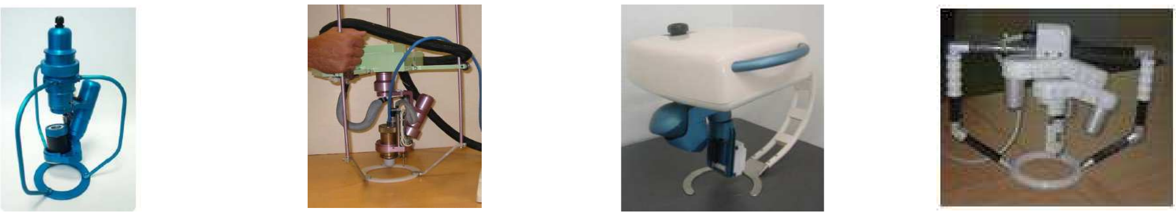

Fig. 2. TERESA, OTELO 1, OTELO 2 and ESTELE robots from PRISME laboratory.

Fig. 3. TER, RUDS, Masuda's and Najafi's robots.

Haptic devices are often used for tele-operated task. They can be very different from each over in term of structure, motion sensing technology, etc (Fig. 4.). Several serial haptic devices provide a large workspace and force control and feedback. PHAMToM interfaces are commercialized by Sensable Technology since 1993. It is a 6-degree-of-freedom (DoF) haptic device which architecture merges pantographic structure with a ball and socket joint and allows the operator to apply important forces on 6 directions. The University of Laval created the 3-DoF haptic device SHaDe. This spherical parallel structure allows the operator to control the orientation of a distant robot with force feedback. OTELO prototypes are controlled by a single-DoF interface. It is a hand free haptic device that offers the operator a total freedom of movement and a very large workspace since it is not mechanically linked with a support. It also provides force feedback with a capstan system.

Fig. 4. PHAMToM, SHaDe and OTELO haptic devices

The design must be defined like a complex activity with several reasoning process using several sources of knowledge [8]. It is different from the sciences because the solution is often a compromise which responds to the different criteria of several contradictious specifications. In the literature, several authors proposed to decompose the design process in different phases [9, 10]. The design process chosen is described in section 1. The common thread of these design processes is: knowing the need, define the problem to satisfy the need, conceptualized the solution and optimized it. In the design of medical robot context, after the medical expert has expressed his need, we must study the medical gesture to determine the robotic constraints and the specific constraints of the application. After having written the specifications we will develop the phase of conceptual designed. Then, an optimization of the chosen structure respecting the tele-echography specifications is described. The last section will present the detailed phase: the tele-echography prototype obtained from the design process.

Design Process for a Tele-Echography Robot

The design process often used is the Pahl's process [11] is composed of four phases sequentially executed. This process is adapted to design a tele-echography robot. The medical gesture must be traduced in robotic constraints (Fig. 5). Two different studies were made for this first step.

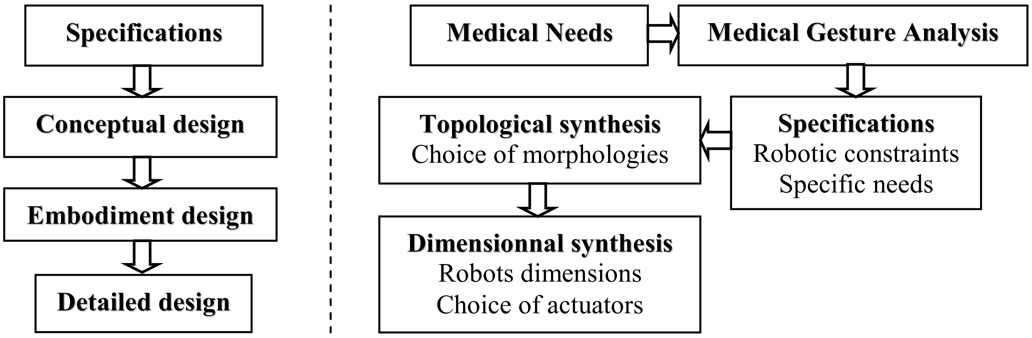

Fig. 5. Pahl's design process (left), tele-echography robots design process (right).

Analysis of the Medical Expert Gesture

We have run experimentations to study the gesture of a medical expert performing an ultrasound examination. These have been done, through two experimental studies, in a clinical environment at the University Hospital of Tours with the collaboration of Pr. Arbeille (INSERM) [12]. First, the expert gesture had already been studied by Al Bassit in 2004 using a Flock of Bird system. Second, we have proposed an experimental protocol based on the use of the motion capture system Vicon Nexus to study the expert gesture.

6D Magnetic Localization: Flock of Bird (FoB). This equipment is composed of a two main pieces: a receptor and a transmitter. The transmitter can evaluate the position and the orientation of the receptor. Al Bassit [13] placed the receptor on the ultrasound probe that was manipulated by a medical expert during an examination, so the transmitter could evaluate the 6 DoF of the ultrasound probe among the time. This study allowed determining the following tele-echography requirements:
-when the probe is positioned on the patient's skin, the contact between the probe and the skin must be kept during the exam (Fig. 6. left)
-the probe must be inclined lower than $\theta = 35°$ by reference to the normal direction of the patient's body, Z_0. The probe axis stands more often inside a 10° angled cone.
-the probe can be turned on its own axis
-the probe can never be inclined with an angle exceeding 75°, named safety angle, to avoid any collision with the patient (Fig. 6. right).
This study shows that the robot must generate 3 rotations around a distant point: the Remote Centre of Motion (RCM). A spherical wrist structure must be chosen to reproduce the tele-echography medical gesture.

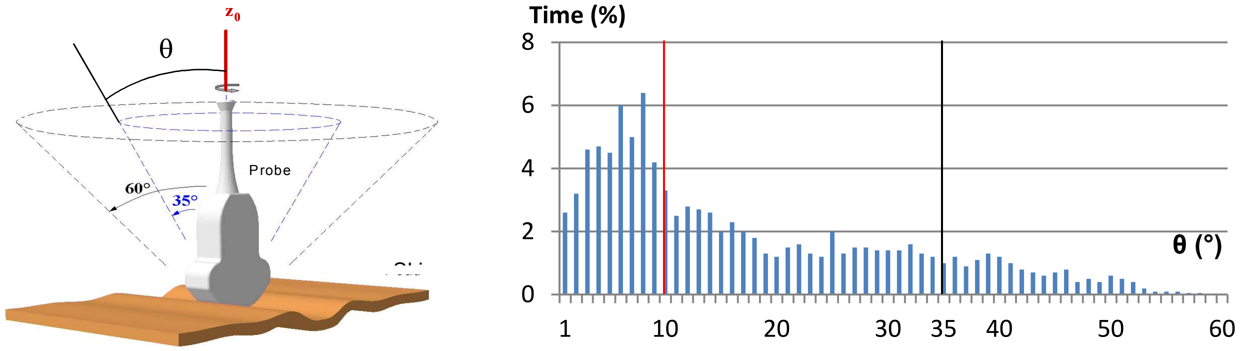

Fig. 6. Probe workspace cone (left), statistical measure of tilt angle measured by FoB (right)

3D Reflective Markers Tracking: Vicon Nexus. The system is composed of a number of high resolution cameras that can evaluate the 3D position of reflective markers. We placed some markers on the ultrasound probe and on the arm of the medical experts [14]. Then, we recorded them while performing ultrasound exanimation on real patients. By processing these records, we could reconstruct the position of each reflective marker in the space and export their coordinates. With these coordinates, we computed the orientation of the ultrasound during the examination of several important organs. Our first conclusion was to confirm the choice of the spherical wrist as the necessary kinematic for the slave robot. With the second experimentation, we have highlighted three main zones used by the medical expert. The second one seems to confirm the result of Al Bassit's experimentations since it goes from 20 to around 40° (see Fig. 7.). The third is occupied by the ultrasound probe when exploring organs reachable from the flank like kidneys. This one will not be considered for the robot's specifications.

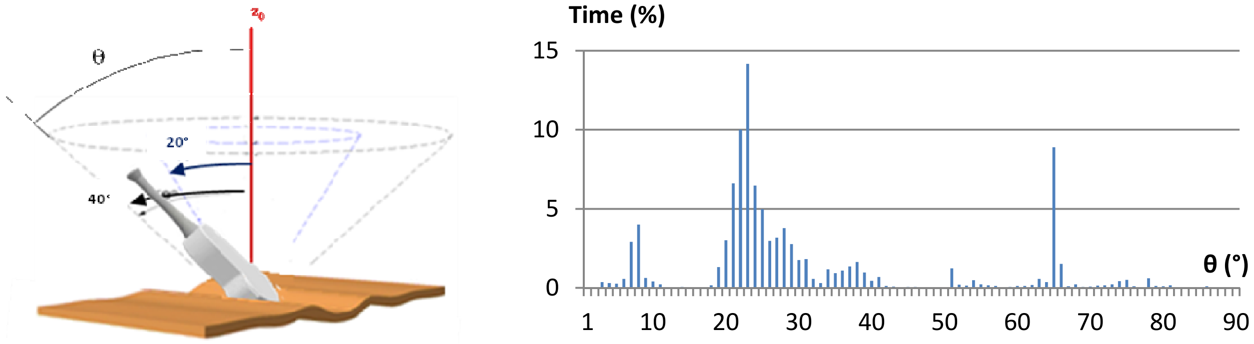

Fig. 7. Probe workspace cone (left), statistical measure of tilt angle measured by Nexus (right)

Observations and Results. Through the analysis of the medical procedure during an ultrasound examination, the area swept by the probe is described by a cone with vertex angle θ and RCM.
The operational method of this clinical act is the same for all experts for the two types of experimentations performed. The ultrasound examination can be described in two phases: a tracking phase of the organ and a diagnostic phase. The first phase is characterized by rapid and random movements to search the targeted organ. In this phase, there are large amplitudes of rotation. Once the organ is located, the experts control his actions in searching for the best cutting plane. This second phase is characterized by low amplitude and slower rotational movements.

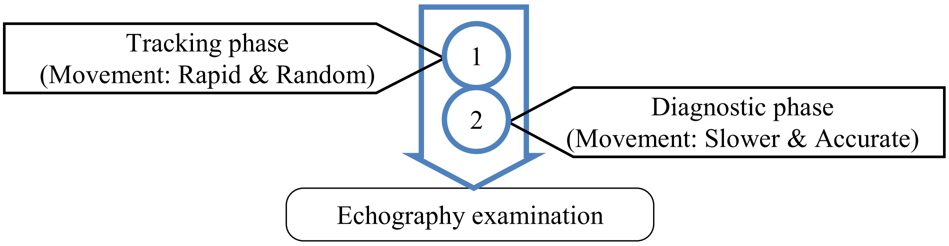

Fig. 8. Ultrasound examination process.

The different of tilt angles occupied by the ultrasound probe between these two experimentations can explained by the fact that they were not performed with the same medical expert. We have been notified by them that there is several possible ways to explore the same target using an ultrasound probe as illustrated in Fig.9.

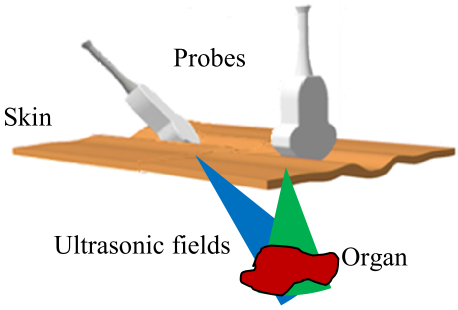

Fig. 9. Organ targeting methods.

We were also notified that applying a force is very important for the expert to obtain good ultrasound images and even to displace internal organs, as the expert sometimes needs to press the patient's belly to displace internal organs.

Specifications of the Robotized Tele-Echography System

After a long work of observations, analysis and discussions with medical expert, we established several important points of the tele-echography system specification.

Slave Manipulator. The slave manipulator will be held by a medical assistant on the patient. It has to be able to reproduce any movement commanded by a distant operator. The robot trajectories are included in a conical workspace. The robot need three rotations around a fix point which is the contact between the probe and the patient's skin. Some experimentation have highlighted that the tilt angle of the end effector shall be comprised between 0° and 40°. But medical experts have specified that a 35° angle cone (θ_n) is sufficient to perform an ultrasound exam. They would rather sacrifice some amplitude of motion to gain of compacity. To reach more inclined zones, the medical assistant will displace the robot to the desired location.
-the robot must respect high safety conditions. No collision will be allowed between moving part of the robot and the patient's body. This constraint will be provided by including a 75° safety angle. The boundaries given by $\theta_n = 35°$ and $\theta_s = 75°$ are fuzzy limits because they are chosen from medical experiences.
-the robot must allow the operator control the force applied by the probe on the patient's skin.
-the portability of the slave system also implies other constraints. It must be compact and as light as possible. The width of the robot shall not exceed 45 cm. The structure must be supported by a patient, so the weight of the robot will be around 3 kg.
The difficulties to respect the specifications come from the contradiction of constraints. To obtain good kinematic performances, we must increase the robot dimensions which decrease the compactness and the lightweight of the robot.
Master Control Device. The robot will be tele-operated by the medical expert by using a control device. It has to responds to the needs expressed by medical experts. The virtual immersion of the expert during the diagnosis must be as close as possible from a standard examination. It will have the same shape as a real ultrasound probe so the medical expert can intuitively perform a remote examination to reduce the learning period. Lightness and compactness will be also required as characteristic for this haptic device. It has to provide force control and feedback to give the expert the same sensations of the classic examination. So that the operator will be able to control the force apply by the robot on the patient. This force shall not exceed 20N. Note that applying a force is very important for the expert to obtain good ultrasound images and even to displace internal organs, as the expert sometimes needs to press the patient's belly to displace internal organs. Its motion sensing equipment has to be cheap and reliable. Medical experts have clearly demanded an alternative to the expansive Flock of Bird (FoB) technology. Experimentations via Nexus have shown that the angular speed of the ultrasound probe do not exceed 30°/sec.

Kinematic Synthesis

The tele-echography prototypes used different structures to create a spherical wrist: serial, parallel or hybrid. In the PRISME laboratory, the serial spherical wrist has been chosen to design the robots (SYRTECH, TERESA, OTELO 1 and OTELO 2): three revolute joints with concurrent axes. This kinematic is naturally candidate because it is the simplest and offers a compact structure. This choice is validated by two methods: the Angeles's complexity method [15] and the chart of the wrist structure choice proposed in [16], shown on Fig. 10. Moreover, medical experts appreciate this structure because the prototypes are compact, lightweight and easily transportable. The first robot developed (TERESA) was successfully tested on 30 patients hospitalized: 80% of the diagnostic were similar as a classic ultrasound exam and no false diagnosis was made [12]. In 2004, the ESTELE robot was tested on more than 200 patients, in 4 Secondary Hospitals as patient premises linked with a University Hospital as an expert site.

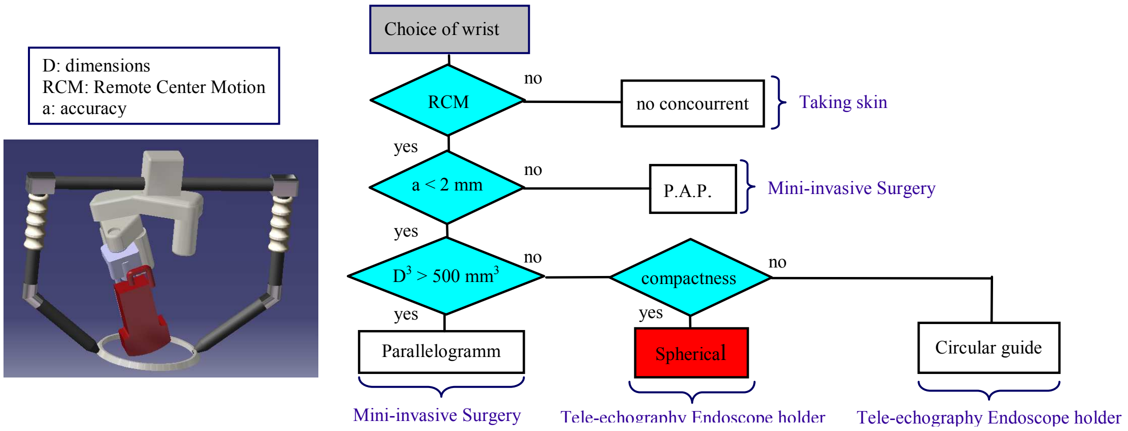

Fig. 10. Wrist choice chart.

All these experiments showed that this kinematic structure is well fitted for this application. But a limitation due to the location of a singularity in the center of its workspace. This central singularity results a local decrease of mobility. Near the singularity, a small displacement of the probe involves large and fast motions of the entire structure. So, a brisk robot displacement could harm to the diagnosis. The central singularity of the spherical wrist is a position often used by the medical expert during an exam because it is the reference position to search an organ and to have a good quality of ultrasound image. To avoid this phenomenon, we propose a new kinematic structure: a spherical wrist inclined with angle α_0 from the normal direction to the patient's skin (Fig. 11). We validated the inclined structure ESTELE-2 ($\alpha_0 = 45°$, $\alpha_1 = \alpha_2 = 40°$) by kinematic criteria: manipulability w [17].

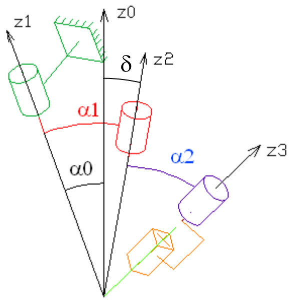

Fig. 11. Kinematic sketch of ESTELE robot inclined an angle α_0.

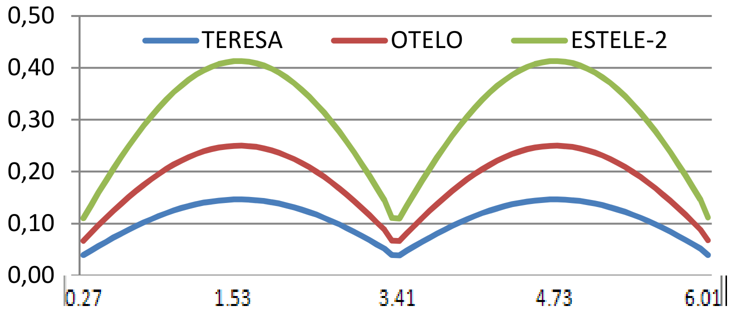

Fig. 12. Manipu lability of Teresa, OTELO and ESTELE-2 robots.

We can observe on Fig. 12. that the manipulability is improved with the inclined structure ESTELE-2. This remark allows us to perform the dimensional synthesis to find the optimal dimensions of this kinematic structure.

Dimensional and Form Synthesis

Dimensional Synthesis. An optimization study is carried out to determine α_0, α_1, α_2 geometrical parameters of the inclined structure according to both good kinematic performance near the singularity to offer a better medical gesture following and a compactness. This criterion is defined in [19]. To realize a multi-criteria optimization considering global dexterity η and global compactness C_g, we use an objective function f_0 which is obtained by aggregation of the two criteria:

$$f_0 = \gamma * C_g + (1 - \gamma) * \eta \tag{1}$$

$$\text{With } C_g = \int_w C dw / \int_w dw \tag{2}$$

$$\text{Where } C = 1 - \max(\alpha_0, \delta)/\theta_s \tag{3}$$

And $\eta = \int_w (1/\kappa(J))dw / \int_w dw$, where $\kappa(J)$ depends on θ_2. (4)

If $\cos\theta_2 \leq -\cos\alpha/(1+\cos\alpha)$ (5)

Then $\kappa(J) = \left(2 + Y + \sqrt{Y^2 + 8\cos\alpha^2}\right)/\left(2\sqrt{Y - \cos(2\alpha)}\right)$ (6)

If $\cos\theta_2 \geq -\cos\alpha/(1+\cos\alpha)$ (7)

Then $\kappa(J) = \sqrt{\left(2 + Y + \sqrt{Y^2 + 8\cos\alpha^2}\right)/\left(2(1 - Y)\right)}$ (8)

Where $Y = -\sin\alpha_1 \sin\alpha_2 \cos\theta_2 + \cos\alpha_1 \cos\alpha_2$ (9)

We want a 35° conical workspace respecting the tele-echography specifications constraints and authorizing singularity in the workspace. We have also defined a 75° tilt angle to never exceed. Two equations are established to respect these two constraints. The following equation allows the structure to comply with the 35° angle cone workspace.

$$\alpha_1 + \alpha_2 - \alpha_0 \geq 35° \quad (10)$$

The other relationship permits to respect the safety constraint.

$$\alpha_1 + \theta_n \leq 75° \quad (11)$$

We consider that $\alpha_1 = \alpha_2$ to avoid any dead zone in the workspace. In this particular case, we obtain the following Pareto's front of solutions presented in Fig. 13.

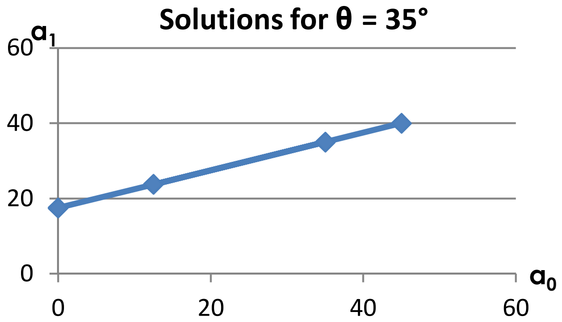

Fig. 13. Pareto's front of solutions for the inclined spherical wrist [14]

For a high value of γ, we obtain a compact solution close to TERESA robot dimensions (α_0 = 0°, α_1 = 17.5°). For a low value of γ, we obtain the limit solution respecting the safety constraint, ESTELE 2 (α_0 = 45°, α_1 = 40°). This solution has been designed and rapid prototyping manufactured (Fig. 14). It offers the best dexterity but its width is too important to a tele-echography application (460mm). We obtain two intermediate solutions:

-the first solution is more compact with a singularity in a rarely used zone of the workspace (α_0 = 12.5°, α_1 = 23.75°)

-the second solution presents higher kinematic performances without singularity on workspace but it is more voluminous (α_0 = 35°, α_1 = 35°)

The final choice of the kinematic parameters of the structure has been given to integrator Robosoft. They have made a compromise between kinematic performance and compactness of the structure. For this reason, we have chosen the dimensions of a third solution to design the PROSIT 1 prototype (α_0 = 10°, α_1 = 22.5) presented in Fig. 15.

Fig. 14. CAD and a rapid prototyping model of ESTELE 2.

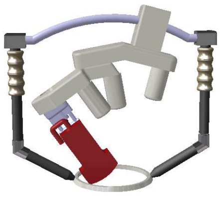

Fig. 15. PROSIT-1 CAD

Form Synthesis. In this step of design process, two different points were taken into consideration. The first one was to verify the mechanical resistance of the robotic arms of PROSIT 1 and determine the arm thickness; the second one was to transform the handles of the robot to improve the appearance of the robot.

In a first step, we have validated the dimensions of the PROSIT-1 arms with finite elements analysis. Here, we present the study made on the arm 1 which is embedded on z_1 axis (Fig. 16.). The load requirement for the robot is to sustain a maximum force on the probe of 20 N on z_2 axis. We considered a plastic material for the robot with following mechanical characteristics: Young modulus E = 2.2 GPa, Poisson's ratio = 0.38, yield strength Re = 160 * 10^7 N/m^2, density = 1200 kg/m3. We can remark that the maximum of Von Mises stress is on the z_1 axis: $\sigma = 9.49 * 10^5$ N/m^2 is lower than the yield strength Re = 160 * 10^7 N/m^2. The part could have a lower thickness.

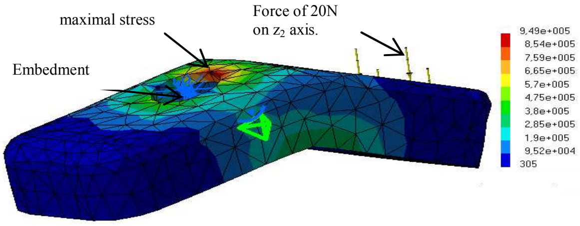

Fig. 16. Von Mises stress on arm-1.

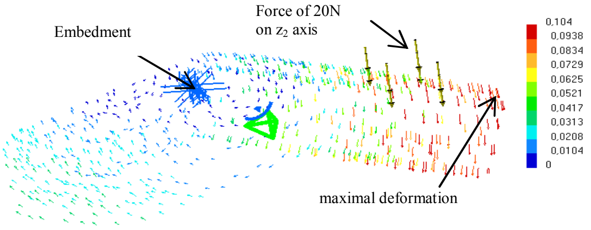

Fig. 17. Deformations on arm 1.

If we study the deformation yield, we remark that the arm-1 sustain the stronger displacement (0,104 mm) at the end of the arm, because it is loading in bending. The value is not negligible because it has a great influence on robot accuracy. A shape optimization study allows increasing the rigidity of the part without greatly increasing its mass. We have noted that a 29% deformation decrease leads to an 11% mass increase of the part with this specific material and if the geometrical parameter is the height of piece. This increase is small compared to the actuators mass. It is acceptable to respect the global mass of the robot: 3kg.

A step of collaborative design[1] with designers is performed for the improvement of the robot design. Specifications dedicated to designers are written: the inclined spherical wrist is considered, the structure must be ergonomic, lightweight to be easily transportable, the contact between the structure and the patient must be improved to adjust to the patient anatomy, cables must be hidden and the patient must be reassured by the general aspect of the robot.

After a search phase which allowed us to keep five concepts, a development phase was carried out. The propositions and the model manufactured are presented in Fig. 18.

Fig. 18. Propositions of designed inclined spherical wrist and rapid prototyping models.

We (and medical doctors we have solicited for tests) are particularly interested in the proposition named "Huggy" (see Fig. 15, central and hight proposal) because it better corresponds to the tele-echography specifications than the others. In 2010, the 5-DoF Protech prototype with "Huggy" design, shown on Fig. 19, was manufactured from this solution.

---

[1] The collaborative study was carried out with the Design Product department of the technical school of La Souterraine (23320)

Fig. 19. Proposed design and CAD model of Protech.

We note that the prototype is easily portable because it is well balanced. We can remark that a person does not know mechanical and robotic disciplinary can contribute to improve the appearance and ergonomics of the product. It is the interest of collaborative design.

Detailed Design

Slave Manipulator. The CAD model of PROSIT-1 is obtained from the modifications of the ESTELE robot. To design PROSIT-1 numerical model with Catia Software, Fig. 21, we conceived a cradle allowing a 10°-tilt between the z_1 axis and the normal direction. The dimensions of the arms are the same as the ESTELE robot. The arms are actuated by lightweight DC motors associated to pulley-belt links. The width of PROSIT-1 is 420 mm.

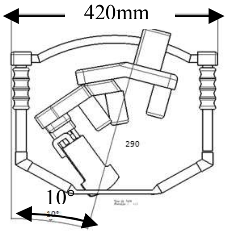

Fig. 20. Plan of Prosit-1 prototype.

Fig. 21. CAD of the arm-1.

Fig. 22. Picture of PROSIT 1 prototype.

Master Control Device. Almost all robotized and carriable tele-echography systems are controlled by FoB technology. In order to detect the motion of the DP, we use an inertial measurement unit (IMU) composed of three single-axis gyroscopes and one three-axis accelerometer. This technology is a cheaper alternative to FoB. The upper part of the DP is designed to accommodate these instruments. The lower part includes a force feedback system using a force sensor to allow the medical expert to control the force applied on the patient's skin, and an actuator provides the sensation of resistance normally generated by the contact between the ultrasound probe and the patient. This hand free interface is managed with our own software SMAR [20] to obtain numerical and visual feedback. The programming of the control strategy is carried out by the Visual C++ environment. Motions estimation via the mentioned technology is often solved by implementing a Kalman Filter, which is a very effective predictor-corrector estimator for a large class of problem. In the present application, we have chosen to modify it in order to increase the attitude estimation accuracy. This control strategy method has been validated by using a motion capture system [20].

Conclusion

Several authors have worked on design processes adapted to mechanical systems. But the particularity of design process of robot for a medical application does not have a lot study [21]. After having presented the principle of the robotized tele-echography, we have introduced a tele-echography prototype and its haptic control device already developed. The design process used for a medical application is presented. Then, each step of this process is detailed for the tele-echography application. Several studies of medical gestures are been carried out to identify the robotic constraints. These constraints are written in the form of required specifications. Then, a serial kinematic structure is chosen and optimized to satisfy at best to the tele-echography robot requirements. A collaborative design study with designers is performed. It allows increasing significantly the aesthetic and the ergonomic of the robot to make them field more reassured about the presence of the robot. The detailed phase allows manufacturing the prototype PROSIT-1. Now, a phase of medical experimentations is being performed to validate this prototype and the medical robot design process presented.

Acknowledgment

This work is supported by the “Agence Nationale de Recherche” grant number ANR-CONTINT 2008-2011. The PROSIT project is certified by the S2E2 cluster of competitiveness.

References

[1] A. Gourdon, Ph. Poignet, G. Poisson, P.Vieyres, P. Marché, A new robotic mechanism for medical application, ASME 1999, USA.

[2] A. Vilchis and al , TER: A System for Robotic Tele-Echography, Lecture Notes in Computer Science, vol. 2208, pp. 326-334, Springer Verlag, 2001.

[3] P. Vieyres and al., A tele-operated robotic system for mobile tele-echography: The OTELO project, M-health, Emerging Mobile health Systems book, Springer publisher, ISBN: 0-387-26558-9, Chapter 23, pp. 461-474, 2006.

[4] M. Mitsuishi and al, Remote Ultrasound Diagnostic System, Proc. IEEE Int. Conf. Robotics and Automation, pp. 1567-1574, Korea, 2001.

[5] K. Masuda and al., Three Dimensional Motion Mechanism of Ultrasound Probe and its Application for Tele-echography System, Proc. of International Conference IROS, pp. 1112-1116, USA, 2001.

[6] Information on http://www.medirob.com.

[7] F. Najafi, N. Sepehri, A novel hand controller for remote ultrasound imaging, Science Direct-Mechatronics, 2008.

[8] D. Brown, Artificial Intelligent for Engineering Design, Analysis and Manufacturing, Special Issue: Configuration Design, vol. 12(4), pp. 301-306, 1998.

[9] N.P. Suh, The principles of design, Oxford University Press, New York, 1990.

[10] D. Scavaretti, Prior formulation of a design problem, for design assistance in preliminary design, Ph.D. dissertation, Ecole Nationale Supérieure d’Arts et Métiers, France, 2004.

[11] G. Pahl, W. Beitz, Engineering Design, The Design Council, London, Springer, 1984.

[12] P. Arbeille, J. Ruiz, P. Herve, M. Chevillot, G. Poisson, F. Perrotin. Fetal tele-echography, using a robotic arm and a satellite link. Ultrasound Obstet Gynecol, vol. 26 (3), pp. 221-226, 2005.

[13] L. Al Bassit, Spherical mechanical structure optimized for a mobile medical tele-echography robot, Ph.D. dissertation, University of Orleans, France, 2005.

[14] M.A. Laribi, T. Essomba, S. Zeghloul, G. Poisson, Optimal Synthesis of a New Spherical Parallel Mechanism for Application to Tele-Echography Chain, ASME 2011 IDETC/CIE, August 29-31, Washington DC, USA.

[15] L. Nouaille, Design process of medical robots. Application to a tele-echography robot, PhD. dissertation, University of Orleans, France, 2009.

[16] N. Smith-Guérin, L. Nouaille, P. Vieyres, G. Poisson, A medical robot kinematic design approach based on knowledge management, Industrial Robot, pp. 316-323, 2008.

[17] L. Nouaille, N. Smith-Guerin, G. Poisson, Modeling and geometrical validation of a tele-echography robot, Proc. of International Conference IROS, Nice, France, 2008.

[18] L. Nouaille, N. Smith-Guérin, G. Poisson, Optimization of a 4 dof tele-echography robot, Proc. of International Conference IROS, Taipei, Taïwan, 2010.

[19] S. Zeghloul, B. Blanchard, M. Ayrault. SMAR: A Robot Modeling and Simulation System, Robotica Journal, vol.15, pp 63-73, February 1997.

[20] T. Essomba, M.A. Laribi, J.P. Gazeau, G. Poisson, S. Zehgloul, Contribution to the design of a robotized tele-ultrasound system, IFToMM ISRM 2011, November 3-5, Shanghaï, China.

[21] G. Poisson, P. Poignet, The design of robots for assistance to medical and surgical gestures. Jounées Nationales de la Recherche en Robotique, JNRR'05, 5-7 october 2005, Guidel, France.

Mechanisms, Mechanical Transmissions and Robotics

10.4028/www.scientific.net/AMM.162

Design Process of a Robotized Tele-Echography System

10.4028/www.scientific.net/AMM.162.384