Long Stroke/High Resolution Tip Tilt Mechanism

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Abstract:
Multi degree of freedom (dof) mechanisms are widely required into micro or macro manipulation fields as well as in optronics functions. Commonly available mechanisms may be divided into two main categories. The first is industrial robots (serial or parallel). These offer large range of motion, in rotation and translation. Their resolution is usually limited in the sub-millimeter range. The second category achieves very high resolution motion (sub-nanometer) but is limited to a few decades of microns. A way to combine both long stroke and resolution is to use piezo motors into multi dof mechanisms. The aim of this paper is to present a combination of both advantages into a low volume tripod actuator. The Tripod Actuator by Cedrat Technologies (TrAC) is a 3 dof mechanism offering +/-35° rotation around X and Y axis and a 10mm Z translation stroke into a low volume of Ø50x50mm
Keywords: Piezomotor, Tip-tilt, long stroke, multi-ddl

Introduction

TrAC offers the resolution of each of its three feet, composed of Stepping Piezo Actuator [1] (SPA). SPA is a piezo motor offering a sub-nanometre resolution all along a centimetre stroke due to its structure. SPA is an inertia stepper motor, based on Stick-Slip, already integrated in various field applications, such as biomedical or optical in ambient or low temperature environments [2]. Each foot of TrAC is equipped by an incremental sensor, able to catch high resolution motion on large range. The structure of TrAC has been made to allow an easy control, with a single driver, using the capability of the SPA to hold position without power supply.

Concept presentation

The capacity of the SPA to produce long stroke displacement and blocking force without power makes a multi-dof structure convenient with simple and reliable drivers. Indeed, in order to limit requirements in terms of multi channel drivers, with complex synchronization functions, a structure with independent degrees of freedom has been deployed. This one makes possible pure Rx and Ry rotations with only one actuator motion. Translation along Z axis needs three feet displacement. The three feet structure is visible on Fig. 1.

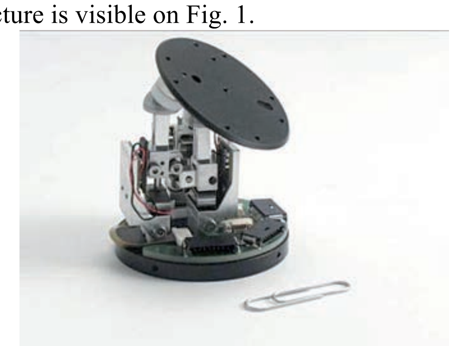

Fig. 1: *Tip tilt mechanism*

Foot geometry and behaviour

Every TrAC foot is composed of a Stepping Piezo Actuator. The principle of such motor is simple and relies on stick-slip effect and dissymmetrical accelerations. Fig. 2 shows the two phases needed to produce one step. First, a slow contraction of the actuator makes the mass moving, without any motion of the shaft, because of clamping friction. Then, a fast actuator expansion gives dynamic forces to mass and shaft and, because of the inertia of the mass, overcomes the friction forces. This moves the shaft into the clamp and one step is completed. By repeating this operation, stroke of several millimetres can be reached. The opposite motion is done by inversing the two sequences. This motion is called "Stepping Mode".

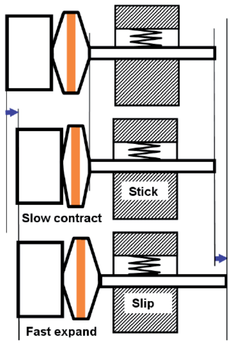

Fig. 2: *Concept of Stepping Mode*

Another way to use the SPA is called "Deformation Mode". In this case, the tool is attached to the mass and it is the actuator deformation which is used, without dynamic effect. By the way, the precise motion offered by the APA allows reaching a high resolution.

Tripod results

Large amplitude displacements

In stepping mode, TrAC is able to produced millimetric displacements. This corresponds to a major difference facing conventional piezo tip-tilt. TrAC design is compatible with such displacements because of hinges allowing every foot rotation. Those hinges are composed of low friction components, preloaded using permanent magnets. This technique constitutes mechanical fuse to prevent motor damage. One of the extreme TrAC angular positions is presented on Fig. 3.

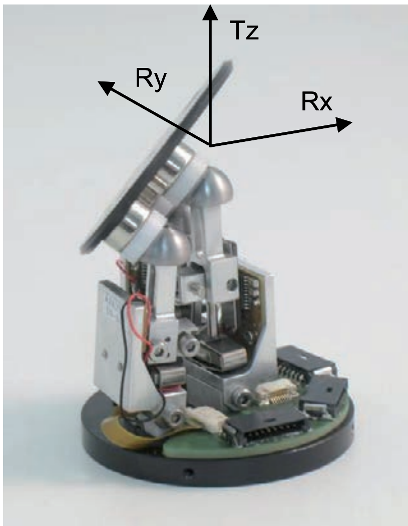

Fig. 3: *TrAC extreme position due to Tz actuator*

As anticipated, stepping mode allows getting large displacements. This one is directly derivate from each actuator shaft length: the shorter it is, the shorter the stroke. However, a slightly larger stroke is reachable using TrAC compared to strictly calculated shaft length. Indeed, Stepping piezo Actuator may be capable to perform steps even when shaft is not fully inside the moving clamp. Therefore a few millimetres stroke supplementary is usable. Displacement ranges are summed-up is following table.

Table 1: *Experimental TrAC data*

Foot	Rx	Ry	Tz	
Linear range	10			*mm*
Max Angle	+/-35	+/-35	+/-45	°
Up speed	20	15	25	*mm/s*
Down speed	40	40	50	*mm/s*

Small amplitude displacements

TrAC tripods, and typically Stepping Piezo Actuators, are well known for their possibility to offer very high resolution motions in comparison with large stroke. This possibility is due to combination of stepping and deformation mode. In this part, characterisation of both modes is made, in order to identify potentialities and current limitations of such mechanism.

To measure small angular displacements, an autocollimator from TriOptics is used. This one gives sub µrad resolution, useful for TrAC motions. It is measuring a small range of TrAC displacement, but gives feedback on tripod behaviour. In our case, TrAC is loaded by a one-inch mirror, exactly as a laser application may use (see Fig. 4).

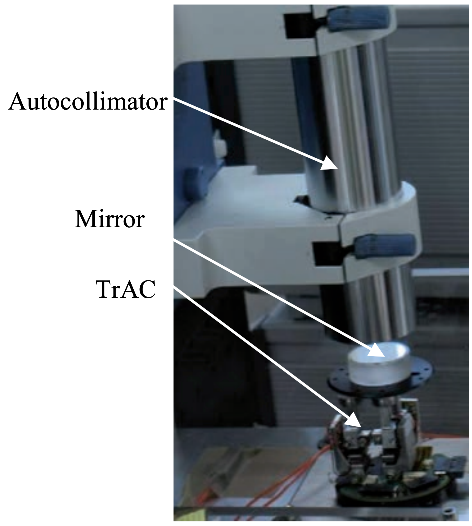

Fig. 4: *Autocollimator test bench*

Deformation mode is firstly checked. This one corresponds to a classical Double Tilt Translator (DTT), widely used in space and industry [3]. For this measurement, TrAC is put in Zero level, corresponding to bottom position for each foot. This gives insurance of correct alignment between autocollimator and TrAC top mirror.

Every foot is composed of a LSPA35XS, including a 55µm stroke actuator. Therefore, using a 15mm lever arm, an angular range of 3.67mrad should be attained. Moreover, the centre foot has a more important influence on angular position due to its shorter distance to rotation axis, compared to rotation actuators placed at 90° each. Therefore, lever arm is reduced to 15/(2^0.5)=10.6mm. This leads to higher rotation of 5.18mrad.

Realised measurements are using a standard linear amplifier LA75B from Cedrat Technologies. Signal generation is made using National Instruments generation Board USB-6259. Command is a simple 1Hz [-1;7.5]V amplitude sine. Considered stroke is difference between maximal autocollimator measurement and minimal. Each foot is tested independently of others, in order not to introduce parasitic measurement. Results are plotted on Fig. 5 and compared to theory values in Tab. 2.

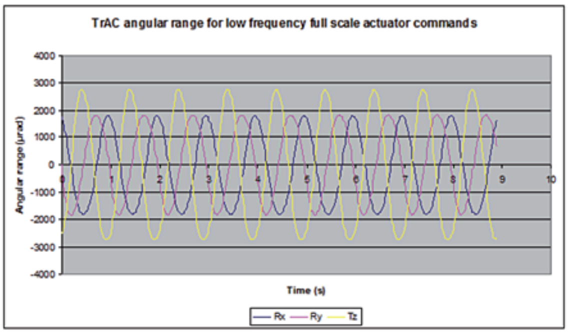

Fig. 5: *Angular deformation mode measurement*

Table 2: *Angular deformation strokes*

Foot	Rx	Ry	Tz	
Measurement	3595	3640	5483	*µrad*
Theory	3667	3667	5185	*µrad*

Those measurements are close from previsions. Therefore, actuators seem to be implemented in a coherent way. Coming from this observation, stepping mode may be analysed.

Stepping mode angular measurements have been done using same devices, in terms of generation and drivers. This time, quasi-statiques signals [4] are used. They are determined and generated using dedicated Labview software. In this case, a quadratic signal is applied, 2ms period. A 1 second delay time is used between two steps in order to allow the autocollimator getting the reached position. Step size is determined compared before after step positions. Fig. 5 shows an example of displacement on Ry actuator using autocollimator. 3 steps are clearly visible, with stable positions between every level. Symmetry between up and down step size is interesting.

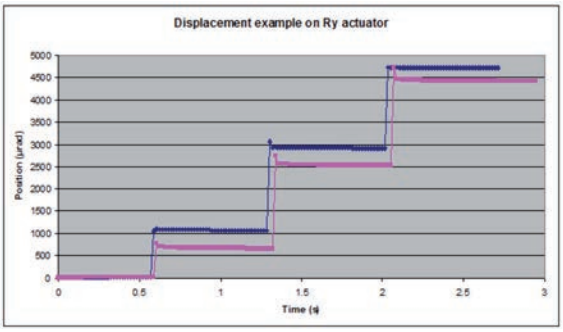

Fig. 5: *Stepping mode example*

Same tests have been realised on each of the three feet in order to establish first performances status. Results are visible on Fig. 6.

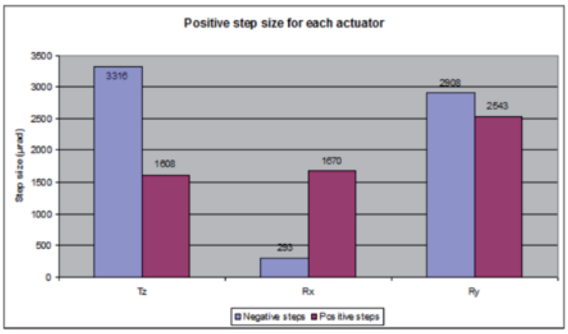

Fig. 6: *Step size versus actuator*

Positive step size shows higher reliability compared to negative one. This may be due to hinges technology that authorises displacement is stepping force is higher that preload force. Moreover, preloading force may be slightly different from one foot to the other one, justifying speed inconsistency from one foot to the other one.

Lessons learned

This paper presents configuration and results of a Tripod Actuator from Cedrat Technologies so called TrAC. This one allows reaching large range of angular positions, with high resolution. The available stroke of the TrAC is about +/-35° (equiv. +/- 610mrad) and 10mm linear in vertical direction. Each foot is equipped with a linear incremental sensor, allowing reaching 2µm linear resolution (corresponding to 0.13 mrad resolution). After rough positioning with stepping mode, deformation mode can offer a range of 3.7 mrad. Overall volume is a 55mm diameter and 50mm height.
Limitations may appear facing tangential stiffness of each foot. Moreover, different loading conditions between each foot may also produce a differential behaviour. To reduce the drawbacks, additional guidance, individually linked to each foot, as already involved in Stepping Piezo Stage (SPS), can be put into the mechanism

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